Ana Sabogal

Ecosystem and Species Adaptations in the Andean-Amazonian Region

Traditional Land-Use Systems in Peru

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To my father, who showed me the Andes and their complexity.

Preface

The elaboration of this book is a result of many years of research and teaching about diverse topics related to plant ecology. The text focuses on plant adaptations and diversity, posing the questions: Why is there so much biodiversity, and how can plants endure such diverse climates, within so many ecosystems and challenging environments? How can we preserve our history and connect it to those adaptations?

The research about the dry forest, the Andean paramo and the jungle of Pucallpa, forms the essential axis of this book. As an agricultural engineer, I can't separate my observations regarding the Andes as an ecosystem from those about its anthropic use. Understanding the landscape and its human construction is essential to the study of these lands.

When developing this project, I drew from my experience as a teacher. The Ecology class I taught as part of the university's General Studies allowed me to incorporate my students' questions, which came from their eagerness to understand and explain the world. The Plant Ecology class, as well as the Landscape, Geography and Environment class, forced me to investigate and put my own questions into written words.

How to define the Andes is a complex topic, and the discussion includes the reflections of several authors, who write from the point of view of multiple disciplines. This book's perspective combines the science of plant ecology with that of agronomy, as well as with traditional Andean studies, taking into account human geography. From this perspective, the Andes is a complex space, one that is not restricted to just the highlands, but that also, through the use given to the space and through traditional migrations, combines the history of the highlands with that of the lower hills, both on its western and eastern slopes.

I believe that in order to study the Andes, we need to acknowledge its multiple links to the territory. Only then will we be able to understand its complexity. For this reason, the book recollects classical studies about the Andean world and combines them with others on the topics of plant ecology, landscape and the use of the space.

Just like plants have had to adapt and change according to the dynamic of their environments, humans have also found ways of life that allow them to incorporate these changes into the development of lifestyles adapted to agriculture.

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Ana Sabogal

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About the Author

Ana Sabogal is an Agronomic Engineer, Doctor in natural sciences from the Technic University of Berlin, Plant Ecologist and Academic Scholar. Her current research includes the study of the impact of vegetation changes and the human impact in the Amazonian forest ecosystem. Her publications are about plant ecology of moorland ecosystems, plant distribution, in degraded grassing ecosystems, urban ecosystems and the influence of human impact. Other important previous research and publications included study of vegetation, grazing in the forests of northern Peru with emphasis on the distribution of *Ipomoea Carnea* Jacq. and management of dry forests in the northern coast of Peru. She developed and established the postgraduate program of Master study in Environmental Development at the Pontificia Universidad Católica del Peru and was previously Director of Research and Information in the Peruvian Ministry of Environment (2012–2013). Her work as a researcher and consultant at international and national levels is oriented towards the linking of interdisciplinary knowledge in many levels. Currently Ana Sabogal is the Director of Master Studies in Environmental Development and principal professor at the Pontificia Universidad Católica del Perú, at the Section of Geography and Environment.

Chapter 1
Basic Concepts of Ecology Applied on the Neotropic Ecosystems

1.1 Introduction

Ecology is the science that studies interactions between living organisms and their environment, including the relations of organisms to one another as well as to their surroundings. Therefore, the study of ecology includes interspecific, intraspecific relations, study of populations and the influence of the environmental medium on the species, understanding environmental mediums as water, air and soil. Each species has a range of conditions necessary for it to live and develop called ecological niche. From this angle, when we refer to concepts of ecology applied to neotropical ecosystems, we are referring to the ecology of species inhabiting the tropics and subtropics of South America; characterized basically by the presence of the Andes which modify the climatic conditions corresponding to the latitude due to the altitude as well as the fact that they constitute a geographical barrier.

The science of ecology derives from biology. Ernst Heackel in 1869 defined "ecology", separating it conceptually from biology. Ernst Heackel points out that each organism has its own individual development (ontogenesis), with the ability to incorporate changes in its development and modify as a group of individuals (phylogenesis), thus, each form is a stage in its development (Haeckel 1989: 9). However, the theories which are currently considered fundamental pillars of ecology were developed in the twentieth century. Among them, we can mention as milestones the theory of ecosystem succession, developed by Frederick Clements, which describes the changes that occur in the ecosystem over time¸ while Evelyn Hutchinson, in the mid-twentieth century, proposed a definition for "ecological niche", distinguishing it from habitat or place inhabited by the species and defining the multiplicity of physical and biological factors required by the species to function (Smith and Smith 2001: 19). Taking this into account, the ecological niche is formed by the habitat (place where the species lives), the food required, temperature, humidity or the species it lives with, among many other factors that enable the species to be functional

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in a particular ecosystem. Each species has a range of factors for its ideal development, which forms its ideal niche. However, species cannot always access all the factors of their ideal niche and often have to be content with the factors of the ecosystem where their habitat is located. Such cases are referred to as "successful niches". Lynn Margulis' theory of endosymbiosis posits that the cell is born from symbiosis between primitive organisms (Campbell et al. 2001: 334). According to this theory, chloroplasts and mitochondria evolved from symbiotic prokaryotes located within other prokaryotes (Campbell et al. 2001: 334).

While biology studies living organisms, ecology focuses on the interactions between organisms and the environment they live in. Therefore, it requires knowledge of biology as well as other sciences such as geography, edaphology or climatology, among others. The etymology of the word "ecology" comes from the Greek words oikos, which means house or home including the management of the house, and logos, which means treaty or study.

Although, as mentioned above, the term "ecology" is relatively recent, it was in 1866 that the zoologist Ernst Haeckel defined the term to name the relationships of living beings with their environment. Nevertheless, we must not ignore Charles Darwin, who in 1859 published "The Origin of Species". His initial studies in geology are essential, since he combined the study of fossils with geological studies. The discovery of fossils leads to the idea of changes in nature. Before that, changes over time were not studied. Combined studies of biology and geology unite several dimensions of time by incorporating evolutionary aspects into the study of biology. Darwin's last work "The formation of the vegetal mulch" studies the worms and their importance in the formation of the soil, a topic clearly related to ecology. Ecosystems are also constantly changing and the organisms within them are in constant adaptation so it is possible to identify and study the phases and changes of ecosystems or ecological succession.

Defines ecology as the "study of the structure and function of nature", highlighting, on one hand, the relationships between the parts of a system and, on the other, the function of the living beings within it, forming the ecosystem in this way. Thus, an ecosystem has interactions among its components within a space or habitat. Neotropical ecology then studies the ecosystems within a neotropical space or the new continent.

1.2 Ecology as a Science

Ecology is a practical science, since its specific object of study is ecosystems. Therefore, it requires field trips, laboratory work and deskwork. Currently, it also uses remote technology, satellite photos and maps connected with methods to study geography. Additionally, ecology contemplates several dimensions, which range from unicellular organisms and their interactions to distribution and analysis of the distribution of tree populations. It studies terrestrial and marine ecosystems, as well as the intermediate spaces between various ecosystems. In fact, ecology studies all the spaces with life on earth, but not those such as the centre of the earth or the stratosphere, where there are no living beings. Therefore, the object of study of ecology is the biosphere. The same applies to neotropical ecology which studies spaces of the new world where there is life, including the surface of the earth and the aquatic spaces. Neotropical ecology is also Andean ecology, where the Andes are fundamental to the characteristics of the environment.

The methodology applied in the study of ecology uses exact methods often in combination with qualitative methods, especially when it focuses on the study of anthropogenic change and modification in the ecosystem. It is important to point out that for ecology, humankind is just one more organism causing change in the ecosystem and it is not the centre of study, in spite of being considered a dominant species. Ecology bases its hypotheses on field observations combined with previous theoretical studies. The hypotheses often explain causes which have to be validated so that models can be built based on several repetitions in different environments leading to theories. Models should be repeated enough times and have reliable data obtained with similar methodologies in order to enable valid comparisons.

An ecological study chooses one dimension; it defines the communities or spaces of interaction within an ecosystem where interactions among individuals are closer, and then studies its dynamic. Considering this, a choice of study could be the ecology of vascular plants or organisms that inhabit the soil, or the decomposing bacteria of spaces where oil exists. Another dimension called "ecosystem succession" studies the evolution of ecosystems over time; ecosystem adaptations and development.

1.2.1 Approaches of Ecology

The approach used in ecological studies depends on the knowledge that one has of the ecosystem. The *functional approach* studies the different interactions within an ecosystem, interpreting and explaining the reason for these interactions within populations, communities and the ecosystem as such. From this approach, the ecosystem can be defined as a system where all the factors that compose it interact with one another. For this reason, the changes that occur in the ecosystem affect all the living beings in it and the ecosystem itself. This approach can be applied when the components of the ecosystem are known and the relationships occurring in it can be analysed. The *evolutionary approach* studies the changes in the ecology over time. It studies the reasons natural selection has favoured and facilitated the presence of the organisms that compose the ecosystem. Changes in the ecosystem are understood as a continuous process that has allowed the survival, and the adaptation of the species to the changing conditions of the ecosystem. In this way, evolutionary ecology studies changes that occur in populations, their distribution and their relationship with the environment. Finally, the *descriptive approach* describes the organisms that compose an ecosystem, the vegetation, the animals and their relationships with each other. This approach first studies a living being as a study unit to relate it to the environment it inhabits. It is used when there is no previous study of the space. It has been applied by multiple naturalists at the beginning of the twentieth century and it is very common to find exploratory studies of Neotropical ecology using this approach, since there are still few ecological studies of these spaces.

1.2.2 What Does Ecology Study?

Ecology studies ecosystems. Within each ecosystem we find communities or spaces where interactions between different species are more intense and enable the survival of its inhabitants. Additionally, all ecosystems compose the biosphere and interact with each other, with transition spaces between ecosystems or ecotones that contain characteristics of both ecosystems and tend to be more diverse.

An ecosystem contains several communities, and these in turn contain several populations, and populations are made up of several individuals of a single species. Ecotones are the spaces of interaction between the different communities. The limits of an ecosystem depend on the set of living beings that form it, their distribution, their abundance and the function of each population within the ecosystem or community. Two ecosystems can be different, even if they are composed of the same species.

In turn, each population is composed of individuals of a species that can be studied individually by biology or as a group by ecology. An ecosystem is composed of several communities and each community has different populations. They are all intertwined, in the ecosystems which contain the communities that at the same time contain the populations, just as a set can belong to a larger one in the set theory. What defines an ecosystem are not the separate populations but the interactions between them and the proportions of each one. Hierarchies are thus established between populations, some being dominant over others. Thus, for example, a population of howler monkeys (*Allouatta palliata*) can be dominant in the northern Peruvian dry forest and be key to the dispersion of seeds of many fruits, while capuchin monkeys (*Cebus* sp.) that inhabit the high forests of the Amazon interact with humans or nearby spaces to obtain food (Fig. 1.1).

1.3 Ecosystem

An ecosystem is a set of communities, made up of diverse species that interact with each other and with their environment. It includes all the physical, chemical and biological elements that allow the ecosystem to exist. An ecosystem in its classic sense is made up of abiotic components: air, water, soil and biotic components: plants, animals and microorganisms. An ecosystem is thus a unit made up of various components that only function when they are together. In order to study ecosystems, we can determine their components and each one of their functions.

Fig. 1.1 *Capuchin monkeys (Cebus capucinus)*. (*Author* Ana Sabogal)

Ecosystems are not isolated, they have relationships with one another and indirectly influence one another. In most ecosystems it is very difficult to determine when one ecosystem finishes and the neighbouring ecosystem begins. The space of interaction between two ecosystems is called "ecotone".

No two ecosystems are alike. The composition, distribution and operation of each is different. Each one has a defined geographical location. Therefore, it is important to study geographic factors such as slope, winds and location as well as the ecosystem's surroundings which greatly affect the ecosystem's climate in addition to all other factors. Some examples of ecosystems are: the Atacama desert, the tropical rainforest of the Peruvian Amazon, the marine ecosystem of the Pacific coast, the mangroves of Tumbes, the dry forests of the Peruvian northwest or the moors, all of these ecosystems of the neotropics.

1.3.1 Components of an Ecosystem

For the study of the ecosystem we divide its components into abiotic and biotic components. The *abiotic components* of the ecosystem are found in the air, water and soil. These contain inorganic substances or elements such as carbon dioxide (CO_2), water (H_2O), oxygen (O_2), phosphorus (P), nitrogen (N) and some salts, among others. Inorganic substances: Although they are usually present in small quantities, they have a great influence on the other components of the ecosystem and on the distribution of living beings on the planet, since they can easily cause significant chemical reactions. Biotic components are in all living beings. They are classified according to their trophic level into producers, consumers and detritivores. This classification determines the level of dependency of each food group produced by other organisms.

- *Producers*: these are the organisms that carry out synthesis processes. They are the only ones capable of transforming inorganic substances and compounds into organic compounds. Plants are the main producers in the case of terrestrial ecosystems, and algae in the case of aquatic ecosystems. Examples of producers are the giant ferns of the Amazon, the ceibos (*Ceiba pentandra*) of the dry forest or the Andean grasslands (*Stipa ichu*).
- *Consumers*: organisms that feed on other living organisms. In this way they take advantage of the synthesis made by other organisms. They cannot use abiotic substances as food and are dependent on processed matter. Consumers are the white-tailed deer (*Odocoileus virginianus*) of the northern Peruvian dry forest, the spectacled bears of the Andean forests (*Tremarctos ornatus*), and the zooplankton of the sea in the Humboldt Current.
- *Decomposers (detritivores and degraders)*: organisms that carry out decomposition processes of living organisms after they die. Detritivores initiate the decomposition process by decreasing the size of dead matter, followed by degraders that transform organic substances into inorganic substances. Detritivores can be large or small, degraders are mostly microscopic organisms. Earthworms or piglets are detritivores, while degraders include fungi and bacteria that decompose organic matter. Their presence is directly correlated with temperature. Thus, in cold ecosystems such as the puna, decomposition is very slow.

1.3.2 Processes Within an Ecosystem

Constant change is needed in an ecosystem for it to work. Certain processes have to take place to ensure its continuity and adjustment to changes in the environment. The *physical environmental factors*, including the *climatic factors*, such as lightning, thunder, rain, and the quality of light, generate changes in the ecosystem.

The main processes that enable an ecosystem's continuity are:

- *Synthesis*: it includes photosynthesis performed only by plants and algae and the synthesis performed by animals throughout their feeding. However, for ecosystems, the only process of synthesis to be studied is photosynthesis, since it allows animal feeding. In short, synthesis is the absorption of energy that will be stored in the body to enable the growth and development of living beings. The synthesis of plants is performed through photosynthesis and it is called primary production, whereas that of animals is done through food.
- *Respiration*: performed by all living beings: plants, animals, fungi and bacteria. It includes the decomposition of matter as organic compounds disintegrate, and the absorption of oxygen to transform it into carbon dioxide in order to release energy for the different vital processes.

- *Nutrient cycling*: the process by which matter goes from being part of living beings to being part of the soil, air and water. Without this cycle, matter would not be renewed within the ecosystem.
- *Biogeochemical cycles*: cycles that define an element as a component of an ecosystem as well as outside it. The cycles include a chemical element and the way it forms part of compounds, transferring among the different living beings, air and soil in an ecosystem. The study of the elements usually includes more than one ecosystem. It implies studying a chemical element since it starts transporting itself from an ecosystem until it returns, changing into different forms and going through a diversity of ecosystems through time. The name biochemical reminds us to study the element within a biological ("bio") and abiotic ("geo") component and as an element in its different forms (chemical).
- *Ecological succession*: or stages of development and change of an ecosystem over time. It can also be described as the legacy received by each stage of development of the ecosystem from the previous stage. Ecosystems become more complex and biodiversity increases until it reaches its peak. The last stage is the climax stage where we can find fragile ecosystems such as the Amazon rainforest.

1.4 Community

A community is a group of populations of different species that coexist in a space of an ecosystem and interact with each other. Within an ecosystem there are several communities. The community has a defined space and shared functions among its members. In a community, individuals of different species coexist and support each other. However, the community is not independent of the ecosystem. Two examples of communities are the organisms that inhabit a rotting log in the Amazon rainforest and a group of plants that grow in a space overgrazed by goats in the northern Peruvian dry forest.

The communities have defined characteristics that distinguish them These characteristics are:

- *Diversity of species*: Number of different species *that form a community*.
- *Biological Structure*: defined by the species that compose it.
- *Physical Structure*: determined by the way it grows or the form of the species and the space it occupies in the community.
- *Dominance* is determined by the species that controls the conditions of the community. Dominance may be due to the greater number of individuals of the species, the behaviour which enables access to resources or the way it grows which determines the space it occupies.
- *Relative abundance*: number of individuals of the same species in relationship with the total amount of individuals of all species that form the community.
- *Trophic structure*: feeding relationship between species.
- Every community also has dispersion patterns; or typical forms of occupation.

1.5 Population

Smith and Smith (2001) define population as a group of individuals of the same species occupying a space at the same time. A species is made up of individuals of the same species that live together and can exchange genetic information. Therefore, they share a space at some point in their lives and possess the same number of genes.

Populations are not static and change over time; they can adapt to changes, evolve or become extinct. It is important to emphasize that evolution is a process undergone by a population and not an individual; while individuals adapt, populations evolve. It is the population that evolves through the selection or survival of some genes. In a homogeneous environment, some genes tend to become extinct, while others are prioritized. Additionally, in a changing environment, the prioritised genes tend to be varied so the population is more diverse; in this case, over time, different species can appear since ecological niches separate and groups of individuals of a species specialize. For example, birds like parrots have adapted to living in trees, whereas birds like ducks have adapted to living in the water, thus, there is no competition between them.

Some examples of population are the goats in the dry forest (*Capra aegagrus hircus*), the puna ichu (*Stpa ichu*) or the taricaya turtle (*Podocnemis unifilis*) in the Peruvian amazon.

Metapopulation Populations in one ecosystem may interact with populations in other ecosystems. In particular, when a population grows and individuals compete with each other, many individuals seek other spaces, which also occurs when there is an ecosystem catastrophe. In these cases we are dealing with a metapopulation composed of several populations that interact with each other. A population interacts with other populations when it spends the coldest seasons in other ecosystems, when rivers overflow periodically as in the Amazon, when a forest is burned to renew its nutrients as in the dry forest, or when the forest is cut down.

1.6 Ecosystems and Species Adaptations

Ecosystems and species are in constant change and modification. Whereas evolution is a characteristic of a population that is reflected in its genetics, adaptation is a response of individuals to change. Adaptation is not inherited; evolution modifies the gene pool of the population, adaptation does not. However, not all individuals can adapt since they need to be capable of doing so, thus, although adaptation is not inherited, individuals that do not adapt will not be able to endure in the ecosystem so they will either die, causing the elimination of their genes from the population gene pool, or they will migrate to other areas, hence the population gene pool will change. Evolution influences the distribution of genes in a population and may prioritize some genes over others. Therefore, the two concepts are closely correlated.

The classic misconception in the definition of adaptation is the example of the giraffe's neck described by Lanmark. According to his hypothesis known as the inheritance of acquired characteristics, from the early nineteenth century, the giraffe's neck stretched as it fed on the leaves of trees, allowing its offspring to inherit this characteristic. Although the giraffes that survived were those that were able to feed from the tallest trees because their necks were longer, this characteristic was inherited in the genetic group of the population, but not by the individuals and not by their offspring.

Evolution is not linear and it is either accelerated or slowed down by environmental conditions. Thus, according to the *intermediate disturbance hypothesis* postulated by Huston & Cornell, diversity is maintained due to competition caused by the disturbance that makes species maintain diversity (Smith and Smith 2001: 405). Without disturbance, dominant species displace those of earlier stages of ecosystem succession; on the other hand, when there is excessive disturbance, migration and extinction occur, reducing diversity (Smith and Smith 2001: 405). If we think about the ecosystems of the Amazon rainforest and compare them with the highland rainforest, we see that the diversity of the ecosystems of the highland rainforest is greater. This is because the highland rainforest has more slopes and a greater variety of temperatures so there are more disturbances in the environment and consequently more diversity.

In addition, *adaptive radiation*, or evolution from a common ancestor (Smith and Smith 2001: G15) is a characteristic of isolated ecosystems in which a few representatives of a population that remain in a space mark the evolution. This effect is called the *founder effect.* When environmental differences are moderate, the adaptive-evolutionary processes are not interrupted and ecotypes and endemisms originate. This characteristic is very frequent in the ecosystems of the Andes where the mountains become natural interruptions of the space causing isolated ecosystems or archipelagos in evolutionary terms which lead to a process of divergent evolution and endemisms. We found a large number of endemic species in the northern Peruvian moorlands that form isolated ecosystems due to the altitude and the adjacent high Andean forests. Species survive in ecosystems slightly different from those of their origin and form ecotypes and evolutions separate from their original population, thus filling different ecological niches at great speed. In the Andes of the southern highlands isolation and altitude cause a large number of ecotypes such as potato ecotypes. Finally, if the species survives in a radically different environment, evolution occurs. Let us remember that evolution is a population characteristic that allows the inheritance of adaptations by genetic recombination.

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Chapter 2
Natural Resources and Sustainable Development in Peru

2.1 Introduction

This chapter is about the distribution and use of Peru's natural resources throughout history and their relationship with sustainable development. When referring to natural resources, it is important to focus on the use of resources. For this reason, the chapter concentrates on mining resources, biodiversity and guano, which played an important role in history and are becoming relevant again considering the global situation and the scarcity of agricultural products that could pose a threat to food security.

The history of resource extraction in Peru is the history of various extractive booms caused by international demand and prices.

Humboldt and von Planck expeditions that followed the first resource maps elaborated by Raimondi were key to drawing the baseline that allowed this task.

In this way, and taking into account Deusta (2009), we can summarize the history of the booms as follows: the silver boom with the mining of Potosí between the sixteenth and seventeenth centuries, the increase in silver mining in Cerro de Pasco (1830), followed by whaling and the subsequent mining boom that was replaced by the exploitation of guano between 1840 and 1870, followed by the rubber boom between 1879 and 1912 and its comeback between 1942 and 1945.

The whaling boom took place from 1830 to 1861, being the port of Paita of utmost importance (Fernández 2008 cit. Díaz Palacios et al. 2016: 169). This industry reached its peak in Peru in 1830 and was characterized by the exploitation of the sperm whale, which can be found commonly in the Peruvian ocean since this whale inhabits the Humboldt current ecosystem (Cushman 2018). The remains of the sperm whale were used to mix with guano as fertilizer. At that time, the condor that migrated to the Peruvian coast in the dry season of the highlands developed more than ever because of the whale entrails that they fed on. (Cushman 2018).

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Between 1840 and 1870 Peru's main revenue came from the guano industry (Cushman 2018). Humboldt's description is key in the studies about Guano. Humboldt researched the uses of guano and together with Bolivar promoted the development of this industry (Cushman 2018). Little was known about guano, only that bat guano was used in Africa (Cushman 2018). According to Garcilaso de la Vega's chronicles, Incas used human dung as fertilizer in the Cusco highlands and on the Collao plateau they used that of llamas and alpacas, whereas bird guano was used on the coast (Mala and Chilca) (Garcilaso de la Vega cit. Cushman: 43). In addition, llama herders of the Puquina ethnic group collected guano from the coast then they came to use the pastures on the hills during the drizzle season. They also collected salt, red algae, shellfish and fish, until the mid-1950s.

The worldwide guano boom allowed the development of agriculture and led to the search of new areas to get more guano. Diverse islands in the Pacific Ocean were searched. John Arundel (1841–1919), main guano and labour trader of the Pacific islands, extracted guano from 12,000 km of islands around the world. Additionally, he extracted products such as shark fin, sea cucumbers, Chinese mushrooms from the island of Niue, turtle shells, pearl shells and wood. He also traded agricultural products such as rice, meat, cloth, steel knives and bells, tobacco and soap (Cushman 2018). Palm soap and coconut oil that came from the Pacific islands was white. It replaced the soap that muleteers brought from the highlands. This soap contributed to reducing death by dysentery.

Peru resorted to Easter Island labour (1862) to extract the guano and managed to decimate the population, to the point that in 1863 the Peruvian government prohibited the importation of Easter Island labour (Cushman 2018).

Guano studies and the development of the chemical industry were key to the shift towards chemical fertilizers. The guano boom was followed by the exploitation of phosphates. The development of the chemical fertilizer industry is intertwined with agronomic studies that led to important laws of ecology. The law of the minimum, postulated by Justus von Leibig in 1840 and first elaborated by Sprengel (1828) to explain which are the elements necessary for plant growth demonstrates that plant growth does not depend only on the elements that are abundant, but on those that are found in limited quantity. Thus, if there is too little or too much of any of the 16–17 elements, the plant will be deficient not only of the missing element but also of other elements that could be blocked by those in overabundance (Fig. 2.1).

An excessive contribution to the soil of an external element can unbalance or produce a deficiency of other elements and vary the pH, which can destroy the ecosystem. Thus, the contribution of any element has an effect on the others, and a balance between the elements in the soil is vital. Since the entrance of deficient elements could be blocked by an excess of certain elements, it is necessary to have a minimum and maximum of each element to prevent one from going missing. This principle is called the *law of minimum* and it is applicable to all soils as well as to all the elements that form the ecosystem.

In this way, soil equilibrium is sustained when all the elements that compose the soil are recycled within the same ecosystem. If one element is missing, the whole system deteriorates. The contribution of any other element affects production

Fig. 2.1 Peruvian booby (*Sula variegata*) guano producer. (*Author* Ana Sabogal)

negatively. The first contributions of the missing elements produce an immediate positive effect. However, successive contributions produce increasingly smaller effects until a point of maximum yield over which successive contributions will produce no effect at all. An even greater increase in this element produces a negative effect on yield. This principle, "the law of the minimum", is applicable to soils as well as to all the elements that form the ecosystem.

The law of tolerance, elaborated by Shelford (1913), of great importance for ecology, predates the law of the minimum. The law postulates that organisms possess a range of minimum and maximum factors within which they can survive and fulfil their function within the ecosystem (tolerance range). Within this range, each organism has an optimum value for each factor that allows the organism to develop to its full potential.

This is a significant concept to understand what we know today as an ecological niche. It is Joseph Grinnell who in 1917 defined the ecological niche as the space where species can circumvent the limitations of the environment (Smith and Smith 2001: 18). It is only Charles Elton who, in 1927, associates the ecological niche to the function of the species within the biotic community. Finally Hutchinson defines niche as we know it today, which includes the diverse physical and biological variables that the species requires (Smith and Smith 2001: 19). The niche can be achieved within the range of optimal variables, or ideal ones when the variables are already optimal.

The guano boom is then replaced by the uncontrolled extraction of timber from the rainforest. This dates back to the rubber boom between 1879 and 1912, which coincides with the collapse of mining in 1890, and rubber exploitation resurges between the years 1942 and 1945, to be replaced in the 1950s by the oil boom which also takes place in the rainforest (Cushman 2018).

At the same time, carob wood and orcein dye used to paint boats, from the Roccella tinctoria lichen, were exploited (Cushman 2018). Seaweed, salt and fish were also used by migrant herders who carried products from the coast to the puna (high plateau) (Cushman 2018). Soap production from sheep and cows in the highlands of Peru was part of the seasonal labour circuit of the coastal haciendas.

Another milestone in the development of the ecological vision regarding the extraction of resources and considerations about monoculture that are closely related to the principles of ecological agriculture is the so-called "potato famine" that occurred in 1845 which affected all of Europe, but especially Ireland as a result of the destruction of potato crops by the late blight fungus (*Phytophthora infestans*) and which killed more than 1 million people (Curtis and Barnes 1997: 1157). Wild potatoes were then used for the genetic improvement of the species.

As a result of this famine there was an important migration wave from Europe. In Peru the government of Ramon Castillo, after abolishing slavery in 1854, promoted German migration to Pozuzo in 1849 (Cushman 2018).

The abolition of slavery is directly linked to the extraction of resources, since it was financed by the government with the revenues from the guano. Several historical events changed Peru's history. One of them was the promotion of Chinese migration in 1874, replacing the highland labour force and enabling the development of agriculture. While silver mining collapsed, the industrial agriculture of cotton and sugar flourished.

Saltpetre deposits were found in the south in the Atacama desert: sodium nitrate ($NaNO_3$) and potassium nitrate (KNO_3). Thus, the production of sulfuric acid (H_2SO_4) and fertilizer by-products: ammonium sulphate and superphosphates. This led to a boom in the agricultural industry and an increase in revenues in Peru. In addition, the mixture of saltpetre with sulfuric acid produces sodium carbonate (Na_2CO_3), which is widely used in industry, and nitrate which is used in the manufacture of explosives. In this context and linked to the exploitation of resources in southern Peru, the Pacific War (1879–1884) broke out causing Peru to lose resources.

In 1912, Fermín Tangüis developed the Tangüis cotton, a variety resistant to cotton wilt (*Fusarium oxysporum formae vasinfectum*), which helped the growth of cotton plantations on the coast. During the viceroyalty cotton was also grown in Piura, Tacna and certain areas of Chincha, and sugarcane was grown mainly in Lambayeque, Trujillo, Lima and Ica (Díaz Palacios et al. 2016: 153). Although we have completely left aside the cultivation of wheat on the coast, it again acquires importance in the context of the war in Ukraine and the consequent shortages. Wheat was grown on the coast until the 1680s–1690s when this activity ceased due to pests and the importance given to the cultivation of sugarcane (Huertas 2009, cit. Díaz Palacios et al. 2016: 154).

In the sixteenth century cotton and goat were produced in the north in Piura and Tumbes. From Lambayeque to Lima sugarcane was predominant, and from Ica to Arica there were vineyards and olive groves. The northern highlands had cattle, whereas the central highlands had corn and wheat and the southern highlands had potato and oca as well as grazing of cattle and camelids (Sanchez 2009 cit. Díaz Palacios et al. 2016: 155). So it was then when the current crop distribution originated, but there have been some important changes such as the introduction of export crops in the Ica valley and agricultural expansion along the coast.

There is an interesting turn in the development of Peru in the early twentieth century. In 1914, most of the extractive industries were in the hands of Peruvians (Cushman 2018). The rubber boom resurged in 1942 and 1945 until rubber and wool were replaced in 1950 by oil and copper. 1970 was marked by fishing causing depletion of the anchovy. In 1990, with the rise in international prices of metals, fishing was replaced by the boom of copper and gold.

We will describe a diversity of resources that have been relevant for Peru's sustainable development. We have considered mineral resources, soil resources in relation to agriculture and timber resources in relation to biodiversity.

2.2 Mineral Resources

Mineral resources are the rocks formed by a mixture of inorganic compounds as well as minerals formed by homogeneous compounds. In Peru, the main minerals extracted are copper, lead, zinc, iron and gold.

2.2.1 Mining in the Environmental History of the Republic of Peru

Mining in Peru began in 1537, just 5 years after the Spanish conquest (Patrucco 2016: 129). The two most important mines of the colony were the silver mine of Potosí, and the mercury mine of Santa Barbara (Patrucco 2016: 129). The greatest mining activity took place between 1600 and 1680 (Patrucco 2016: 129) and the greatest production of Potosi is reached between the sixteenth and seventeenth century, whereas the silver mining of Cerro de Pasco reached its peak in 1830 (Cushman 2018). It is worth noting that at the beginning of the eighteenth century the silver production of the Potosi mine was lower than the mita in 1580–1650 (Chocano et al. 2010 cit. Patrucco 2016: 130). Although the mines of Cerros de Pasco were important they never matched those of Potosí (Patrucco 2016: 130). During the colony part of the mines were abandoned, either due to resource depletion or technological limitations (Patrucco 2016: 132). Development of the nitrogen-based explosives industry was essential for closed-pit mining, enabling the exploitation of mineral resources (Cushman 2018).

The greatest mining activity in Peru took place between 1600 and 1680 (Patrucco 2016: 129). In the nineteenth century, mining expanded and new minerals were exploited. During this mining boom, new technologies were used (Review quote Patrucco 2016: 132).

Mineral prices played a role in the exploitation of mining resources. The fall in the price of silver in 1892 and at the same time, the boom in international demand for copper, together with the construction of the train to La Oroya from 1870 to1893, led to the diversification of mining operations; prior to this, metals were transported by muleteers with mules and llamas owned by local traders (Deusta 2009). The extraction of new minerals began and the number of mines doubled.

After the boom of gold production in Peru 1897 the main gold mines in Peru were in Puno (Sandia and Carabaya), in northern and central Peru and in Junin (Chuquitambo) and Casapalca. After 1878, in the 1890s came the fall in the price of various minerals, affecting the production of minerals, such as the fall in the price of silver in 1892 (Deusta 2018), that as we can see in chart N°1 affected the number of mines and led to the substitution of minerals for new ones such as copper, benefitted also by the operation of the train in 1893 and the polymetallic extraction in la Oroya, providing production with a new structure and promoting the search for new natural resources. The mining boom is displaced by the cotton boom, as already mentioned above.

2.2.2 Environmental Liabilities

According to the National Inventory of Environmental Liabilities, Peru has 8616 environmental liabilities (MINEM 2015 cit. MINAM 2016: 133), a problem that dates back from colonial times (Díaz Palacios et al. 2016: 133). Furthermore, colonial mining increased levels of water and air pollution severely (MINAM 2016: 139), specifically mercury contamination from the Potosi mine had a considerable effect on the Pilcopayo (75%), Amazon (20%) and Desaguadero (5%) watersheds (Ogawa 2008 cit. MINAM 2016: 136–137). These argentiferous minerals also contain arsenic, lead in addition to mercury (MINAM 2016: 137). According to the data recorded in the Quellcaya glacier, the mining activity in the Inca period (1438–1532) did not generate a significant amount of contamination (MINAM 2016: 139).

2.2.3 Scientific Theories About the Extraction of Resources

There has been much discussion on the role of resources in development. One of the interesting theories that applies to Peru is the Resource Curse theory postulated by Richard Auty, 1993. This theory argues that countries with economies dependant on non-renewable resources do not develop their economies based on the taxes of the population, but rather make the country's economy dependent on mineral prices, thus, they neglect to provide the basic services for which any State ruled by law is responsible, such as health and education, generating an inequality gap between social groups, since the State does not regulate inequalities through basic services, leaving the responsibility to fulfil this role to the mining companies, role that is not actually theirs. Consequently, the State depends on the capital of the companies that take on the State's role and loses its independence. There are then great differences among the different sectors of the population causing conflicts due to inequality as well as the differences in cultural visions. Therefore, environmental problems can become great conflicts.

2.3 Soil Resources: Agriculture

Soil is a resource that is closely related to agriculture.

2.3.1 Soil

The process of soil formation is very long, lasting hundreds of years, and the time it takes to form depends on physical-environmental and biotic factors. Actually, its formation is much slower than its destruction. The geology of the space as well as its morphology define its characteristics. In this process, the environment and the slope play a fundamental role. It is estimated that around 0.7% of the world's cultivated area is lost annually due to erosion (Miller 1994). In fact, in Peru, the steep slopes of the Andes and the accelerated deforestation of the Amazon make the erosion process considerably faster than that of soil formation. Since the soil is not covered, it is dragged by winds, rivers and rainfall, causing landslides and forming gullies. Poor water management is another cause of soil deterioration.

The quality and use of Peru's soil is not the same throughout the country. Inadequate soil use causes soil loss. The vast majority of Peru's territory is not suitable for agriculture, with large areas of desert on the coast and forest in the Amazon. There is a map of "Land Use based on the top natural fertility of the soil" (ONERN 1985) updated by INEI (2012) which classifies land in terms of its natural fertility to enable an improvement of its use. It shows that land suitable for seasonal crops only covers 3.81% of the national territory and land for planting permanent crops such as fruit trees or coffee is 2.11% of the territory. If we add these two figures together, we are surprised to find that only 5.92% of Peru's land can be used for agriculture. Thus, the average amount of agricultural land per inhabitant in Peru is 0.3 hectares. This is alarming if we take into account that feeding a family of 6 members requires 3 hectares in the highlands and coast, and 10 hectares in the rainforest. With the use of technology for irrigation as well as agricultural machinery, this percentage has grown enormously. Agricultural land use has reached 30.1% of the Peruvian territory.

Regarding other land uses according to this classification, 13.94% is for grazing, 38% of the land is suitable for forestry production and 42% is protected land. The other less important uses for land include activities such as tourism, industry and/or mining. This classification includes deserts, which have grown enormously.

Inadequate agricultural land use, contamination by pesticides and fertilizers, inadequate mining, and overexploitation of aquifers, among others, have serious repercussions on soil quality.

2.3.2 Agriculture

According to the last national census, Peru's agricultural land is equivalent to 30.1% of Peru (38,74242464.68 ha) (INEI 2012). Of this 30.1%, 11.5% is located on the coast (INEI 2012). The expansion of the agricultural area of the coast is mainly due to water management, irrigation infrastructure and dams.

Many of the coastal valleys have pockets of water; overexploitation of the aquifers leads to their depletion and the deepening of the water table. In areas close to the sea, the sea enters the water table and the water becomes saline and loses agricultural quality. The salinity of the soil, together with the high temperatures and the lack of rain that characterizes the coast, causes high evaporation, which leads to an increase in surface salts. Soil salts found in deep areas are carried along with evaporation to the surface, increasing the salinity of the topsoil and damaging the quality of the soil.

On the coast, agriculture is highly technified. There are traditional crops and export crops. The main traditional crops are sugarcane, rice, cotton and starchy hard corn for fattening cattle from the highlands. The most important export crops are asparagus, paprika peppers, organic bananas, mangoes, grapes and olives.

The Andes are characterized by a drastic change between day and night temperatures. Since there are frequent night frosts, agriculture is always at risk. Partly this is the reason for land parcelling and the use of different altitudinal levels in highland agriculture. The presence of crops on different altitudinal levels allows for a diversity of types and crops. This reduces the risk of losing all the harvest, since some of the areas with different types and crops could survive (Golte 2001). The soils are acidic due to their volcanic origin. In the highlands, more than half of the land has a steep slope that accelerates soil erosion. The areas with lower slopes are used for cattle grazing, but there is overgrazing in the highlands (see Chap. 10).

The rainforest is very varied, while the lowland rainforest is flat, the highland rainforest has steep slopes. The high acidity and low fertility of the washed and dragged soils make fertile agriculture difficult. This is why the traditional agriculture of the jungle is an extensive agriculture in which the populations combined agriculture with the extraction of plants and hunting of forest animals. A transhumant agriculture, in which the populations move from place to place, allows the soil to recover. Nowadays, when living conditions have changed drastically, the forms of production include agroforestry systems which include agriculture with forestry, combining the three strata: arboreal with trees such as cedar, mahogany and others, shrubs such as banana, coffee, tea, cacao, achiote or coca and finally the low stratum with plants such as corn or beans.

2.4 Biodiversity Resources: Forests

Biodiversity is defined as the variety of ecosystems, species and genes within a population. The importance of biodiversity is not in the number of species that the ecosystem possesses, but how it adapts to the environment. Spaces with very large variations in topography cause great diversity, which is why Peru's spatial variability is reflected in the multiplicity of ecosystems with their own characteristics and species. The number of diverse genes that each species possesses determines the population's capacity to respond to changes. Ecosystems with very few individuals per species are fragile and, therefore, can be easily destroyed by resource extraction, depending on the genetic variability of the population. Peru has enormous potential for biodiversity in its forests. These have trees, but also fauna and flora that are little studied and represent an enormous potential.

The tropical rainforest is one of the most biodiverse and fragile ecosystems. It provides man with multiple resources, such as wood, fuel, genetic resources, medicinal plants and meat, among others. But its main importance lies in purifying the planet's environment by absorbing carbon dioxide in the photosynthetic process. The Peruvian rainforest represents about 60% of the country's territory and possesses an immense amount of forest and wildlife resources. For the Amazon rainforest, it is estimated that there are about 65,000 different plants harbouring 56% of the world's tropical forests and 60% of the planet's living beings (Brack and Mendiola 2000). An area of ten square kilometres of tropical rainforest can contain up to 750 tree species (Smith and Smith 2001: 503). The highland rainforest, due to complex topographic factors, has a greater diversity of ecosystems (Brack and Mendiola 2000: 205).

It is a very fragile ecosystem, since it has very few representatives of each population. Therefore, it must be used in a planned manner which must consider the renewal of felled trees, the conservation of natural areas and ecological corridors that intertwine ecosystems and allow the conservation of species in case of catastrophes and fires. In order to protect the forests, 17% of Peru's territory is under the category of Natural Area Protected by the State.

2.4.1 The Forest in Peruvian History

Although Peru still has a large expanse of forests, deforestation dates back to colonial times, when wood was used as a source of energy, construction, agricultural expansion and forest exploitation (Díaz Palacios et al. 2016: 185–186). Deforestation was concentrated in areas of higher economic production (Seminario and Zegarra 2014, cit. Díaz Palacios et al. 2016 185). Much of the forests were disappearing and it was necessary to resort to increasingly remote areas to obtain firewood, both for the city of Lima (Díaz Palacios et al. 2016: 191), as well as for the mining areas of Potosí and Huancavelica (Díaz Palacios et al. 2016: 193). This is why Andean grassland (ichu) is resorted to as an energy resource as nearby forests deteriorated (Rey de Castro 2011, p. 16 cit. Díaz Palacios et al. 2016: 193). The forestry industry is developed in Peru only when the forests in Central America are depleted (Díaz Palacios et al. 2016: 200). At first even cedar wood was imported from Nicaragua and Guayaquil (Mateos 1964, p. 280 cit. Díaz Palacios et al. 2016:207). During the colony and the early years of the republic, cedar exploitation concentrated on the Andean species of cedar or cedro de altura *Cedrela angustifolia, Cedrela montana, Cedrela weberbahueri* and *Cedrela lilloi* (Díaz Palacios et al. 2016: 216). Such is the case in Cusco where cabinet making used the local forest cedar coming from the highland rainforest (Díaz Palacios et al. 2016: 216). The exploitation of cinchona (chinchona) forests in Peru dates from the late eighteenth century when the Loya cinchona forests were seriously damaged (Jaramillo and Carrera, n. f cit Díaz Palacios et al. 2016: 203) until the mid-nineteenth century when cinchona forests were planted in the island of Java with seeds brought from Ecuador (Díaz Palacios et al. 2016: 205).

Uncontrolled extraction of rainforest timber dates back to the rubber era between 1879 and 1912 (Cushman 2018). The first large-scale exploitation of rainforest timber was in Iquitos with the Astoria sawmill and in 1956 when the Sociedad Maderera Ciurlizza Mauer Ltda. was founded, with its headquarters in Lima (Dourojeani 2009: 45). In addition to rubber, other forest species such as palo rosa (*Aniba rosea-dora*) and copaiba (*Copaifera paupera*), among others, were exploited during the rubber boom, which is why in 1947 and 1948 regulations were passed to prevent the destruction of these species (Dourojeani 2009: 44).

2.4.2 The Forests and Biodiversity Management

The tropical rainforest is one of the most biodiverse ecosystems. It provides man with multiple resources, such as wood, fuel, genetic resources, medicinal plants and meat, among others. But its main importance lies in purifying the planet's environment by absorbing carbon dioxide in the photosynthetic process. About 40% of the national territory is occupied by tropical rainforests. It is a very fragile ecosystem, since it has very few representatives of each population. That is why its use should be planned and should include the renewal of felled trees and the conservation of natural areas. We have 17% of Natural Protected Areas, but they are poorly conserved.

2.4.3 Forests and Climate Change: Forest Fires

Today we see how many forests in southern Europe are burning; the fires have reached incalculable dimensions covering Spain and Portugal. The number of fires in Brazil, Bolivia and Peru has also increased. This is a global catastrophe; the lungs of the world are being destroyed. When the forests burn, they emit greenhouse gasses, increasing the emissions of carbon dioxide and in the long run, decreasing their absorption. This leads to a new situation in which together with the rise in global temperatures and carbon dioxide emissions from cities and industry we also have the decrease in the absorption of green gasses by the forests.

In Peru, the main cause of deforestation is the change in land use for agriculture and livestock, land invasions which cause the loss of forest, anthropogenic fires for forest clearing and weed control, in addition to natural fires caused by rising temperatures. Deforestation through skimming wipes out the most valuable species; this is not reported in figures, we only monitor the forest area and do not analyse the quality of the forests.

Nowadays, forest fires can be prevented. In most forest countries, there are early warnings of the danger of fire such as the humidity of the air caused by the evaporation of the trees and the direction of the winds, among other factors. Although Peru has a large part of the planet's green lung, there aren't early warnings of fire. However, the Fire Prevention Plan of the Ministry of Agriculture and Irrigation contributes somewhat, but we require a more dynamic proposal in which SENAHMI should play a key role. We must prepare for what is already evident: the increase in temperatures worldwide, and undoubtedly also in the Amazon. There are still very few meteorological stations with real-time data, which is a priority for the country, given the increase in the frequency of fires. This requires investment and perseverance on the part of the government and the population.

There are techniques to reduce fire spreading such as the creation of corridors. Furthermore, dry branches should be cleared through adequate felling management. When an area is consumed by fire, the forest can be restored with fire-adapted species, as explained by Johann Goldammer, director of Global Fire Monitoring (Euronews 22/7/22). Reforesting should be done with less combustible species to avoid the future spread of fire. Even though there would be a different diversity of species organized differently as well, we would have a reforested Amazon rainforest. If we do not act, the scenario will become more and more persistent.

There are ecosystems that have a fire climax, which allows them to store nutrients in spaces where it is not possible for organic matter to decompose in any other way: due to lack of water in the case of deserts, temperature in the case of high Andean ecosystems, or oxygen in the case of wetland areas, so to encourage fires, plants develop phenols, wax and oils. Each tree has other components, resins, various more or less combustible; when replanting we should analyse the plant's composition to avoid replanting those that are more combustible.

To protect the habitat, we must take into account the principles of the landscape: the size of the patch to be restored, the connectivity between spaces, the new species diversity and the corridors, since these allow connectivity. If we do, we can achieve new restored forests less sensitive to forest fires. We will only reach this objective when the ecological processes are restored, all of which takes time. Maintaining natural ecological processes such as predators, fire and flooding allows a balance of opportunities for all species.

In the restoration we use umbrella species because they trigger the processes and protect other species. In the Amazonian forests the jaguar and the cedar are umbrella species, in the inter-Andean forests the spectacled bear is one.

2.5 Sustainable Development and Natural Resources

For many years, there has been a debate on the possible definitions of the term “sustainable development”. The discussion began with the publication of The Brundtland Report, published in 1987 and entitled Our Common Future. The Report was presented to the UN by the then Norwegian Prime Minister Harlem Brundtland and prepared by several countries. This document defines sustainable development as follows:

> Sustainable development is the development that meets the needs of the present without compromising the needs of future generations.

The Intergovernmental Panel on Climate Change created by the UN in (1998) after the report, recognizes the anthropogenic origin of Climate Change.

In 1992, the United Nations Conference on Environment and Development, known as “Rio 92”, drew up Agenda 21, which proposes how to apply the concept of sustainable development. This agenda draws attention to the global environmental situation and recognizes the anthropogenic role in the process.

The specific mechanisms of Agenda 21 are particular to each country; in Peru, the Ministry of the Environment is responsible for its application. The Agenda establishes 3 mechanisms of action to be fulfilled at the extent determined by each country. The tools that allow the agenda to materialize are:

1. Carbon credits that allow trade of emissions among the signing countries.
2. Clean Development Mechanisms that certify the reduction of emissions.
3. Exchange of projects among industrialized countries.

In the year 2000, the UN proposed the Millennium Development Goals as an agenda for Sustainable Development. These are concrete objectives that should lead the world towards sustainable development. The Millennium Development Goals are:

1. Eradicate extreme poverty and hunger.
2. Achieve universal primary education.
3. Promote gender equality and empower women.
4. Reduce mortality of children under 5 years old.
5. Improve maternal health.
6. Combat HIV/AIDS, malaria, and other diseases.
7. Ensure environmental sustainability.
8. Promote a global partnership for development.

The 2005 United Nations World Summit concluded that the concept of sustainable development should be based on three interdependent concepts:

- Social Development.
- Environmental Protection.
- Economic Development.

In 2015, the Millennium Development Goals were replaced by the UN Sustainable Development Goals and the environmental policy is focused on their fulfilment.

2.5.1 Sustainable Development Objectives

The seventeen Sustainable Development Goals (SDG) are broader in scope and each country determines the emphasis of their application. They are based on the same principles of sustainable development in the sense that to reach sustainable development it is necessary to overcome basic social problems like governance, insecurity, social and gender equality, health, illegality in order to finally focus development on the preservation of the environment.

The SDGs are:

1. End poverty.
2. End hunger and achieve food security, improve nutrition and promote sustainable agriculture.
3. Ensure a healthy life and promote well-being for all ages.
4. Ensure inclusive, equitable and quality education and promote lifelong learning opportunities for all.
5. Achieve gender equality and empower all women and girls.
6. Ensure water availability and sustainable water management and sanitation for all.
7. Ensure access to affordable, safe, sustainable and modern energy for all.
8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.
9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.
10. Reduce inequality within and among countries.
11. Make cities and human settlements inclusive, safe, resilient and sustainable.
12. Ensure sustainable consumption and production patterns.
13. Take urgent actions to combat climate change and its impacts.
14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development.
15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation and halt biodiversity loss.

16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all, and build effective, accountable and inclusive institutions at all levels.
17. Strengthen the means of implementation and revitalize the global partnership for sustainable development.

Taking into account these 17 SDGs, Peru has established 241 indicators with 169 targets that are monitored by the Strategic Planning Center (CEPLAN) and the National Institute of Statistics and Informatics (INEI). The full report can be found at the following link: https://www.ceplan.gob.pe/wp-content/uploads/2016/12/Objetivos-de-Desarrollo-Sostenible-ODS.pdf.

The two main *challenges* on the agenda for ecosystem sustainability in Peru are:

- Thermal stress in the Amazon: as estimated when the average temperature in the Amazon rose, the extinction of species will be determined by their level of tolerance. Faced by this scenario, changes have to be monitored and ecosystems have to be protected by not letting the Amazon desertify. In order to do this, it is important to consider species that can survive and ensure the survival of biotic interactions. Therefore, the continuity of ecosystems and landscapes has to be ensured with a thorough monitoring of ecosystems and landscapes as well as the planning of ecological corridors, fragmentation and communities.
- Andes deglaciation: glaciers in the Andes are melting at full speed, anticipation of the effects of their deglaciation in the highlands should be a priority to prevent changes and damage to local populations. Monitoring is required to foresee the vulnerability of populations and ecosystems.
- Changing water regimes on the coast: climate change and deglaciation on the coast will modify the water regime. In the first stage, we will have large amounts of water due to the melting of glaciers, followed by a decrease in river water once this stage is over. Agriculture in both the highlands and the coast will have to be planned and adapted to these changes. It should be noted that due to the rise in temperature, the line of agriculture in the highlands will rise, reducing pastures, which will result in the loss of carbon stored in the moorland and an increase in greenhouse gasses (GHG).

All of the above entails several challenges for ecosystem management and research, with real-time monitoring and data systems being essential.

2.6 Summary

Throughout our history there have been several mining booms, which have definitely influenced the development of the country. However, the current mining industry can feel the repercussions of the prejudices that have also existed historically. The social differences between rich and poor are abysmal, creating great conflicts and unsatisfied expectations. The population does not feel part of the State. To change this vision requires the development of institutions by the State.

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Chapter 3
Classification of the Peruvian Ecosystems

3.1 Introduction

The diversity of ecosystems depends on a series of factors. One of them of great importance in the Andes is topography. The more rugged the topography, the more variety of spaces there will be for different species and ecosystems to develop. The high altitude and slope of the Andes is a major factor that generates biodiversity. This explains the greater diversity existing in the high jungle areas compared to the low jungle. Other factors that are essential for biodiversity are the changes in climatic conditions, the variable temperature throughout the year, high humidity and precipitation conditions as well as enough oxygen in the soil to ensure decomposition. The isolation of spaces with variable conditions as those generated by the diversity of spaces is a prime factor in the Andean-Amazonian spaces. This is why we find a diversity of ecosystems and endemic (unique) species in the highlands, especially in the inter-Andean areas. Chapter 4 describes the diversity of Peruvian ecosystems and the conditions that cause it.

3.2 Diversity

3.2.1 Intermediate Disturbance Theory

The Intermediate disturbance theory, described by Cornnel (1978), mentions that disturbance is necessary to cause diversity. This leads to changes in the ecosystem and enables to maintain regional diversity. However, according to Cornell, when disturbances are excessive and they do not allow species to regenerate they lead to a reduction of diversity. These disturbances that alter the ecosystem directly affect the competition among species, leading to changes and preserving genetic diversity.

A. Sabogal, *Ecosystem and Species Adaptations in the Andean-Amazonian Region*, https://doi.org/10.1007/978-3-031-44385-5_3

Internally, each ecosystem needs to renew because without renewal it cannot ensure the recycling of nutrients, therefore, the renewal ensures its continuity. Depending on the ecosystem and its limitations, when a renewal begins it may be seen as a disturbance and damage to the ecosystem since diversity decreases temporarily. However, renewals help with the survival of species and temporarily modify the competition between species. Thus, for example, fire is necessary in the northern Peruvian dry forest and moorland ecosystems, since it ensures the recycling of nutrients in conditions where water, in the first case, is a limiting factor, or cold, in the second. In both cases, fire is generated by the concentration of alcohols and oils that the species produce as a consequence of evolution and adaptation to the ecosystem.

3.2.2 The Theory of Island Geography

Several authors have studied the factors that define biodiversity. MacArthur & Wilson defined the *theory of Island Biogeography* in 1963 according to which the number of species depends on immigration and extinction; there is a point of equilibrium between these two factors in the sense that in one space new species can only arrive if others become extinct (Smith and Smith 2007: 320). The factors that define this limit are determined by space and the possibility of finding free niches, but they also depend on the characteristics of the new individuals and their capacity to displace the previous ones. The conditions in which the species lives and all the factors that allow its development make up its Ecological Niche. Each species has ideal conditions that allow its development; it is called an ideal niche. However, it is rare for species to find these ideal conditions. But species are not alone in the ecosystem and compete with others. When the factors are within the range of conditions in which the species can develop, it is called an Achieved Niche. So competition plays an important role since the niches are occupied. Thus, the Theory of Island Biogeography establishes that diversity has its limitations.

In the first stage of space occupation the genetic characteristics brought by the individuals will allow or not their adaptation and installation in the space. These characteristics are the basis of the Founder Effect theory. The genes brought by the individuals to this new space in the long term will moderate evolution. This founder effect depends on the specific genes and the number of diverse genes that individuals migrating to the new ecosystem may carry. Evolution occurs as a result of the interaction between the individual and the environment in which it lives. If the number of genes and individuals is limited, it is likely that recessive characteristics will be expressed by inbreeding (Smith and Smith 2007: 281). This characteristic will be shaped by the environment. As a result, genetic drift may occur leading to directional selection which in turn will allow the formation of new ecotypes and then, over time, new species. Ecotypes are thus the phenotypic expressions of genetic groups under specific environmental conditions (Curtis and Barnes: 1017). However, genetic drift will lead to a decrease in the variety of genes in the population and thus reduce genetic variation by favouring a group of genes that appear in smaller numbers in the original population. This selection will depend on environmental conditions. That is why for a population to survive in a space it requires a minimum viable population, especially if the space is isolated and there is no communication with other individuals of the population (Smith and Smith 2007: 283). The result of natural selection is the adaptation of the population to the environment (Curtis and Barnes: 1017).

3.2.3 Growth Strategies

The diversity of an ecosystem will depend on both species and environmental factors. Along these lines, species have two survival strategies inherent to their biology; they have evolved in a certain environment and they depend on competition. Thus, we can identify generalist species, which have gone through a simpler evolutionary process, and specialist species, which are more specialized. These strategies are directly correlated with the stability of ecosystems. Therefore, when ecosystems are stable and close to the maximum diversity of the ecosystem, specialist species increase, always coexisting with generalists. However, in every ecosystem we find both generalists and specialists, since every ecosystem has communities that are in different stages of ecological succession or ecosystem development. We define both strategies as follows:

- *Generalists (R-strategist):*

These species have a high reproductive rate with a large number of offspring. They have a very short life span and reach sexual maturity very quickly, dedicating little or no care to their offspring. The strategy of the generalists consists of using all their energy to make the most genetic combinations to ease adaptation to environmental changes. Therefore, even though they have many offspring, their mortality rate is high. The generalists colonize the space after the disturbance of the ecosystem and facilitate the conditions for the arrival of the specialists. Populations that present this type of strategy are bacteria, algae, rodents, ferns, annual plants and insects.

- *Specialists (k-strategists):*

These species have a low reproductive rate and a low number of offspring. They dedicate a large part of their lives to breeding, thus reducing the risk of death of their offspring and ensuring that the greatest number of young individuals reach the adult stage, which in turn reduces the expenditure of energy invested in the creation of new offspring. Populations that present this type of strategy belong to high links in the trophic chain, such as the populations of felines, bears and wolves, among others.

3.2.4 Evolutionary Process

The evolution of species is a long process that goes through speciation and results in environmentally-adapted species. However, as we are dealing with a process, many attempts at speciation and adaptation are either in the stage of speciation which means still forming new species, or are attempts that will eventually fail to adapt and become extinct. In this process, populations constantly modify their genetic distribution, which depends on competition between and within species. The Red Queen Hypothesis refers to the constant competition between species to survive in an environment. Thus, species can survive only if they constantly adapt and change (Curtis and Barnes 1993: 995). In contrast to this hypothesis, the Tangled Bank hypothesis refers to the need for diverse environmental conditions (Curtis and Barnes 1993: 994). As mentioned above, species have two strategies; constant genetic recombination as well as a large number of progeny which is typical of the generalist and allows a rapid recombination, essential in environments with great alterations, or speciation that ensures the survival of species in an already stable environment. Both strategies occur at the same time in every ecosystem, ensuring diversity and survival in the environment.

The evolutionary process goes beyond the temporality of the ecosystem. Speciation, or species formation, is a long process that occurs within ecosystems but transcends them. Speciation can originate by competition (sympatric speciation) or by separation of spaces (allopatric speciation). In this sense:

- *Allopatric speciation*: the formation of new species as a consequence of the geographic separation of a population, preventing the original individual from mating with one another. Part of the genetic diversity lives under the new conditions subjected to new limitations, the other part remains in the same space.
- *Sympatric speciation*: the formation of a new species that occurs when a population explores a new ecological niche through competition, for example, looking for a new space in the ecosystem or a new type of food, becoming different from the previous population, finally forming a new species as a result of the process.

Speciation is correlated to limiting conditions. In ecosystems such as the northern Peruvian dry forest, where there are limiting conditions like lack of water, species must develop very specific mechanisms in order to survive. Such is the case of the carob tree (*Prosopis palida*)which has roots that reach great depth to get underground water to survive, and seeds that can wait for years for the arrival of the El Niño event to germinate (Sabogal 2009). Under these conditions, genetic drift will favour directional selection, reducing genetic diversity and favouring genes that are of lower value in a population. Thus, over time, genetic diversity will be reduced.

In the case of the Amazonian ecosystem, competition plays a fundamental role in the formation of new species. Such is the case of the diversity of birds that, in order to reduce competition, explore new strata within the ecosystem. Thus we find birds that are located in the high stratum such as the harpy eagle (*Harpia harpyja*), the middle stratum of the crowns such as the macaw parrot (*Ara ara arauana*), the middle stratum of the trunks where we find the woodpecker in its various species and the low stratum of the understory where we find the trumpeter (*Psophia cripitans*) (Brack and Mediola 2000: 227).

3.3 Landscape

In order to understand how an ecosystem develops, we must understand that it is influenced by both space and time and that ecosystems form a set of landscapes. According to the hierarchy theory, there is a relationship between temporal and spatial scales. Furthermore, phenomena that develop in large areas are slower than those that develop in small spaces. According to the size of the ecosystem and applying the theory of the Biogeography of the island, to reach the maximum biodiversity of a space, it requires a period of time in relation to its size. If we think and compare two ecosystems of different sizes such as the immense Amazon jungle and the inter-Andean forest isolated by the mountains, we see that while the Amazon jungle is characterized by its biodiversity, the inter-Andean forest stands out for its endemism.

This same theory of hierarchy puts emphasis on the interaction between the factors that define ecosystem processes with a broader view than the ecosystem, taking us to the scale of the landscape when it mentions that the higher levels define the processes, while the lower levels define the limiting conditions. Thus, if we analyse a river, we see that it is formed by diverse tributaries, just as a biome encompasses several ecosystems, and an ecosystem has many communities that have a diversity of species. The changes at the lower levels or scales will be greater, while as we go up the scale the changes are slower. All this helps us understand the differences in the scale of analysis and the interactions that go beyond the ecosystem and have an effect on it as well as the processes that occur within it. It is important to point out that phenomena with different speeds of interaction actually interact very little. Thus, although the formation of the Earth's crust is decisive for the formation of the ecosystem, it is altered by intermediate processes that modify its natural state and define the type of soil in the ecosystem. Therefore, not all processes are intertwined; this depends on the scale of the processes and the limiting conditions.

The Percolation theory applied to a landscape (author, year) makes reference to the connectivity of the landscape and its elements. The elements of the landscape are connected, so there is an influence of their distribution and connection between the spaces of the landscape. The elements or factors influence or percolate into the surrounding spaces. The same theory applies to disturbances or alterations of the landscape. Such is the case of deforestation or selective logging in the Amazon rainforest. This influence will depend on a series of factors and on the characteristics of these factors and the dimension of the impacts. The results are therefore multiple. In order to predict and reduce the randomness of the effects, factors are classified and similar groups are grouped together, considering the connectivity between them (Turner and Gardner 2015). Changes in landscape and connectivity modify the connection between populations, and landscape fragmentation can have an impact on the group of populations in the landscape (meta-population), especially if populations are only subsisting. Each landscape has its own organization, following specific patterns and processes. A new organization can emerge from them as a consequence of their own organization (Turner and Gardner 2015).

The discontinuity of nature's patterns causes gaps in the landscape that allow for the migration of plants and animals by freeing or modifying spaces (Higgins and Stearns 1993, cit. Turner and Gardner 2015). The causes of altered landscape patterns can be multiple, local inequities, deforestation, and overgrazing, among many others. Such is the case of the Peruvian moorland, where overgrazing has modified biodiversity conditions, leading to the development of new resistant species.

In an ecosystem and when studying the landscape, the Prisoner's Dilemma applies, which refers to the advantages that individuals gain from cooperation. By cooperating both within the ecosystem in communities and within populations, individuals and populations increase their chances of survival if they help each other. As in a game, in inter-species relationships and within populations, cooperation allows the maximum advantage for the population as a group.

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Chapter 4
Peruvian Ecosystems Geography

4.1 Introduction

The mountain ecosystems of the Andes are still in constant transformation. The rise of the Andes was caused by the collision of terrestrial plates, and the folding of the oceanic plate beneath the South American plate, which led to volcanic explosions. The high volcanic activity of the Andes is a consequence of the angle of convergence of the oceanic plates and the subsequent fusion of the mantle of the plates. The volcanic origin of the Andes is the cause of the great richness of minerals in these mountains. The Andes are young mountains with steep slopes. Consequently, there is a high level of erosion which leads to very rich soils since erosion carries azonal soils to the high plateau where they combine with the zonal soils of the area.

Defining the Andes is more difficult than it may seem. Above all, speaking specifically from an ecological point of view, the Andes have a large number of ecosystems in a small space due to the changing altitudes and formation of valleys, which modify the climatic conditions that define ecosystems. Therefore, although the classical definitions of altitude and latitude should be considered, they should be seen in a separate context. Other parameters should also be included in the definition such as *micro-climatic* factors which can strongly determine climate. Among them, the most important ones are topography, wind, evaporation and consequently humidity, rain shadow phenomena, and thermal inversion. All these aspects modify the conditions of space and are essential to defining the ecosystems.

One of the problems of ecological studies is that many of the classifications made for Peru are local and, therefore, cannot be integrated into global ecological theories since they do not consider the aforementioned micro-climatic aspects, important not only for Peru but also for other geographical areas with mountains. For this reason, it is necessary but difficult to have an ecological classification that considers universal parameters and can be compared to other ecosystems in the world.

A. Sabogal, *Ecosystem and Species Adaptations in the Andean-Amazonian Region*, https://doi.org/10.1007/978-3-031-44385-5_4

4.2 Peruvian Ecosystems Geography

One of the interesting approaches for the ecosystem classification is the definition of Life Zones, proposed by Holdridge. According to this author, a Life Zone is defined by the parameters of precipitation and bio-temperature, which in turn determine the potential evaporation. Biotemperature is calculated and recorded hourly and if this data is not available, the temperature is multiplied by the altitude, taking into account the direct relationship between altitude and temperature. Thus, three parameters define the Life Zones: bio-temperature, humidity (potential evaporation), and altitude defined by Holdridge, 1967. Potential evaporation is also correlated with altitude as it depends on air density. In this study, Holdridge defines 120 Life Zones, 84 of which can be found in Peru, due to the complex ecosystems there are. This classification is currently used for ecological and environmental impact studies.

In 1967, Javier Pulgar-Vidal proposed an interesting but local approach that defined eight Natural Regions determined by areas with similar environmental factors in terms of climate, relief, soil, subsoil, underground and continental waters, the sea, flora, fauna, latitude, and altitude, in which man plays a vital role. According to this classification, the highlands are divided into the Natural Regions Quechua located between 2300 and 3500 m.a.s.l., Suni or Jalca located between 3500 and 4000 m.a.s.l. Puna, located in the elevated plain between 4000 and 4800 m.a.s.l. and Janca or Andean foothills with perpetual snow located between 4000 and 6768 m.a.s.l. The importance of the definition and classification of Peru into Natural Regions is that it considers the use of Natural Resources, which in later classifications is lost. However, by limiting ourselves to the division of the Andean ecological area into Puna, Hanca, Suni (Halca), and Quechua, we simplify the complex reality of this area defined by very diverse micro-climatic factors.

Two factors are key to defining the Andean area, climate, and altitude, and most authors consider them, Pulgar-Vidal (1996) and Dollfus (1981), among others. As in the rest of the world, in Peru, climate changes according to altitude. In Peru, due to the pronounced altitudinal variation in the Andes, this change is very marked which reflects on the adaptation and distribution of plants. However, the adaptations of plants at different altitudes, even at the same latitude, can be very different since they depend on the micro-climate.

Troll (1968) emphasizes that the Andean regional geography features geography with longitudinal and latitudinal variables that define the area. Troll coined the concept of ecotope, very specific to Peru, defining it as the smallest unit in the study of the landscape, made up of natural and cultural components. The ecotope is later resumed in the study of landscape, as landscape units that outline the bases guiding the development of a specific landscape, which are physical, biological, or anthropic (Troll 1966). In his studies about mountains, Troll emphasizes the change of climate during the day and night and defines the Andes based on its geographical position and ecological characteristics as an area marked by low temperatures and frequent night frosts. He considers it a climate of changing frosts, coining the German term

[Forstwechselkima] (Troll 1943 cit. Beck 2008), distinguishing the Andean ecosystems from ecosystems with changes in temperature throughout the year (Troll cit. Frey and Lösch 2004). The classification also considers natural resources, according to which the Andes have mineral resources in the higher areas and agricultural production of Andean grains and tubers in lower areas. Whereas the limit of inhabitants with permanent residence is at 5200 m.a.s.l., the limit of perpetual snow is at 5000 m.a.s.l., the limit area with variable frost is between 4700 and 3600 m.a.s.l., the number of frost days increases with latitude, as well as with altitude, which is between 4900 and 5000 where the number of frost days reaches 350 (Troll 1968). While the limit for agriculture is above 4000 m.a.s.l., we can also find the limit for the forest in the Andes which is replaced by the high Andean grasslands, situated at around 3600–3800 m.a.s.l. depending on micro-climatic factors. The slope, which influences the humidity, determines that above 4000 m.a.s.l., there is a considerable decrease in the number of trees (Lauer et al. 2003).

In this sense, Dollfus (1981) defines the Peruvian Andes as a climatic area determined by latitude, altitude, air density, geological substratum and soils, vegetation cover, and human activity characterized by little distance between ecological floors and with vegetation marked by high endemism. Considering these parameters, he defines the geo-systems formed by thermal floors (Dollfus 1981). He divides the geosystems into northern equatorial Andean geosystems, where there is high-altitude grassland or moorland, and southern tropical Andean geosystems, where there is high-altitude steppe or puna, both at similar altitudes (Dollfus 1981). While moorland is characterized by deep, humid peat bogs or morreras with a large amount of peat matter and higher humidity, the south has flat sedimentary and volcanic plateaus with lake formations and lower humidity (Dollfus 1981).

When Brack (1986) defines an ecoregion he includes soil, water, and flora conditions as well as fauna. Brack defines three Ecoregions for the Andean ecosystems: the steppe highlands, the Puna, and the moorland (Brack and Mendiola 2000). While the Puna is a dry and flat ecoregion, the moorland is also flat and humid and the Steppe Highland, located on the western flank of the Andes, has steep slopes.

Among the micro-climatic factors that determine the formation of ecosystems, the *thermal inversion* in the highlands' narrow valleys is decisive. Cold and frost increase with altitude, partly because the higher the altitude, the lower the air density and, therefore, the faster the cooling during the cold hours. However, the topography is a determining factor in the microclimate. In the narrow valleys surrounded by mountains, unlike in the puna, air circulation is minimal, producing a phenomenon known as thermal inversion. During the night the air close to the ground cools down, increasing in temperature with altitude, as the cold air descends due to its weight and replaces the warm air close to the ground. The warm air does not leave the valley as the mountains are high. The next morning, at sunrise, during the early morning hours, the air warms up and rises to meet the cold air and is temporarily trapped under the cold air. The humidity in the valley is much higher due to the lack of wind, so the valleys have much higher temperatures and allow for the development of a greater diversity of species and crops. However, they are surrounded by big mountains that produce isolated ecosystems and endemism (Fig. 4.1).

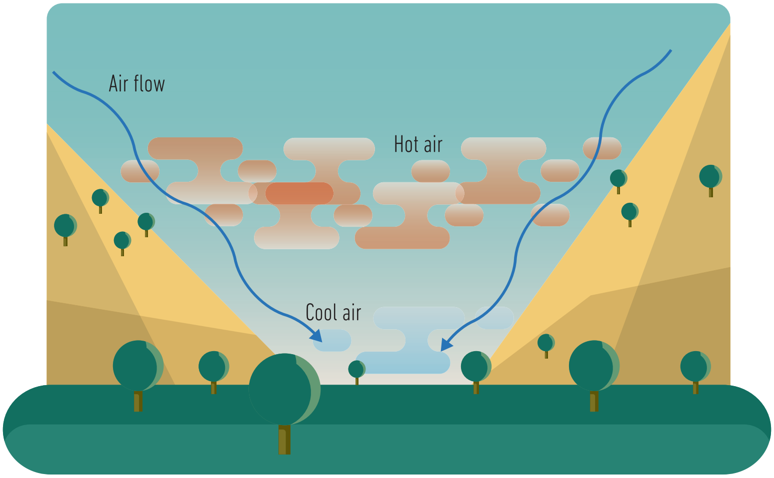

Fig. 4.1 Thermal inversion. (*Author* Ana Sabogal, designer Juan Pablo Bruno. *Source* Smith and Smith 2001)

Mountains cause the *Rain Shadow* phenomenon. They produce a micro-climatic change by stopping the moisture-laden wind. Under these conditions and since the ground is warmer than the air, as the cloud collides with the mountain it starts raining due to the condensation of the air caused by the change in temperature. This phenomenon allows vegetation to develop on the side of the mountain where the wind is stopped. On the opposite side of the mountain but higher up, as a result of the rain in the lower zone, the air is dry and the climate is cold. At the height where the wind stops and the air is full of humid air, the Andean forests develop but, higher up there is not enough humidity so grasslands form, however when the mountain is high, the air can be recharged with water again and produce forests again. For this reason, Andean forests have an altitudinal band defined by humidity and develop high Andean grasslands higher up. A forest cannot row in even higher, flatter, and drier areas due to the wind that causes low humidity. In the inter-Andean valleys behind the eastern and western mountains, the air is dry and as a consequence, dry forests with columnar cacti grow. These inter-Andean spaces are usually isolated because they are between high mountains, making it impossible for most species to cross. Therefore, in the isolated inter-Andean valleys, ecotypes and endemic species develop through natural selection (Fig. 4.2).

Microclimatic factors define the conditions for plant growth and consequently guide the presence of other ecosystem components. A primary characteristic of mountains is altitude, which affects many physical aspects of the environment that are a priority in the selection and adaptation of plants. In this way, with altitude the air density changes, the air is thinner and the oxygen and humidity content of the air is lower. This has an impact on solar radiation, increasing its intensity. Under these conditions, the change in temperature between day and night is greater. The intensity of sunlight and relative humidity is decisive in the adaptation of plants to

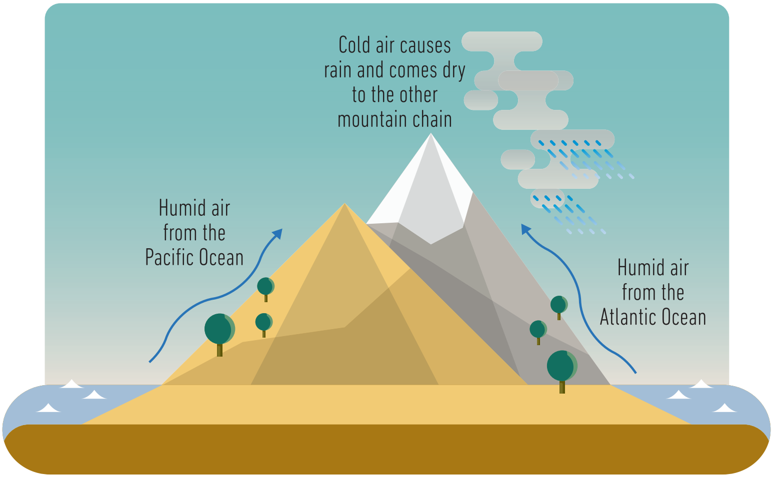

Fig. 4.2 Rain Shadow. (*Author* Ana Sabogal, designer Juan Pablo Bruno)

mountain ecosystems. The intensity and number of hours of light vary with the shade produced by the mountains, thus modifying the temperature. Furthermore, it may influence the hormonal composition of the plant.

The genetic selection of plants is determined by the intensity and timing of solar radiation and their resistance to low temperatures. Although the air temperature varies more rapidly due to the lower density of air, the soil maintains its temperature longer because of its higher density in comparison to the air. This is why the shape of the plants is decisive for their survival, hence, small plants that are tightly packed into the soil survive better.

The change in temperature throughout the day forces plants to *adapt* to resist both heat and cold and even frost. However, few species can adapt to frost. Plant adaptation is long and involves genetic selection, resulting in varieties adapted to live under these conditions. The adaptation process includes an ecological strategy in which the plants protect each other by forming compact groups of different species; in this way, they are better protected from the dry wind of the puna and can survive the night frosts. The plants also seek strategies directly related to the environment around them, so, for example, they grow on sun-facing slopes, where the shade of the mountains does not fall, in places close to stones, as these heat up during the day and give off heat at night, protecting them from frost.

When the air vapour in the atmosphere condenses, it produces dew in the early morning. The moment when water vapour turns into liquid is called the dew point. As the water near the leaves condenses when the temperature is the coldest, the water in the form of vapour releases temperature as it becomes liquid, radiating heat and protecting the plants. If the plant has serrated, corrugated or hairy leaves, it withstands low temperatures more efficiently, as leaf depressions or hairs trap the water from the air. Furthermore, rocks allow water to accumulate, keeping the temperature high (Pfitsch 2008).

Woody plants resist the cold best because they are compact and grow close to the ground or have underground organs that enable them to survive the coldest stages below ground. The xylem of woody plants can withstand temperatures as low as −40 °C by increasing the amount of pectin in the plant (Lira 1994). Underneath the frost-cracking points, the plant develops suberous parenchyma, which helps it to resist the cold. The leaves are the most sensitive part of the plant to low temperatures, whereas the buds are not only protected but also have a higher concentration of glucose and can survive. Another strategy used under these conditions by many plants, including cacti, is to coat the leaves with wax so that they can withstand the low temperature more efficiently. This is why we can find the Cactaceae family in the Andes since the wax on their xeromorphic leaves can withstand solar radiation (Lauer et al. 2003).

When a plant freezes, the water in it occupies more space, as the volume of the ice is greater than that of the water, which causes the cell to break and die. In response, the plant reacts by exporting the water from the cells to the intercellular spaces. However, as the water leaves the cell, the salts concentrate in it, and this increase in salts becomes a partial solution. The increase in salts delays the freezing point by increasing the osmotic pressure, but the pH changes, proteins precipitate, and the cell collapses and dies. Plants adapted to frost increase the amount of internal water and the production of sugars to delay the freezing point by increasing the number of leucoplasts, which store sugars in the form of starch. By doing so, the leaves can withstand temperatures ranging from −5 to −12 °C, depending on the variety (Plant Physiology book). The increased water concentration in the stems characteristic of cacti enables them to survive under frosty conditions since their modified leaves protect them from the cold. The organs most exposed to frost are the leaves; that is why the leaves of Puna cacti often have modified spines in the form of hairs to protect the plant from the cold.

In his botanical study, Gentry (1993) divides the Andes into three botanical areas, taking into account the botanical distribution, which is reflected in the altitude (Bracko and Zarucchi 1993). Thus, Andes I is located between 500 and 1500 m.a.s.l., where the most abundant families are Fabaceae and Moraceae, and the flora is similar to that of the lowland rainforest; Andes II is located between 1500 and 3500 m.a.s.l. with an abundance of woody species of the Lauraceae and Fabaceae families, whereas among the herbaceous species, we can find monocotyledons, including a large number of orchids; finally, Andes III is located between 3500 and 4500 m.a.s.l.; in this area, there are only woody species sporadically and the most abundant families are Asteraceae and Poaceae.

One of the few tree species that can be found in this area is the Queñual (*Polylepis* sp.), which can form small groves in the most protected areas. Other tree species such as *Azorella* sp., known as Yareta, typical of the central Peruvian Andes, grow in the form of compact, stunted cushions close to the ground, thus resisting the elements. The cushion-shaped growth form is typical of the Andes (Rundel 2008). It dominates in the northern and central Andes above 4000 m.a.s.l. (Rauh 1988 cit. Rundel 2008). The closeness of the plants to the ground prevents heat dissipation, so plants surviving above the cloud forest line are dwarf plants (Wilkinson 2009).

Fifty per cent of the cushion plants grow in the Andes (Schroeter and Hauri 1914 cit. Cleef 1978), most of them in the high Andes of Peru and Bolivia (Cleef 1978).

Orchids are species adapted to the limiting conditions of the Andes. They are monocotyledonous and can develop as epiphytes or lithophytes. The germination of their tiny seeds is associated with symbiosis with mycorrhizae of the genus Rhizoctonia, as the embryo is very small and the endosperm has collapsed. The symbiosis together with the large number of seeds per capsule, which can reach up to 4,000,000, are the strategy for survival. The mycorrhizae help the small embryo to quickly find food and survive. Their large leaves and thickened roots that form pseudo-bulbs allow them to accumulate water and nutrients to survive in the coldest periods, while the velamen that forms secondary roots serves as a root.

The Asteraceae and Poaceae families are even better adapted to altitude and cold. Among the Asteraceae, although mostly herbaceous, the predominant adaptive characteristics are the presence of latex or essential oils, and the rosette form growth which protects the meristem of the plants against the cold and dry wind at altitude and allows heat accumulation due to the parabolic effect of the geometrical shape of the rosette (Smith 1974 cit. Meinzer et al. 2008). For this reason, there is a higher accumulation of temperature when the sun's rays are parallel to the axis of the rosette, thus protecting the apex of the plant (Meinzer et al. 2008). The rosette form also modifies the shape of the plant, producing movement and therefore heat, as the turgidity of the plants varies with the heat of the day.

The rosette form raises the temperature of the plant by protecting the leaves, which in turn increases photosynthesis and thus plant growth (Rundel et al. 1994). Rosette plants protect the stem with thick bark and the young stem with dead leaves (Beck 2008). Low temperatures cause injuries at the base of the plants, dicotyledonous plants such as asteraceae or poaceae close injuries by producing thick bark. Only 11 % of the leaves on rosette plants are alive, the dead leaves allow the temperature of the plant to be maintained by creating a small microclimate (Verweij and Beckman 2008). These dead leaves also serve as food for the plants. The presence of acaulescent rosettes depends on the amount of wind (Cleef 1978). Where there is a strong wind, there are acaulescent rosettes, since they can protect themselves against the cold of the Puna. The typical forms of the elevated zone are the giant rosette, tufted grasses, acaulescent rosette, cushion plants, and hard-leaf.

The adaptive characteristics of the widely distributed Poaceae family are their protective leaves and their growth in compact clumps. In such a manner, the groups of plants maintain their internal temperature, and withstand the wind and the cold of the puna. Rauh, 1979, calls this growth form of the puna plants bunch grasses and puna grasses. These grasses dry out in the dry season and green up with rain (Rauh 1979). Dead leaves, which can be found in both rosette plants and poaceae, play an important role in protecting against low temperatures, as they allow water to accumulate at the base of the plants and, depending on the temperature, support soil fauna (Verweij and Beckman 2008).

Although some tree species can be found above 4500 m.a.s.l., this is not frequent. The forest is limited by temperature and water deficiency (Lauer 1981). This water deficiency is closely linked to temperature; when it is low, the rate of absorption is also low and even more so at freezing temperatures. The forest limit, thus, coincides with the decrease in water absorption (Lauer 1981). Below 2 °C root growth stops, resulting in physiological aridity; this explains the absence of vascular plants at these temperatures (Lauer 1981). Because of the cold, the roots are shallow, so most of them accumulate nutrients and develop a large surface network. As temperature is low throughout the year, plant growth is limited whereas tree growth is especially limited because trees are higher. This explains why, as the altitude increases, the size of the plants decreases, which is also the reason there are no forests in Andes III. Although reducing the number of stomata is vital to reducing evaporation and preventing water shortage, in the high Andes this is not the case since there is little carbon dioxide so stomata do not play such an important role. Under these conditions, vascular plants protect against cold and desiccation through the production of lignin (Wilkinson 2009).

Temperature can be regulated in herbaceous plants by the leaf. In this case, evaporation plays a vital role since plant temperature depends on it. Temperature determines the change of state of the water and the subsequent release of energy. The leaf temperature is regulated by changing the angle of leaf exposure which determines the amount of sun it gets and the leaf pubescence allows to change the movement of the air on the leaf surface (Wilkinson 2009). As long as the leaves can change their sun exposure angle throughout the day, thus varying leaf temperature, plant temperature can also change considerably depending on how close the plant is to the ground (Smith and Smith 2001). Ground temperature changes more slowly than air temperature due to density differences. In this way some plants can protect themselves below ground, such as the solanaceae family and other cryptogamous plants, keeping the cold away. The solanaceae like the potato have another adaptation quality which is the accumulation of starch and the pubescence of their leaves.

The altitudinal limit of plant distribution is also influenced by soil colour and the presence of rocks. Black soil or rocks allow a higher absorption of heat. The texture defines the water retention and the speed of temperature change. In this way, the altitudinal limit of the plants depends on many factors, among which we can mention the landscape shaped by the wind, the texture of the soil, and the amount of water.

4.3 Agriculture

Agriculture in the Andes is difficult due to the adverse climatic conditions, especially in the high plateau where, due to the wind and the intense cold, it is difficult to cultivate. One of the limitations of agriculture in the highlands and the reason for the altitude limit is frost. In order to cultivate on the high plateau, above 4000 m.a.s.l. the Pucara culture had to develop elaborate agricultural techniques. They would cultivate on the edge of oxbow lakes when the lakes did not have much water and had remains of decomposing vegetation. In these areas, the soils rich in organic matter and the microclimate generated by the oxbow lake would allow a good harvest. When the water on the edge of the oxbow lake freezes, it emits heat, creating a small microclimate that prevents the crops from suffering the consequences of frost. Another technique used in this area by the Aymara culture, following the same principles, was the construction of ridges, which were fifty-centimetre-deep grooves with water in them and crops planted on their edges. This agricultural technique used the heat released by the water in the ridges, which by solidifying and transforming from liquid to solid, prevented the frost from killing the crops.

In the Andes, agriculture has adapted to the slope, so the population has been able to cultivate this area under very difficult conditions. In fact, with the exception of the valleys, it is difficult to cultivate the Andean area without modifying it. Terraces are used for cultivation, avoiding frost, and maintaining temperature. Good management of the terraces makes it possible to vary the microclimate and to have different microclimates for cultivation. The management of the slope and the width of the platforms can vary the incidence of sunshine, rain, hailstorms, and frost, influencing the temperature and moderating frost. Platform width and irrigation have a direct influence on frost resistance. Since the terraces reduce the slopes, they have a direct effect on moderating erosion.

There are several techniques for building terraces. The most simple, with the least human intervention, uses sticks and hay on the edge of a slope to accumulate earth dragged by erosion.

Somewhat more elaborate terraces use stones to build walls and create a flat area that can be cultivated. Finally, there are also complex terraces used for elaborate agriculture, formed by placing stones of several sizes with the biggest at the bottom and the smallest at the top. The shape of the walls is trapezoidal in order to stop erosion. To allow easy movement between the terraces, some stones protrude from the wall, forming stairs. The base of the terrace is also shaped by stones, covered first by a layer of sandy soil, and then by one of fertile soil (Santillana 1999). This system offers good draining possibilities by connecting watering channels, as the water of the higher levels can be shed over onto the next level taking along nutrients and fertile soil. This is why crop rotation is considered for these terraces from the higher to the lower levels.

Andean agricultural management traditionally assigns allotments on different altitude floors for each family, which can assure a harvest in at least some of the spaces by growing several species and varieties (Golte 2001). The enormous diversity of potatoes, corn, and sorrel of many colours and flavours, is the result of this cultivation method. Since the Andes mountains have different exposure, the temperature may vary on each terrace, so a wide range of species may be cultivated. For this reason, the central characteristic of traditional agriculture in the Andes is that terraces are on different levels, also reducing the environmental risk of frost and loss of crops (Golte 2001). At the same time, this helps to avoid monoculture and the related outspread of plagues; after everything mentioned before, it is clear that terraces are an excellent agroecological strategy. However, the maintenance of the terraces demands constant intervention and labour with great physical strength, so as people have joined the market economy, they have abandoned them. Consequently, migration and rural abandonment have caused many terraces to lay barren nowadays.

It is important to mention that from the productive perspective, most of the Andes were populated as part of a process of conquest, first by the Incas and later by the Spaniards. Both conquests displaced the population from the Quechua region to the Puna and to the mining areas in the Hanca or ridges. These areas are hard to cultivate due to the extremely cold climate and the night frost that kills the plants. For this reason, the main activity in the Andes, besides mining, is the herding of camelid cattle. Camelids are part of the native fauna of this region, whereas sheep and, in lower areas, beef cattle have been introduced. However, none of the foreign species have adapted to the great heights, where only the camelids live in the wilderness.

In this area, migration is a survival strategy for small agriculture (Trivelli et al. 2010). Farmers use several different elevation levels to reduce the risks for the crops, sharing the work among the entire family, including adults and children. Another way to reduce the risks of the Andes and ensure the livelihood of the family is through seasonal transmigration circuits. Therefore, in times of drought, shepherds move to areas that still offer fresh grass. Quite often this means taking the cattle to the hilly ecosystems which are green from July to September, for example in Atiquipa, where the migration roads go from the hills back to the mountains of Ayacucho. In this way, the shepherds travel along these migratory routes, securing grass for their cattle. However, the migratory routes have been disappearing in these last decades because it is more profitable to have a wage-paid job on the coast and consequently, the hilly ecosystems are being affected by overgrazing.

There are also migration routes connecting the dry forest to the Andes. There is a particular Inca road that connects the mountains through the Amotape forest and reaches the coast (Hocquenguen 1998), where the Incas could collect fish and seafood from the Tumbes mangrove forest. The dry forest circuit is particularly interesting because, through cattle migration, it connects the dry forest with the Tumbes forest, which is the lowest point of the Andes, allowing the flora and fauna of the mountains to communicate with that of the northern Peruvian rainforest. While the cattle that already know the route migrates on their own, the human population comes to collect wood and seafood from the mangrove forest ecosystem (Sabogal 2009).

Migration circuits from the mountains to the rainforest are also common, though they are more recent. The farmers from the mountains migrate seasonally into the rainforest to expand their cultivation area or to complement their income through mining.

The classic definition of the Andes does not consider its typical production circuits, nor the social and trade connections between the mountain and rainforest or coastal valleys. This shows that defining the Andes isolated without considering the production cycles is only possible when the description is limited to the ecosystems. However, in order to develop a sustainable conservation of Andean ecosystems, it is necessary to consider the production circuits as part of the dynamics necessary for the sustainability of these ecosystems. This is why it is necessary to support an expanded definition of the Andes to include the foothills into the coast and the rainforest as well as the natural regions of river Yunga and marine Yunga.

We define the Andes as including three areas: the summits, including the snow-capped peaks, the east and west spurs, and the foothills. This considers part of what we call Amazonia.

4.4 Cattle Herding

In the high areas of the Andes, extensive camelid cattle herding is traditionally combined with low-production agriculture based on techniques adapted to the environment. These techniques include furrows and cultivation on the edge of oxbow lakes, which reduce the cold to achieve a good harvest. The area is not very appropriate for agriculture, yet a specialized development in herding, including the selection of native species and complex systems, has allowed the human inhabitants to survive. In the grazing areas of the Puna region, the wind dries the plants and produces friction on the leaves, adding to the friction of hail and rain. For this reason, the area is nearly impossible to cultivate. Plants here are mostly grasses growing in small groups, like the ichu (*Stipa ichu*). There are also acaulescent rosettes that conserve the temperature by keeping the leaves close to the ground, some of which are used as pastures for camelid cattle.

Overgrazing is a problem now widely extended in the Andes, especially where there is a subsistence economy (Recharte et al. 2002). It is mainly seen in areas below 3800 m.a.s.l. The grazing areas of most mountain communities are divided among co-proprietors, some being for shared use and others private. The community-owned grazing grounds are exposed to higher pressure and therefore subject to overgrazing (Sabogal 2014). Traditional grazing is extensive, due to the low productivity of natural highland grass. It does not consider the use of forage or its conservation in spite of the cold temperatures and frost seasons, surely due to the low productivity of the grass and the difficulty to harvest it. There have been attempts to introduce cultivated grass in this area, but they have remained unsuccessful, on the one hand, due to the production structure commending the herding to children and, on the other hand, because of the low productivity of grasses and therefore of beef and ovine cattle. Child labour is a part of this economic system, in which every family member needs to contribute in order to ensure the survival of the group. The cattle graze in areas of great altitudes that are not appropriate for cultivation. Animals of European origin are not well acclimatized and consequently offer lower productivity than those in their place of origin. Nonetheless, they represent an opportunity of income and savings for the farmers of the high Andes, in order to profit from lands that would otherwise remain unused.

Overgrazing damages the soil structure and makes it more compact, which leads to erosion, loss of soil fauna, and consequently, the decline of ground fertility. Compacting modifies water filtration and availability, changing the structure for plants. The low temperature in the Andes slows down decomposition, which added to the soil compacting affects the release of nutrients and further lowers ground fertility. Under these conditions of low fertility, farmers burn the grass in an attempt to improve the grasslands, releasing nutrients so that new grass may grow. In the long term, however, soil fertility is reduced, since most nutrients are actually dispersed into the air, and carbon is lost, simultaneously producing greenhouse gases. Finally, as burning destroys the dry leaves that protect them, the exposed ground is more sensitive to erosion, which is also stronger due to compacting, especially if the slope is steep.

Burning also modifies the competitive conditions for plants and, therefore, changes the ecosystem, even more if it occurs in connection to overgrazing. The ecosystem restructures and modifies ecological succession, producing a secondary one. Pioneering species of fast growth occupy the area. The changes in the ecosystem affect competition; after the burning the fastest-growing plants gain space in the sunny places and modify the plant associations.

In this case, the ecosystem needs to restructure and change its ecological chain to create a secondary chain. Pioneer species of quick growth will take over the space. The changes in the ecosystem will have an effect as part of the competition, since after the burning, plants that grow faster will gain the spaces with the most sunlight and change the plant groups. Burning is usually performed during the dry season, between July and August, but due to the lack of rainfall, the plants will not resprout quickly. The surface of the soil exposed to the first rains and compacted by overgrazing is quickly washed away. In the long term, the area becomes desertified and erosion intensifies.

If the ground is left fallow, there is a chance for the ecosystem to recover, since the stronger impact of sunlight raises the ground temperature and therefore the activity of microorganisms, mycorrhizae, and similar (Rennenberg et al. 2010). Plants can thus receive nitrogen. The exudates of roots produce soil aggregates (Blume et al. 2010), which may improve the ground structure necessary for plant growth.

Edible plants are the most affected by grazing and usually become replaced by non-edible species. Due to the constant cutting performed by the cattle, the number of buds increases, so the plant has to invest a great number of nutrients to renew and ends up expending all of its reserves. In consequence, in the long term plant groups need to reconfigure. In time, the ecosystem might recover, but only by forming new plant groups (Sabogal 2009). Plants cannot manage to produce seeds and roots wear out. Only the less edible, lignified species can survive. In overgrazed areas, plants that contain toxic substances increase, mostly cacti (Sabogal 2009), or other species resistant to the trampling of the cattle as part of overgrazing (Sabogal 2014). The stemless rosettes resist cattle trampling and are harder to eat; therefore, they proliferate in areas like the pastured moors (Mena-Vásconces 2011). The change of vegetation also occurs due to soil compacting and loss of structure (Suárez and Medina 2001). Finally, the increase of herding, in an attempt to improve the productivity of the inhabitants of the mountains, has led to the introduction of plants for cattle consumption, which modify the Andean ecosystems. Some of the various species introduced are *Agropyron* sp., *Dactylis glomera*, and *Lolium perenne* (García and Beck 2006).

4.5 Climate Change

With climate change, we can expect a raise in the vegetation elevation limit, a process that is already clear in most spaces of the Andes. When plants colonize new spaces, plant groups play an essential role. The genetic variation of plants determines their adaptability. Plants of the Andes have been forced to adapt to small niches and tough climatic conditions, often in spaces isolated by elevation or other limits. As a result, these adaptations spread along a great variety of niches forming ecosystems with specific ecotypes in small and particular spaces. This is why, in such spaces, it is difficult for native species to adapt to new conditions.

The way each area develops under the new conditions of climate change will depend on each of the microclimates in the Andes. In the high planes, a rising temperature may increase the extension of crops and herding. In deep valleys, an ongoing problem that will worsen, due to the rising humidity as the glaciers melt, is erosion. This process will be more intense in the central and south Andes, where the glaciers and highest mountains are. Some valleys, which are protected from the wind and far away from the glaciers, will remain isolated and dry, as is the case of the Marañón Valley, for example. In the ecosystems of the north Peruvian moors, as the temperature rises, the decomposition will also become stronger, which in turn will produce more emissions of methane as the decomposing plant rests remain moist and even increase the soil humidity.

Endemism develops in isolated areas where the climatic factors have little variation and there are no invading species to force the new species to adapt or to displace. Under these conditions of isolation, it is common for old taxons to survive. The formation of ecotypes from a single species is common in this situation, because of the low competition and the lack of contact with species external to the ecosystem. Speciation and the subsequent restriction of genetic diversity will make adaptation of such natural systems difficult. As temperature rises and glaciers melt, it is very likely that the elevation limit of agriculture will rise, displacing natural ecosystems in the high plains and other areas.

Adaptive radiation is an important process found in mountain ecosystems and is produced due to the isolation of species. If the adaptation process is the result of moderate environmental differences, under which the adaptive-evolutionary processes remain uninterrupted, ecotypes develop, as is the case for many native forms of potatoes and tubers. However if, as in many mountain ecosystems, species are isolated by terrain or elevation, the evolutionary result creates endemism out of diverging evolution. Different ecological niches are thus filled very quickly, with species departing from a common ancestor to produce either ecotypes or endemic species. With climate change, adaptive radiation allows covering empty niches quickly in areas that are not entirely secluded. In this case, adaptive radiation is caused by some species surviving under radically different climate conditions, which results in a new evolution process.

It must be noted that speciation depends on each ecosystem and climatic stability. The stability of factors produces a stabilizing selection, removing the genes that are not appropriate for the environment. Survival depends in great part on the initial genetic selection and the founder effect. Therefore, the bigger the isolation, the smaller the chance for the ecosystem to survive when changes occur once again due to Climate Change. In isolated spaces where the adaptation process is old and there is little genetic variation because there is usually no climate variability, species survival is difficult, most likely causing wastelands with no vegetation. These new wastelands, in turn, are strongly affected by erosion, finally producing desertification. However, in protected areas where climate varies less because of isolation, some ecotypes may survive, as was the case, for example, during the Pleistocene ice age, when some species found refuge to withstand the era (Simpson 1973 quoted in Meudt and Simpson 2006).

A stable and isolated space determines the possibility of speciation and ecotype formation. The difference in elevation and humidity enabled the formation of microhabitats and plant groups, forcing plant evolution and adaptation, which led to the formation of ecotypes as well as diversification and consequently the formation of species. This process can reoccur in the space of high mountains, where enough genetic diversity still exists. For example, frequent landslides create new niches that are constantly recolonized (Mutke et al. 2014). These conditions are common to many ecosystems of the Andes where the slopes are extremely steep. In this case, the chances of survival under conditions of Climate Change are much higher, since the ecosystem is already adapted to change and ensures genetic variability.

The Andean forest shows us the effects of climate conditions and the direct relationship between space diversity and niche diversity in isolated spaces. In this respect, the diversity of niches in the Amotape Huancabamba region is particularly high due to the heterogeneous space (Mutke et al. 2014). In areas protected on both sides, as is the Marañón forest, the low humidity allows for the growth of small dry forests with a high degree of endemism due to their isolation. On the other hand, in connected spaces, trees are in valleys and on mountainsides protected from the wind or near human settlements, where the temperature is higher, as well as near rocks that absorb solar heat.

With elevation, solar and ultraviolet radiation increases. Even though plants are adapted to high levels of radiation and can make use of them, it is limited by light saturation which is defined by the speed of photosynthesis. Climate Change has caused an even higher increase in ultraviolet light. However, anti-cyanates accumulate in chlorophyll and antioxidants balance out the stress created by higher radiation, which all together allows for better protection from extreme radiation (García and Beck 2006). Leaves reduce the loss of water by turning over and controlling the exposition of stomas. As part of their adaptations, plants in the puna protect their transpiration organs by rolling up their leaves (García and Beck 2006), at the same time reducing leaf exposition (Smith and Smith 2007). The colour of flowers and leaves plays an important role as well. Species of the Ericaceae family that grow in cold areas have flowers and vegetable structures that attract insects by reflecting ultraviolet rays (Culley 2009 quoted in Klooster et al. 2009). Wax produces a silver colouring that plays an important role to protect the plant from excessive radiation.

Small, hard, and hairy-shaped leaves allow the plant to maintain humidity inside and resist radiation (Mena-Váscones 2011). The pubescence of leaves and the proper angle towards the sunlight to reduce exposure minimize the impact of radiation at noon, when the evaporation is strongest (Pfitsch 2008). All these adaptations can become important for their survival in times of climate change.

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Chapter 5
Biodiversity and Endemism of the Andes

5.1 Introduction

Biodiversity is the multiplicity of species, ecosystems, and areas inhabited by living beings in nature. The total number of species on the planet is not known for certain, and new species are discovered every day. It is estimated that, in total, there are between 40 and 80 million species on the planet. In Peru, there are still many undefined species and ecosystems to be explored. About 50% of the existing species are found in tropical rainforests (Smith and Smith 2001: 503). The greatest diversity of species in this ecosystem is found in the insect and bird groups. The highland rainforest has one of the highest biodiversities on the planet. An area of 10 km^2 can have up to 1500 species (Smith and Smith 2001: 503).

The number of species is directly related to latitude, altitude, the amount of water, and temperature. Thus, the lower the latitude and altitude, the greater the number of species. Abundant rainfall without flooding, also generates a greater number of species, as water, oxygen, and adequate temperature, lead to decomposition which causes the recycling of nutrients that enables diversity.

Biodiversity is subject to constant change and alteration as a result of changes to the ecosystem and competition between species. New species are constantly appearing and disappearing as a result of evolution. However, both speciation and extinction are long processes occurring over several generations and beyond the lifetime of an ecosystem and are affected by environmental changes. It is estimated that the creation of a new species requires between 2000 and 1,000,000 generations (Miller 1994). The degree of speciation is different for each species and depends on the species and its biological characteristics as well as on the ecosystem and the stability of its component factors.

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5.2 Biodiversity Conservation

Biodiversity conservation involves conserving the diversity of genes, species, and ecosystems. It should be noted that genetic diversity depends on the variety of genes that make up a population. It also depends on space and the connection between ecosystems. Some species have a greater influence than others on the dynamics of ecosystems. Moreover, a greater number of species depend on them. These species are known as keystone species and should be prioritized for conservation. We must also identify ecosystems and species that require conservation because they are more fragile.

The characteristics of the ecosystems that define their conservation priority are:

- High biodiversity.
- Endemic species or degree of endemism.
- Fragile habitat.
- Island ecosystem.
- Very narrow niches.
- Extinction and presence of critically endangered species.

5.2.1 Endemic Species

Endemic species are those that have a limited distribution in certain ecosystems, and their conservation is therefore particularly important. They are usually highly evolved species that have undergone a long process of adaptation and have very specific reproductive patterns dependent on the conditions of the ecosystem in which they live. Changes strongly affect their populations. For example, the storm swallows (*Oceonodroma tethys*), which are found on the islands off the Peruvian coast and are endemic to the Humboldt Current and nest on the mountains and islands near the Paracas Peninsula, show a high mortality rate of their offspring during the "El Niño" phenomenon. Were they to become extinct we would lose track of this evolution and natural history. In isolated ecosystems it is common to find endemic species, which have developed an evolutionary path separate from other species, for example in the ecosystems located in the Huancabamba depression we find characteristic species of the genus Nasa, Ribes, and Urtica (Mutke et al. 2014). In the moorlands of Peru, there are many endemic species such as Chuquiragua spinosa, a species with beautiful orange flowers and great potential as an ornamental plant (Mutke et al. 2014).

5.2.2 Fragile Habitat

Fragile habitats are areas where the balance of the ecosystem is at risk. Most of these habitats are ecosystems or communities in a state of equilibrium called climax. Fragile habitats are also those areas that are a source of food for species in ecosystems in a state of intermediate ecological succession (sere), allowing the subsistence of many migratory species. Fragile ecosystems are those that if lost would affect other habitats, which need to be conserved as a priority.

Particularly fragile are sites that are used within the migration routes of animals, such as marshes and lakes used by waterbirds. Other priority fragile habitats are species breeding areas, such as the edges of aquatic ecosystems, estuaries, such as the mangroves of Tumbes, and islands, such as the guano islands of San Lorenzo. Particularly fragile ecosystems in a climax state include tropical forests and coral reefs.

5.2.3 Islands

Islands, both geographical and ecological (ecosystems surrounded by other different ecosystems, with variations in slope, altitude, and climate) are fragile ecosystems; on them, many species are endemic, since being separated by geographical barriers they develop a unique evolutionary pathway. Such is the case of the Galapagos Islands, where many endemic species are found. Island ecosystems are also found in the inter-Andean valleys separated by slopes, such as the Marañón forest or moorlands described below (see 5.3).

5.2.4 Ecological Niche

The ecological niche is everything that a species requires to fully develop in the ecosystem. The ideal ecological niche is made up of the ideal conditions necessary for species to thrive. The realized or achieved ecological niche is made up of the conditions that allow the species to survive but they are not ideal for its development.

5.2.5 Evolution and Extinction

The evolution of species refers to the changes that occur in populations over time. Natural selection is the mechanism that leads to these changes.

Extinction is a natural process that is constantly occurring in ecosystems. Intra- and intraspecific competition and adaptation to the environment play a major role. However, if caused by external disturbances to the ecosystem dynamics, catastrophic consequences can occur. The extinction of plant species has greater ecological consequences than the extinction of animal species, as it leads to the alteration or extinction of the upper trophic chain and thus of all animals that depend on the plant species that becomes extinct. The total number of species is around 1.75 million. Of these, there are an estimated 250,000 plant species, although many of them remain unknown. Only plant species used for human benefit amount to as many as 5000 (Miller 1994). If the unknown plants were to become extinct, the possibility of expanding the spectrum of useful and medicinal plants would be lost.

The study of species or ecosystems allows us to learn about their evolutionary processes. If species and ecosystems are lost before they are known, we lose the clues to evolutionary processes which, in turn, allow us to learn about the history of evolution and even prevent catastrophic processes. It is estimated that the loss of one plant species can lead to the loss of 30 animal species that depend on it (Miller 1994). For example, tree canopies are home to many species of birds, monkeys, and insects. The destruction of trees puts all these species at risk.

Animals and plants that may be endangered have common characteristics that make it possible to prioritize the conservation of these species even before they become eminently endangered. These characteristics are:

- Restricted or endangered ecological niches.
- High levels of the food chain.
- The large size of individuals.
- Low reproductive rate.
- Threatened and restricted habitat with limited breeding and feeding areas.
- Fixed migration patterns.
- Competition with humans for resources.
- Fixed established behaviours.
- Strategists k (specialists).
- Senescent species in climax ecosystems, or those that have not evolved in synchronicity with the changes in the ecosystem such as rhinos.

Changes of anthropogenic origin external to the dynamics of ecosystems lead to more rapid extinction processes, in most cases, giving species no time to adapt. Climate change in the Andes has caused the elevation of the crop line since the average temperature has risen. Furthermore, it has caused variations in the occupation of space, a decrease in grazing areas, and an increase in arable land, which has also led to changes in the flora and fauna of the space, as well as changes in erosion processes caused by the movement of arable land and processes of organization and management of the peasant communities.

On the other hand, changes in species are largely the result of interactions between populations in the ecosystem. These interactions can lead to co-evolution or joint evolution of different populations which may evolve together, both benefiting and developing dependency on each other. In this way, populations collaborate in a community that has developed over time, changing their behaviour as well as the morphology of the population.

5.2.6 Natural Selection

Another factor that produces the evolution of species is natural selection, which is the mechanism by which the individuals that possess characteristics to survive and reproduce better than other individuals can perpetuate their genetic information in a population. Thus, for example, in the tropical rainforest, large, old trees fall, leaving large bare areas in the forest, in which different seeds begin to germinate, taking advantage of the light and the soil. Gradually, however, the seedlings that are best suited to the soil conditions and make the best use of the available light remain in this area. The rest of them die without reproducing and their genes are not passed on to the next generations of plants.

In a community, one or more species influence each other favourably or unfavourably; these interactions cause changes throughout the community and allow it to develop. Plants and animals develop together since changes in one carry changes in the other, and vice versa.

The "Borrachera" (*Ipomoea carnea*) is an example of selection and co-evolution in the dry forest of northern Peru. This plant is a shrub that grows only in areas where there is no shade, so it cannot grow under carob trees. When the carob trees are depredated, the "borrachera" spreads quickly. This shrub contains large quantities of alkaloids and selenium in its chemical composition, so when eaten by animals, they become dependent and eat large toxic quantities until they die of poisoning. When we study the situation, we find that animals like goats eat the carob tree, deteriorating the carob forest, so the number of "borrachera" increases and kills the animals that feed on it, balancing the ecosystem. However, a serious problem arises in the dry forest when the amount of livestock is so great that the carob trees cannot recover. In this case, the ecosystem has to go through a prolonged stage of secondary succession. This change affects the whole community.

On the other hand, species do not only change due to interactions between populations in a community. Some changes are random and non-directed, affecting the genetic composition of populations. These changes are called mutations.

5.3 The Andes and the Huancabamba Depression

The Andes do not have a homogeneous altitude; they vary and change orientation in the so-called "nudos" (knots). The Andes have 3 "nudos" with reversed orientations. The Nudo de Pasto, in Colombia, and the Nudo de Loja, both located in northern Peru and the Nudo de Vilcanota, in southern Peru. In addition, there are areas where the altitude decreases, allowing passes from one side of the Andes to the other. The change in the orientation of the Andes has an effect on both geographical and climatic factors, which influences the ecology and the distribution of species, giving different characteristics to each area. The change in the Nudo de Loja is followed by the Huancabamba depression caused by the change of orientation of the Andes (see Fig. 5.1).

The Huancabamba Depression is located in northern Peru and is the narrowest pass in the Andes. This depression includes the eastern and central mountain ranges. The lowest point in this area is the Porculla Pass, situated at 6°S and 2145 m asl (Emck et al. 2006). This change influences the flora caused by the Amotape-Huancabamba Depression. Here the humidity comes from both sides of the Andes,

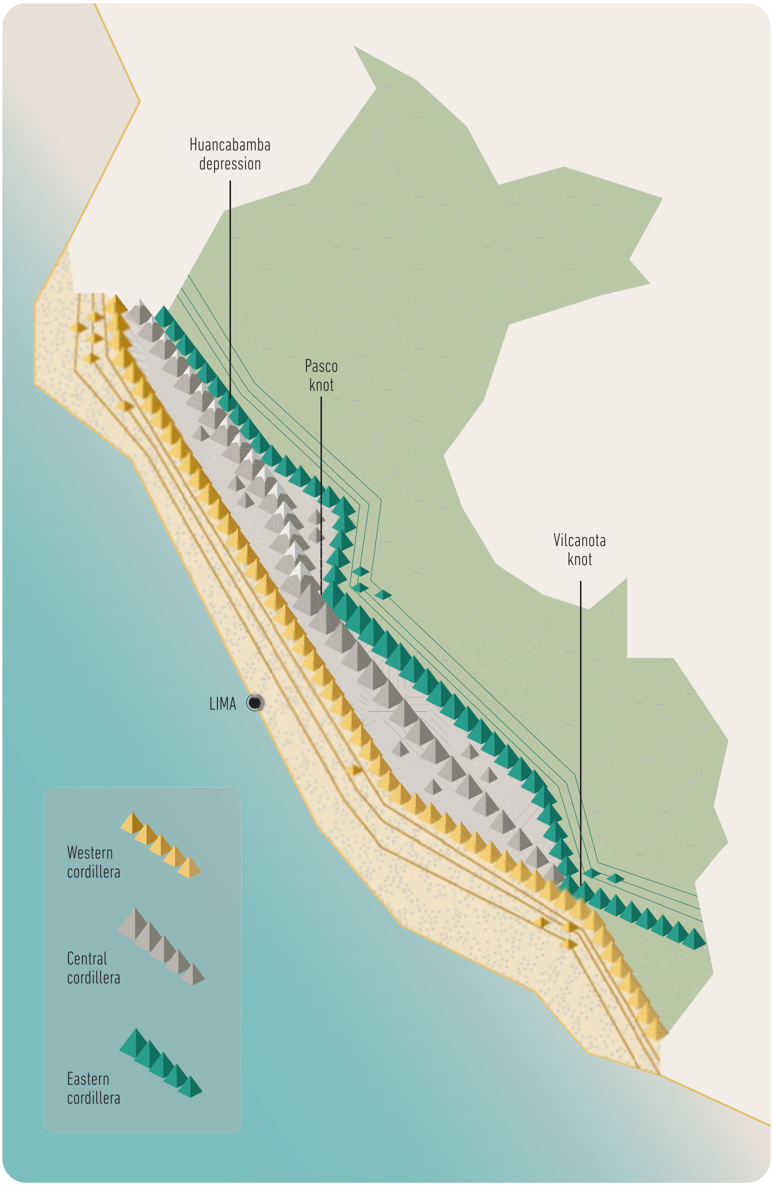

Fig. 5.1 The Andes knots. (*Author* Ana Sabogal, designer Juan Pablo Bruno)

from the west and from the east, which is why the wind is dry and the mountains offer no barrier for the Rain Shadow phenomenon to occur so humidity is not stopped. The area is also affected by the "El Niño Phenomenon" (ENSO).

The Amotape-Huancabamba corridor lies between grade 3 and grade 8 south (Mutke et al. 2014). It is an area of high biodiversity. For example, the Chamaya riverbed, located in this area, is 6–8 times larger than in the surrounding areas to the north and south (Henning 2011). This is caused by the overlapping of species from the north and south and it is also a refuge area for ancient taxa; there is a large number of endemic species, with both neo-endemic and paleo-endemic plants (Henning et al. 2011). The altitudinal variability with differences in humidity has allowed the formation of microhabitats and plant communities and forced the evolution and adaptation of plants, so ecotypes have been formed as well as diversity within genera and consequently the formation of species. This is why there are so many species within each genre. The heterogeneity of the space is high, resulting in niche diversity (Mutke et al. 2014). The formation of niches has forced species to evolve, and the species that remain are those with the capacity to do so. In addition, anthropogenic use creates a large number of patches, which contributes to the formation of diverse ecological niches in relatively small spaces.

The deep valleys between the foothills are characterized by high erosion due to the slope. The frequency of landslides creates new niches that are recolonized, every year (Mutke et al. 2014). Some wind-protected valleys remain dry, such as the *Marañon Valley*, while others are wetter. In the deep valleys, protected from the wind, thermal inversion occurs, in the others, it does not, which contributes to the diversity of ecosystems. The eastern valley between the eastern and central mountain ranges forms the Marañon forest. It is a dry forest as it is protected from the wind on both sides. The forest is composed of flora from the Pacific and the Amazon, producing speciation and endemism due to the climatic isolation of the area. The North Andean forest has plants of diverse origin: 65% Neotropical, 10% Holarctic, and Austral-Antarctic, and 5% Pacific, the remaining 15% are Andean-tropical as a result of rapid speciation, due to the relatively stable climate and presence of microclimates, which translates into high endemism (van der Hammen 1989, cit. Richter et al. 2009)

The Adaptive Radiation theory, which postulates that high endemism and biodiversity are the results of high climate adaptation and low extinction rates (Richter et al. 2009), is true in this area. The climate of this area has remained stable since the Pleistocene (van de Hammen and Hooghiemstra 2000 cit. Richter et al. 2009).

The moorland ecosystem is in this area a little higher up between 3000 and 3600 metres above sea level. In places with very low nighttime temperatures, plants have developed ecotypes adapted to the area.

5.4 Biodiversity Conservation Management

Nowadays, after a period of strict conservation of areas in which humans were excluded from the areas to be conserved, the concept of sustainable development is being included in conservation. Therefore, it considers the relationship with the human population in the planning of ecosystems. In this way, the conservation of biodiversity also implies the sustainable use of natural resources and of the areas in which the species live.

The form of species conservation depends on the conservation status of the ecosystem and the species living in it. When ecosystems are still in equilibrium and only a few species need to be conserved, conservation is carried out within the ecosystem by preserving the habitat of the species. We call this type of conservation "in situ" conservation. On the other hand, when the ecosystem is very deteriorated and the species are endangered by remaining in it, species have to be transferred to zoological gardens where they will be conserved and monitored until the habitat can be restored. This form of conservation is called "ex-situ".

Computation and research regarding species status and population dynamics are necessary to know the conservation status of the species. In this way, it is possible to plan the conservation and to see if it is sustainable. It is necessary to know the number of individuals and whether they are in balance with other species and their habitat to determine if conservation can be sustainable, using them and regulating bans. To do so, it is also necessary to define the optimum capacity of the ecosystems.

The seasonal ban establishes periods when hunting or fishing is not allowed. It generally coincides with the rutting and breeding seasons. In this way, species can recover their population without being disturbed. The seasonal ban is for animals that are threatened or endangered. For example, in Peru, there is a shrimp ban in the Tumbes Mangroves or a puma (*Pantera onca*) ban in the Angolo Game Reserve in the dry forest.

Ideally, species should be conserved in their habitat (in situ). Species can be conserved in situ in protected areas (NPAs) or hatcheries that isolate them from predators. Such is the case of the charapa turtle (*Podocnemis expansa*) in the Amazon rainforest. In the *in situ* conservation of fragile ecosystems, it is important to consider biological corridors within the protected area that connect various ecosystems and allow the migration of species in case of ecosystem deterioration.

For in situ conservation, in the case of threatened ecosystems, it is necessary to arrange refuges for wild animals, delimiting areas where species can live and reproduce without problems. For example, in the case of the charapa turtles in the Peruvian jungle, areas are isolated on the beaches where turtles nest. On these beaches, the turtles' nests, eggs and juveniles are controlled, and hatchlings are assisted to reach the river. For species conservation, populations of endangered species need preservation and restoration. Furthermore, their reproductive capacity needs to be maintained. It is also necessary to conserve fragile ecosystems.

When the population density of the species is very low, inter-specific competitive relationships prevent the rapid and safe increase of the species, so it is essential to reduce the negative effects and inter-specific relationships and increase the favourable conditions. These species are conserved in zoological gardens or botanical gardens outside their habitat (ex-situ conservation). To perform ex-situ conservation, we have to know the population's characteristics, feeding, and inter-specific relationships of each species. It is precisely the need for this detailed knowledge of each species that makes ex-situ conservation difficult to achieve. Many animals suffer greatly in captivity. They may become depressed and stop feeding themselves.

For ex situ conservation it is not enough to conserve one specimen of each species. It is necessary to conserve the genetic diversity of each population. The question is how many specimens of each species must be conserved for them to survive.

The answer depends on each population, its social organization, and the individuals themselves. It is not a question of the number of individuals of each species, but of the genetic diversity of the population to be conserved, where “genetic diversity” is understood as the number of different genes in a population. Each population has a critical population size, below which the species become extinct, as mortality exceeds the birth rate. When this is not achieved naturally, scientific laboratory work is used, such as artificial insemination, and in vitro culture, among others.

Genetic diversity is the multiplicity of genes in a population. The number of responses of populations to the environment depends on it. The greater the genetic diversity, the greater the number of resulting genetic combinations and thus the greater the population’s chances of survival. There is a direct relationship between the number of individuals in a population and its genetic diversity. When the number of individuals in a population is very low, the genetic diversity is also low, although this depends on the ecosystem. In very stable environments, genetic diversity is lower.

Another form of biodiversity conservation is to preserve the genes of species in a gene bank. Although this type of biodiversity conservation is costly, it requires less space. This form of conservation is particularly used for cultivated species, as it allows the genes to be conserved in the form of refrigerated seeds or the form of eggs and spermatozoa, thus preserving genes that are not widely distributed in cultivated varieties. In such banks, species are kept in cold chambers in which the genes can be preserved for a very long time. There are gene banks in the world for the main cultivated species, which makes it possible to ensure a response if the species suffers from a pest or climate change. In Peru, the International Potato Centre in Peru is dedicated to the preservation of the different potato varieties.

It should be noted that conservation should, as far as possible, be carried out in different areas at the same time, to better ensure survival in the event of a disaster or loss of an ecosystem.

5.5 Causes of Biodiversity Decline

The causes of biodiversity decline are diverse. Poverty and the population density of human societies are the main ones. Species conservation must therefore go hand in hand with sustainable development and the population must be involved in this process.

5.5.1 Green Revolution

During the 1960s, the so-called “Green Revolution” was initiated, increasing the external energy (fertilizers) of agricultural ecosystems to increase production indefinitely. When this theory was put into practice, it encountered many limitations, as it did not take into account intra- and inter-specific relationships, such as competition and predation. Due to monoculture, insect populations found abundant food and increased in number, which made it necessary to use increasingly sophisticated and toxic methods to control them. Today, even in subsidized ecosystems, such as agricultural ecosystems, interspecific relationships, and food chains are taken into account, and biological control using the trophic chain to control pests has been developed.

There are studies on the effect of fertilizers on the soil and it is now known that fertilizers affect the soil flora and fauna. This has an impact on the decomposition and replenishment of soil nutrients, affecting soil dynamics and making plants dependent on inorganic fertilization. The use of organic matter, unlike synthetic fertilizers, enables and activates soil life by improving nutrient cycling processes.

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Chapter 6
Ecological Communities, Populations, and Metapopulations

6.1 Introduction

The ecosystem is composed by multiple communities. The community permit the interaction between the population from the ecosystem. But the population of the different ecosystems conforms the metacommunity, metapopulation. It is composed by multiple populations and ecosystems and permits the conservation in a landscape dimension. The metapopulation interacted through the corridors. The landscape dimension permits the conservation of the ecosystems and populations.

6.2 Ecological Community

A community is a space where diverse populations live and interact with each other. Each community has its dynamics with inter-specific relationships, associations, and advantages for all the populations that inhabit it. An ecosystem has several communities. Every community also interacts with the ecosystem. An example of a community is that of the tree-dwelling orchids in the Amazon rainforest that depend on mycorrhizae for pollination and the canopy-dwelling mosses inhabiting the canopy of trees in the rainforest.

Communities allow multiple species to survive by creating space and helping each other. In an ecosystem, we find many communities in various stages of development and conditions. Communities have distinct characteristics that allow them to be differentiated from one another.

A. Sabogal, *Ecosystem and Species Adaptations in the Andean-Amazonian Region*, https://doi.org/10.1007/978-3-031-44385-5_6

6.2.1 Delimiting and Defining the Community

To study an ecosystem, we must identify the communities that are essential to the ecosystem. Based on the objectives of our study, we may choose to work with those that harbour fragile species. The study of a community allows us to know the state of the ecosystem and the populations that inhabit it.

First, it is necessary to delimit the community by applying the Similarity Index, also known as Sorensen's Index, which allows us to establish the space occupied by a community. The delimitation of a community depends on the objective of the study and the dimension. If we want to study, for example, fungi and soil bacteria in the high forest, the community to be defined is different from that inhabiting the relict forest of the Marañón community. Although both are in the same area, the dimension of the study is different.

The Similarity Index compares the number of species in two different areas. This index fluctuates between 0 and 1, and can also be expressed as a percentage when multiplied by 100. The following formula is applied to calculate the percentage of similarity:

$$\mathbf{S} = \left(\mathbf{2c} / \mathbf{a} + \mathbf{b}\right) \times \mathbf{100}$$

where:
a = the number of species in the community 1
b = the number of species in the community 2
c = the number of species in common in both communities

This index measures the diversity between communities, better known as "beta diversity". If all the species are present in both areas, the result (S) is equal to 100%, which shows that the areas chosen were not selected correctly, thus, both are part of the same community. If the result is close to 0%, it demonstrates that the two communities are very different. The lower the result of S, the lower the similarity between the two communities.

6.2.2 Community Characteristics

After establishing the ecological community for the study, we must define the following characteristics: species diversity, physical structure and biological structure, species dominance, relative abundance, and trophic structure. A description of these characteristics is below.

- *Physical structure:* Common growth forms or forms the species occupy the community space. It describes the morphological features of the most relevant species. The height and shape of the plants in the community determine it. For example, in a forest, the dominant structure is that of vertical trees, whereas, in the case of grassland, it is horizontal.

- In a terrestrial community, the larger plants define the physical structure. For instance, in the Queñuales forest (*Polylepis* sp.), the height of the trees determines it. In an aquatic community, the physical structure of the organisms is also vertical due to the physical properties of water. Water changes its density with temperature and salinity and, therefore, structures the aquatic environments. It is also necessary to consider that water absorbs light. As light intensity decreases with depth, it conditions the presence of living organisms. Therefore, the abyssal plain of the seabed has a characteristic structure.
- *Biological structure:* It refers to the composition of the species that make up a community, both in number and forms of distribution. The biological structure is defined by the species' composition, abundance, relationships within the community in their current state, and their dynamics. It includes the trophic relationships within a given community. The following characteristics determine the biological structure.

  (a) *Species dominance*: It is the species that controls the conditions of the community. Dominance may be due to the greater number of individuals, their behaviour and preferential access to resources, or the species' outstanding size over others, leading to occupancy of space.
  (b) *Relative abundance:* The number of individuals of the same species compared to the total number of individuals of all the species that make up the community. It shows the proportion of the number of individuals of each species.
  (c) *Dominance:* A dominant species exerts considerable influence on the other species or on the conditions of the community it inhabits. Dominance may be due to the species' number, size, activity, or control of nutrients in the community. Species dominance may change when invasive species occupy the community. Therefore, we need to define the criterion of dominance in the context of the research (Smith and Smith 2001: 305).

      The species that exerts dominance is called "ecologically dominant", while the species over which the dominant species exert dominance are called "secondary" or "subordinate".
  (d) *Richness:* It is the total number of species in a community.
  (e) *Diversity:* It is the number of species and the proportion of each species in a community.
  (f) *Trophic structure:* relationships between species within a food chain.

A community is considered to be more complex the greater the number of species that compose it (species diversity) and the less dominant the species are with each other (relative abundance). The characteristics of the community are constantly changing, as is the ecosystem. If the characteristics remain constant, we speak of a "near climax" or "stable" community.

To differentiate between communities, we can compare autotrophic communities when we are interested in studying plants such as grassland or heterotrophic communities when the object of study are species that depend on autotrophy for their activity (Smith and Smith 2001: 304).

6.2.3 Association

An association is a vegetation assemblage formed by a composition of relatively uniform species with peculiar habitat characteristics. Ecologists call an association an autotrophic community. In an association, species relate to each other for their benefit; one species may be dominant and the other subordinate or there may be no dominance at all. It is a space distinguished by uniformity with common characteristics that define it (Smith and Smith 2001:340). According to the first definition, the species in an association have a common evolutionary history and similar responses to the environment, so they form distinctive units (Clements, cit. Smith and Smith 2001: 340).

An association is defined not only by the presence of species but also by how they occupy space and the role each one undertakes in the association. It is a term used in plant studies (Smith and Smith 2001: 304).

The associations include in many cases peculiar abiotic features. Examples of associations are:

- The rocky grassland plant association in a high Andean ecosystem.
- The cactus association of the occidental highlands of Peru.

6.2.4 Species Diversity of a Community

The diversity of a community depends not only on the number of individuals of each population but also on the balance of species or relative abundance. Diversity is very different if the number of individuals of the species is small and there are dominant species in a high number to the contrary.

The simplest way to measure species diversity in a community is to count the number of species and their proportion to each other. However, this is not as straightforward as it sounds, as the recount should consider only species native to the site. It should not include incidental species. Successive recounts are required to rule out accidental species.

When measuring species diversity, we need to compare the number of species to the abundance of each species in the community by using the *Shannon-Wiener Index (H)*, which correlates the number of species *(richness)* with the proportion of each one within the community *(relative abundance)*. In this way, it is also a measure of balance; if two communities have the same species, the diversity may be different according to the abundance of each species.

As follows is the formula to calculate species diversity:

$$\mathbf{H} = -\sum_{\mathbf{i=1}} \left(p_i\right)\left(\log_2 p_i\right)^{s}$$

where:
H = species diversity index
S = number of species
p_i = the proportion of the total sample corresponding to species i
$\log_2$ = Log Base 2

The higher the diversity index (H), the higher the species diversity. This calculation tells us how high the diversity is within the community. It is known as “alpha diversity”.

6.2.5 Equity Within a Community

There is a limit to the number of species a community can support called the *maximum diversity* (H_{max}). We can compare the maximum diversity in an ecosystem with the diversity observed in the community studied, calculating it with the Shanon and Wiener Index. If both are equal, the community is in balance, which means that the number of species is within limits. The comparison of both results is the *equity index (E)*. The more similar the diversity obtained on the field (H) to the theoretical diversity (H_{max}), the higher the equity index. The community studied is near the limit of species it may support. Thus, it is a mature community near balance. In this case, the community is fragile, so any change in the conditions could provoke an imbalance.

The following equation is applied to calculate the Equity Index:

$$\mathbf{E} = \mathbf{H} / \mathbf{H}_{max}$$

where:
E = equity index
H = species diversity calculated with the field data of the studied community
H_{max} = maximum diversity of species = log $_n$S (natural logarithm of the species diversity)

6.2.6 Metacommunity

Communities are often connected permanently or seasonally. Groups of communities may form a *metacommunity* connected by a few species. These connecting spaces may occur in ecological corridors such as river banks. Connections can also be periodic, for example, in intertidal zones where communities connect during the flood season. Management and conservation of protected natural areas should consider metacommunities.

6.3 Population

Smith and Smith (2001) define a population as a group of individuals of the same species occupying an ecosystem simultaneously. Individuals that exchange genes and have fertile offsprings belong to the same species. Therefore, they share an ecosystem at some point and have the same number of genes. Individuals inhabiting the same ecosystem are a population. When they are in separate ecosystems temporarily connected, they are a metapopulation. Species can now transcend generations through genetic engineering and the conservation of eggs or sperm.

Populations are constantly changing in the number of individuals and their genetic composition. They can adapt to change, evolve, or become extinct. It is important to understand that populations evolve, not the individuals. The species, formed by populations, evolves through the selection or survival of certain genes in the population that may be passed on to the next generation. If there are no changes in the ecosystem for a long time, the number of genes in the population diminishes, and some genes tend to become extinct, due to the decrease in the range of the factors that make up the species' niche. On the other hand, if the ecosystem is subject to change, the variability of genes is greater, and new ecotypes may form; eventually, after several generations or even centuries, different species may form as the ecological niches separate.

An example of a population is the carob tree in the northern dry forest (*Prosopis pallida*), but in the south, the common species is the *Prosopis juliflora* of the same genus. The jaguar (*Felis onca*) and the puma (*Felis concolor*), both of the same genus inhabit the Peruvian rainforest (Brack and Mendiola 2000).

6.3.1 Characteristics of a Population

To study populations, we must define their biological characteristics. The biological factors specific to each species, such as gestation time, life form, and aggressiveness, among many others, determine a series of population factors.

A study of populations considers the following characteristics: habitat, density, age distribution, sex ratio, genetic composition, distribution patterns, and social organization. Each of these is defined below:

- *Habitat:* The place where a species lives. We could say that it is the home of a species. The "habitat" is specific to the species. It is where the species spends most of its time day and night. Each species has a defined habitat; it has a defined physical space.
- *Population density*: The number of individuals found in a space in the ecosystem. There is a maximum number of individuals that can live in a given area, known as the "carrying capacity". This limit is given by the resources available to a population. Biological factors and interspecific relationships determine the lower limit of population density. The limit is highly variable and depends very much on the social organization of each population. The lower the trophic level of the population, the higher the population density and the higher the number of individuals.

- *Sex ratio:* The ratio of males to females in a population. The sex ratio (R) is calculated by dividing the number of males in a population and the number of females and multiplying it by 100 to express it as a percentage. The formula is:

$$R\% = N°\text{males} / N°\text{females} \times 100$$

In a stable population, the R-value does not vary over time. Each population has its characteristics. The sex ratio depends on the social organization of the population, but can also vary according to climate and dietary characteristics.

- Genetic composition: The characteristics contained in the genes that make up the population. These depend on genetic selection and therefore on the environmental conditions and the ranges of factors that respond to each gen.
- The pattern of distribution: The way individuals are dispersed in an ecosystem. Distribution depends on the social organization of individuals and the resources available. Within populations, there are three characteristic forms of distribution: random, clumped, and uniform. Commonly, this distribution is altered during the breeding and reproductive seasons.
- Social Organization: The form of a population to organize for life. There are various forms of social organization, such as herds, groups, shoals, colonies, or solitary individuals. Depending on the social organization of the population, the values of R have different interpretations. R is only useful for comparing populations of the same species.

An example of a random solitary population is the tarantula of the northern Peruvian dry forest that inhabits caves in the ground occupying empty burrows (characteristics of the tarantula).

Although there are many tree species per unit area in the tropical rainforest, each species has a defined distribution. Furthermore, the distance between individuals of each species responds to many factors like the weight of seeds which affects where they fall, or the type of animal that feeds on the seeds. The distribution of the species is usually uniform.

However, in the relict forests of queñual (*Polylepis incana*) in the highlands of Peru, the distribution of trees depends on soil nutrients and climate. They are usually agglomerated. The trees are on slopes sheltered from the wind, forming small copses.

In addition to the characteristics of a population, some factors determine its dynamics: birth, death, emigration, and immigration. These four factors define the growth rate.

6.3.2 Population Dynamics

Population dynamics are the changes in populations over time. These changes include the variation in the number of individuals that make up the population, which increases with births and immigration (n) or decreases with deaths and emigration (m). To calculate it, population growth (ro) has to be defined as the increase in population over a certain period. Population growth is expressed as a percentage called the population growth rate and is calculated as follows:

$$r\% = (\mathrm{n} - \mathrm{m} / \text{initial population}) \times 100$$

If the population growth rate is positive, there are more births than deaths, and therefore the population is growing. If, on the other hand, the rate is zero, there is no population growth. If the rate is negative, the population is decreasing.

Mortality (m) The number of individuals killed in a given time. It largely depends on external and abiotic factors and negative interspecific relationships. However, it is also limited by existing resources. When the influence of these factors is minimal, mortality is by natural death (ageing), a "physiological factor" also called "minimal" mortality. The mortality rate is calculated by dividing the number of dead individuals (m) by the initial population and multiplying the result by 100:

$$\text{Mortality rate} = (\mathrm{m} / \text{initial population}) \times 100$$

Natality (n) the number of individuals in a population born alive in a given time. Natality depends on biological factors which define the population, called biotic potential and are, for example, the gestation period and the start of the reproductive stage. It also depends on external factors like changes in abiotic aspects. Natality is expressed as "birth rate", which is the number of births (n) among the initial population, expressed as a percentage:

$$\text{Birth rate} = (\mathrm{n} / \text{initial population}) \times 100$$

Maximum Birth Rate It occurs when there are no adverse factors. There is only a maximum birth rate when external factors are optimal. Some factors influencing it are the number of individuals per sex, the age at the beginning and end of the reproductive stage, the gestation period, and the number of offspring per litter. All these factors depend on the biology of the population.

Biotic Potential When natality approaches the physiological limit determined by the maximum number of offspring per female, mortality is minimum and individuals die of old age, the Biotic Potential is maximum. At this point, the number of births is maximum and the number of deaths is minimum. The biotic potential is impossible in nature. It is only possible in a laboratory. In ecosystems, all populations are subject to competition and environmental variations influencing and decreasing both birth and death rates.

Age Distribution It is also known as the age structure of a population. It is the age distribution of the individuals that form a population. Its analysis can explain fluctuations in the population and the effects that external factors may have had on the population at a given time. Thus, an increase in the number of individuals of a certain age demonstrates there has been a favourable factor. For example, during the El Niño event, the carob trees in the northern Peruvian dry forest germinate.

The age of individuals in a population can be defined according to growth parameters, shape or size of a body part (such as leg length and head size), or the presence of certain structures such as teeth in felines, horns in deer, number of tree rings, etc. Once the age of each individual is established, it is placed in a horizontal bar graph. The most common resulting graph is that of a pyramid. This shape shows that there are more young than old individuals and that the population is growing. It allows us to predict future changes in population size. When the resulting graph is a square, it shows that a population has remained constant over many generations. When the resulting graph is an inverted pyramid it shows that the population is decreasing. It is important to analyse the causes of the variations to achieve population conservation.

Population Structure It is determined by the characteristics of the individuals that form a population. The factors that determine the population structure are sex, age, and social organization. The population structure makes it possible to estimate the future development of a population.

6.3.3 Population Growth Models

In nature and especially in Amazonian ecosystems where there is a lot of competition between and within populations, population growth depends on the availability of resources. This type of growth is called logistic growth. On the other hand, when growth is unlimited, we are dealing with exponential growth. This occurs in the highlands, in populations that inhabit isolated ecosystems or in ecosystems those with huge erosions rate, so generalists prevail (see Sect. 3.2).

- *Exponential model:*

In these cases, population growth is calculated by dividing the variation in the number of individuals (dN) and the variation time (dt):

$$\mathbf{rN = dN / dt}$$

where:
r = intrinsic population growth rate or population biotic potential and
N = number of individuals
Logistic model:

When the carrying capacity (K) is an important factor in determining the potential increase of a population, the population growth is calculated as follows:

$$\textbf{Population growth} = \mathbf{rN(K - N)/K}$$

where:
r = Instant growth rate
N = number of individuals,
K = carrying capacity.

Carrying capacity (K) can be defined as the maximum number of individuals that a place can support until the population increase stops due to a lack of resources. When the population uses all resources, the carrying capacity reaches its limit, and the ecosystem cannot support any more individuals from this population. If the values of N are small, or if the population is small, (k − N)/k tends to be 1, showing no food limitation. However, when K approaches N, (K − N)/K tends to be 0. This means the population has reached the carrying capacity and can no longer increase. If N is greater than K, it means the population has exceeded the carrying capacity, so if this continues, mortality is bound to increase due to a lack of resources and the equation will transform. The Optimal Carrying Capacity is the number of individuals that an ecosystem can sustain in the long term and represents 50% of the maximum carrying capacity. Maintaining populations at their optimum carrying capacity is paramount to keeping the population and the ecosystem in balance.

6.4 Metapopulation

Most populations are not completely isolated from other populations of their species, but interact throughout their lives with other populations, forming an assemblage beyond the ecosystem. This assemblage is called a metapopulation and includes populations from different ecosystems that at certain times interact with each other. The connections that enable metapopulations are relevant for genetic diversity, as they reduce competition when populations grow too large and enable populations to flee in case of danger or disease as well as when the number of predators in their ecosystem increases too much. “Metapopulation" can be defined as populations connected through occasional movements of all or some of the individuals in a population.

Restoration and conservation plans should consider these routes. When routes used by a population are altered by fragmentation or pollution, the population can be in danger. Often habitats lacking resources force migration, which can be positive for genetic diversity and thus for the survival of the metapopulation. Island ecosystems do not have metapopulations. In these areas, populations remain undisturbed. These may be useful to restore damaged ecosystems. Any damaged ecosystem has to be restored, as the lack of high-quality habitats cannot be compensated

Fig. 6.1 The Landscape of the dry forest, north Peru. (*Author* Ana Sabogal)

by the preservation of low-quality habitats. When habitats are damaged by human activity (or other reasons), there is migration in search of new patches. Thus, patches of fragmented areas with species that have survived are then useful to repopulate the damaged areas (Fig. 6.1).

6.5 Diversity Gradients

If we compare tropical habitats with habitats in temperate or polar regions, we can observe that tropical habitats harbour greater species diversity. The main factors that determine these differences are:

- *Time:* the time of an ecosystem is directly related to the speed of its development. This is dependent on temperature and the balanced presence of water and oxygen. Therefore, at higher temperatures, the development of the ecosystem is faster.
- *Spatial heterogeneity:* the less homogeneous the ecosystem, the more habitats there are and the greater the diversity of species.
- *Competition and predation:* competition and predation lead to species selection and thus species diversity.
- *Environmental stability:* applying the Theory of Intermediate Disturbance (see 3.2.1), diversity is higher if environmental stability is intermediate since it allows an ecosystem to continue developing, but it still needs to adapt to change.

Table 6.1 Example of animal life

Species	*Amazonian pink Dolphin Inia geoffrensis*	*Tangarana Ant Formica rufa*	*Andean or Spectacled Bear Tremarctos ornatus*	*Gecko de Lima Phyllodactyllus sentosus*
Distribution	Amazon and Orinoco River Basin and its main tributaries	Tropical rainforest	Andean-Amazonian region of South America	Huacas of the city of Lima
Social Organization	Generally solitary, they are also found in groups of up to 4 individuals or mother and offspring pairs. They group seasonally to breed	It associates with the Palo Santo tree (*Triplaris americana*), defending it from possible predators	Solitary animals, they only come together during the mating season. They usually leave traces on trees to be visible to other bears of their species. Mothers accompany cubs during the first year	Solitary, they often make chirping sounds to communicate with other geckos. They only group to mate
Feeding	Newborn: breast milk Adult: fish, turtles	Omnivorous, it feeds on insects, fungi and tree sap	Mainly vegetables, supplemented with insects, eggs, birds and other small animals	Insectivorous
Factors that limit growth	Deforestation, over-hunting and other human activities that reduce and alter their habitat	Presence of human beings	Habitat depletion due to hunting, logging and agriculture	City growth
Type of strategy	Specialist	Generalist	Specialist	Specialist

Author Ana Sabogal
Source Sabogal, 2014 (Prepared by Fresia Vargas and Ana Sabogal)

- *Productivity:* the higher the productivity of the ecosystem, the higher the diversity, because productivity allows greater availability of resources for the development of species (Table 6.1).

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Chapter 7
Succession and Change of the Ecosystems

7.1 Introduction

Ecosystems, including populations and their communities, are constantly changing since they have to adapt to the variations in internal conditions and the environment. Changes occur over time, and we can identify typical stages. It is worth noting that while ecosystem changes take place over centuries of development, evolution has a much longer timescale and can span millennia. Ecological succession describes the process of change in the ecosystem. In ecological succession, we can distinguish several stages, called "stages of succession". Although we call them stages, they are a series of continuous changes.

As to landscape development, we can identify processes at macro, meso, and micro scales. The microscale processes last under 500 years and include El Niño phenomenon, population processes, and succession; the mesoscale processes last between 500 and 10,000 years and include drainage, watershed formation, and species distribution; The macroscale processes last between 10^4 and 10^6 years, and include speciation and glacial and interglacial landscape dynamics (Duivenvoorden and Duque 2010: 361). In addition, ecosystems are influenced by seasonal processes lasting less than a year like the seasons and cyclical processes that recur every 7–10 years, such as El Niño event, and processes that occur every 40 years, such as earthquakes (Odum and Warrett 2006). Organisms influence the processes of ecosystem change by enabling self-regulation and defining ecological succession.

Succession is the process of evolution and change in an ecosystem and within communities. Thus, ecological succession includes changes in the components of each ecosystem. This results in changes in populations and communities. The study of succession analyses the changes that occur in the community and the causes and consequences of these changes. In the process of succession, community populations change both in the number of individuals and species. Changes leading to speciation may also occur in another dimension of time. Succession occurs in a

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relatively short time, less than 1000 years, centuries, or decades, called "ecological time", which corresponds to the development of the ecosystem.

An ecosystem grows and develops during succession until it reaches equilibrium or stability. The speed and characteristics of the succession process depend on biological factors and the environment. These factors are oxygen, water, and temperature. Too little or too much of these factors delay the process or may even block it. The factors that define an ecological niche such as sunlight, water, organic matter, and space for organisms to develop determine the process. Other factors that influence the process are the organisms and the landscape. The isolation of the ecosystem or the existence of corridors connecting a metapopulation is vital (see Sect. 6.4).

Species use strategies that result from species co-evolution to enable the succession process in different ecosystems. In this process, most species abandon the community, leaving the ecological niche free and allowing the arrival of new species. At the beginning of succession, competition between species plays an important role, while in later stages, intraspecific relationships (between individuals of the same species) and their social organization become important. Coevolution, although a process that transcends the time of succession, helps to maintain certain species over others when they are more adapted to the environment.

7.2 Ecological Succession Process

The first stage of ecosystem development is called the "**pioneer stage**". This stage leads to soil formation. In this stage, a group of species arrives at a new site and starts its development. The species colonizing the site, called "pioneer species", are the ones that define the evolutionary course of the ecosystem. Pioneer species are to be replaced by the new species that win the battle for the resources formed in this first stage. According to the Founder Effect, the genes carried by the individuals in the population that begin the process of ecosystem formation define this process, especially if the ecosystem is isolated.

Autotrophic species are the founders of most ecosystems as they do not need another species for food. In terrestrial ecosystems, these may be lichens, a symbiosis between fungi and algae. Lichens can live independently, in symbiosis without any other species. In this symbiosis, the fungi feed on the decomposition of the plants, and the plants benefit from the fungus which helps to form organic for the plant to feed on. Depending on the ecosystem, the oxygen released by the plants is also important for the fungus. In the process, as the rock begins to decompose due to the presence of the lichens, the soil will slowly form.

The next stage is called the "sere" stage. It starts with the replacement of species. In this stage, mosses and small annual plants may appear in terrestrial ecosystems, depending on the humidity, followed by species of various grasses and semi-evergreen herbs, and finally shrubs and small trees. During this stage, formed by several phases, also called seral phases, as the soil develops, new species will colonize the spaces. The autotrophic stage continues throughout this process, in which biomass production is more important than ecosystem respiration. This allows nutrients to accumulate.

Finally, after the long process of formation, the ecosystem reaches the stage of equilibrium called "**climax**". During this stage, there is a balance between respiration and production. Here, large trees and shade-tolerant species prevail. At this stage, all resources are used, and both matter and energy flow proportionally, allowing a balance between biotic and abiotic factors. However, humans should not use these resources, as this could cause an imbalance in the ecosystem.

Climax ecosystems are particularly fragile. The tropical rainforest of the Peruvian rainforest and coral islands are climax ecosystems. Diversity and the internal processes occurring during the climax stage result in a high number of species and a complex ecosystem. Any activity involving resource extraction, such as deforestation, hunting, or fishing, does not allow the ecosystem to replenish at the rhythm required, breaking the balance of the ecosystem since the ecosystem doesn't replenish at the required rhythm. This makes the activity unsustainable in the long term and destroys the ecosystem.

Ecosystem imbalance begins at the "post-climax" stage and can have various origins. It could be caused by the dominance of one species, interspecific competition, or human intervention. During this stage, the ecosystem deteriorates and, if not reversed, may become extinct. The post-climax is also called the release phase (Holling 1993). In this stage the ecosystem collapses because the consumption of nutrients by the ecosystem's individuals as a whole exceeds the production of the ecosystem, making it unsustainable. This leads to a new cycle of succession that forms a new, similar ecosystem.

7.3 Types of Succession

Depending on the ecosystem's development, there are two types of succession, which include possible damages to the systems along the process: a continuous succession without interruption, called primary succession, and one that receives external impacts during the development process, called secondary succession.

Primary succession entails the processes of soil formation and the constitution of the ecosystem, including each stage of development. When water is scarce throughout the development, it is referred to as xerosere. During this process in the first stage, lichens occupy the space, help the stones decompose, and detain humidity. They are followed by mosses that use the little soil formed, then grasses, shrubs, and finally trees. Each of these stages takes place in the ecosystem, forming various communities. In the case of a humid ecosystem, a succession known as hydrosere occurs. The succession in this case starts in an aquatic space. In the first stage, it is the algae that produce biomass. As the bottom soil forms, submerged plants occupy the space, and as the lake dries out, some of them emerge partially to the surface, some leaves, flowers, and seeds may emerge to capture the light blocked by the floating plants on the aquatic surface.

As the succession progresses, the slope becomes less steep, plants occupy the edge, emerging from the surface, and the bottom becomes more nutrient-rich. Finally, the area dries out, and grasses, shrubs, and finally trees appear. Again, in the ecosystem, we find all the stages of succession distributed in the communities that compose it.

The processes of hydrosere and xerosere were first described by Clements (1936) as linear. However, many factors interact and alter it. Therefore, although the process appears linear, it is not always so, as not all ecosystems reach their climax stage. It depends on the interaction between the environment and the ecosystem's typical species. Some examples are the formation of glacial lakes in the highlands, tropical rainforests in humid areas, and the succession of coastal hills in arid areas. These are primary ecosystems in which, if alterations have occurred, they have not destroyed the ecosystem.

Secondary succession happens when an ecosystem suffers a disturbance in the formation process, altering its structure and dynamics. The ecosystem needs restoration, and the process can lead to different outcomes. Secondary succession rebuilds new energy flows, hosts other species, and has different population dynamics than primary succession. The speed of the ecosystem regeneration process depends on the extension of the destruction. Size, landscape disturbance, and metapopulation connectivity can affect it as well as species survival or extinction, which can alter dominance.

Examples of secondary succession are ecosystems affected by an oil spill or erosion caused by logging, or a landslide (avalanche of mud and stones) which swept away the vegetation, denuding and dragging the soil. In the Peruvian highlands, there are many ecosystems where the slope is constantly washing away the surface and is in a constant state of regeneration. Pioneer plants such as ferns, bamboo, and grasses are fast-growing. More examples of successional ecosystems are the riverbank in the Amazon called riparian ecosystems or barzales, made up of fast-growing species. They change and disappear temporarily with tidal changes and plants quickly reoccupy the space as soil and plant debris remain in place. On the coast, hilly ecosystems are also secondary. They have a regeneration dynamic dependent on moisture brought by the wind from the Pacific Ocean and many have been subjected to grazing and afforestation.

In Peru, the formation of the Andes is relatively young compared to the rest of the mountain ranges in other parts of the world. Here, the mountains are still growing and have not been shaped by the climate, so the slopes are very steep, and rainfall may cause avalanches. When it rains, mud comes down the steep slopes at great speed, also carrying stones in its path. This phenomenon is commonly known as "huaico", and it is very common in Andean countries. Over time, the huaico is shaping the mountains, gradually decreasing the slopes. Often the landslides have a recurrent path and can form large cracks in the mountains known as gullies. This process also occurred on other continents when they were still young. There are thus two different time dimensions, one geological in the formation and shaping of the continent, the other in the formation of the ecosystems. Today, the melting of glaciers is adding to this process and accelerating it. Recognizing the dynamics of the continent is essential for proper planning and sustainable development.

When an ecosystem has been destroyed, the time it takes to recover depends on the degree of destruction. In cases where the ground has been completely cleared, it is impossible for the original ecosystem ever to reconstitute itself. If a forest is partially cleared with a power saw, the replenishment of the ecosystem will result in a heterogeneous forest community after a few years. Constantly logged forests are known as purmas; these forests will never reach the diversity of the original forest. If, on the other hand, logging is done with large machines that destroy the soil structure and remove the trees, the formation time of the new ecosystem may be longer than 100 years and may result in grassland or shrubland ecosystems. In the first case, it is then a secondary succession. In the second case, the whole ecosystem will have to re-form, as the soil structure has been damaged, initiating a new primary succession.

Ecosystem resilience is the capacity of ecosystems to return to their initial state. Holling (1993) defines this capacity as the “Adaptive Cycling of ecosystems”. The Adaptive Cycle is, according to this author, the capacity of ecosystems to reorganize after suffering a disturbance. In this way, ecosystems have a self-regulating capacity called “resilience”. This cycle is made up of several stages. During the first stage, known as the “exploitation stage”, biomass production and diversity increase. This stage is the equivalent of the sere stage. It is followed by the conservation stage, in which the ecosystem’s components increase their complexity and connectivity reaching the climax stage. Then comes the ecosystem release stage, in which there is more competition and carrying capacity. Finally, in the regulation stage, new rules are established in the ecosystem and the cycle repeats itself.

In contrast to the traditional view described above, Holling introduces the concept of ecosystem resilience, or the ability to respond to limitations by constantly regenerating. In this way, ecosystems may experience collapses as part of their development, which are followed by a stage of adaptation and readjustment. Every ecosystem can reorganize, transform, and innovate, to evolve and initiate the next phase of growth.

The ecosystem’s capacity for regeneration and resilience, however, is limited by several factors such as the amount of matter and energy accumulated during the ecosystem’s process of formation, its populations‘specialization, the intensity of the damage, the speed of change and finally, species subsistence after the change. If proper conditions are not met, the ecosystem will not be able to recover and the so-called point of no return is reached, followed by the decline of the ecosystem.

7.4 Factors Leading to Climax

Depending on the importance of each of the factors leading to the climax stage of an ecosystem, two types of climax can be distinguished: climatic climax and edaphic climax. It is important to emphasize that it is the factors that lead to the formation of the climax and not the actual state of the climax that determines the type of climax.

- *Climatic climax*: when climatic factors determine the process culminating in climax formation. For example, climax states in a desert or tropical dry forest.
- *Edaphic climax*: when the characteristics of the soil or subsoil water, or topography, determine the process leading to climax. Examples of edaphic climaxes are a coastal lagoon or tropical rainforest.
- *Catastrophic climax*: when an ecosystem leads to its extinction, without an external factor destroying it. In this case, it is the nature of the ecosystem itself that leads to the post-climax and subsequent death of the ecosystem. Most lagoons are catastrophic ecosystems because when they develop they lose connection to the water table and dry up.

Understanding the succession process allows the development and sustainable use of the ecosystem's resources because its productivity, diversity, and stability differ according to the stage of succession the ecosystem is in, so to be able to determine the use it may be subject to it is necessary to know the ecosystem's stage of development.

7.5 Types of Succession According to Productivity

Depending on the balance between production (amount of biomass produced) and respiration (energy used by the ecosystem) of the ecosystem, there are two types of succession:

- *Autotrophic succession*: in this type of succession, photosynthetic or producing organisms dominate the process. Examples of autotrophic succession driven and dominated by plants are the natural grassland of the puna and the moorland. In both cases, the cold causes a slow decomposition, so organic matter accumulates.
- *Heterotrophic Succession*: in this type of succession the heterotrophic organisms dominate the process. In these communities, the number and importance of consumers and disintegrators is greater than that of producers. The disintegrators play a key role in the recycling of nutrients. Examples of heterotrophic succession are the processes that occur in oxidation ponds, composting ponds that use organic waste to form fertilizer, and human-polluted lakes, such as Lake Titicaca. Heterotrophic successions are also those that occur in an ecosystem of fallen logs in the rainforest, where fungi and invertebrates that decompose organic matter are predominant.

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Chapter 8
Biodiversity of the Amazonia Basin

8.1 Introduction

This chapter defines biodiversity and describes its peculiarities in the Andean-Amazonian area. It also discusses biodiverty's natural conservation. In this sense, it questions how biodiversity is maintained and reproduced despite anthropic modifications and human intervention, correlating it to cultural conservation in which humans have always played an important role and have devised ways of conserving the diversity and integrating human use.

There are three levels of biodiversity conservation: ecosystem, species, and genetic. Conservation deals with the development of biodiversity and the peculiarities that have enabled the richness of the Andean-Amazonian, responding to modifications over time in which environmental factors, soil, and geology have played a key role.

It also describes the peculiarities of biodiversity use from the perspective of cultural ecology in the Andean-Amazonian. The use of different altitudinal zones and the system of migration, grazing, and hunting are part of biodiversity conservation.

8.2 Biodiversity

Biodiversity usually refers to species diversity, although the term also refers to the variety of ecosystems. The total number of species on the planet is not known for certain, and new species are discovered every day. In the Amazon, there are potentially 12,500 tree species (Ter Steege 2010: 349).

Species inhabit diverse ecosystems. The number of species is directly related to latitude, altitude, and the amount of water available in the form of snow, hail, or rain. This translates into the distribution of ecosystems and biomes. There is a direct

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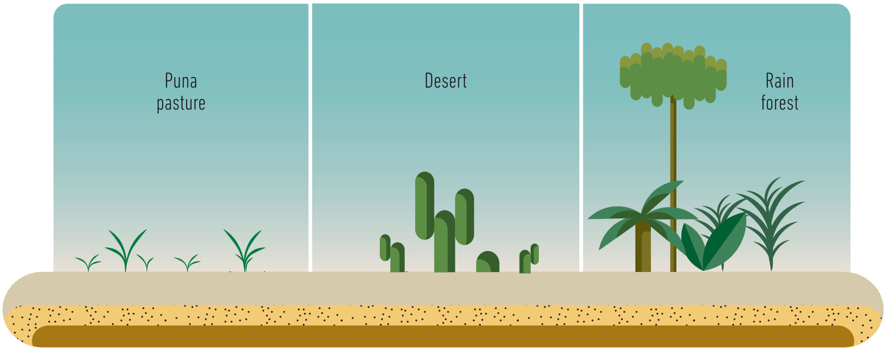

Fig. 8.1 Biodiversity and grow form. (*Author* Ana Sabogal, designer Juan Pablo Bruno. *Sources* Miller 1994)

correlation between latitude and altitude and the diversity of ecosystems as long as water, oxygen, and nutrients are not limiting factors. In terms of ecosystems, the highland rainforest has one of the highest biodiversity on the planet, much higher than that in the lowland rainforest, partly due to topography. In this way, topography, moderate changes in ecosystems, climatic variations, competition, and interspecific relationships, among others define and enhance biodiversity.

Changes in the ecosystem and competition between species cause biodiversity to be subject to constant change and alteration. New species are constantly appearing and disappearing as a result of evolution. However, both speciation and extinction are long processes occurring over several generations and beyond the lifetime of an ecosystem and are affected by environmental changes. The formation of a new species is estimated to be between 2000 and 1000,000 generations (Miller 1994). What is important is that extinctions occur slowly enough to allow the formation of new species (speciation). This process is estimated to occur in time intervals of between 10^4 and 10^6 years (Duivenvoorden and Duque 2010: 361) (Fig. 8.1).

8.2.1 Biodiversity Conservation

Extinction is a natural process that regulates an ecosystem. However, if caused by external disturbances to ecosystem dynamics, it may result in catastrophic consequences. Undoubtedly, human pollution has been a major cause of extinction in the last century. The loss of plant species has greater ecological consequences than the extinction of animal species, as it carries with it the disruption or extinction of the upper trophic chain and, consequently, the extinction of all animals that depend on the extinct plant species. Many species have not been discovered yet; there are many unexplored ecosystems like those in the deep sea. New species are discovered every day.

The total number of species is about 1.75 million and 250,000 are plants (see Sect. 5.2.5). The study of species or ecosystems allows us to learn about their evolutionary processes. The loss of species and ecosystems before they are discovered means the loss of the clues to evolutionary processes which allow us to learn the history of evolution so we can prevent catastrophic processes. We would lose the possibility of learning evolutionary clues and preparing for Climate Change. The climate is directly influenced by the species that inhabit the land, on which the cycling of nutrients and water depends. The distribution of rain, heat, and wind is directly related to the distribution of species.

It is necessary to remember that species are not found alone in nature. Trophic chains, interspecific relationships, and the habitat that each species occupies within the ecosystem allow the recycling of nutrients, the optimal use of space, and the very functioning of ecosystems.

8.2.2 Ecosystem Conservation

Ecosystem conservation depends on the ecosystem's characteristics and how these interact. The number of species is not relevant but the complexity of the ecosystem is. Nowadays, there is great interest in the ecosystems that have adapted to changing conditions, especially climate change. The characteristics of ecosystems that determine conservation priority are endemism, isolation, biodiversity, niche narrowness, the existence of species in critical condition, and fragile habitat.

8.3 Amazonic Basin Diversity

8.3.1 Geology and Climate

The Amazon is known for its great biodiversity. However, the greatest biodiversity in the Amazon is found in southern Ecuador and northern Peru. One of the reasons for this diversity is the Palaeocene climate, which seems to have influenced evolution and caused speciation and species extinction (Ter Steege 2010: 349) more than the current climate. Continuous changes in forest climate have resulted in the loss of about 200 genera in the southern Amazon forest (Ter Steege 2010: 357). Out of 12,500 Amazonian tree species, the rarest species are found in more stable climates in western Amazonia and are more vulnerable to habitat changes and climate change (Ter Steege 2010: 357).

The geology of the eastern and western Amazon makes subsoil fertility very different. Species distribution reveals this difference (Ter Steege 2010: 349). The combination of geology and rainfall results in the difference in soil fertility. In addition, the high fertility of the Cenozoic soils of the western Amazon has allowed high levels of soil decomposition and evolution, thus greater diversity of trees (Ter Steege 2010: 349). The north of South America suffered several climate and tectonic changes during the Cenozoic, which resulted in a varied landscape (Wesselingh et al. 2010: 421), undoubtedly causing species diversity. Therefore, on a smaller scale, differences in habitat have played an important role in diversity (Ter Steege 2010: 349).

The granitic sediments of the eastern Amazon come from Brazil and Guyana (Fine et al. 2005 cit. Pennington and Dick 2010: 380). These sediments make infertile soils and occupy 3% of the Amazon (Pennington and Dick 2010: 380). Climatic weathering and sediment deposition from the Andes produce the most fertile soils. Sand and gravel deposited in the Pliocene and Pleistocene produced terrace soils, whereas the erosion of Cretaceous metamorphic rocks from the Andes deposited in swamps, shallow and deep lakes forming the incrustations produced clay soils in the western Amazon (Hoorn 1993, cit. Pennington and Dick 2010: 380).

In summary, the chronology of the formation of the Amazon would be as follows:

- Early Cretaceous- Eocene (83–43 M.y.): the marine scenario disappears, the cratonic river system dominates (Wesselingh et al. 2010: 426).
- Middle Eocene-Oligocene (43–34 M.y.): the Andes rise and the marine inlet closes (Wesselingh et al. 2010: 427).
- Oligocene (34–24 M.y.): influence of the sub-Andean river and denudation of the surrounding areas (Wesselingh et al. 2010: 427).
- Late Miocene (11–7 M.y.): influence of the wetland and the transcontinental water corridor (Wesselingh et al. 2010: 428).
- Late Miocene-Pleistocene (7–2.5 M.y.): start of the current river system (Wesselingh et al. 2010: 428).
- Quaternary (less than 2.5 M.y.): ice age in the Amazon (Wesselingh et al. 2010: 429).

8.3.2 Landscape

The landscape has gone through macro-, meso- and micro-scale processes that have shaped the area (see Chap. 7). At the mesoscale level, the geology correlates with the topography, creating diverse habitats for species and driving the varied ecosystems of the Amazon (Duivenvoorden and Duque 2010: 360). The variety of the landscapes in this area features the Andes and the cratonic fluvial system, which form ancient continental masses that have not been broken up by orogenic movements (Sioli 1984 cit. Duivenvoorden and Duque 2010: 360). The landscape of the northwestern Amazon includes a greater diversity, with a positive correlation between geological units and species distribution (Duivenvoorden and Duque 2010: 360).

8.3.3 Amazon Rivers and Diversity

The lower areas of the southern and western Amazon have lacustrine deposits of the Pebas-Solimóes formation. In contrast, there are fluvial-volcanic deposits on the surface of the sub-Andean basin located in the lower areas of the western Amazon surface (Duivenvoorden and Duque 2010: 362). Rivers born in the high Andean areas, such as the Napo or Putumayo, carry suspended sediments and fine-grained suspended clay, but farther downstream there is dissolved acidic organic matter that gives the river a brown colour (Duivenvoorden and Duque 2010: 362). This determines soil fertility and can be observed in the inflow of the rivers into the Amazon River.

Rivers also play an important role in the diversity of soils. In the northwest Amazon, the diversity of soils in low and flat areas depends on the rivers that transport the soil. Here we find dominating flood and inter-river areas. Most of the ground is deeply scoured (Sánchez and Boul 1974; Duivenvoorden and Lips 1993 cit. Duivenvoorden and Duque 2010: 362) forming acrisols and ferrosols (IUSS 2007 cit. Duivenvoorden and Duque 2010: 362). Whereas in sediments derived from the formation of Pebas/Solimóes, there are alisols and acrisols (IUSS 2007 cit. Duivenvoorden and Duque 2010: 362). Rivers shape the landscape through soil deposits forming alluvial terraces, these terraces are found along Andean rivers like the Napo River (Räsänen et al. 1998 cit. IUSS 2007 cit. Duivenvoorden and Duque 2010: 362). The Napo River is a tributary of the Amazon River. Temperatures and frequent rains cause scouring and ferralization (Duchaufour 1982, cit. Duivenvoorden and Duque 2010: 363). This process dominate in the low interfluvial area. This process is dominant process is low under interfluvial areas (Duivenvoorden and Duque 2010: 363).

The northeast of the Amazon has the most biodiversity (Gentry 1988, cit. Duivenvoorden and Duque 2010: 363) due to its geology and habitat diversity (Duivenvoorden and Duque 2010: 368). At a mesoscale level, water and nutrients explain the great biodiversity (Duivenvoorden and Duque 2010: 368). However, speciation correlates to the quality of the soil, dispersion, and species interaction (Duivenvoorden and Duque 2010: 368). Microrelief defines drainage and sediment accumulation that influences diversity in flat areas (Duivenvoorden and Duque 2010: 368). The river and meanders play an important role in sedimentation. Erosion and the speed the water flows or leaves the sediments are fundamental, as well as the erosion of the river's edges in the flat areas (Duivenvoorden and Duque 2010: 364). The changes in the meanders that form outbox lakes, used by animals for drinking have the most nutrients, enrichening underground water with sodium and potassium (Lip and Duivenvoorden 1991 cit. Duivenvoorden and Duque 2010: 364). At a microscale level, land shape and drainage density or river dendrometry define biodiversity (Duivenvoorden and Duque 2010: 366).

8.3.4 Species Diversity

To study biodiversity we need to link data from palaeontology, biology, and geology (Lovejoy et al. 2010: 414). The diversity of Amazonian flora includes 473 tree species per hectare (Valencia et al. 1994 cit. Wesselingh et al. 2010: 421). Evolution and ecological interactions in the area should also be considered (Wesselingh et al. 2010: 421). The north of South America has gone through several climate and tectonic changes during the Cenozoic that shaped a varied landscape dominated by plains and river diversifications (Wesselingh et al. 2010: 421). In the Miocene, the Andes were connected to the Atlantic through an incipient Amazonian river (Wesselingh et al. 2010: 421). From the late Miocene onwards, edaphic diversification emerged in the western Amazon from former lakes (Wesselingh et al. 2010: 421). Lakes formed at the beginning of the Miocene. The current basin system also dates back to the Miocene (Figuereido et al. 2009 cit. Wesselingh et al. 2010: 422); this is followed by flora diversification (Jaramillo, cit. Wesselingh et al. 2010: 422) as well as fauna (Latrubesse et al. 2007 cit. Wesselingh et al. 2010: 422). Nutrient-rich deposits appeared in the eastern and central Amazon, coinciding with the diversification of new terrestrial taxa (Wesselingh et al. 2010: 421).

The current biodiversity richness is attributed to the combination of humid climate and warm climate, and the diversification of soil strata (Wesselingh et al. 2010: 421). Species distribution occurred in the Quaternary (Wesselingh et al. 2010: 421). Amazon biodiversity materialized over long periods (Raven and Axelrod 1974 cit. Wesselingh et al. 2010: 422). The Quaternary ice age was a vital process to promote biodiversity (Haffer 969 cit. Wesselingh et al. 2010: 0.422), together with other processes that interacted over various time scales (Bush 1994 cit. Wesselingh et al. 2010: 422).

Fragmentation of the hydrographic system dates back to the Pleistocene in the Fitzcarrald isthmus of the Amazonian basin when the riverine biota fragmented and generated allopatric divergence (Espurt et al. 2007 cit. Wesselingh et al. 2010: 423). The heterogeneity of soil types is considered the cause of the great concentration of flora biodiversity in the western Amazon (Ruokolainen et al. 2007 cit. Wesselingh et al. 2010: 423). The Niño event affected the area in the Pliocene (Molnar and Cane 2007 cit. Wesselingh et al. 2010: 423). Sediment transport and soil denudation date back to the last 3 million years (Figuereido et al. 2009 cit. Wesselingh et al. 2010: 423). Since the appearance of the Andes, there has been a lot of erosion of the Andean slopes, generating the soils at the foothills (Mora et al. 2008 cit. Wesselingh et al. 2010: 423).

Pleistocene climatic changes seem responsible for most of the biodiversity in the Amazon (Antonelli et al. 2010: 386). Phylogeny and species distribution patterns suggest that climatic cycles triggered speciation (Antonelli et al. 2010: 386). Species biodiversity in the Amazon seems to be a consequence of neogenesis rather than long-term speciation changes, but this depends on the species. Whereas tetrapods, amphibians, and reptiles have older clades than those of birds, mammals have both recent and ancient clades (Antonelli et al. 2010: 386).

The Miocene-Pleistocene period marks a milestone in the Amazon biodiversity (Antonelli et al. 2010: 396). The rise of the Andes, marine incursions, and climate changes marked biodiversity. The neogenesis was crucial for the diversification of species in the neotropics (Antonelli et al. 2010: 396). The ancient presence of the tropical rainforest and the humid, tropical climate seem to be the cause of in situ biodiversity development. In addition, disturbances throughout history that altered and fragmented the forest ecosystem, such as marine incursions, geotectonic events, wetlands, and climatic fluctuations, created the pressure that led to evolution, generating both diversity and extinction of species (Antonelli et al. 2010: 398).

The Amazon aquatic fauna biodiversity is immense. There are estimated to be more than 3000 species of fish, making it the richest area in continental aquatic fauna (Lundberg et al. 2000; Reis et al. 2004 cit. Lovejoy et al. 2010: 405). The Amazon aquatic fauna makes up 20% of the world's freshwater fish fauna (Lundberg et al. 2000; Reis et al. 2003 cit. Wesselingh et al. 2010: 421). The taxonomic complexity of the ichthyofauna is also remarkable with a very large taxonomic diversification (Lovejoy et al. 2010: 404). The time of diversification of aquatic species in the western Amazon coincides with the greatest amount of wetlands in the Miocene epoch representing the marine-continental interface (Levejoy et al. 1998 cit. Wesselingh et al. 2010: 425).

8.3.5 Plant Diversity

The Amazon has been around for 55 million years. Furthermore, non-angiosperm species have been found in Cretaceous deposits (Jaramillo 2006 cit. Wesselignh et al. 2010: 425). Plant pollen has shown us that angiosperms dominated the tropical forest in the Palaeocene and are still found in low diversity (Wesselingh et al. 2010: 425). Plant biodiversity increased in the Eocene when there was even more biodiversity than now, but it decreased in the late Eocene at the beginning of the Oligocene, coinciding with cooling (Zachos et al. 2001, 2008; Jaramillo et al. 2006 cit. Wesselingh et al. 2010: 425). Montane plant biodiversity increased in the Andes in the Quaternary (Hooghiemstra and van der Hammen 2004 cit. Wesselingh et al. 2010: 425–426).

In the past, the Amazon was in contact with other biomes (Pennington and Dick 2010: 379). Some Amazon plant clades are confined to the Amazon in the tropical rainforest, others are also found in other biomes such as the seasonally dry tropical forest (Pennington et al. 2000 cit. Pennington and Dick 2010: 379) and in the Brazilian Cerrado (Pennington et al. 2006b cit. Pennington and Dick 2010: 379). The genus Ruprechtia of the family Poligonaceae is found in both the Amazon and in the seasonally dry forest. It is an ecological speciation between biomes across the Andes, however, this appears to be rare for Amazonian species (Crisp et al. 2009 cit. Pennington and Dick 2010: 380).

The tropical rainforest has a diversity of habitats, resulting from the diversity of precipitation, seasonality, temperature, and soil type. This habitat diversity leads to high species biodiversity (Pennington and Dick 2010: 379). There is also edaphic influence, with species evolution coinciding with soil associations. Thus, the speciation distribution corresponds to the edaphology in the Amazon (Pennington and Dick 2010: 379). There is also a correlation between soil and interspecific competition, with species growing in clay soils attacked by herbivores when they grow in sandy soils (Finc et al. 2004 cit. (Pennington and Dick 2010: 379)).

The diversification patterns of the lowland Amazonian plants, dispersed over millions of years is known as “dispersal overwrite” or the geographically grouped Amazonian flora caused by the lack of geographic dispersal of the flora during plant phylogenesis (Pennington and Dick 2010: 382). Factors such as the form of reproduction, pollination, and the species‘ability to conquer space define this characteristic (Pennington and Dick 2010: 382). In addition, in the Amazon, there is a conserved phylogenetic niche, because lineages tend to maintain the ecological ancestral predilection (Harvey and Pagel 1991 cit. Pennington and Dick 2010: 380). Patterns of plant diversification in the Amazon have developed over millions of years, and the study of multi-locus development and nucleotide polymorphism may shed further light on whether this correlates more to specific events or it is a continuous process (Pennington and Dick 2010: 380).

The most abundant families in the Amazon are Fabaceae, Rubiaceae, and Moraceae (Gentry 1993). The families Annonaceae, Lauraceae, Melastomataceae and Euphorbiaceae are also abundant (Gentry and Ortíz 1993, cit. Gentry 1993). The family Fabaceae (Leguminosaceae) is the most dominant in Amazonia and predominates where poor soils prevail. This is because the species of this family have microbial symbiosis that allows them to grow in these spaces. In addition, the toxicity of their seeds prevents competition with other species, preventing the growth of other species in the surrounding soil, thus ensuring food (Ter Steege 2010: 349). Whereas in eastern Amazonia leguminous plants are abundant, in western Amazonia the most abundant families are Chrysobalanaceae and Lecythidaceae together with Moraceae, Miristicaceae and Urticaceae (Ter Steege 2010: 357). Other important families in the southern Amazon are Orchidaceae and Acantaceae (Foster 1990 cit. Gentry 1993).

The distribution of tree communities in both the Peruvian and Ecuadorian Amazon correlates with the geology and soils (Duivenvoorden and Duque 2010: 360). Edaphic speciation of some tree species suggests speciation across diverse habitats which is an important cause of diversification in the Amazon forest (Pennington and Dick 2010: 380). The plant tribe Protieae of the family Burceraceae evolved from terrace soils to clay soils and white sands (Pennington and Dick 2010: 380). According to Fine et al. (2005) this may be the cause of the extinction of the ancient lineages from the white sand habitat (Pennington and Dick 2010: 380).

8.4 Plant Adaptations in the Tropical Rainforest

The tropical rainforest is located in the equatorial belt between 10°S and 10°N (Smith and Smith 2007: 502). The tropical rainforest in the lowland rainforest has average temperatures between 24 and 26 °C, and relative humidity over 75% and minimum temperatures between 1800 and 2000 mm/year (Brack and Mendiola 2000: 220). The biomass in the tropical forests is around 300 T/ha and the net annual production 22 million T/ha (Smith and Smith 2007: 506). In general, high levels of rainfall cause the soils to be poor and highly acidic with a high aluminium content.

The diversity of ecosystems in Peru's tropical rainforest is enormous and varied. It is different in the highland and in the lowland rainforest. Topography, drainage, and soil origin are largely responsible for this diversity (Smith and Smith 2007:504). In the lowland rainforest, we can find the following:

- Flood forests: located along the rivers also known as varzeas with species adapted to temporary flooding. Some typical species of this ecosystem are the lupuna (*Ceiba* sp.), the palo balsa (*Ochroma* sp.), and the cetico (*Cecropia* sp.), among many others.
- Mainland forest: its composition depends largely on the type of soil which could be sandy, terraced, alluvial, or heavily scoured nutrient-poor red soils.
- Aguajales: flooded soils whose main species is the aguaje palm (*Mauritia flexuosa*).
- Humid soils: dominated by bamboo known as paca (*Guadua* spp.).
- Marshes: flooded areas consisting of grasses, ferns and wetland plants.
- Intervened forest formations: areas with human disturbance and secondary vegetation (Brack and Mendiola 2000: 222).

However, there is a diversity of soils depending on the area. Thus, we find soils of fluvial origin that contain sediments from the Andean soil (Brack and Mendiola 2000: 220). Among the soils of the lowland rainforest of Peru, we find entisols, ultisols of low fertility, which make up almost half of the Amazonian soils, entisols, or young and shallow terraced soils (12.8%), inceptisols or young soils with defined profiles that are occupied by aguajales (10.5%), alfisols, vertisols, and molisols or moderately fertile and highly scoured soils, very infrequent (3%) and spodosols or very infertile sandy soils, in a very low percentage (0.1%) (Brack and Mendiola 2000: 220). Thus, it is an area of edaphic climax where the soil defines the characteristics of each area.

The cycles are biological, producing a rapid decomposition, which practically does not go through the soil. Decomposer bacteria and fungi transform organic matter at full speed, and soil microbial symbiosis directly uses the nutrients produced by the plants, being fungi the main link in the trophic chain. This decomposition is assisted by the animals, earthworms, insects, fungi, and bacteria composing the soil stratum.

Species diversity is enormous, containing several million species, almost 50% of the planet's diversity (Smith and Smith 2007: 503). One of the outstanding features is the large number of strata in the area. The high stratum is made up of trees that can reach between 40 and 80 m in height (Smith and Smith 2007: 503). On these, grow macro epiphytes including bromeliads, orchids, ferns, and cacti, as well as micro-epiphytes like mosses, algae, fungi, lichens, macro-epiphytes: orchids, bromeliads, cacti, and animals such as frogs, tree frogs, monkeys, toucans, and many others. Most of the plants have adapted to grow in the undergrowth with a low amount of light. Here we can find various ferns, and araceae with huge leaves. In addition, we find lianas that climb to reach the light and strangle plants that compete with the trees. Most of the roots are shallow and bifurcate to form a dense shallow layer above the ground. Trees develop buttresses or elevations and widening of the top of the root ensuring the stability of the trees.

Young trees grow rapidly, maintaining a monopodial form without branching, until they reach the light (Smith and Smith 2007: 505). Other trees, such as rubber trees or many ficus trees, direct some of their branches towards the ground which, when anchored in the soil, stabilize the tree; these branches are called "adventitious roots". The change in the direction of branch growth, known as positive geotropism, involves a hormonal change and it is an adaptation to space. At first, the tree has a predominance of gibberellins in the upper bud, which allows rapid growth, in addition to the plant hormone auxin, which affects the tropism of the plants, causing the shoots to bend in the direction of the light (Lira 1994: 208). Subsequently, the hormonal balance is modified by increasing the auxins that cause the growth of lateral branches, modifying it into a sympodial growth form.

The canopies form a dense network that reduces the passage of light and rain and the circulation of air. This increases the concentration of carbon dioxide in the shaded area, which reduces the number of animals. In theory, there could be an enormous amount of photosynthesis, but photoinhibition occurs in this shady area due to the lack of light. In shady environments, the rate of photosynthesis declines when there is more light because the enzyme rubisco, which is necessary for the process, is not present in sufficient quantity, and the plants reach light saturation point very quickly, and as the quantity of light increases, photosynthesis is blocked. This is called photoinhibition (Smith and Smith 2007: 57). Plants in shady areas, therefore, have a reduced rate of photosynthesis, which slows down their growth (Smith and Smith 2007: 59). On the other hand, the excess temperature damages enzymes and proteins, preventing photosynthesis.

In the shade, full-fringed leaves reduce water loss by evapotranspiration and lower the temperature by allowing air to circulate. On the other hand, to compensate for the lack of light, the plant adapts by increasing the size of the leaves, producing thinner leaves, and increasing the density of chloroplasts per leaf unit. The chloroplasts are oriented parallel to the sun in order to increase the absorption surface and compensate for the lack of light.

In the tropical rainforest environment, we find C4 and C3 photosynthesis. C4 plants have a higher resistance to temperature and are found in spaces where there is less humidity, such as the canopy of trees. C4 photosynthesis saves water and takes advantage of low levels of carbon dioxide (Smith and Smith 2007: 26–27). The thin leaves contain a lagoon-like palisade tissue to increase the air in the leaf and decrease leaf temperature (Smith and Smith 2007: 26–27).

Plant seeds in these environments contain a large amount of pulp and fat, which aids dispersal and rapid germination in the poor soil and ensures food for the seedlings. The disadvantage is that seed viability is short due to the rapid oxidation of fats.

The trophic chain includes various groups. In general, there are more plants than animals as a consequence of the absence of phosphorus which implies a lack of proteins and a high level of carbon dioxide. The forest is in a state of climax in which everything that is produced is used by living beings with very narrow ecological niches. Therefore, there is a great diversity of species, but with a small amount of each species, there is great competition for resources and therefore many interspecific and intraspecific relationships that help the survival of the species.

8.5 Forms of Growth in the Andean-Amazon Region

The growth form of the plants has a direct influence on the resistance to climatic conditions. Rosettes, shrubs, cacti, and succulents are the most resistant. Many other factors influence this resistance, such as the shape of the leaves, their arrangement, proximity to the ground, self-shading, and the amount of leaf litter.

The most common growth forms are:

- Phanerophytes: trees.
- Chameophytes: shrubs.
- Hemicryptophytes: plants with meristems on or near the surface.
- Therophytes: annual plants, which avoid growing during unfavourable seasons, remaining stored as seeds until the next season.
- Cryptophytes or geophytes: plants with meristems below the ground like the bulbs, rhizomes, and tubers.
- Hydrophytes: plants with meristems under water (Fig. 8.2).

8.6 History of the Use of Biodiversity from the Perspective of Cultural Ecology in the Andean Amazonian Area

Historically, the use of resources is widely varied in the different Andean-Amazonian areas. In the Andes, from at least the classical period, societies depended on vertical control. These micro niches allowed economic and social independence by exploiting diverse ecological potentials (Onuki 1985: 352). On the other hand, the richness

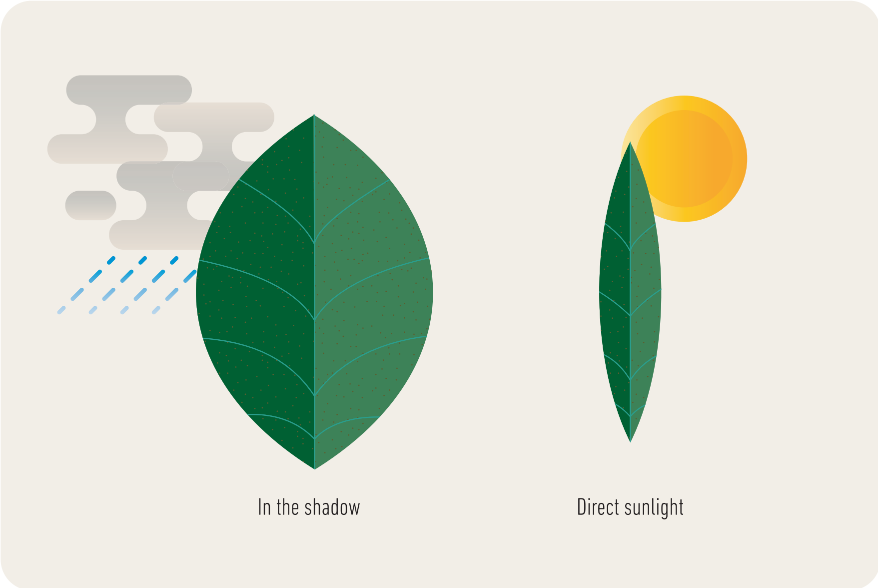

Fig. 8.2 Leaf in different ecosystems. (*Author* Ana Sabogal, designer Juan Pablo Bruno. *Sources* Smith and Smith 2007)

and variety of ecological niches on the coast allowed societies to depend on horizontal control (Onuki 1985: 351). In the Amazon, societies traditionally practised transhumance, occupying a wide area and alternating use with hunting.

Vertical distribution of resources is not exclusive to the Andes but it is also used in other mountainous regions of the world such as the Himalayas, Ethiopia, and New Guinea (Rappaport 1968 cit. Onuki 1985: 348). There are local strategies to exploit the vertically distributed resources (Onuki 1985: 348). In the Peruvian Andes, the form of utilization of the environment was Puna-Suni and Quechua-Yunga, creating ties of economic dependency based on the exchange of products (Onuki 1985: 350). There is a maritime Yunga-coastal exchange of products and water management for coastal irrigation (Onuki 1985: 350). The key products for exchange with the yunga area were maize and cassava. The maritime yunga area was crucial for this exchange (Onuki 1985: 350). Between the maritime yunga and the Andes, the different societies exchanged ideas and products (Onuki 1985: 351).

To describe the discontinuous territoriality of ethnic groups in the Cajamarca region in 1570, Rostworoski posits that in the Andes there is a “dotted” or “discontinuous” management of resources (Rostworoski 1977 cit. Ramírez 1985: 423), whereas Murra calls them islands (Murra 1972 cit. Ramírez 1985: 423).

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Chapter 9
Peruvian Protected Natural Areas

9.1 Introduction

The concept of a "national park" is relatively recent. The world's first national park is Yellowstone in the United States, created in 1872 (Dourojeanni 2009: 449). Habitat conservation allows the ecosystem to function, so communities, interspecific relationships, population dynamics, and landscapes can also function. Therefore, conservation in a protected area goes beyond conserving a few individuals of each population. Species conserved within the Natural Protected Area are in their natural habitat, so it is an in situ conservation.

The concept of conservation has changed over time. Initially, there was an isolated conservation of parks with no human influence. Over time, this vision changed and Biosphere Reserves were created. These spaces added transition areas and ecological corridors to the protected area or core area. In this way, populations can move between different areas, and thus population densities can be controlled. Biosphere Reserves were declared a World Heritage Site in 1971 to conserve valuable areas of the world. The Peruvian Biosphere Reserves are national areas registered by UNESCO as natural heritage of humanity, subject to the World Heritage Convention (Brack and Mendiola 2000: 474). The Man and Biosphere Programme of the United Nations recognizes that these spaces need to be preserved not only for the protection of species but also for the benefit of future generations.

Nowadays, landscapes are also protected areas and include a broader space with rather fragile areas and metapopulations (see Sect. 6.4). The concept of landscape as a space that contains the interaction of natural and anthropic spaces considers that human creation must integrate livelihood into conservation, allowing the population to benefit from it (Council of European Landscape Convention 2000).

Today we start with the need to maintain ecological processes within protected areas. To adequately protect the habitat of a species, it is not enough to conserve and isolate a space. It is necessary to consider the size of the space, connectivity, and

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species diversity, distinguishing between native species and ecological corridors. Maintaining natural ecological processes allows for a balance of all species.

Natural protected areas (NPAs) are intended to preserve the space, but they also serve for research, environmental education, and ecotourism. NPAs are also culturally, religiously, and historically important spaces (Suarez de Freitas, in Solano 2005).

9.2 History of NPAs Creation in Peru

The first National Protected Area (NPA), Reserva Nacional Cueva de las Lechuzas, was established in 1950 (Solano 2005: 38). Before this, Pacaya-Samiria was created in 1940 as a paiche (*Arapaima gigas*) fishing reserve (Dourojeanni 2009: 451). In 1958, the conservation categories Forest Reserve and National Forest were legally created (Supreme Decree 2 of 1958) with the support of the US government (Solano 2005: 39). The objective of the category of National Reserves is to preserve the forest, whereas the objective of the category of National Forests is to sustainably manage an area, but both are under the direction of the Ministry of Agriculture (Solano 2005: 39). In 1961, 90 years after Yellowstone Park, Cutervo National Park, was created (Solano 2005: 40). The first area that took into account wildlife management by local populations was the Pampa Galeras National Reserve established in 1967 (Solano 2005: 45). In 1968, the law's regulations included National Parks, National Reserves and National Sanctuaries, as well as the possibility of declaring areas for hunting and fishing reserves (Solano 2005: 47). It was at the beginning of the 1970s that most of the current NPAs were established (Solano 2005: 52). Furthermore, in 1977, three Biosphere Reserves were established and recognized by UNESCO as World Heritage Sites. In 1980, Peru had 19 NPAs covering 3.6% of its territory (Solano 2005: 63). Currently, NPAs represent 17.26% of Peru's area (SERNANP 2022b).

In 1990, the National System of Natural Areas Protected by the State (SINANPE) was founded as part of the Agriculture sector (Solano 2005: 70). An important milestone for Peru was the foundation of INRENA (*Instituto Nacional de Recursos Naturales*) in 1992 as a decentralized organization of the Ministry of Agriculture in charge of NPAs (Solano 2005: 80). Furthermore, in 1992, the current administrative organizations were founded: FONANPE (*Fondo Nacional para las Áreas Naturales Protegidas*) and PROFONANPE (*Fondo de Promoción de las Areas Naturales Protegidas*) that was founded as private non-profit funds to manage the NPAs (Solano 2005: 82). The NPAs could be managed by private non-profit organizations. The first two were managed privately. They were the Coto de Caza el Angolo and the Comunidad Campesina Santa Catalina de Chongoyape (Solano 2005: 107).

In 1997, the Law for Protected Natural Areas was approved (Solano 2005: 90), incorporating the categories of Landscape Reserve and Wildlife Refuge (Solano 2005: 93). A relevant point for the conservation and management of the latter is the recognition of the buffer zones of the NPAs (Solano 2005: 93). These recognized Buffer Zones are adjacent to the NPAs and their objective is to ensure the conservation of the protected area. Their location is defined according to the requirements of each NPA (Solano 2005: 202).

Another important milestone was the creation of the National Environmental Commission (CONAM) in 1994, which in 2008 became the Ministry of the Environment. The SERNANP (National Service of Natural Protected Areas) was created in 2008 to manage and direct the NPAs. Currently, the SINAMPE (National System of Natural Protected Areas) depends on the SERNANP, which is part of the Ministry of the Environment.

9.3 NPAs Definition and Categories

The Peruvian government designates rich and fragile ecosystems with endemic species as NPAs. These areas are classified into different conservation categories, according to their importance and their historical, scenic, and scientific value.

The NPA can be of direct use when its resources can be exploited under approved management plans and indirect use when the resources cannot be extracted or exploited directly. The classification of NPAs classifies protected areas into ten different categories according to the form of conservation. There is a temporary category, the Reserved Zones, which includes areas that have not yet been classified (SINANPE 2022).

- National Parks: are spaces with ecosystems that need to be preserved because of their value and the value of their species. They are areas that can only be visited with a State authorization. Only scientific, educational, tourist, and cultural activities can take place.
- National Reserves: areas with relevant biological diversity. Local populations can use the flora and fauna, both aquatic and timber resources. In order to do so, they must present management plans that the State must approve.
- National sanctuaries: are important areas for their richness, landscapes, or natural formations. They can only be used for research, tourism, and education in defined areas. They are often composed of several ecosystems.
- Landscape Reserves: anthropic landscapes of great beauty and cultural importance that must be conserved. Local populations can use resources for traditional use and local agriculture or terracing.
- Wildlife Refuges: relevant areas for species reproduction and must be preserved due to their ecological relevance. They constitute a habitat for endangered, rare or migratory species. They are spaces that local populations can use under Management Plans approved by the State.
- Communal Reserves: communal spaces of direct use where the sustainable use of resources by local populations is allowed. The local communities have a management contract with the State and manage the area together with SERNANP according to the Management Plans.

- Protected Forests: areas where erosion can be high if not managed sustainably such as the upper watershed and aquatic-terrestrial ecotones like the riverbanks. These areas can be used under management plans.
- Game Preserves: areas for hunting that can be used by local people under management plans. They regulate wildlife populations by allowing the hunting of animals with excessive populations.
- Reserved Areas: areas identified as necessary for conservation. However, they need to be categorized because they lack detailed studies.

Biosphere Reserves were created in 1970 within the framework of UNESCO's "Man and the Biosphere" programme (SERNANP 2022a). Biosphere Reserves are areas to be conserved as a global example of the world's natural heritage. They include a National Park which is the core zone, an ecotone which is a buffer zone, and a transition zone where there can be human activity, allowing a transition between natural and anthropic space, thus enabling the sustainable development of the local populations and at the same time the conservation of the area.

9.4 Natural Areas in Peru

The Natural Protected Areas in Peru are organized in three levels, according to the form of management: National Management Area, Regional Management Areas (RMA), and Private Conservation Areas (PCA) (SERNANP 2022b). This allows local people to be involved in managing the NPAs (Solano 2005: 93). The State can delegate management to the private sector. An estate may be managed by its rightful owner as long as it is done on a non-profit basis. NPAs' management is granted through management contracts. The Coto de Caza El Angolo is the first PCA, managed by the Club de Caza, Pesca y Turismo de Piura (Solano 2005: 150). The PCAs also include communities (Solano 2005: 205). The Chaparri PCA, which belongs to the Comunidad Campesina de Santa Catalina de Chongoyape, provides ecotourism, and wildlife protection. We also have the Natural Forest El Cañoncillo which belongs to the Cooperativa Agraria de Usuarios Tecapa Ltda (Solano 2005: 240). Both NPAs are located in northern Peru in the seasonally dry forest ecosystem. The RMAs are directed and managed by the Regional Government (Solano 2005: 152). Finally, In the NPAs, there are Concessions for Tourism Services in areas of direct use (Solano 2005: 153).

In addition, in the Buffer Zones, which are not included in the NPAs, conservation may be provided on private property under the so-called Ecological Easement, in the properties considered for conservation and with State recognition (Solano 2005: 205). For State-owned land, there are two types of Concessions. The first is a Free Title Concession, which includes concessions for Forestation and Reforestation, and the second is the Onerous Title Concession. Both categories allow for an economic benefit (Solano 2005: 206–207). Among the Onerous Title Concessions, we have concessions for ecotourism, for the exploitation of forest products such as Brazil nuts, and wildlife management (Solano 2005: 208–209).

Some oppose NPAs, such as some sectors of the extractive industry, but also local people who have to adapt their traditional forms of use to the NPAs' and the State's rules (Suarez de Freitas cit. Solano 2005). Currently, NPAs occupy 17.26% of the Peruvian territory, this figure includes National, Regional, and Private NPAs. 15.4% are National NPAs and 1.86% are Regional and Private NPAs (SERNANP 2022b). Although the percentage is increasing, their management and conservation are complicated. They are subject to encroachment, and lack of budget, among other problems (Dourojeanni 2009: 484–488). Therefore, it is important to determine whether to establish more NPAs or to improve the management of existing ones (Dourojeanni 2009: 493).

As follows there is a list of NPAs based on their category (Table 9.1):

In addition, Peru currently has seven Biosphere Reserves: Manu, Northwest Amotape-Manglares, Huascarán, Oxapampa Ashaninka-Yanesha, El Gran Pajatén, Bosques de Neblina Bosque Central and Avireri-VRAEM (SERNANP 2022a). Also, there are Private Conservation Areas and Regional Conservation Areas as explained above.

9.5 Species Conservation Management

The subsistence of populations requires genetic diversity. It is not enough to conserve one specimen of each species for the species to survive. It is necessary to preserve each population‘s genetic diversity (see Sects. 5.2 and 9.3). The question then arises as to how many individuals of each species must be preserved in order for them to survive. The answer depends on the population, its social organization and the individuals themselves, and the biotic potential, among others. It is thus not the number of individuals of each species, but the genetic diversity of the population that must be conserved. This means, the number of different genes within a population. Each population has a critical population size. A species is extinct when the mortality rate exceeds the birth rate, even if there are still individuals of the species.

To decide which species should be conserved, it is necessary to know their population‘s characteristics. The prioritization of the species to be conserved in Peru follows the International Union for Conservation of Nature (IUCN) classification. The flora species to be conserved are listed in the Supreme Decree number 043-2006-AG, the categories of fauna species are determined in the D.S. 004-2014 MINAGRI and are detailed in the "Red Book of endangered wildlife".

In this way, the categories for the conservation of Peru's flora are grouped into three conservation appendices in compliance with the CITES convention: Appendix I contains species in danger of extinction, Appendix II contains species called "look-alike species"that could become endangered if measures are not taken to control their trade, and Appendix III contains species listed for trade control (MINAM 2018: 5).

Table 9.1 List of natural protected areas in Peru

Conservation categories	NPAs
Indirect area use	
National Park	Alto Purus
	Bahuaja Sonene
	Cerros de Amotape
	Cordillera Azul
	Cutervo
	Güeppi-Sekime
	Huascaran
	Ichigkat Muja-Cordillera del Cóndor
	Manu
	Otishi
	Río Abiseo
	Sierra Divisor
	Tingo María
	Yagüas
	Yanachaga Chemillén
National Sanctuary	Ampay
	Calipuy
	Cordillera de Colán
	Huayllay
	Lagunas de Mejía
	Manglares de Tumbes
	Meganoni
	Pampa Hermosa
	Tabaconas Namballe
Santuario Histórico	Bosques de Pomac
	Chacamarca
	Machu Pichu
	Pampa de Ayacucho
Área de uso directo	

(continued)

Table 9.1 (continued)

Conservation categories	NPAs
National Reserve	Apahuayo Mishana
	Calipuy
	Dorsal de Nazca
	Ilescas
	Junín
	Lachay
	Matsés
	Pacaya Samiria
	Pampa Galeras Bárbara D'Aquile
	Paracas
	Pucacuro
	Salinas y Aguada Blanca
	San Fernando
	Sistema de islas, islotes y puntas guaneras
	Tambopata
	Titicaca
	Tumbes
Refuge for Wild Fauna	Bosques Nublados de Udima
	Laquipampa
	Pantanos de Villa
Landscape Reserve	Nor Yauyos –Cochas
	Sub cuenca del Cotahuasi
Communal Reserve	Airo Pai
	Amaracaeri
	Ashaninka
	Chayu Nain
	El Sira
	Huimeki
	Machiguenga
	Purús
	Tutanain
	Yanesha
Potected Forest	Aledaño a la Bocatoma del Canal Nuevo imperial.
	Alto Mayo
	Pagaibamba
	Pui Pui
	Puquio Santa Rosa
	San Matías – San Carlos
Game Reserve	El Angolo
	Suchubamba

(continued)

Table 9.1 (continued)

Conservation categories	NPAs
Reserved Zone	Ancón
	Bosque de Zarate
	Chancaybaños
	Cordillera Huayhuash
	Reserva Paisajística Cerro Khapia
	Río Nieva
	Santiago-Comaina
	Sierra del Divisor

Sources SINANPE (2022)

The conservation categories for fauna species in Peru are: critically endangered, endangered, vulnerable, extinct, extinct in the wild, and regionally extinct. There are two additional categories for species that are not extinct: near threatened and least concern. Furthermore, we have the categories insufficient data and not evaluated (SERFOR 2018: 18). In terms of flora, Peru has 404 species of pteridophytes, 332 species of the Orchidaceae family and 41 correspond to the threatened Cactaceae family (D.S. 004-2014 MINAGRI). Regarding fauna, Peru has 64 critically endangered species, 122 endangered, 203 vulnerable, 103 near threatened, and 43 insufficient data (SERFOR 2018: 18). The endangered fauna species are found in The Red Book.

The categorization of endangered fauna species included in the red book is as follows:

(a) Extinct or extinct in the wild: species that have become extinct.
(b) Critically Endangered, Endangered, and Vulnerable: species that are globally threatened.
(c) Near Threatened: species that are on the borderline and could become extinct if not protected.
(d) Least Concern: at lower risk of extinction.
(e) Data Deficient: species that could not be considered due to lack of data.
(f) Critically Endangered (possibly extinct): species that are possibly extinct, but need to be confirmed (UICN 2022).

It should be noted that the inventory is carried out on the species known to us, as there are species that may be extinct or in a category that we do not know about.

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) prohibits trade in wild species that are endangered or threatened. Peru has been a party to the CITES agreement since 1975. The species on the CITES list have been classified in two appendices, according to the conservation category to which they belong.

9.5.1 *Ecological Corridor Applied to the Protected Natural Areas in Peru*

An ecological corridor is a space that allows circulation and connection between landscape patches. It is the transition space between two ecosystems and a refuge for species from disasters and inter- and intra-specific competition. Corridors are often more diverse than the surrounding ecosystems, producing what is known as the edge effect. The edge has the species from both ecosystems. It includes the ecotone which is crucial for the conservation of the species. However, there is a difference between the ecotone and the edge. An edge is a transitional space between two or more ecosystems while the ecotone is the space where ecosystem populations meet and interact (Smith and Smith 2007: 316). Edges can be abrupt and have no ecotone. They can be made up of species from both ecosystems or have different species (Smith and Smith 2007: 317).

If we apply these concepts to the landscape, we can say that corridors may have species from both ecosystems and they may also have species that are not in the patches. Edge species are usually generalists or pioneers, and their requirements differ from those of the surrounding communities. They are usually less shade tolerant and adapted to drier environments (Smith and Smith 2007: 317).

Before defining and characterizing conservation areas, we must establish how the corridor, the edge, the ecotone, and the species that characterize it are constituted. For example, in the tropical rainforest, mahogany trees (*Swietenia macrophylla*), when they fall, clear the space allowing new seedlings of this species to grow. Small mahogany plants require a lot of light to grow quickly and occupy space by taking advantage of the light allowed by the falling tree. This characteristic is also used in mahogany reforestation to form mahogany corridors when replanting.

Ecological corridors allow the existence of metapopulations by enabling the connectivity of populations (see Sect. 6.6.3). In the case of animal species, they often have periods of population migration, occupying different spaces depending on the time of the year; in the mating season, they tend to group. In other cases, animals have nomadic migration cycles. Migrating animals can use edges, but these spaces can often be dangerous for some species as predatory species may lurk here. However, this danger is compensated by the possibility of connection and reproduction with populations of different ecosystems.

Ecological corridors allow the balance of species within the protected area and the balance between the inside and the outside. The ecological corridor becomes the Buffer Zone of a Biosphere Reserve. Some animals find refuge in the corridors of protected areas. This is the case of the white-tailed deer (*Odocoileus virginianus*) that moves out into the dry forest in north Peru clearings where the pressure from pumas (*Pantera onca*) is lower.

In cities, ecological corridors are used to maintain connectivity between wild populations. Corridors can be planted with species that could not live in other spaces, such as species resistant to pollution from lead, sulphur or nitrate emissions. Species that pass through these corridors do not stay for long and use them as a transit route to connect with other habitats, search for food, or other individuals of their species. In road areas, the negative effects of the road can be compensated by building parallel corridors or bridges over highways, based on water distribution. Well-managed canals and rivers such as the Rimac River in the city of Lima can also serve as corridors for many native species such as the Santa Rosita Swallow (*Pygochelidon cyanoleuca peuviana*) or as a refuge for some species such as the Lima Toad (*Rhinella limensis*).

9.5.2 Landscape Conservation Management

Landscape is a cultural concept, which is why landscapes have been included as conservation areas: They enable the survival of metapopulations and thus regulate genetic diversity. According to the European Landscape Convention, landscape is the result of the interaction between natural and human factors (Council of European Landscape Convention 2000).

The causes of the deterioration of biodiversity are diverse. Poverty and the conquest of new areas for cultivation are some of the most important; for this reason, the conservation of species must go hand in hand with sustainable development, ensuring that the population participates in conservation without damaging ecosystems. The challenge is to achieve the ecological balance of the ecosystem and this requires a view that includes various ecosystems and anthropic dynamics as part of the landscape.

Ecological balance is dynamic. Ecosystems are in constant regulation. Equilibrium is achieved when the ecosystem is self-regulating, free from disruptions, but not from disturbances. Therefore, the proportion of each factor and their spatial distribution in the landscape remain constant and incorporate changes.

Ecosystems can be closed and isolated from the surrounding environment or open receiving external influences. The first are more fragile to change and the second are more common. Open ecosystems are regulated by internal and external factors, constantly incorporating disturbances and admitting human influence. They only appear to be in equilibrium at certain temporal and spatial scales. Although the mosaics may vary from site to site, it is important that their percentage remains stable, and that populations and ecosystem processes keep facing disruptions until the ecosystem returns to equilibrium (see Holling's cycle 7.3) (Fig. 9.1).

Fig. 9.1 Wood recollection in the dry forest, north Peru. (*Author* Ana Sabogal)

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Chapter 10
The Paramo Ecosystems

10.1 Introduction

The paramo moorland ecosystem is located in the Andes mountain range. It is a wet grassland ecosystem with a high accumulation of organic matter due to the cold temperatures of the highlands and the retention of fog caused by surrounding mountains. This allows the ecosystem to store water and recharge its aquifers, as well as to retain a high amount of carbon dioxide in the form of organic matter. The ecosystem is connected to other paramo ecosystems of South America, reaching part of Ecuador's highlands, Colombia and Venezuela, and thus forming a discontinuous and peculiar landscape that shows different characteristics in each location.

By their vegetation, the paramo moorlands are classified as prairie biomes, with an ecological succession that corresponds to an intermediate stage (see Sect. 7.1.1). However, in some cases prairies can reach a climax stage with specialized vegetation, such as in Great Britain, Switzerland and Scandinavia (Smith and Smith 2001: 450). Long ago, prairies used to cover 42% of earth's ecosystems, but they currently occupy only 12% of them (Smith and Smith 2001: 450). There are approximately 4 million square meters of moor landscape in the world, and 10% of the Amazon basin is covered by moorlands (Succow and Joosten 2012: 2). These ecosystems have a positive carbon balance and produce more organic matter than they decompose (Succow and Joosten 2012: 2). In large part, the degradation of prairies is due to overgrazing, and to their progressive transformation into farmlands (Smith and Smith 2001: 450). The same problems can be observed in Peru's paramo moorlands.

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10.2 The Ecosystem

The paramo moorland ecosystem differs from the puna ecosystem in its higher humidity and lower fluctuation of diurnal temperature (Rundel 2008, cit. Sabogal 2014: 11). One of the causes of the climatic difference between the paramo and the puna is the depression of the topography in Huancabamba, where the lowest mountain pass of the Andes (2145 m above sea level) is located. The mountain range's height increases to the north and south of this location, creating the Porculla mountain pass. Besides having a lower altitude, the location of pass is narrower (85 Km), and in it the Andes have a single branch (Emck et al. 2006 cit. Sabogal 2014: 12). This allows the paramo to have a lower altitude. The Peruvian paramo moorland's altitude ranges between 3200 and 3400 m above sea level (Brack and Mendiola 2000: 194). The river basins that correspond to the paramo in the Peru highlands are those of the Quiroz, Huancabamba and San Ignacio rivers (Brack and Mendiola 2000: 194).

Precipitation in prairie ecosystems fluctuates between 250 and 800 yearly millimetres (Smith and Smith 2001: 450). In the paramo, the average yearly precipitation fluctuates between 750 and 200 millilitres (Lauer 1981 cit. Sabogal 2014: 15), and in some cases reaches 300 millimetres (Luteyn 1992, cit. Sabogal 2014: 16). However, air humidity comes not only from precipitation in the form of rain, but also from the vespertine fogs that reach the zone and are captured by the surrounding mountains.

Temperature in the paramo fluctuates between 22 and 8 °C (Rundel et al. 2008). The yearly temperature variation limits are of 0 °C and 12 °C, and the daily temperature varies greatly, reaching 0 °C during the night and 25 °C during the day (Poulenard et al. 2001 cit. Sabogal 2014: 13). Due to these significant shifts in daily temperature, Troll classifies this weather as shifting frosts [*Forstwechselkima*] (Troll 1943 cit. Beck 2008 cit. Sabogal 2014: 13).

Organic material accumulated in the paramo moore ecosystem is made of dead, humified plants that pile up on the ground from the bottom to the top. They accumulate due to the high humidity, and their structure remains visible (Succow and Joosten 2012: 9). The exogenous factors that contribute to the accumulation of organic matter are the lower temperatures in high humidity conditions, the lack of decomposer organisms and high oxidation conditions. The endogenous factor is the vegetal composition, which is slow to break down (Succow and Joosten 2012: 3).

The food chain in this environment corresponds to that of herbivores. Herbivory is characterized by generalist strategies, with populations regulated by the presence and development of plants, particularly herbaceous plants that are preferred by insects. Grazing modifies the physiological condition of plants, affecting them by increasing their underground mass and causing the thickening of their stems. Over time, genetic changes also occur in these plants. For these reasons, and because of the weather, plants in these areas keep a large percentage of their structure underground. The soil is humid and waterlogged, and holds an abundance of organic matter. The vegetation is made of highland grasses and forests, as well as bushes.

Their distribution and ratios vary with the altitude and weather: At lower altitudes, in the forested areas, there is a higher amount of evergreen bushes, bamboos can be found in the middle altitudes, and they become absent in the highest areas.

Lauer (1981) classifies paramo moorlands as:

- Sub-paramo, which appears in the transition between the Andean forest and the paramo moor. Its vegetation is composed of grasses, bamboos, acaulescent rosettes and evergreen bushes.
- The paramo proper and the grassland paramo, which shows the same type of species, with a predominance of grasses and a lower amount of evergreen bushes and cushion plants.
- Super-paramo, where acaulescent rosettes and cushion plants predominate.

10.3 Origin of Diversity

The eastern part of the Colombian Andes rose to approximately 2000 meters above the sea level during the coldest pleistocene. This created the necessary conditions for the dispersion of plants and animals (Van der Hammen 1973). The heating of the Andes that followed during the interglacial period caused the isolation of plants and animals of the paramo moors (Cleef 1978). The similarities between the weather and environment of the paramo and the subarctic allowed for the development of similar life forms in these biomes. These resulted in similar physiognomies and taxonomies of their vegetal ecologies (Cleef 1978). There is no evidence of the paramo's existence until the late pleistocene. This ecosystem appeared when the Andes elevated above the upper limit of the forests (Hooghiemstra et al. 2006).

The high amount of diversity in the Andes is a consequence of the *migration and isolation* of species (Hooghiemstra et al. 2006). Changes in the Andes' elevation and the species migration that followed defined the flora of the lower altitude zones. They also caused the current vegetal composition of the Colombian paramo moores (Hooghiemstra et al. 2006), and probably that of other paramos as well. The richness of species in the Andean paramos was partially caused by longitudinal migration. In this way, the continuity and temporary isolation due to the glaciation and deglaciation resulted in a paramo rich in species diversity. This is why some genera present a large number of endemic species; for example, the *Diplostephium, Baccharis, Berberis, Hypericum* and *Lachemilla* genera (Hedberg 1992 cit Sabogal 2014).

The highland forests, mostly of the *Podocarpus* species, have been studied in great detail. Paleontological records show the presence of several *Podocarpus* species that progressively disappeared due to the rising of the Andes, as well as to deforestation (Hooghiemstra et al. 2006). During the coldest lineal glaciation, the forest line descended by 2000 m (1200–1500 m below its current altitude), and later rose again due to the rise in temperature and humidity (Van der Hammen 1974). During the quaternary stage, in the warmest time of the interglacial period, the highest forest line rose by close to 200 m, that is, from 3200 to 3400 m above the sea level (Wille et al. 2001 cit. Hooghiemstra et al. 2006). Consequently, the area covered by paramos varies over time: it went from small highland areas in the peaks of mountains during the interglacial periods, to occupying a larger amount of terrain in the glacial periods (Van der Hammen and Cleef 1986). These changes in altitude caused migrations and speciation (Hooghiemstra et al. 2006). The absence of dense forests during the pleistocene's *glaciation* allowed for the migration of other taxa (Cleef and Chaverri 1992). Changes in the weather and vegetation allowed for speciation and the formation of current taxa (Van der Hammen 1974). The current flora is the result of this speciation process, and of the development of new taxa belonging to the local neotropical flora as a result of the elevation of the Andes and the arrival of migrant taxa, both from the north and from the south (Van der Hammen 1974). Currently, the flora has a lower percentage of species originating from the south than from the north (Hooghiemstra et al. 2006 cit Sabogal 2014).

10.4 Vegetation and Growth Forms

The morphology of plants is directly related to temperature, while their growth forms respond to the space's characteristics (see Sect. 8.6). The cold of the paramo's nights has influenced the growth forms, giving predominance to rosettes and subshrubs, and, at higher altitudes, bushes and cushion plants. Low-growth rosettes protect their leaves and meristems by burying them under layers of densely overlapped leaves; grassy subshrubs survive by growing in densely packed groups to protect each other; and cushion plants reduce their size to densify their mass. All these plants grow closer to the floor for protection, as it remains hot longer than the air. In the prairies, rhizomes, underground stems and other subterranean parts add up to almost 50% of plant matter (Smith and Smith 2001: 453). The same happens in paramos due to the cold: underground vegetation prevails, using roots, thickened stems and other underground parts. High-altitude plants reduce their size and increase their amount of hair to better endure the night frosts (Lauer et al. 2003). Bushes also develop tough leaves (Hedberg 1992). Meanwhile, plants with short vegetative periods retreat from the frosts (Weaver and Clements 1944). At the small scale, microclimates determine biodiversity and their composition (Mandl et al. 2009). In this way, through evolution, adaptation and ontogenetic modification, plants adapt to the space by forming ecotypes (Körner 2003).

Vegetation varies with the weather and the soil's origin: while herbaceous grasses and evergreen bushes with small leaves can be found in areas closer to the forest line, lignified rosettes with perennial leaves thrive at higher altitudes (Rundel et al. 2008). At medium elevations, there are creeping shrubs, grasses and small perennial weeds.

Half of the families that comprise the flora of Peru are present in the paramo. There are 241 families and 2635 vegetal genera among Peru's flora (Jorgensen et al. 2012). In turn, the paramo's flora has 112 families, 478 genera and between 3000 and 4000 species of vascular plants (Luteyn et al. 1992). The most abundant family in the paramo is the Asteraceae, while the dominant grass species is the Poaceae, with 53 species (Luteyn et al. 1992). While herbaceous plants predominate in the grasslands, bushes are more common in the bush paramos, and ferns are common in both. Bromeliads are almost exclusively present in bush paramos (Keating 1999).

In the paramos of the Cajamarca department, 11.5% of found species were pteridophytes, 18.7% monocotyledons and 69.8% dicotyledons. Among the monocotyledons, Orchidaceae were the most common, followed by Poaceae and Liliaceae. Among dicotyledons, the most representative groups in terms of diversity were the Asteraceae, followed by the Ericaceae, Melastomataceae, Scrophulariaceae, Campanulaceae and Rosaceae (Marcelo et al. 2006). Regarding the paramos of the Piura department, in the conserved paramo of San Juan and Samanga we found more biodiversity.

Endemism is very elevated in paramos, sometimes reaching up to 60% of the territory (Mena-Váscones 2011). This endemism tends to be relatively low in terms of genus, but very high at the species level (Luteyn et al. 1992). The distribution of species changes with the altitude, and are present in the different types of paramo in the following way (Sabogal 2014: 50–51):

- The *sub-paramo* is located between 3000 and 3500 masl (Fosbesberg 1944 and Cuatrecasas 1958 both cit. Cleef 1978). It forms the transition between the Andean forest and the upper paramo. Here, groups of plants belonging to the Ericaceae and Asteraceae families can be found. At higher levels, dwarf *Arcythophyllum nitidum* (Rubiaceae) and *Gaylussacia buxifolia* (Ericacea) bushes predominate, as well as various grasses (Cleef 1978).
- The *paramo proper, or grassland paramo*, tends to be covered in grasses, mostly from the *Calamagrostis* genus (Cleef 1978). Here, the vegetation is dominated by branched rosettes from the Compositae (Asteraceae) family, in the form of smaller specimens. In this intermediate paramo, small scrubs of *Hypericum* spp. or *Senecio vaccinoides* (Asteraceae) grow in places that are sheltered from the wind, as well as isolated forests of *Polylepis* spp. (Rosaceae) (Cleef 1978). A large amount of endemic plants can be found in this space (Luteyn et al. 1992).
- In the *super-paramo*, the typical species belong to the *Draba, Lycopodium, Lachemilla, Poa* and *Agrostis* genera. Additionally, there are Asteraceae and a large amount of lichens and bryophytes. Small bushes such as the *Loricaria*, of the Asteraceae family, are frequently found in moraines and rocks of the lower super-paramo (Cleef 1978).

As the humidity diminishes and the fire climax becomes more critical, herbaceous grasses become more prevalent and rosettes less frequent.

10.5 Fauna

The fauna of the grasslands is largely herbivores that haven't been properly studied. The paramo's fauna originates in the Amazon, with a smaller percentage of animals originating from the north (Brack and Mendiola 2000: 194). The paramo tapir (*Tapirus pinchaque*) and the red paramo deer (*Mazama rufina*) are part of the fauna that dwells among the shrubs of the paramo. The pudu or sachacabra (*Pudu mephistophiles*) inhabits the area that extends from the paramos to the cloud forests. In the grasslands, the wild rabbit (*Sylvilagus brasiliensis*) and the shrew (*Cryptotis* sp.) can be found (Brack and Mendiola 2000: 194). Additionally, the jambato frog (*Atelopus* spp.), some other highland frogs such as the *Telmatobius* sp. and *Gastrotheca* sp., and many types of birds can be found among the insectivore fauna.

Organic matter also influences the fauna, facilitating the formation of dens for several species (Smith and Smith 2001: 453). There are also herbivorous insects present in the grassland biomes.

10.6 The Paramo's Soil

The soil in the paramo has its origin in the elevation of the Andes during the miocene and pleistocene, which allowed the mountain range to rise over 3000 masl (Hungerbuhler et al. 2002 cit. Buytaert et al. 2006). Later, it was influenced by the melting of glaciers (Kehrer and der Kaaden, 1979 cit. Buytaert et al. 2006). The topography includes deep valleys, slopes and flat areas in the upper mountain zones (Buytaert et al. 2006). The freezing and unfreezing caused by the lower nocturnal ground temperatures in the upper zones of the paramo lead to the solifluction of the soil (Smith and Young 1987).

Soil in the paramo is humic and acidic, with a *pH* that fluctuates between 3.7 and 5.5. The soil is saturated with water due to the presence of organic matter. The amount of sand and rock content increases with the altitude (Luteyn et al. 1992).

Due to the cold temperatures and the formation of organo-mineral complexes resistant to microbial destruction, organic matter accumulates in the soil, which causes its dark and humic nature, and a porose and open structure (Blume et al. 2010). In this way, macroaggregates of low productivity are produced, which are made of organic waste that attaches itself to the minerals, reducing the availability of nutrients (Blume et al. 2010). The organic soil retains metals like copper, cadmium and zinc. This retention is 6–16 times higher than that of mineral soils. In this way, the soil prevents the contamination of the phreatic layer (Blume et al. 2010). By retaining large amounts of water, the paramo soil also accumulates and retains heat, which aids in the microbial processes.

The *erosion* rate of undisturbed soils in the paramo is low (Poulenard et al. 2001). Together with the aluminium and iron, organic matter forms aggregates that protect the soil from erosion (Verweij and Beckman 2008). The soil microorganisms form siderophores from the liberated iron, resulting in aggregates that help diminish the soil's erosion (Blume et al. 2010). In volcanic and glacial soils, cyanobacteria in the soil's surface produce a mucilage, which protects the soil from possible drying and erosion, to which these young soils could be exposed (Blume et al. 2010). The abundance of grasses and accumulated organic matter allow for the expulsion of these siderophores from the grasses' roots, from the bacteria and from the soil's fungi. In turn, these protect the plants from pathogens, toxic products and desiccation. Additionally, they allow the iron to be available for the plants' use (Blume et al. 2010).

The glacial origin of the paramo is the origin of its porous soils, which allow the passage of water through subterranean channels that flow through cracks in the ground. This means that underground water reservoirs have to exist (Buytaert et al. 2006). Its glacial origins have resulted in a terrain that has slopes, plains and valleys, and that contains lakes, swamps and humid prairies (Buytaert et al. 2006).

Besides the organic matter, the iron and aluminium in the paramo's volcanic soil also retain *water* (Poulenard 2000 cit. Buytaert et al. 2006). The soil's macroaggregates retain *water* in the soil, accumulating it and slowly releasing it (Hofstede 2003). The andisols have an open and porous structure that allows for high water retention, due to the amorphous minerals present in the allophane (which contains iron) and the imogolite (which contains aluminium) (Poulenard 2000 cit. Buytaert et al. 2006). The allophane has a high amount of silicon (Blume et al. 2010). The shrinking of the allophane, caused by its desiccation, depends on the ratio between aluminium and silicon: soils with a high amount of aluminium have a higher microporosity, and therefore, are capable of retaining more water (Rousseaux and Warkentin 1976 cit. Buytaert et al. 2006). In andisoles without allophane, water retention results from the presence of organic carbon (Buytaert et al. 2006). Organic carbon increases the volume of micropores, which results in a higher amount of retained water. This water doesn't enter the paramo's hydrological cycle (Buytaert et al. 2006), since it remains in the soil's micropores. The andic histosols, also present in the paramo, have a high capacity for water retention (Poulenard et al. 2004).

10.7 Grazing

Grazing affects the vegetation by, on one hand, compacting the soil, and on the other, influencing the amount of organic matter accumulation in it. While low-intensity grazing consumes grass that grew during the new season, a moderate-intensity grazing results in the compacting of the ground, which increases microbial activity and reduces the most recent layer of organic matter, as well as the ones that had been accumulated before. Finally, a high-intensity grazing reduces the accumulation of organic matter (Smith and Smith 2001: 453).

Overall, prairies are adapted to the natural grazing of wild animals as well as to fires, and these adaptations have happened over millennia. The vegetation keeps part of its structure underground, and sprouts again after being consumed. This grazing forms part of its natural cycle, and the production of faeces and urine serve as fertilizer for the plants (Smith and Smith 2001: 455). 40–50% of food consumed by grazing animals returns to the ecosystem in the form of guano (Smith and Smith 2001: 378). Approximately 6–10% of leaves are consumed by herbivores, and the plants increase the photosynthesis rate of their remaining leaves as a response (Smith and Smith 2001: 229). When the plants' meristems grow underground, animals consume the exposed parts of the plants first. These are older leaves and adult tissue. This process stimulates the growth of young buds and increases the penetration of light, which produces a positive balance for the vegetal production (Smith and Smith 2001: 229–231).

Grazing also produces changes and modifications in communities of vegetables (Smith and Smith 2001: 455). Plants have evolved to resist natural grazing through physical and chemical defences (Smith and Smith 2001: 459). The amount of organic matter present also influences the vegetation, as a larger amount increases the presence of woody plants (Smith and Smith 2001: 454). For this reason, overgrazing can be said to affect carbon balance and the retention of water as well.

Grazing is more intense in flat zones of the paramo. Shorter grasses and tufts of weed such as the *Lachemilla orbiculata, Aciachne pulvinata, Calamagrostis coarctata* and *Lupinus microphyllus* are present in these areas (Verweij and Beckman 2008). In grazing zones, the types of vegetation change with the altitude in the subparamo, between 3000 and 3500 masl, patches of bushes and small trees alternate with the grazing lands; in the grasslands, between 3500 and 4100 masl, grazing terrains predominate, while in sheltered zones closer to flowing water, patches of bushy species such as the *Polylepis* are frequent; and finally, in the upper paramo between the grasslands and the snow line, vegetation is scarce (Buytaert et al. 2006).

With the loss of vegetation, the soil absorbs more heat due to its higher exposure and its lighter colour. Grazing means that there is a constant pruning of vegetation. Plants respond by increasing their amount of stems in proportion to their leaves, which diminishes their palatability. Excess grazing fosters the development of thorny species and toxic herbs among the grasslands (García and Beck 2006; Sabogal 2014). Finally, overgrazing also deteriorates the availability of nutrients in the soil, and for this reason, after some years of use, grazing lands tend to be abandoned. Grazing produces the effect of pruning, triggering the new sprouts, and in grazing zones grasses remain cut, unable to produce seeds. If this cycle continues, the proportion of uncovered soil increases, which generates erosion and desertification, and plants become lignified. As a result, their palatability is also reduced, which means that over time, the ecosystem can be recovered, although with a different vegetable composition (Sabogal 2014). If burnings happen in addition to this process, the palatability does not diminish, leading to a loss of vegetable cover. In this way, the amount of nutrients accumulated in the roots and the plants' seed production are both lowered, which leads to a change in vegetable composition and to the loss of vegetation (Sabogal 2014).

The increase in soil temperature can accelerate the assimilation of nitrogen into the soil, since it comes with an increase in microbial activity and in the amount of mycorrhizae, among other changes (Rennenberg et al. 2010). As a consequence of the presence of ectomycorrhiza, there is an increase in the plants' photosynthesis due to the higher demand for it. All of this increases the exudation of the roots (Pinton et al. cit. Nehls et al. 2010). The exudation produces aggregates in the soil (Pinton et al., cit. Nehls et al. 2010).

In prairies, palatable plants that are preferred by animals hold carbohydrates in their subterranean organs to quickly recover the loss of leaves caused by natural grazing (Smith and Smith 2001: 459). Each species has specific preferences in consumption. While insects prefer the herbaceous parts, deer prefer the woody parts and mice prefer the seeds (Smith and Smith 2001: 222). Considering the ecological equivalents in paramos, the red deer of the paramo (*Mazama rufina*) favours bushes and the woody parts of plants, and the shrew (*Cryptotis* sp.) the herbaceous parts.

Plants develop defences to grazing and herbivory, sometimes even chemical defences such as the production of toxic substances (Smith and Smith 2001: 223). Almost nothing is known about the special action mechanisms of species in the Peruvian paramo, and their interspecific relationships. One which is common in spaces where herbivory takes place is mimicry. There is *Batesian mimicry*, in which an edible species mimics in order to lower its own predation, and *Müllerian* mimicry, in which two toxic species share a similar appearance to collectively defend themselves from predation in this way (see Sect. 9.3). Many predators synchronize their litter production periods to the times of higher food availability, such as rain seasons, when plants produce more young sprouts.

Fire in the prairie eliminates manure produced by large herbivores and releases nutrients, making them available to plants. However, a great part of the carbon and nitrogen is released into the air in the process. Fire stimulates the growth of legumes that assimilate nitrogen, and improves the structure for worms. This makes the nutrient available for plants to consume (Smith and Smith 2001: 456).

Remains of manure can be found in zones of intense grazing (Molinillo and Monasterio 2002), which explains the increase in organic carbon. The agricultural use of lands of glacial origin strongly reduces their volume, as they lose the capacity to retain water and drain it properly due to the formation of compact blocks of soil. This produces water logging in the land's surface (Blume et al. 2010). The same occurs with grazing. Lands overgrazed by sheep present a reduction in their capacity to retain water (Buytaert et al. 2006).

Due to the above, in order to keep an adequate management of the soil, it is necessary to:

- Regulate grazing.
- Explore alternatives for improving the conversion efficiency of cattle, reducing their pressure on the soil.
- In the highest parts of the basin, the improvement of grasslands and agricultural zones should not include any type of chemical fertilization.
- The distribution of parcels should be improved to lower the pressure on zones of communal use, and redistribute the use towards zones of private use.

All of this implies working in conjunction with the paramo's communities (see Sect. 10.8).

Overgrazing consumes organic matter on the ground's surface and compacts the soil, producing erosion and impeding the accumulation of water and the recharging of the aquifers. Additionally, plans deteriorate due to a lack of nutrients, and desertification occurs (Smith and Smith 2001: 456). For this reason, in many prairies of the world, domestic animal grazing is practised as a productive system, incorporating plants that are productive for animal consumption, as well as external sources of fertilizer (Smith and Smith 2001: 456). However, since the paramo is a fragile ecosystem with a large amount of endemic species, we must consider a way to control their carrying capacity and execute the rotation of parcels in an adequate way. Other forms of prairie management should be explored, ones that foster the development of local palatable species and control the increase of undesirable ones.

Overgrazing in the paramo is linked to the distribution of grazing lands. In the paramos of Piura in Espindola, San Juan and especially Frías, communal lands are distributed among co-proprietors, some on the form of private land, and others as communal grazing lands. The overloading of communal lands' carrying capacity is much larger than that of those managed by families. In communal lands where overgrazing is present, the carrying capacity is surpassed often (Sabogal 2014). The paramo's carrying capacity is very low, at only 2 Animal Units per Habitant. This is the optimal capacity to maintain the succession cycles (Molinillo and Monasterio 2002). For this reason, bovine animals require great effort (4–9 h a day) to acquire their food in the paramo (Schmidt and Verweij 1992).

In the zones of San Juan and Espindola that were studied, each family owns a different amount of animals, which graze as a group. However, in the paramo of Frías, some grazing zones are used privately and others communally. Carrying capacity is controlled in private spaces, but not in the communal ones (Sabogal 2014).

Due to overgrazing, the soil is very degraded in Frías, in San Juan and in Samanga. To reverse the damage, a better management of the land is required to control the animal capacity and guide the ecological succession, so that fragile species aren't lost. In the upper parts of the basin, the improvement of soils should not include any type of chemical fertilizers. To achieve this, alternatives for the improvement of cattle conversion should be explored. This will reduce the pressure on the land. The distribution and communal use of the land must be improved to lower the load imposed on communal parcels, redistributing it to privately used spaces.

The paramos of Frías show a high amount of pressure exerted by ovine and bovine cattle, very much above its carrying capacity, as well as the presence of very low-production agriculture intended for the community's own consumption. The cattle graze in communal lands, where the pressure is strongest since, even though some proprietors own private land, they still mainly use the communal ones. Families' herds consist of five cows and six to ten sheep (Sabogal and Watson 2009). This affects the conservation and distribution of vegetables in an observable way, since vegetable conservation and the regulation of carrying loads are essential for conservation and production, as well as for the recharging of aquifers and the continuity of hydrological cycles. The cattle is local, and has high levels of *Fasciola hepática* (Sabogal and Watson 2009).

10.8 Anthropic Ecosystem

The paramo is an anthropic ecosystem that has been used by men for *farming* purposes for the last 3000 years (Hofstede et al. 2002). Human presence in the paramo goes back to pre-Columbian times (Schjellerup 1992 cit. Buytaert et al. 2006). For a substantial part of the colonial and republican eras, the paramo ecosystem in the highlands of Piura was the breadbasket of the city of Piura (Trivelli et al. 2010). During colonial times and up to the implementation of the agricultural reform in the 1970s, the paramo belonged to the local agricultural haciendas. It remains a priority for the agriculture of Piura's coastal zone to this day.

Facilitation allows for the change and modification of anthropic vegetable communities. Climate conditions are modified in the process, as is the soil. In the paramos, succession lacks intermediate stages, or is an auto succession, which shows a disturbance. These successions are characterized by an initial stage in which pioneer species appear, such as herbaceous pioneer plants, ruderals. Most of them are introduced, such as the *Rumex acetosella*. On a second stage, paramo species with low requirements appear, such as the *Lupinus meridanus*, and then bushy species like the *Baccharis prunifolia* and *Hypericium larycifolium*. Finally, grassland plants like the *Calamagrostis effusa* appear (Sarmiento et al. 2003). The recovery process takes about 12 years. *Rumex acetosella* is the most prominent species during the first 9 years of the process, and species diversity is doubled during the first 4 years (Sarmiento et al. 2003). Most paramo species are slow to recover, until eventually the initial abundance of diversity is reached (Sarmiento et al. 2003). The ecosystem‘s recovery capacity depends on its complexity of organization and its ability to incorporate the effects of the disturbance and modify itself (see Sect. 7.4).

Part of what we currently call the paramo is a result of a *paramization* process, which happened as a consequence of forest logging and grassland deterioration. Approximately 90–95% of Andean forests have disappeared (Henderson et al. cit. Hofstede et al. 2002). The result is the homogenization of the paramos' landscapes and the transformation of forests into grasslands (Laegaard 1992). The presence of humans and the deforestation lead to the presence of species of the *Rumex* and *Spermacoce* genera (Wille et al. 2002). Burnings modify the ecosystem too, by increasing the frequency of species such as the *Gynoxis* in place of the *Polylepis* (Lauer et al. 2003). In this way, the forest ecosystem is reduced as the anthropic paramo increases.

Several species of *Podocarpus* have been recorded in fossil records. These species progressively disappeared as the Andes rose and lands were deforested (Hooghiemstra et al. 2006). According to the fossil records, 200 years ago dense forests would reach up to 3600 masl, and sparse forests up to 3950 masl. The current forest line reaches 3600 masl (Wille et al. 2002). It's likely that the current presence of these species at 3950 masl is a consequence of the dispersion of seeds originating from the dense forest line (Wille et al. 2002). The existence of relict species from the forest, such as small types of moss, indicates that there were once forests in the area (Moscol and Cleef 2009). The limit line for the Polylepis species is at 4200 masl (Vareschi 1970: 14). The increase of stoniness above 3500 masl in the Andes may explain the presence of dispersed Polylepis, due to the increase in temperature caused by stones heated by the sun. Farmers from Lampa, in southern Peru, use this knowledge to replant Polylepis trees, surrounding them with stones to retain heat.

Like grasslands, paramos have a *fire* climax. In these ecosystems, fire is produced naturally, and it allows the incorporation of nutrients into the biochemical cycle. These nutrients would otherwise remain in the organic matter, where plants wouldn't be able to absorb them. This is why burnings allow for the resprouting of grasses, which is utilized by farmers in the puna. Due to their growth forms as hemicryptophyte culms, grasses have meristems that are protected in the centre of the culm, and shelter each other by growing in groups.

Many plants protect each other from *fires* by forming groups. In the paramo, for example, ferns from the *Blechnum* genus have a low tolerance to fire when solitary, but are resistant to it when in groups (Laegaard 1992). The *Gentiana* and *Gentianella* genera, which have thin stems, survive the fire by forming compact cushions with other species, such as the *Plantago rigida* (Laegaard 1992). Patches of forest can often be found by the water's edge, in gallery shapes. These are probably remains of forests that managed to survive after a fire (Laegaard 1992).

10.9 Sustainable Development

As previously mentioned, the Peruvian paramo exists under several sources of pressure. The shrinking and reduction of colliding forests, the burnings and overgrazing lead to the paramization of the ecosystem. These pressures are not just present on the Peruvian paramos, but are part of a common dynamic that affects all the world's grasslands. However, the paramo is an anthropic ecosystem, and although it suffers from a heavy pressure applied by cattle, by achieving its conservation through an adequate management of grazing, and linking it to the rest of the Piura region, the sustainable development of local communities could be achieved, which could lead to its conservation.

Looking back at the history of these spaces, we can observe that the highlands of Piura, which have a paramo ecosystem, functioned as the breadbasket of the city of Piura during the colonial and republican periods (Trivelli et al. 2010). The task of articulating strategies that link the regional, local and national scales remains to be completed (Trivelli et al. 2010). This task is harder in the department of Piura, which is very heterogene: In its coastal areas, wealth is produced by recent agricultural efforts meant for exportation; while in the paramo, the population's quality of life, and their production capacities, are minimal. There is a great inequality, both in terms of resource production and in the distribution of incomes among the population. In Piura's paramo zones, the levels of chronic malnutrition and bronchopulmonary diseases are both very high.

Little has been done for the articulation of these spaces. Three commonwealth communities were created in Piura through the Commonwealth Municipal Law

(2007): Serrán and Bigote (Morropón and Huancabamba), Señor Cautivo de Ayabaca (Ayabaca) and Central Andean (Morropón and Ayabaca). These communities are articulated around sub-basins and have a corridor structure meant to link the highlands and the coastal zones of Piura (Trivelli et al. 2010). However, this concept has not been yet properly executed. Although advances are being made at the theoretical level, they differ greatly from reality. In large part, there is interest in linking regional and local needs to achieve a common strategy towards development. However, there is a lack of common language among the different populations of Piura, its companies, and the state. It should be noted that there are both mining and farming companies in Piura. There are also other parties with interests that escape the limits of legality, both at the local and regional levels. Corruption and narcotraffic also exist in the region, which negatively affect the possibility of common dialogue.

Climate change is another topic that has a progressively larger effect on the sustainable development of the region, and this effect will increase over time. It is affected by the speed and quantity of carbon sequestration. The decomposition time of tundra soils is approximately 2000 years (Blume et al. 2010). The amount of carbon accumulation of moor ecosystems is related to their age. The difference between carbon sequestration in the puna and in the paramo is immense, and is fundamentally due to the difference in humidity caused by lake of decomposition in the paramo ecosystems.

Moor ecosystems have a positive carbon dioxide balance, in which organic matter is accumulated (Succow and Joosten 2012: 2). Approximately between 2% and 16% of primary production accumulates in the soil's organic matter (Succow and Joosten 2012: 13). The quantity of accumulated carbon depends on climatic and soil composition factors, as well as on anthropic activity. There are very few studies on the amount of accumulated carbon in the paramo. While 2 kg of carbon per square meter is accumulated in the puna, the paramo's carbon sequestration is approximately 35 kg/m^2, 33 kg of which are accumulated in the soil in a stable form (Pansu et al. 2009). In the puna, the time needed for a 50% exchange of the carbon stock is over 2000 years, while in the paramo it is over a million years. This difference is due to the soil's carbon sequestration (Pansu et al. 2009). The amount of dry matter accumulated in the paramo reaches 40 tons of dry matter per hectare, which is equivalent to 20 tons of elemental carbon (Recharte et al. 2002).

The possibilities of agricultural development in the paramos are not a profitable option, in large part due to the low production levels of the soil. However, there are some local crops that could be successfully developed, such as local native potatoes and other Andean tubers, as well as lupin, which is widely used and appreciated by the local population. While their development could be productive, it would mostly be focused on local consumption and as gourmet products, in conjunction with a specialized market that allows for pricing that is adequate for productors. There is also a large amount of medicinal and aromatic plants that are commonly used in the zone, which could be developed as products.

Livestock farming was and will continue being the option that is most accepted by the population. The low yields caused by poor management and the overexploitation of resources will have to be considered and discussed with the population. Farming's socio-productive organization needs to be improved by implementing management systems for the grasslands, such as the rotation of grazing lands and of the carrying capacity. Otherwise, it will not be possible to preserve the paramos.

Environmental services are a potential possibility for the preservation of paramos, and go hand in hand with the preservation of basin headwaters. Much research will be needed to learn more about the volume and paths of stored water, and of the water and carbon holding capacity of paramos.

The creation of an ecological corridor that includes the paramo areas has created expectations in the population and put the spotlight on conservation tourism as an activity. However, there is no adequate infrastructure to implement it. Existing highways are poorly built, and the large distances make accessibility to the space limited.

10.9.1 Results of Research on the Paramos

There were four *research zones* located in the Piura department: the Samanga paramo, Pacaipampa, Frías and Huancabamba. The Samanga paramo is located in the Ayabaca province and district, and is part of the Espindola and El Toldo sectors (community of Samanga, El Toldo and Espíndola premises). The San Juan sector is located in the Pacaipampa district, San Juan sector. The paramo that was studied in this zone is part of the San Juan de Cachiaco community, and of the Totora and San Juan premises. The Frías paramo is located in the Ayabaca province, Frías district. Finally, Cajas, located in the Pacaipampa district; and Segunda, in the Huancabamba district, were also studied. These last two localities are influenced by the Río Blanco mining project, and are areas of high conflict. For this reason, the soil analysis and vegetal recollection could not be carried out. All researched locations are located at an altitude above 3000 masl. The researched locations were:

- The settlements: Arenales, Pircas, Rangrayo, Altos de Poclus, México, San Diego, Pechuguis, Florecer, San Pedro and Nogal. All researched settlements are located in the upper part of the San Pedro basin, in the paramo of the Frías district.
- The research zone of the Samanga community paramo, El Toldo and Espíndola sectors.
- The paramo in the San Juan de Cachiaco premises, in the San Juan and Totora settlements.
- The paramos in the Segundo and Cajas communities, in the Pacaipampa and Huancabamba districts, Segundo and Cajas localities.

These researched localities can be seen in map (Fig. 10.1).

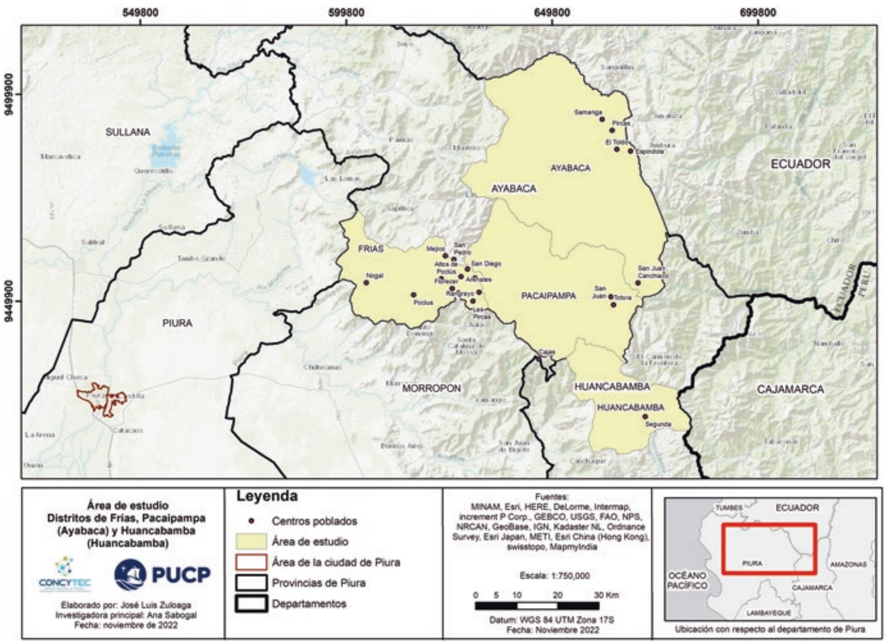

Fig. 10.1 Researched localities. (*Author* Ana Sabogal, designer José Luis Zuloaga, 2023)

10.9.2 The Locality of Frías

In Frías, the **soil** has a limey-sandy texture due to its origin, and to the low temperatures that slow down its decomposition. The soil is highly compacted by overgrazing. Its limey-sandy texture is caused by the altitude (3089–3363 masl), by the soil's origin and by the low temperatures in the area. Its pH is highly acidic, with an average of 5.12. Low pH is characteristic of soils of glacial or volcanic origin. There is a high amount of organic matter in it (4.38%), which creates stable complexes that, when linked to the soil's aluminium, are hard to break down (Sabogal 2014). The low pH is also due to the presence of pyrite and aluminium, and to the high amount of precipitation, which allows for the decomposition of rocks because of the soil's geology. The high amount of organic matter in the soil is due to the large amount of grazing in the area, in combination with the low average temperature. The low pH of the examined parcels and the low electrical conductivity of the soil seem to be associated with the large presence of organic matter and aluminium. This also explains the low amount of phosphate, which was probably precipitated together with the aluminium. The high amount of aluminium is due to the soil's origin.

Soils of glacial origin have a large amount of *pores* in them, which is why they have a high capacity for water retention (Blume et al. 2010). The use of these lands for farming highly reduces their volume, in some cases causing hydrophobia and poor drainage due to the formation of compact blocks of soil, and creating water logging on the surface (Blume et al. 2010). In this way, soils that are overgrazed by sheep present a reduction in their capacity to retain water (Buytaert, et al. 2006).

From all 30 studied parcels, 63 vegetable species were collected. Among these plants there is one fern (1.59%), one moss (1.59%) and one lichen (1.59%), which were included due to the species frequencies. Six of the species couldn't be identified (one of them was only identified at the level of family) due to the fact that the examinations were carried out during a period of drought, and also due to overgrazing. For some samples, genus could be identified, but not their species. 22 families were found in total, distributed among 48 genera and 63 species.

From the study of the vegetation, it can be observed that the most abundant family is the Asteraceae, with 16 species (25.39%), followed by the Poaceae, with 12 species (19.05%). The number of samples belonging to other species is below 5. This means that 44.89% of the plant population belongs to only two families. The high amount of Asteraceae and Poaceae and the low percentage of species from other families could be linked to overgrazing. It should be noted that plants from the Asteraceae family are characterized by a growth form in the shape of acaulescent rosettes, while plants from the Pocaceae family grow in shrubs, which allows them to better resist being stomped on, and are present in areas where burnings and grazing are practised. The paramo of Frías is highly altered, which can be confirmed by the large number of species found in a single parcel, such as: *Ageratina* sp.*, Lepechinia meyenii, Agrostis breviculmis, Pennisetum clandestinum, Polystichum cochleatum, Bartsia aff.* sp.*, Stevia andina, Baccharis* cf. *peruviana, Rumex* sp.*, Plantago* sp., *Nassella* sp., *Bouteloua simplex* and one unidentified one (Fig. 10.2).

Fig. 10.2 Altos de Frías. (*Author* Ana Sabogal)

Table 10.1 Distribution of strata in the studied spaces, own authorship

Localities	Weeds	Bushes	Trees	Vines
Frías	66.66	33.33	0.00	0
Samanga	58.21	34.33	4.65	0
San Juan	56.98	36.05	4.65	2.32
Promedio	60.62	34.57	3.1	0.73

Source: Sabogal (2014)

10.9.2.1 Locality of the Samanga and San Juan de Cachiaco Community

Soils from the San Juan premises, in Pacaipampa, which were analysed by the Páramo Andino project, have a loamy texture, a neutral reaction and very light salinity. They present a low amount of organic and calcareous matter (Proyecto Páramo Andino et al. 2009).

67 species, 51 genera and 25 families were collected from the *Samanga paramo*. Of all the phanerogams, 88.06% are dicotyledonous, 11.94% are monocotyledonous and 1.49% are gymnosperms.

The distribution of species in the Samanga paramo differs greatly from the one found in Frías. The main difference was found in the stratum. The total amount of woody plants add up to 40.3%. Table 10.1 shows the percentages of each strata for each studied locality. The high presence of dispersed woody plants is notable, as they add up to 40.3% of the total species. This zone is located close to the forest, and shows the presence of *Podocarpus glomeratus*. From this, it can be deduced that there were forests in the area that were cut down and damaged by overgrazing, becoming a paramized space.

In *Samanga*, the Asteraceae family was also the most abundant, adding up to 23.88% of the total. The second most abundant family in regards to the amount of species was the Ericaceae, with 10.45%, followed closely by the Poaceae, with 8.96% (see Table 10.1). In descendant order, the five most diverse families were: Asteraceae (16 species), Ericaceaa (7 species), Poaceae (6 species), Apiaceae (4 species) and Scrophulariaceae (4 species). The total number of endemic species in the Samanga locality was 8 (11.94%). Of these, 50% belong to the Asteraceae family and 25% to the Gentianaceae family. The Samanga paramo has been highly altered by anthropic activities, which leads to lesser diversity and endemism.

The *San Juan* paramo is more humid than the previous ones. This is evidenced by the presence of creeks and ponds dispersed around the area, and in the presence of 6.90% of species from the Cyperaceae family. As with the previously described spaces, the most common family is the Asteraceae. 86 families were found here, counting both angiosperms and gymnosperms. 67 genera and 33 families were found. The 4 most diverse families in descendant order were: Asteraceae (21 species), Rosaceae (8 species), Ericaceae (7 species) and Cyperaceae (6 species). The percentage of endemic plants in this space was 14.28%, which, although still low, is higher than that of other studied areas.

The richest families were: Asteraceae (24.14%), followed by Rosaceae (9.20%), Ericaceae (8.05%) and Cyperaceae (6.90%). In both localities, the *Jarava ichu Ruiz & pav* species was predominant. Once again, the high presence of arboreal species is notable, being higher than 40% in both cases. Finally, there was a high amount of rare plants found both in Samanga and in San Juan, which were present only once or twice among all parcels. They were plants like the *Ageratina piurae* (B.L.Rob.) R.M.King & H.Rob. or *Podocarpus glomeratus* Don in Lamb., among others.

The species with the most frequency in *Samanga and San Juan* were: *Jarava* cf. *ichu* Ruiz & Pav., which was found in 100% of the studied parcels, and the *Orthrosanthus chimboracensis* (Kunth) S.F. Baker, which was found in 78.33% of the parcels. Both species are widely distributed in grasslands, which is why the studied spaces can't be considered unaltered island-paramos, or intact paramos. A high amount of rare plants was also found both in Samanga and in San Juan. They were present only once or twice among all parcels. They were plants like the *Ageratina piurae* (B.L.Rob.) R.M.King & H.Rob. or the *Podocarpus glomeratus* Don in Lamb.

Although these two spaces are geographically close to each other, they belong to different vegetable communities, since their similarity is only 26.09% (Fig. 10.3).

Fig. 10.3 Fig. Paramo ecosystem, the river origin. (*Author* Ana Sabogal)

10.9.2.2 The Segundo and Cajas Locality

Soil in the high zone of the Huancabamba sub-basin has a high porosity due to its rocks' volcanic and metamorphic origin, but little permeability, which impedes the storage of water (Valladolid and Portilla 2014: 339). Huancabamba makes for 24.24% of the hydrological resource provision (Valladolid and Portilla 2014: 339). In Huancabamba, the paramos contribute to 80.66% of the space's hydrological supply (Valladolid and Portilla 2014: 339).

Agricultural and livestock activities contribute equally to the change of the land's use in Huancabamba (Valladolid and Portilla 2014: 341). In the districts of the Huancabamba sub-basin, the main crops are potatoes, corn, the oca tuber, the olluco tuber, cassavas, peas and sweet potatoes. These districts are: Sóndor, Sondorillo, Huancabamba, Huarmaca, El Carmen and San Miguel (Valladolid and Portilla 2014: 341). In Huancabamba, crops are mostly meant for local consumption. The main crops there are: peas, corn, potatoes and wheat. Additionally, oca, beans, sweet potatoes, cassava and oyuco are also farmed (Valladolid and Portilla 2014: 347). Each farmer in Huancabamba owns approximately 1.34 hectares with implemented watering infrastructure (Valladolid and Portilla 2014: 346). The loss of soil quality leads to the abandonment of parcels and agricultural expansion, and there is a high demand for forest wood from families (Valladolid and Portilla 2014: 343). Low productivity in the parcels is partially due to the low pH of the soil.

The studied zone also presents a high index of migration from rural areas into the city (Valladolid and Portilla 2014: 342). The expansion of the agricultural borders that also causes a rise in the demand for water affects the hydro-physical structure of the soil (Tobón 2009 cit. Valladolid and Portilla 2014: 341). There is also a high level of deforestation. Approximately 82% of the population uses firewood as a source of energy (Censo 2007 cit. Valladolid and Portilla 2014: 343).

One of the largest threats to the sub-basin is that of climate change. In the studied area, the temperature has risen 0.2 °C between 1994 and 2014, which has increased the hydrological demand of the crops (Sabaté 2009 cit. Valladolid and Portilla 2014: 344–335). Precipitation has decreased 7% on average. In this matter, Huancabamba is one of the most affected districts (Valladolid and Portilla 2014: 349). These two factors will cause the zone to be more affected in the next few years.

Results drawn from the analysis of this space are theoretical, as accessing the area itself is difficult due to a lack of support from the local population. This comes as a consequence of threats from the local informal mining industry.

10.9.2.3 Comparative Botany of the Studied Spaces

When comparing all three spaces, it becomes evident that the San Juan Paramo is better preserved, and that it shows a larger number of species, genera and families. As observed in Table 10.1, the San Juan paramo has 33.33% more families than Frías and 24.24% more than the Samanga paramo. This correlation is also true for the number of genera and species.

Table 10.2 Comparative table showing vegetal diversity in the three localities, own authorship

Locality	Number of families	Number of genera	Number of species
Frías	22	48	63
Samanga	25	51	67
San Juan	33	67	86
Total	44	117	178

Source: Sabogal (2014)

When analysing the strata of all three spaces, the absence of trees and higher number of herbaceous species in the Frías paramo is easily corroborated (see Table 10.1). San Juan has the highest number of woody species, which coincides with its state of preservation and that of the other spaces.

In all three spaces, the family with the most frequency of appearance is the Asteraceae, and it has a similar number of genera in each case. There is also an observable difference in the number of species from the Poaceae family. 19.05% of species in the Frías paramo are from this family, and in the San Juan paramo only 3.49%. In Samanga and San Juan, there are more species from the Ericaceae family. The presence of species from the Cyperaceae family in the San Juan paramos indicates a higher humidity in the space. In the parcels of San Juan, the presence of *Cladina* sp. *Vain.* was observed. This is a lichen that hasn't been included in the calculations because it doesn't belong to either the angiosperms or the gymnosperms. Pteridophytes were also not included.

In all three spaces, endemism is focused on the Asteraceae family. The paramo of Frías has been highly altered by anthropic activities. In it, a lower diversity can be observed at the levels of family, genus and species (Table 10.2), as well as a lower level of endemism. In all three spaces there are also several species that show up with a low frequency, and only in a few parcels (rare species).

10.10 Sustainable Development of the Study Spaces

Both bovine and ovine grazing are carried out in the Frías paramo zone. The space is highly grazed, very much above its carrying capacity. The division of grazing parcels is uneven, which leads to the overgrazing of communal spaces (Sabogal and Watson 2009).

In the Samanga paramo, as in the San Juan paramo, grazing is extensive and grazing lands are mostly communal. Only some farmers have access to privately used spaces. The ownership of cattle varies greatly, ranging from 1 to 40 units per farmer (Sabogal 2014). In the Samanga, Espíndola and El Toldo paramo, cattle are kept away from the living settlement, which allows for a better conservation of the land.

The population of San Juan de Cachiaco (San Juan and Totora hamlets) endures substantial pressure from mining companies, which the population strongly opposes. The paramo is even farther away from the settlement than in Samanga: 8 h by horseback. For this reason, many farmers must sleep in the paramo to take the cattle to graze. In many cases, younger farmers take on this task. In the lower zones of the communities, lupin, bean and quinoa are farmed for private consumption. The difficulty of accessing the land and the large distance to the city of Piura mean that there's a low presence of commerce. A small percentage of the cattle is taken to Piura periodically by local merchants, though sporadically.

In Segundo and Cajas, the forest is largely still being conserved. The steep slopes and large distance from the city of Piura, as well as the poor state of highways, have kept this area in better ecological conditions. This location is different in that it faces the eastern part of the basin, and not the western part, as is the case with other studied communities. Its proximity to the Cerro Blanco mining project and the illegal production of poppy make this a complex case, as the space is entangled with illegality.

Among the main factors that determine the conservation of the paramo in its pristine state, are: a rugged topography that allows for endemism and the fragmentation of the habitat; a low-temperature weather with nocturnal frosts, which are partially responsible for its peculiar biodiversity; and the retention of water and organic matter, which cause the low pH in the soil. These elements are key to allow the conservation of the space.

The factors that determine the conservation of the anthropic paramo are the communal organization to regulate overgrazing and the adaptation in the face of climate change, which requires changes on the part of the population, as well as the development of new management systems. This will probably increase agricultural pressure on the space. For this reason, creating a sustainable, high value form of agriculture, and selecting local products to make use of the local flora's potential, are topics to be developed (ver 10.7.2). There are many risk factors for the space, including the genetic erosion caused by overgrazing and the habitat's fragmentation, the migration of exotic species and the diminishing of biodiversity. Climatic change will produce a rise in greenhouse emissions by decomposing organic matter as a consequence of the rise in temperature. Overgrazing also has an undoubtable effect on the soil. It reduce the water retention, as well change the undergrow watter flow. This is one of the main dangers to the conservation of the space.

10.11 Pending Research

As previously mentioned, little research has been done on the paramo, and there is a lack of updated information about it. The changes in biodiversity are already happening. In the paramos of Piura, which haven't been altered significantly, there is more biodiversity than expected. The process of change in the ecosystem is on its way, as are the changes in habitat, ecological niches and biochemical cycles. The effect of these changes will only become observable in the future. In anthropized paramos, the extinction debt has been fulfilled. This can be deduced from the biodiversity analysis from Frías in comparison to that of Pacaipampa. The biodiversity analysis that was carried out shows a heightened amount of endemism and the presence of rare species, present with only a few specimens.

The loss of biodiversity doesn't happen immediately, but as a process. The loss of habitat and fragmentation produce the extinction of species, not instantly, but also in a prolonged way (Diamond 1972; Lindborg and Eriksson 2004; Kuussaari et al. 2009 all cit. Mikishima et al. 2021: 446). The distribution of plants is correlated to the history of the place's utilization (Kuussaari et al. 2009; Krauss et al. 2010 cit. Makishima et al. 2021: 446). The extinction debt appears when fragmentation factors such as the amount of habitant and connectivity aren't explained by the current state of the ecosystem, but by past stages (Kuussaari et al. 2009; Krauss et al. 2010 cit. Mikishima et al. 2021: 446). The processes are still taking place, and aren't necessarily evidenced by the current results of biodiversity studies. It's important to keep in mind that the paramo's ecosystems are very sensible to environmental changes and fragmentation (Chapin et al. 2000; Daimaru and Yasuda 2009; Sasaki et al. 2014; Kudo et al. 2017 cit. Mikishima et al. 2021: 447). For this reason, monitoring and observation of these modifications is necessary.

Table 10.3 summarizes the state and potentialities of research focused on the paramo. The pending investigations being proposed correspond both to the nonexistent baseline and to the required monitoring, which could elucidate us regarding the current and future state of the paramo.

One of the key points to improve the space is the modification of *grazing* conditions. They must be adapted to the local carrying capacity of the land. In addition to exploring alternatives for improving the efficiency of cattle conversion to lower the pressure on the soil, there is also a need to consider alternatives, such as the introduction of smaller livestock. This could improve the living conditions of the population by lowering the impact on the grasslands. The distribution of parcels must also be improved in cooperation with the local population in order to lower the pressure on communal parcels and redistribute it among privately used parcels.

It should be noted that, since these spaces exist in the upper parts of the basin, the improvement of the soils should not include any type of chemical fertilization, neither for agriculture nor livestock farming.

Table 10.3 State and potentialities of research focused on the paramo, own authorship

Factor	Problem	Research proposal
Landscape	Fragmentation	Fragmentation and continuity of the landscape. Landscape restoration proposals, including the size of fragments, patchform effect and internal area, border area. Designing ecological corridors taking patches into consideration, and analysing connections according to each one's degree of endangerment.
Biodiversity	Loss of biodiversity	Study and monitoring of biodiversity and endemism. Fragmentation of habitat.
Ecosystem	Loss of complexity in communities	Genetic erosion. Dynamic of vegetable communities: Biodiversity, extinction, presence of foreign species. Invasive plants.
Conservation	Loss of the ecosystem	Define conservation priorities taking into consideration: *Hotspots*: IUCN and the presence of endemism. Define the biosphere's reservation: Nuclear zone, transition zone and ecological corridors.
Grazing	Overgrazing	Determine carrying capacity; rotation of parcels and rests. Cattle management systems compatible with the conservation of local species. Improvement and monitoring of the health conditions of animals.
Soil	Erosion; change in pH Loss of organic matter	Study of soils and their capacities, and the process of desertification; calculation of the erosion levels. .Monitoring of the loss of the soil's organic matter.
Agriculture	Loss of soil and water retention capacity	Study of crops of native species, medicinal plants, lichens and Andean tubers; ecological crops.
Deforestation	Loss of biodiversity; erosion	Propagation and reforestation of native species; study of forest's diversity; forest management proposal.
Water	Loss of water retention in the ecosystem	Soil porosity, compaction. Water dynamic and recharging of aquifers. Soil's water retention: Time and amount. Monitoring.
Sustainable development	Low population income	Zonification; diversification; market studies.
Climatic change	Loss of organic matter Increase in agricultural pressure	Study on temperature change and biodiversity. Monitoring of greenhouse emissions. Altitudinal effect and change of use on agricultural lands.
Mountain landscape	Esthetic degradation of the landscape Loss of biodiversity	Esthetic generation of environments through ecological tourism. Restauration of soil, water and biodiversity in high-priority zones.
Social organization		Development of a sustainable management system in cooperation with the population.

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Chapter 11
The Humboldt National Forest

11.1 Introduction

During the middle of the twentieth century, the Alexander von Humboldt National Forest was created as a productive forest, in an area of the Amazon that was rich in species. It was meant to be a focal point for national forest development, but over time, due to political and social problems, the area was deforested, transforming into a sparse forest. Currently some forest areas remain in a preserved state, but most of it has been stripped of its resources, leaving only species with the least economical value. This is where the analysed space is situated.

The Alexander von Humboldt settlement is located 56 km from the city of Pucallpa, formed around the intersection of two roads that connect the jungle region to the rest of the country. It's a socially tumultuous zone, where ethnic, governmental and social problems converge. Nature is exuberant and full of life, but the competence between species is abundant. The town, populated mostly by recent migrants, subsists in large part through commerce, complemented by agriculture and cattle farming. This chapter presents the space and its biological potentialities, attempting to propose sustainable solutions for its development.

11.2 The Ecosystem

The rainy tropical forest in the Amazon basin where the Alexander von Humboldt settlement is located has a warm climate, with temperatures that fluctuate from 18 °C to 36 °C, a relative humidity of over 75% and a precipitation of approximately 2000 mm/year (Brack and Mendiola 2000: 220). The species Diversity in this ecosystem is immense. There is also a large variety of ecosystems. The

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studied zone corresponds to a semi-natural forest formation where wood has been extracted in a selective manner (Brack and Mendiola 2000: 222).

Biological cycles in the area are quick. Organic matter decomposes rapidly due to the presence of high temperatures, abundant water and a large amount of decomposers, including fungi, worms and bacteria. Nutrients from dead plants and animals are reintroduced quickly into the trophic chain without being retained by the soil. This allows for the nutrients to be used by the ecosystem, instead of being lost and washed away by the rains. As a result, the ecosystem develops at a fast pace.

The soil, which is regularly washed by rains, is acid, decomposed, and poor in nutrients. Nutrients in the soil are pushed towards the deeper layers of soil, or washed by the filtered water into the river. Because of its decomposition, the soil is also rich in aluminium, which blocks the existent phosphorus. For this reason phosphorus in the soil is scarce. The mycorrhizae, symbiotic unions between plants and fungi, allow roots to acquire nutrients by extending their reach and their capacity for assimilation. By occupying the roots, they prevent nitrogen from reaching the atmosphere and phosphorus from reaching the soil, allowing it to be assimilated by the plants.

The photoperiod is stable throughout the year. There is no significant difference among the seasons, so trees are evergreen and photosynthesize all year long. Rains are scattered throughout the year too, but intensify from January to March.

Trees reach up to 45 m in height. On their trunks and branches grow ferns, epiphytes, bromeliads and cacti that are trying to reach the sunlight. The trophic chain is sustained by a high level of symbiosis, which allows for the survival of species in a highly competitive environment. Scarce light reaches the lower canopies, so leaves grow larger to capture as much light as they can get. In order to stay balanced over the superficial soil, trees widen their bases, forming platforms that other species use as habitats. The ground is covered in roots that form caves and refuges for many animals. Many other animals, especially monkeys, use the trees' canopies as trails. Their tails allow them to maintain stability and balance, but also to hang from branches and impulse themselves to jump. Each group of monkeys knows and defends their preferred paths through the branches.

Ucayali used to be the main centre of couch tapping for Fermín Fitzcarrald, the businessman popularly known as the "king of rubber" (Dourojeani 2009: 43). Rubber (*Hevea brasiliensis*) can still be found in the zone, as well as tinder species like the shihuahuaco (*Dypterix odorata*). The zone has an abundance of other tinder trees as well, like the palo rosa (*Aniba roseadora*) and the copaiba (*Copaifera paupera*), among others.

11.3 The Alexander von Humboldt Settlement and the Forest

Alexander von Humboldt is a small settlement located 86 km from the city of Pucallpa, in the Ucayali department. It's situated in the basin of the Amazon river, between the coordinates of 8°49′39.3″ S and 75°03′23″ W, at 0 masl. It's a largely degraded space, with a very recent cultural landscape.

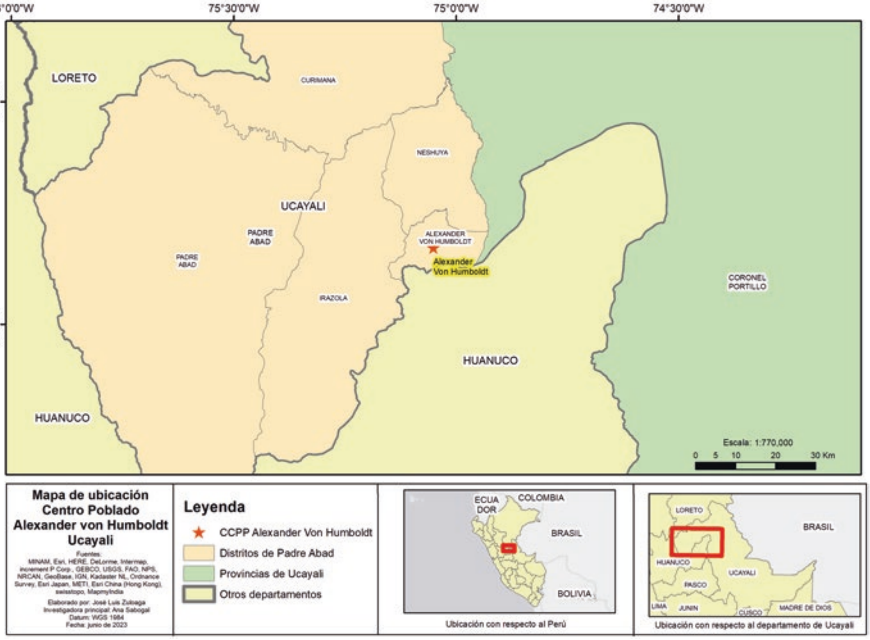

Fig. 11.1 Location of the Alexander von Humboldt settlement. (Designer José Luis Zuloaga)

The settlement was created as a commercial space, at the intersection of two roads that go deeper into the jungle: The Belaunde Terry road, also known as the jungle's border road, which links the jungle with the coast of Peru, and the Jorge Basadre road, which goes deeper into the mountains of Huánuco. These roads were created for political reasons; on the one hand, with the hope of leading to a reduction of illegal coca farming lands, and on the other, to create a commercial axis that would connect several major cities from the coast, mountains and jungles of Peru, becoming a centre of commerce (Fig. 11.1).

The zone was the stage of great conflicts during the subversive war that forced the population of nearby settlements to migrate. It still remains a conflictive space, due to its proximity to the valley of the Apurimac, Ene and Mantaro rivers known as the VRAEM, a territory where coca is still being produced. The population is mostly migrant, having come from different parts of the country as a result of a policy intended to populate the jungles.

The settlement was built after the creation of the Alexander von Humboldt National forest, which is located between the coordinates 08°25′ to 9°26′ south latitude and 74°59′ to 75°30′ west longitude. The forest's altitude ranges from 250 masl to 500 masl, has an average temperature of 25 °C, and a precipitation of approximately 4000 mm/year (INRENA 1998). The forest was established as a productive forest, a sustainable management centre for high-quality wood, in 1965. At the time, the forest had trees that could produce very valuable wood. The national forest is a few kilometres away from the settlement. It is currently in a degraded state, and has been stripped of its most valuable species. It lost its National Forest status in 2005.

In the Alexander von Humboldt settlement, the population is mostly migrant in origin, having come 20–30 years ago from the cities of Pucallpa, Huanuco and other nearby locations in search of opportunities. The native population, meanwhile, is absent from the town. The territory has gone through constant changes of use, experiencing deforestation and the occupation of lands, first for cattle raising and then for agriculture. The zone's population is mostly of mixed race, and the native inhabitants, who are part of the Pano and Arawak people, formed 5% of the local population in 1988 (INRENA 1998). Today, they are practically absent from the settlement. Currently Alexander von Humboldt has 7500 inhabitants, who have taken ownership of the territory, and lead their lives completely separated from the native population. Native people are not present in the settled areas at all, and have no contact with the population, leading to two parallel existences. There are very few mixed families that include members from the native population.

The inhabitants are mostly settlers that arrived after the initial constructions in the 1980s, due to the roads being built. Their main activities are commerce and agriculture (55%), cattle raising (18%) and to a lesser extent, foresting (13%) (Sabogal 2021). On average, their farmlands are 40–50 hectares in size. These lands were received from the government when they migrated. Their main crops are cocoa, banana, pineapple and papaya, among others (Sabogal 2021).

The type of agriculture being practiced is extensive, of low investment and with little dedication on the part of farmers. Most have incomes outside of cultivation, and all of them farm cacao. Because most of the population is migrant, no traditional agriculture is done in the area.

Foresting encourages the cultivation of teca (*Tecona grandis*) and bolaina (*Guazuma crinita*) for their rapid growth and harvesting. It's complemented by other timber species with longer vegetative periods such as the capirona (*Calycophyllum spruceanum*), as well as with the large-scale cultivation of cacao and oil palm (Fig. 11.2).

11.4 Socio-environmental Conflicts

Although the area is rich in resources, it is affected by many conflicts that are difficult to overcome, from territorial disputes and land invasions to social challenges brought about by the legal and illegal exploitation of timber. The process of land invasion has several stages: first, the forest is slashed down and burned to extract the wood. Then, once the land is clear of trees, it is used for agriculture. Finally, once the soil's productivity diminishes, the lands are sold to private buyers. Most of these timber producers have documents that prove their possession of the land, but not property titles, and much less permits for the extraction of valuable species. Since this means they can't harvest timber legally, they tend to associate with communities that do have those permits. There is a significant illegal market of timber

Fig. 11.2 Agroforestry. (*Author* Ana Sabogal)

operating in the area. Since the procedures for acquiring official titles and permits are complex and tedious, many timber merchants end up selling their products to third parties for reselling.

This area is in a state of constant modification due to the strong migration of inhabitants in search of better opportunities. These modifications have been happening at a fast pace since the decade of the 1980s, in part due to the creation of the roads and also as a consequence of the armed conflict from that period. From 1985 to 1992, riparian crops and vegetation increased in the area by 60.7%, and currently, the forest has been significantly reduced in size (Sabogal et al. 2022). The increase in population from 2007 to 2017 was mainly due to commercial activities (Sabogal et al. 2022).

The combination of climate change and deforestation represents a significant risk (Adams et al. 2014: 49 cit. Bergmann et al. 2021: 107). Deforestation modifies and affects the hydrological cycles. In the last few decades, forest fires have increased in size, and reached particularly large extensions between 2015 and 2019 (Bergman et al. 2021: iii). They have also increased in frequency (Fernández et al. 2011 cit, MINAM 2016: 150). Some of the main causes for these fires are agriculture, droughts and the emission of greenhouse gases (MINAM 2016). All these

Fig. 11.3 Forest fire. (*Author* Ana Sabogal)

conditions modify and affect the climate, first at the micro-climate level, and later at the macro. An increase of forest fires due to droughts is predicted to take place in the future (MINAM 2016). The most extreme climatic scenarios predict an increase in temperature of 4 °C in Peru's jungles, which would create heat stress in the zone and limit the flourishing of life, while in the best scenario there would be an increase of 2 °C and migrations from Lima to the jungle zones, increasing deforestation and the pressure applied on the area's resources (Bergmann et al. 2021:2–3) (Fig. 11.3).

The local population doesn't participate much from the main socio-political dimensions of these discussions. Although governmental agents and societal actors are welcome, the population itself remains detached. Many do get involved in state projects meant to offer financial support, such as cacao cultivation projects and the creation of the company of cacao producers, since they offer direct benefits for them. The population also maintains close relations with other nearby settlements and the city of Pucallpa. But their separation from the native communities is socially, culturally and racially evident. In large part this is the consequence of the internal conflicts that resulted in the native population being expelled or killed by the Lightened Path terrorist group, leading the few remaining native groups to move to deeper zones of the forest. Finally, although the population's day to day has many obstacles, there is no awareness of the risks of climate change, neither from the population nor from local political actors.

11.5 Sustainable Development

Many attempts have been made to achieve the sustainable development of the space, some with more success than others. Settlements located closer to the city of Pucallpa, like Alexander von Humboldt, tend to receive more attention from the state. However, this remains a conflictive space, and its location close to two main connective roads presents both a risk and an opportunity.

The first proposal, which originated the settlement, was creating a National Forest. This conservation status no longer exists, but the space could be turned into a park or a *landscape reserve* to ensure its restoration and reforestation. This reforestation could include the planting of noble species with high-value timber such as cedar (*Cedrela odorata*), as well as other timber species that were once part of the ecosystem, such as the shihuahuaco (*Dypterix odorata*), the palo rosa (*Aniba roseadora*) and the copaiba (*Copaifera paupera*). Together with the promotion of a touristic node, the space could be transformed for the better. Additionally, a financial benefit derived from the conservation of the ecosystemic services, the biodiversity, the soil and the carbon capture could be provided for the population. A measure that is already being taken by some private companies is the reforestation of deforested areas and of secondary forests, which have undergone a secondary succession. This reforestation and the management of species should be complemented with the support of timber companies for the production of certified timber. To this end, it's important to have adequate nurseries in the zones where native species are planted.

Another option, which takes into account the existing commercial connections, is creating a better-organized *commercial* space where the supply can be enhanced through the introduction and transformation of products. The state has been implementing agroforestry management proposals, but they haven't been adopted by the population except in the university's test parcel, since agroforestry demands intensive management from the farmers. Both agriculture and cattle raising is done in an extensive manner in the zone, and the population combines different economical activities for their subsistence. Through the coca substitution program, the state has been promoting the production of cacao in Peru's jungle areas. Simultaneously, the transformation and production of chocolate and other associated products has also been promoted through the creation of producer associations.

Another solution that has been proposed as a result of multiple investigations is the *titling of lands*. The Land Titling Program, better known as PTR3, is promoted by the World Bank, and is currently being implemented. The program is a response to the fact that, at the moment, many of the farming communities don't have official titles for their lands, nor know their defined coordinates. The same is true for many of the plots. This can lead to many conflicts over the ownership of land, which, combined with the high value of timber, can create environmental conflicts.

Finally, it should be mentioned that there is an oil extraction site a few kilometres away from the settlement, which will surely transform the space, adding to the already existing conflicts.

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Chapter 12
The Northwest Biosphere Reserve

12.1 Introduction

As described in Chap. 9, a Biosphere Reserve is composed of three spaces that need to be managed: A nuclear, intangible zone; a transition zone that's adjoined to spaces occupied by human population; and the ecotone, which is the transition space between the protected ecosystem and other adjoined ecosystems (see Chap. 9). Besides the Northwest Biosphere Reserve, there is the La Paz Forest Crossborder Biosphere Reserve, located in the same dry forest ecosystem. It was created to handle the joint management of the dry forests of Peru and Ecuador.

The Northwest Biosphere Reserve was created in 1997 as part of UNESCO's Man and the Biosphere Program (SERNANP 2023). It currently covers 1,115,948 hectares (UNESCO 2023). It is comprised of the Amotape Mountains National Park, the Tumbes Mangroves and the Angolo Hunting Reserve. The inclusion of the Tumbes Mangroves goes back to 2016, and corresponds to a form of management that includes the use of resources from both the forest and the mangrove.

The Forests of La Paz, created in 2017, are composed of 1,616,988 hectares. They include the Dry Forest Biosphere Reserve in Ecuador, which has 501,040 hectares, and the Amotapes-Mangroves Northwest Biosphere Reserve in Peru, which has an extension of 1,115,948 hectares (UNESCO 2023). The reserve's nuclear area has 237,638.76 ha, its buffer area 478,165.28 ha and its transition area 901,184.38 ha (UNESCO 2023). The reserve protects the seasonally dry forests of Ecuador and Peru, which constitute the heart of the Endemism Region of Tumbes, one of the most biodiverse places in the world, which is classified as a biodiversity hotspot (UNESCO 2023). The Tumbes-Chocó-Magdalena hotspot is recognized as a vital area for its high diversity of birds, and is also influenced by the Chimborazo endemic zone, which is in turn an important refuge from the pleistocene era (SERNANP 2023).

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At the national level, the Biosphere Reserve category is not one that grants protection. For this reason, each reserve area has a national-level equivalent: the Amotape Mountains Park corresponds to a strict protection park; the Angolo Hunting Reserve corresponds to a transition area where sport hunting is permitted; and the Tumbes National Reserve, as well as the Tumbes Mangroves National Sanctuary, are transition zones that allow for the sustainable use of resources.

The objective of a protected zone will depend on its category. These objectives may be: conservation, research, environmental education or ecotourism. The park's objectives are research and conservation. Human activity is prohibited outside of these objectives, and a permit from the National Service of Natural Protected Areas (Servicio Nacional de Áreas Naturales Protegidas, or SERNANP) is required to access it. In the Hunting Reserve, hunting tourism is permitted, as well as conservation, research and environmental education. In the Tumbes Mangroves National Sanctuary, all four activities are permitted: conservation, research, environmental education and ecotourism. Additionally, local inhabitants who lived there prior to the creation of the protected area can extract resources from it in a sustainable manner.

However, there are other zones in the National Park besides the strict protection zone, which makes for 46.82% of its total area. There's the wilderness zone, which contains areas that have been altered by grazing, and occupies 15.6% of the park; the tourist-recreational zone, a special-use zone with human settlements that were present before the park's creation; the recovery zone, which covers 38.29% of the park's area, and where the pink morning glory (*Ipomoea carnea*), an heliophile plant that takes advantage of the sunlight that's let in by cut down trees, has spread due to overgrazing; and the cultural-historical zone, which contains archaeological remains from incan and pre-incan times (SERNANP 2023).

The park is surrounded by an officially recognized buffer zone with an extension of 92,014.54 hectares. It includes the districts of Matapalo, San Juan de la Virgen, Pampas de Hospital and San Jacinto, Casitas and Lancones, among others (SERNANP 2023: 32–33).

12.2 Ecosystems

The Northwest Biosphere Reserve is made from several ecosystems. The Amotape Mountains National Park contains the Forest of Tumbes, a seasonally dry equatorial forest that has fauna of Amazonian origin due to the low altitude of the Andes in the zone. This fauna comes from the evolutionary centre of the Amazonian Hylea (SERNANP 2023) and the mangrove, which has maritime resources.

The National Park is located within the seasonally dry forest ecosystem, and shows several vegetable formations: dry mountain forests, dry pre-mountain tropical forests, dry tropical forests, dense dry plain forests, very dry montane tropical forests, thorny montane tropical forests and dense dry hill forests (SERNANP 2023).

Plants in the forest are adapted to diverse conditions of dryness or humidity. To this end, phreatophyte plants grow taproots, which are deep roots that prioritize the development of the main root, generated by the increase of auxin concentration. Auxins are hormones that cause apical dominance and inhibit lateral buds. These plants allocate a higher proportion of photosynthates to the roots than to the leaves, which also modifies the ionic exchange to impede the excess intake of salts. The salts are then stored in vacuoles and eliminated when the plants' leaves fall. The vacuoles also store water to equilibrate the cell's pH in case it is needed. Many of the dry forest's plants, including cacti, reduce the size of their leaves, which also reduces the density of their stomata. This is done in order to reduce transpiration. Trunks acquire the photosynthesis function, retaining a green colour. The leaves and trunk produce wax and resins to reflect light and reduce heat absorption, as well as retaining water. Leaves modify their orientation to reduce the size of the angle formed with the trunk and diminish solar incidence. Often, they also grow hairs to disperse solar energy. In this environment, flowers are mostly white to avoid evaporation and to be more easily identified by bats in the dark. This is done because, since there are few animals in the area, bats often pollinate the plants (Fig. 12.1).

Fig. 12.1 *Prosopis pallida* with phreatophyte roots. (*Author* Ana Sabogal)

Fig. 12.2 *Ceiba trichstandra* with a green trunk in the seasonally dry forest. (*Author* Ana Sabogal)

During the dry season and when the El Niño Event takes place, ephemeral plants of rapid growth appear, such as grasses that are often eaten by deer and goats. The seeds germinate quickly as the chemical inhibitors of germination are washed away and/or the seed coat is softened (Fig. 12.2).

Due to deforestation and the cutting down of carob trees, heliophile plants that wouldn't normally develop under the shadow of trees bloom. One is the pink morning glory, locally known as borrachera (*Ipomoea carnea*). This plant has a high amount of alkaloids, and is highly sought after by goats. They will eat the plant until they die from intoxication.

The Tumbes Mangroves National Sanctuary is part of the RAMSAR sites (SERNANP 2023). The RAMSAR convention includes several wetlands that must be conserved due to their influence as ecosystems. Since they are connected by webs of underground water, they can influence other ecosystems. The Tumbes mangroves are an estuary ecosystem that connects a river to the ocean, and is notable for having a high diversity of species, as well as a large amount of caves and spaces for animals to raise their young. Many local and migrant birds also build their nests in the mangrove.

The mangrove has four interconnected biotopes, which are shown in Fig. 12.3:

- The mangrove forest.
- The dry forest adjacent to the mangrove.

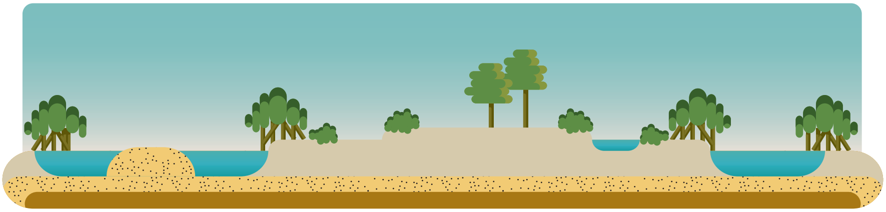

Fig. 12.3 Biotopes of the mangrove ecosystem, own authorship. (Designer Juan Pablo Bruno. *Source* IRENA 2007)

- The estuaries.
- The sandbanks.

The mangrove plant is the predominant species in the mangrove biome. There are five species of mangrove present in the area: red mangrove (*Rhizophora mangle*), zapatero or caballero mangrove (*Rhizophora harrisonnii*), white mangrove (*Laguncularia racemosa*), black mangrove (*Avicennia germinans*) and botoncillo mangrove (*Conocarpus erectus*). These species have developed many adaptations to survive in the swamps.

Water in the mangrove is salty due to it being a combination of ocean and river water. Species adapted to living in salty water excrete the excess accumulated salt through their leaves. To this end, they increase the number of vacuoles in their cells and, once they've been saturated with salt, the leaves fall. This adaptation also means that the plant modifies its hormonal balance. Abscisic acid is the hormone responsible for regulating the falling of leaves. Roots filter out the salt, and then whatever salt has been absorbed by the plant is accumulated in the leaves. This means that there's a change in the root's pressure and in the salt intake control during the ionic exchange in order to acquire the nutrients that enter the roots together with the salts.

The branches of plants have a positive geotropism, which allows them to grow in the direction of the force of gravity. Some branches, called adventitious roots, grow in this direction to improve the plant's anchoring in the swampy soil, and to absorb oxygen by taking the form of crutches. The mangrove's soil is poor in oxygen, so the plants increase their number of stomata to compensate. Caves are formed among the adventitious roots, and become the habitat for several types of shellfish and molluscs, such as the prized concha negra (*Anadara tuberculosa*) and the mangrove crab (*Ucides occidentales*), among others. Multiple birds that feed on these species make their nests in the trees' branches.

The dry forest adjacent to the mangrove is different from the seasonally dry forest. Besides the carob tree (*Prosopis pallida*), there are several other species such as the faique (*Acacia macracantha*), the chope (*Cryptocarpus pyrirformis*), the peal (*Scutia spicata*) and the ceibo (*Ceiba trichistandra*), which form small communities in the upper parts of the mangrove.

The estuaries are water corridors that go through the mangroves and allow for navigation between its different biotopes. There is also a large diversity of aquatic fauna to be found here, as well as different types of birds searching for food.

Finally, the sandbanks are formed through the accumulation of sand in the mangrove as a result of the ocean tides. They have little to no vegetation in them.

12.3 Population That Inhabits the Reserve

The Biosphere Reserve includes both the management of spaces and the traditional use of resources, which include: Riverbed agriculture, which is practised in the National Park to make use of the water that accumulates during the rainy season (Sect. 12.3.1); the extraction of wood from the forest of Tumbes; and extensive grazing of bovine cattle that migrates seasonally from the Cerros de Amotape forest to the forest of Tumbes to make use of grasses in the dry season, when there's no more food in the park.

12.3.1 National Park

The park is a cultural landscape used by the population since before incan times. The park contains part of the incan trail, or Capac Ñan, which was used by the incas as a means of terrestrial and maritime exchange (SERNANP 2023: 29). The population of the Amotape mountains would combine agriculture with shellfish gathering. Remains of conchas negras have been found in forest settlements, which shows that the forest population have been combining the use of forest resources with those from the mangrove since pre-ceramic times (INRENA 2007).

The national park includes populations that had settled in the area before its creation. They maintain the traditional use of its resources, which includes extensive grazing that goes from the park's lands during the rainy season, to the forests of Tumbes during the dry season, as well as wood extraction from the forest of Tumbes, the hunting of several animals, especially the white tail deer (*Odocoileus virginianus*), and shellfish gathering.

During the dry season, the park doesn't produce enough food for the bovine cattle, so animals migrate in search for food to the forest of Tumbes, where grasses remain green due to its higher humidity. The cattle knows which migration routes to take, and after several months, return to the forest on their own, where they reunite with their owners. When raised extensively, bovine cattle are autonomous and will look for food without the need for shepherding. Goat cattle remain in the dry forest to search for food, and during the dry season, find the pink morning glory, or borrachera (*Ipomoea carnea*), which they will eat until they get intoxicated. During the dry season, the population collects from the forest of Tumbes, and also practices logging. The logging is currently controlled. Hunting is also practiced in a

Fig. 12.4 Growth of cola de zorro cacti (*Hageocereus* spp.) in overgrazed area. (*Author* Ana Sabogal)

traditional way, and is also controlled. Part of the population migrates to the mangroves for the collection of seashells. During the rainy season, traditional riverbed agriculture is practised. Overgrazing modifies the ecosystem, encouraging the proliferation of cacti to the detriment of palatable species (Fig. 12.4).

Riverbed agriculture is practised in the Northwest Biosphere Reserve's buffer zone, in the riverbed of temporary streams that appear during rainy seasons. After the rains stop, and once the river's water volume has diminished, seasonal crops are planted. Soil is taken from the slopes, where Fabaceae trees grow, and used to build furrows. The furrows' soil is removed by the rains every year, and renewed before the next planting, so that the soil remains fertile. This type of agriculture is practiced in the reserve's buffer zone, specifically in the settlements of Jaguay Negro-El Papayo, and of Casitas-Cherrelique, where crops are planted directly in the soil by the streams (Fig. 12.5).

Teniente Astete is the only settlement that is permitted to remain within the park. This location existed before the reserve's creation, and to this day carries out agricultural and cattle-related activities. Migration and the creation of new settlements are not allowed in the park, even from relatives of local inhabitants (SERNANP 2023: 28–29). Other settlements, such as Jaguay Negro or Casitas-Cañaveral, exist in the buffer zone.

Fig. 12.5 Riverbed agriculture in the dry forest. (*Author* Ana Sabogal)

Currently, the use of fallen non-timber trees is permitted in the park's buffer zone (SERNANP 2023: 34). The fishing of river shrimp also takes place in this buffer zone, and chemical products that pollute the streams are used in the process (SERNANP 2023: 34). Additionally, mining zones, hydrocarbon processing areas and urban development works are present in the buffer zone (SERNANP 2023: 35). The capturing of parrots for their commercialization is yet another problem in the area (SERNANP 2023: 42–45). All of these issues must be regulated in order to achieve the preservation of the reserve.

12.3.2 Tumbes Mangroves National Sanctuary

The sanctuary's size is approximately 246,000 hectares (INRENA 2007: 11). It's position goes from 3° 24′ south latitude, in the border with Ecuador, to 3° 35′ south latitude (Playa Hermosa), and from 80°13′08″ to 80°31′03″ west longitude-west latitude (ONERN-1992 cit. INRENA 2007: 11). It includes the mangrove ecosystems adjacent to the Pacific ocean's tropical sea, and the equatorial dry forest. Its importance lies in the need for the preservation of the mangrove's ecosystem, in which many species of shellfish and birds live (see Sect. 12.2).

The ancient people who dominated the area belonged to the Tumpis culture. Their language and identity managed to be preserved even after being conquered by the Vicu culture, the Sican culture, the Chimu culture and the Incan empire (INRENA 2007), and later, even after the Spanish conquest. As previously mentioned, the sanctuary's resources were exploited by these forest inhabitants, who would gather shellfish and fish in the lands to complement their diets.

Currently, there is a strong migration into the space due to its touristic appeal. Approximately 65% of the sanctuary's population comes from the Piura department, especially from the provinces of Ayabaca, Huancabamba, Morropón and Sechura (Takahashi 2002 cit. INRENA 2007).

Currently, there are many actors that make use of resources in the area and compete for them. The main actors linked to these resources are the shellfish collectors, who acquire their product in an artisanal way, but who can produce a negative impact by overexploiting the mangrove if their numbers increase; the farmers who plant by the riverside of the Tumbes river, who use fertilizers and pesticides that pollute the river and the mangrove; the shrimp sellers, who create pits for breeding their shrimp and pollute the water when treating it with antibiotics; and the shellfish collectors. Additionally, there's the fishermen, both artisanal and industrial; the informal pig farmers; the illegal land dealers, who exercise a strong influence on the area; touristic entrepreneurs, who respond to a high touristic demand; and finally, state institutions such as the national navy and the army (INRENA 2007: 45). All these actors create a complex web that makes managing the mangrove space and preserving it difficult.

12.4 The El Niño Phenomenon

Peru's weather is influenced by two water currents: the Humboldt cold ocean current, and northern Peru's warm ocean current (Brack and Mendiola 2000: 118). On regular years, the Humboldt currents' influence reaches the latitude of 6° south, while the equatorial current flows from the latitude of 4° north to right before 6° south. The El Niño Event is produced as a result of the advancement of the equatorial current towards the south due to a weakening of the Humboldt current. In the years when the El Niño effect takes place, the Humboldt current's influence on Perú's shores is weakened, allowing the equatorial current to reach farther south. This causes strong rains in the coast and in the seasonally dry forest. The El Niño Event happens with a variable frequency of 7–10 years. This frequency can be altered by climatic change, and it's expected to increase over time.

The El Niño Event produces a diminishment of the sea's fish population, since it suppresses the upwelling of nutrients produced by the difference in temperatures in the ocean. It affects the reduction of the anchovy supply, since they prefer cold waters, and raises the amount of shellfish. While the seasonally dry forest is influenced by the El Niño Event, the mangrove ecosystem is influenced by the warm waters of the equatorial current that also affects the tropical sea.

The dry forest inhabitants are used to the presence of the event. During these years, they become isolated from the coast for several weeks, staying in the forest hills where they normally build their houses, since the stream areas can flood. The El Niño Event allows for the renovation of the ecosystem. Seeds swell and germinate, regenerating the forest by making use of the additional water, since the soil remains wet until the plants can develop their long, fast-growing taproots. It's also a good time for agriculture, as the inhabitants can make use of the humidity to plant seeds in the stream areas through the use of riverbed agriculture once the water subsides (ver 12.3.1).

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Chapter 13
Urban Ecosystems and Sustainable Development

13.1 Introduction

Currently, most of the world's population live in cities. In Latin America, approximately 81% of people are city dwellers, and it's estimated that this percentage will grow by 27% by 2050 (BID 2018: 12). In Peru, 76.7% of the population live in cities, and 23.3% in rural spaces (INEI 2014b cit. MINAM 2016: 18). However, cities tend to be highly polluted spaces, full of noise, greyness, monotony, violence, people rushing to work or struggling to find the means to eat day to day. Drug dealers, petty thieves, and a lack of green and recreational spaces are some of their most common characteristics. How could this vision of cities be reversed, so that they can become beautiful spaces, full of cultural life and accomplishment? So that they can be places that we dream of, places that are loved, where beautiful memories can be made and hopeful futures imagined? We'll settle for at least having what we'll call "livable cities".

Memories of our childhoods can carry us to an ideal world, where everything was perfect and we felt no fear, even in the city where we grew up. How can we go back to that idealized life, so that we can live in peace in the city, without having to self-isolate to avoid dangerous and dark places?

.This chapter uses as its framework the 11th Objective of Sustainable Development: "Inclusive, resilient and sustainable cities", specifically subheading 11.7, which proposes that, by 2030, city dwellers should have universal access to green areas and safe, inclusive and accessible public spaces, specially women, children, the elderly, and people with disabilities (BID 2018: 37).

A. Sabogal, *Ecosystem and Species Adaptations in the Andean-Amazonian Region*, https://doi.org/10.1007/978-3-031-44385-5_13

13.2 Urban Ecosystem

Green areas are necessary for a city to breathe. They absorb part of the emissions generated by cars and industry, but only partially. If we think of cities as part of a green economy, or a circular economy in which all emissions must be reabsorbed, we would need much more than the 8 square meters per citizen that are currently demanded.

Plants in cities are especially resilient, as they must endure pollution, the indiscriminate use of pesticides, being walked on and, in many cases, lack of water. Urban ecosystems are dramatically different from the natural ones that existed in the places where cities were built. This is especially true for areas like that of Lima, where there is a lack of rain and natural vegetation, except for zones where river basins cross the land, though they are scarce. Here, the most prominent species of trees are the Benjamina ficus and the Eucalyptus. There are also some other local South American species, such as the Tipa (*Tipuana tipu*) and the Coastal Molle (*Schinus terebinthifolius*).

Most city plants have been introduced into the environment. They are adapted to disturbances, being stepped on and transit pollution. However, there are always havens for wildlife in cities, which can allow for the development of small ecosystems, adapted to the environment. Therefore, as part of my methodology, it is necessary to discover and develop these spaces. There, plants that can be used in parks can be grown. Each city has particular spaces that are blessed in their ecology and the quality of their landscapes, and these spaces should be preserved or restored. Lima, for example, has a proximity to the ocean, as well as the wetlands of Villa (better known as the Villa Swamps), and the areas around the basins of three rivers that run through it, which hold ecologically rich and beautiful landscapes that should be integrated into the city as public spaces.

The courses of the Rimac and Chillon rivers both run through the city, and are integrated into it. The natural ecosystem that corresponds to this space is that of the riparian forest. In them the Caña Brava (*Ginerium sagittatum*) and the Pájaro Bobo (*Tessaria integrifolia*) (Brack and Mendiala 2000) can be found, as well as trees like the Mountain Molle (*Schinus molle*), Humboldt's Willow (*Salix humboldtiana*) and the Sauco (*Sambucus peruviana*), which grow close to the edges of rivers. These trees are adapted to the changes in the river's water level, and as such are useful as a riparian defence. This is especially important during the times of year when the weather changes and landslides become more common, which is a common occurrence in this climate.

The wetlands of Lima are connected to other coastal wetlands, and so the pollution of one affects the others. These areas are of great importance due to the presence of diverse plants and grasslands, such as the salt grass (*Distichlis spicata*), and the cattail (*Thypha* sp.) communities, which are used by great amounts of local and migratory birds to hide their nests.

Along Lima's coastlands and shores, and in places where beach houses have been built to be used during the summer months, species such as the salada

(*Distichlis spicata*) and the portulaca (*Sesuvium portulacastrum*) can be found, both of them in great quantities. There is also a diverse fauna, which includes many birds. Salt grasses are also present in dry, abandoned parks, as a pioneer species. In zones closer to the sea, where the ground is sandy, and in the humid hills populated by xerophytes that surround Lima, different types of tillandsias (*Tillandsia* sp.) grow over phone lines and cables, feeding off the ambient humidity.

Long ago, in the caverns that dot the cliffs that overlook the ocean, the maidenhair fern or culantrillo (*Adiantum* sp.) could be found among the local flora, in the places that birds and lizards inhabited. In urban zones, like the edges of streets and the berms of avenues, wild plants like the amaranto (*Amarathus dubius*) grow, while in dry, sandy areas close to rivers, the higuereta (*Ricinus communis*) or the mountain molle serrano (*Schinus molle*) can be found.

Finally, hills and knolls such as the hills of Carabayllo or of Villa Maria del Triunfo are another type of ecosystem that is part of the city of Lima. In them, native species such as the amancaes (*Ismene Amancaes*) can be found. This plant has been reintroduced, and is currently being cultivated in some of the parks of Lima. And so, as we can see, Lima is not just a desert, but is rather made out of multiple diverse ecosystems that host many migrant species (Fig. 13.1).

Green areas in the cities are not just made out of plants. They are small ecosystems that also host animals and microorganisms. Understanding the relationship between these ecosystem's inhabitants allows us to ensure their quality and permanence. In Lima, parks constitute such small ecosystems. They contain a rich fauna, which includes birds, some native, but mostly assimilated. The city's fauna is, therefore, very diverse, in many cases more so than that of natural ecosystems.

Fig. 13.1 Green area in Callao. (*Author* Ana Sabogal)

There are animals who find refuge from predators in the city, as well as predators who get access to their prey. The white neck squirrel (*Sciurus stramineus*), for example, migrated to Lima from northern Peru, at the same time as the red-headed parrots (*Psittacara erythrogenys*) during a year of heavy rains caused by an El Niño event. These animals ended up adapting to the city, and currently, the squirrels act as a significant avian predator, since they inhabit a large amount of city trees, moving among them through electricity lines and phone poles. The Harris's Hawk (*Parabuteo unicinctus*) has also been spotted more frequently. They feed on mice and squirrels, and hunt in groups. Among the native birds, we can identify the Chisco or Sonia (*Mimus longicaudatus*) and the Mielerito (*Conitostrum cinereum*). They both feed on insects that occupy the parks, though the Sonia also eats fruits. There are also foreign species such as the saffron finch (*Sicalis flaveola*) or the blue-grey tanager (*Thraupis episcopus*), both originally from the Amazon basin, that have escaped captivity and readjusted to non-domestic life. Similarly, the green Australian parakeets were released from captivity and managed to survive. They now compete with other species.

Birds and other animals make use of trees for their mobility through different spaces. However, not all of them attempt to change their environment unless the linkage between green areas is safe enough. Most connectors are narrow, which only motivates the mobility of fauna that aren't scared of humans, such as doves, sparrows and white-necked squirrels. The height of trees and buildings also has a direct influence on animal populations. Specialist and territorial animals like the peregrine falcon (*Falco peregrinus*) or the Harris's hawk (*Parabuteo unicinctus*) tend to occupy high and quiet places from which they can spot their prey, while other species like the scarlet flycatcher (*Pyrocephalus rubinus*) lives in solitary spaces due to their territorial nature. This is also the case with the peregrine falcon and the amazilia hummingbird (*Amazilia amazilia*).

Plants and animals have to adapt to the city and to local conditions, recreating their original ecosystem or creating a new one with particular characteristics. One peculiar example in Lima is that of the Harris's hawk, which occupies a great part of the American continent. They hunt mice and squirrels in groups. There is also the scarlet flycatcher (*Pyrocephalus rubinus*). The bright red colour present in the males has turned a toasted sienna brown to allow it to blend in.

Finally, it should be noted that these species are negatively affected by the indiscriminate use of pesticides. Although there are municipal laws that regulate their use, as well as some municipalities that apply biological control techniques, and initiatives such as the Ecological Agricultural Network, that promote ceasing the use of pesticides in favour of employing birds of prey for plague control, these regulations are not enough, and are not used city-wide. Many green areas are managed independently and their subsistence depends on the maintenance provided by communities of neighbours.

13.3 Green Infrastructure

Green infrastructure is that which integrates plant life into its design, be it parks, public spaces, or green areas within homesteads. Many solutions for integrating plants into architectonic design have been considered, with the intent of lowering pollution levels. Among these proposals, there is the use of green roofs and green walls.

For green roofs, the weight of the materials requires consideration, especially that of soil and water, as well as the irrigation method and the use of compost that may be taken from the organic waste of the building. In some cases, the keeping of organic gardens is used to encourage social integration among neighbours. However, in a city such as Lima, where weather conditions usually lead to water scarcity, limiting its use both for irrigation and for human consumption, ensuring the success of green roofs is difficult. For this reason, it's important to consider the materials to be used, and adapt them to the conditions of each of the country's cities, keeping their local materials and culture in mind. It should also be noted that wind currents increase in speed and humidity becomes lower at higher altitudes, which makes green roofs harder to maintain.

During the decade of 1970, neighbourhood parks were developed in Lima, taking as a model the concept of public parks linked to sport areas from communist countries. These were green areas such as the Huaynacapac Park, annexed to public pools, playgrounds and recreational spaces, which over time have been occupied by businesses. However, they still fulfil an important function for families who live in districts where the percentage of green areas is below the desired threshold.

In the case of Lima, and depending on the ecosystem, stone, sand and reed or caña brava can be considered local materials. When used for construction it is important the way in which they influence the universal access for people with special needs. This is a topic that, although regulated, is not often considered.

Regarding the management of plants and their agronomic aspects, the passage of time should always be considered. Plants should be able to develop fully without needing to be constantly replaced due to a lack of prevision. Among the basic techniques to be taken into account are the pruning of trees' roots and of the aerial guide for plants, in order to reduce the root and canopy size respectively. Both of these techniques must be executed in the nursery. The trees' growth must be guided in order to orient their shapes and sizes, including that of the branches, towards the light. This allows the penetration of light under the canopy, and the presence of shadows according to the needs of both the trees and pedestrians. All this will greatly depend on the orientation of buildings and their distribution in the space, which also affects the management of ventilation and temperature on green areas. Pergolas and light roofs are just as important for the management of shadows, in order to protect pedestrians from intense sunlight during the summer.

Among the design elements for public spaces and green areas, there are several aspects to take into account, such as the distribution of light in and out of the green areas, in order to ensure the safety of pedestrians both inside the parks and on their

Fig. 13.2 Green area in Piura city. (*Author* Ana Sabogal)

way to them. To this end, the light level must be adequate, not too intense so as to impede vision or alter the tranquillity in the park. Frequently, urban fixtures are associated with crime and local theft. For example, some believe that placing benches will attract homeless citizens who will occupy the space, or that the space will be used for illicit behaviour. These prejudices must be eradicated in order to build an environment where visitors can be integrated.

Finally, but equally important, are the ecological corridors that connect these spaces. The length and width of these corridors will determine which species use them and thus are able to move between them (see Sects. 9.5.1 and 9.5.2) (Fig. 13.2).

13.4 Sustainable Development and Circular Economies in Cities

In order to achieve the 11th Objective of Sustainable Development, "having more Inclusive, resilient and sustainable cities", it's necessary to consider urban ecosystems as an integral part of urban areas. To this end, it should be considered that cities, much like natural ecosystems, should have cyclical economies. Each construction material that is employed and each type of waste that is produced must be considered. The following section will deal with airflow, water, soil and the recycling of used subproducts.

13.4.1 Air

City air in Lima shows very high emissions of Greenhouse Gases, which have grown as the amount of motorized vehicles has increased (SINIA 2023). Additionally, the city is one of the most vulnerable to climate change in the world (see Chap. 14). Urban ecosystems fulfil an important function in the absorption of carbon dioxide, which is essential to reducing the effect of greenhouse emissions. However, there is still a severe lack of green areas, especially in the most impoverished districts of the city, such as Villa el Salvador, where the proportion of green areas is of 0.34 m^2/hab. In Breña, it is 1.01 m^2/hab.; in Rimac, 1.04 m^2/hab.; and in San Juan de Miraflores, 1.65 m^2/hab. In contrast, more affluent districts like San Isidro have 22.09 m^2/hab. Similarmente, Miraflores has 13.84 m^2/hab. and Santiago de Surco has 6.46 m^2/hab. This shows a distribution of green areas that should be reconsidered in order to achieve a more inclusive city. However, it should be noted that in many districts, green areas are often used by inhabitants of different districts. For example, areas in Santiago de Surco tend to be used by citizens from San Juan de Miraflores (Sabogal et al. 2019). In other cities of the country, the situation differs drastically and in highly variable ways. In Huancayo, the proportion of green areas is 5 m^2/hab., but this number changes to 3 m^2/hab. if we only consider public green areas (BID 2018: 136–138).

One great advantage of Lima is that, being a coastal city, there is a strong circulation of wind, which allows the dispersion of greenhouse gasses and impedes their accumulation, as it tends to happen in cities located in mountainous zones (Sabogal 2021). Air circulation can also be managed at a smaller scale, in each park, by adequately managing the planting of trees and bushes, and positioning hills to aid circulation and impede the entrance of gasses into the public space. In this way, trees work as filters, and can be used as curtains that can either filter gasses or block them. It is important to adequately calculate the height of these barriers and their distance to the origin of the gasses so that they are kept out of these spaces, and they don't accumulate inside (Sabogal 2021).

13.4.2 Water

The city of Lima is inhabited by close to 10 million people. It is located along the basins of the Rimac and Chillon rivers, and within the area of influence of the Lurin river. These three courses of water have variable streamflows, and receive water from the mountains, especially in the summer months. These sources of water are not enough for such a large population, and so some districts extract water from the underground.

The city compacts the ground, covers it in cement and acidifies it. By adding acid, oil, microplastics and other pollutants, they modify the living conditions of plants. Compacting the ground also affects the flow of water, modifying and damaging the phreatic layer. Additionally, the extraction of underground water makes this layer progressively deeper, and due to its proximity to the ocean it becomes salinized. Areas close to the ocean such as the Villa swamps, which formed over wetlands, have dried up and modified the water table over time. The same has happened to the cliffs of the Costa Verde, located next to the beaches of the district of Chorrillos. The district's name refers to the small streams of water that used to come out of the cliffs and into the sea, but that are now gone.

It is expected that the onset of Climate Change will not only raise temperatures, but also increase the frequency of heatwaves (IPCC 2022: 11). The architectural discipline will need to consider these new changing conditions, as well as the increase in precipitation frequency, when building. The state of cities is especially critical in coastal zones. It's important to keep in mind that the capital city of Lima is located on the coast, and so resilient systems need to be designed to prepare for changes in the climate. Sustainable construction must be emphasized, and adapted to new conditions such as the increase of rains. Drainage systems will have to be implemented, and flat roofs modified to avoid the accumulation of water, among other adaptations. Construction itself will have to adapt to the increase in rain frequency and the rise of temperature. New cement mixes adapted to these conditions will need to be used in order to avoid the crumbling of structures. In beach areas that function as expansion zones for the city, such as Punta Hermosa and San Bartolo, cement mixes will have to be adapted to high salinity, and drainages will have to be implemented along new types of concretes adapted to the new conditions.

13.4.3 Ground

The city's ground has been compacted by buildings, highways and other constructions. Additionally, concrete and construction waste acidify the soil, gas stations pollute it with oil residues and restaurants pour great quantities of cooking oils on the ground. It also receives a large amount of heavy metals from motorized vehicles and industrial facilities.

One of the problems of green areas in Peru is the indiscriminate use of pesticides and fungicides. This type of pollution affects the quality of life of park visitors, who are in great part children and the elderly. Although pesticides and fungicides are regulated by the National Pesticide Commission (CONAP) and the Ministry of Agriculture and Irrigation, there is little control of their application volume, methods and frequency. The pesticides that damage the environment the most are those that are chlorinated (that contain chlorine), since they have a slow time of decay. Most of them, like DDT and Aldrin, are banned. Phosphatic insecticides (those that contain phosphates) can produce alterations in the nervous system of animals, which negatively affects sea life.

Plants that manage to survive this pollution are pioneers, mostly introduced from other environments and adapted to the city. They are resilient, with fast reproduction times, and often reproduce through runners. In some cases they are native plants like the salt grass (*Distichlis spicata*), or native trees like the mountain molle (*Schinus molle*), but for the most part they are foreign species. For example, there is the Tamarix (*Tamarix* sp.), a species of quick reproduction and easy to spread, which has been used in reforestation efforts and is currently present in the Paracas national reservation. It also grows along the edges of some rivers in the city of Piura, where they have spread through the water flow. Another common example is the mountain eucalyptus (*Eucalyptus globulus*), which has managed to spread all along the lower mountains of the Peruvian sierra. Their leaves are used as a local medicine to treat coughs. There is also the retama (*Retama sphaerocarpa*), which has been so assimilated by the local culture that a traditional folk song (huayno) has been written about it. All these species grow quickly and reproduce easily.

13.4.4 Recycling

Peru has a serious problem with the disposal of solid residues. 45.47% of solid residues are poured on degraded areas without adequate disposal methods. The rest, which are adequately disposed of, are only done so in the city of Lima (SINIA 2023). Waste is separated as follows: 57% are organic residues, 21% are inorganic, 12% are non-recyclable and 10% are dangerous waste (SINIA 2023). Only 18% of municipalities carry out an adequate segregation of waste. 18% of the total residues goes to dumpsites and 18% to landfills, while 10% of municipalities burn their waste. The rest of these residues are improperly stored SINIA 2023). Finally, only 29% of municipalities count with a recycling program (SINIA 2023).

Many municipal plant nurseries use compost generated from municipal solid residues. This compost is usable in green areas, but they sometimes contain microplastics and other damaging wastes that can be dangerous for the users and the environment (Fig. 13.3).

13.5 Cultural Integration

Green areas and public spaces in the city allow for cultural integration to take place. They are spaces where multiple actors from different cultures and socioeconomic levels interact. They also function as recreational spaces, where leisure and cultural activities take place, and where citizens can express themselves in their day to day. They end up serving as spaces of confluence for different cultural backgrounds and customs that help with integration in a society that is highly stratified both socially and economically.

Fig. 13.3 Use of recycled material, green area in costanera, Lima. (*Author* Ana Sabogal)

Lima was founded in 1535, and there are large houses from those times that hold great historical value that must be preserved. Lima's historic centre is one of 140 places in Latin America that have been declared as part of the heritage of humanity by UNESCO, and one of 50 historic centres recognized by the same institution for its cultural characteristics (BID 2018: 28). However, there are also many uninhabitable or overcrowded houses that occupy its dense urban fabric. In this way, the historic centre forms part of the city's cultural identity. Rethinking the transformation of the historic centre while rescuing its local history and creating a new future for it, remains a priority (Fig. 13.4).

In Latin America, one-fifth of city homes are in buildings that can't be repaired, that lack titles of property, that lack water or sewage, or that lack enough adequate space (BID 2018:12). A large number of these homes are located in downtown Lima, where the historic centre is. Additionally, the percentage of green areas within the zone is far below what's necessary. While the Rimac district, which forms part of downtown Lima has 1.13 m^2/hab., Lima Centro has 3.29 m^2/hab. The task of rethinking and restoring this space while keeping sustainable development in mind, remains a task for the future (SINIA 2023) (Fig. 13.5).

Currently, Lima houses over 80% of the country's population. A large part of that percentage represents recent migrants, who come from diverse places of origin and have different cultural backgrounds. In their integration into the city, the population loses a sense of identity related to a specific place, and finds integration in "non-spaces" or neutral places, where they can blend and be freed of an identity (Auge, cit. García 2016: 158). Neutral spaces such as shopping centres, which provide

Fig. 13.4 Recover of the old spaces in Callao. (*Author* Ana Sabogal)

Fig. 13.5 Deteriorate old building in Callao. (*Author* Ana Sabogal)

several recreational activities, allow this population a different type of integration, one in which anonymity allows them to disregard the need for explanations about their origin or the concept diversity, and where inconspicuousness is appreciated (Auge, cit. García 2016: 158). Currently, more and more of these shopping centres can be found both in Lima and in other cities in the country, and they tend to be well received by the citizens.

13.6 Cities and Climate Change

In the face of climate change, cities will need to adapt and change in order to lower the risks to their habitability. There is much that needs to change, which is evidenced in the way that the entire coast of Peru is being affected by the current La Niña event. According to the IPCC's predictions, this phenomenon will increase in frequency over time. The infrastructure of coastal cities is not prepared for rains, and the lack of gutters in houses, the absence of drainage and the general use of flat roofs impede the drainage of water, which leads to great accumulations. These in turn cause damage to infrastructures, but also can cause the spread of recurring diseases such as dengue and infections that may cause diarrhoea. The cities must be adapted to ensure the flow of water through proper drainage, by building gutters and permeable pavements that allow for the adequate flow of water. They must be made into cities that are at least habitable.

In Peru there are no cities connected by transportation nodes, nor have these connections been planned. In the coast, where cities are in danger due to the rising sea levels, this interconnection could heighten the cities' resilience in the face of climate change (IPCC 2022: 34).

Sustainable cities must have green areas, with vegetation and trees that serve to lower the ambient temperature (IPCC 2022: 25). Currently, most of the population lives in cities, which is why urban green areas are of great importance. They also help with the mitigation of greenhouse gasses generated by motorized vehicles. The amount of green areas in a city should depend on the amount of emissions generated in it. By this logic, cities that can be considered sustainable are those that absorb their emissions through green areas and urban forests. However, regulations about green areas in cities remain underdeveloped.

The expansion of green areas should allow for the management of interconnected parks in the long term, so that trees can grow and develop. It's necessary to assign safe zones for the development of green areas, so that these spaces can grow and endure through history, as has happened before with the Exposition Park, located in downtown Lima, or the Paseo de las Aguas, which is in need of being recovered. Parks should not be located in unsafe or residual areas, as it often happens.

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Chapter 14
Climate Change

14.1 Introduction: Current State of Climate Change in Peru

Climate change is a reality that leads to a loss of biodiversity. It's necessary to find ways to limit global warming. Since the pre-industrial era, earth's temperature has risen 1.2 °C (Almond et al. 2022: 11). Taking different possible scenarios and calculations into account, it's been predicted that there's over a 50% chance for temperature to increase by at least 1.5 °C (IPCC 2022: 7). At several international conventions, discussions have been held regarding ways to control global temperature, and at the COP 20 held in Lima, the possibility of reducing emissions to lower the temperature by 2 °C was discussed (MINAM 2016).

Extreme weather events are expected to start taking place, such as changes in the frequency of precipitations, with extreme rains and droughts that will cause the death of forests, as well as forest fires (IPCC 2022: 8). If the increase in temperature of 1.5 °C is not somehow lowered, climate change is expected to become the main reason for the loss of biodiversity in the nineteenth century (Almond et al. 2022: 4). Ecosystems with a lower resilience, such as coastal ecosystems, mountain ecosystems, and glaciers, will be the most affected by this increase of temperature (IPCC 2022: 20). The loss of biodiversity will affect the planet in many diverse ways. This loss is calculated through the Living Planet Index (LPI), which observes changes in the relative abundance of wild animal populations. The global Living Planet Index for 2022 shows a median loss of 69% of wild animal populations between 1970 and 2018 (Almond et al. 2022: 32). Changes in temperature especially affect freshwater animals. Currently, there is a global decline of 83% in freshwater animal populations (Almond et al. 2022: 4). The decrease of median population abundance in Latin America is 94% (Almond et al. 2022: 4). Additionally, the Amazon forest has reduced its size by 17%, and another 17% of it has become degraded (Almond et al. 2022:10).

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The value of the ecological footprint of anthropic effects is estimated to be an overexploitation of 75%, which is equivalent to that of living on 1.75 planet earths (Almond et al. 2022: 66). The point of no return is considered to be reaching a deforestation and forest degradation level of between 20% and 25%. The Amazon's current degradation levels have reached 26%, which means that it is already undergoing a process of forest degradation (Almond et al. 2022: 98). This being the scenario, the regions being prioritized for the conservation of species at a global scale are the Amazon basin and the northern Andes, up to Panama and Costa Rica, in Central and South America.

In summary, the IPCC (2021) report foresees the following scenarios for Peru:

- Jungle: The effects of deforestation influence the increase of surface run-offs, which take the superficial arable soils with it, affecting its fertility.
- Mountains: The effects of the loss of vegetable cover influence the increase of albedo.
- Coast: Evapotranspiration will increase planetwide due to the increase in global temperature.

If these tendencies continue, the Amazon will reach the point of no return (MAAP 2023). This is an especially dire situation, since these forests serve to regulate the temperature and store carbon. From 2001 to 2019, forests have absorbed 18% of carbon emissions generated by anthropic activities. Additionally, forests cool down the planet, generating a decrease in temperature of close to 0.5 °C (Almond et al. 2022: 22). In the last few decades, droughts have been more frequent and severe in the Amazon (Espinoza et al. 2009b; 2011; Espinoza 2009a; Marengo et al. 2011, cit. MINAM 2016), which has produced forest fires (Fernandes et al. 2011, cit. MINAM 2016). It's estimated that droughts in the Amazon have increased the amount of tree deaths by 400% compared to normal years (Brando et al. 2014 cit. MINAM 2016: 150). The death rate of species in the Amazon has been stable for the past three decades (Brienen et al. 2015 cit. MIANM 2016).

In the next 80 years, the sea level is expected to rise 40 cm (MINAM 2016). Extreme droughts are thought to be mostly associated with the warm surface temperature of the tropical Atlantic ocean, and to the El Niño event, while the heavy floods are associated primarily to the La Niña event (Marengo and Espinoza 2015 cit. MINAM 2016: 150). The expansion of agricultural borders and illegal mining operations are also partial causes for the desertification process (MINAM 2016: 46). The degradation of lands in Peru is alarming. From 1981 to 2003, 19,271,100 hectares of land were degraded. This represents 15.3% of the Peruvian territory. If this process continues at the same speed, 64% of Peruvian lands will be degraded by 2100 (MINAM 2014a cit. MINAM 2016: 46). To date, Peru has 30 million hectares undergoing a desertification process, and 3.8 million have already been desertified (Eguren and Marapi 2015 cit MINAM 2016) (Fig. 14.1).

Additionally, the fragmentation process of the forest also influences the loss of ecosystems. Currently, only 10% of protected terrestrial areas are interconnected (Almond et al. 2022: 25). Fragmentation occurs on land, water and air ecosystems, and breaks ecological processes, leading to their deterioration (Almond et al. 2022:

Fig. 14.1 Illegal mining in Madre de Dios River, Amazonas basin, Peru. (*Author* Ana Sabogal)

24). Fragmentation also impedes the movement of species, confining them and causing them to lose the metapopulations that allow for genetic diversity.

Since 1970, the biodiversity of freshwater ecosystems has decreased 83% (Almond et al. 2022:36). The diversity of fishes has also decreased, and migratory fishes are especially affected by these changes. Due to habitat modifications and the limitation of migratory routes, the freshwater migratory fish LPI (Living Planet Index) has decreased 76% on average from 1970 to 2016 (Almond et al. 2022: 37). It should be noted that only 37% of rivers with a length of over 1000 km maintain free courses through their entire length (Almond et al. 2022: 37). Wetlands are also important carbon storages, and as they evaporate they release that carbon into the air in the form of methane, contributing to the greenhouse effect. This process takes place in mangroves, paramos and other lacustrian spaces of Peru's coasts, mountains and jungles.

According to the latest Inventory of Glaciers prepared for the Peruvian state by the National Water Authority, 42.64% of the glacial surface has been lost compared to recorded data from 1970. It should be taken into account that 71% of tropical glaciers are located in Peru (Francou y Vincent 2007 cit. CAN-PRAA-IRD, s.f. cit. MINAM 2016: 161). The melting of glaciers has increased the number of glacial-originating lakes (MINAM 2014a cit. MINAM 2016: 46). There is also an interconnection among the different factors that cause climate change (Almond et al. 2022: 28). Additionally, the frequency of the La Niña events has been increasing over the last 50 years (Takahashi et al. 2011 cit. MINAM 2016).

14.2 Projection of Effects Caused by Climate Change

On a global scale, the effects of Climate Change could be summarized as the modification of hydrological systems, both in amount and dissemination, as well as changes in water distribution globally. Overall, there will be a higher amount of water in the short term, and less freshwater in the short term. Significant changes in wind circulation are also expected, which will have consequences on the hydrological systems.

Changes in terrestrial ecosystems are expected to take place in South America, both in terms of their structures and the species that inhabit them. These changes will affect tropical forests, deserts and mountain regions, and aquatic ecosystems will also be affected (IPCC 2022: 9). On a regional scale, projections for the end of the twenty-first century show an increase in temperature in the Amazonian region. A possible increase of between 2 °C and 5.2 °C is expected, depending on the scenario (Blázquez and Nuñez 2013; Jones and Carvalho 2013 cit. MINAM 2016: 150).

At the national level, increases in average precipitation and temperature are expected. Between 2036 and 2065, an average increase of between 10% and 20% precipitation is estimated, as well as an average 2–3 °C for the maximum temperature and 3–4 °C for the minimum. The largest increase is expected to take place in the highlands (MINAM 2016: 143). The effects of rains caused by the El Niño and La Niña events are also expected to duplicate in frequency (MINAM 2016: 143; MINAM: 144). An increase of temperature on the coast during the El Niño months is foreseen, as well as more frequent rainy years in the Andes and in the Amazon (MINAM 2016:145).

The main rivers of the Amazonian region are also expected to increase their flow during their high water periods, and severely reduce them during their low water periods (Guimberteau et al. 2013 cit. MINAM 2016: 150). The dry season is also expected to last longer (Fu et al. 2013, cit. MINAM, 2016: 150). The dryer and warmer conditions could also transform the Amazon forest into a savannah (Oyama and Nobre 2003; Salazar et al. 2007; Malhi et al. 2008 all cit. MINAM 2016). Studies on weather and vegetation foresee that this savannization of the tropical forest ecosystem could happen by the second half of the twenty-first century (MINAM 2016: 150). Also by the end of the twenty-first century, hydrological stress and the increase of evapotranspiration could turn the tropical forest into a seasonal forest (Malhi, et al. 2009; Costa et al. 2010 all cit. MINAM 2016: 150).

14.3 Consequences of Climate Change for Peru

There are many consequences that come from Climate Change. In general terms, the increase of water surface evaporation will lead to a change in hydrological systems, influencing and increasing carbon decomposition. Also, the increase in temperature will cause the proliferation of plagues and diseases, as it will accelerate the reproductive cycle of insects.

Together with a series of negative consequences, there will also be a window of opportunity for improvement. The following section (14.3.1) will deal with the negative consequences of climate change. Later, heading 14.3.2 will cover the opportunities.

14.3.1 Negative Consequences of Climate Change for Peru

As mentioned in the introduction, the effects of Climate Change will affect all of Peru, including its coastal, mountain and jungle zones, triggering a cascade of effects. The temperature in cities will rise, and heat waves will become more common (IPCC 2022: 11). The IPCC report (2021) summarizes how, as a consequence of deforestation, there will be a strong surface runoff in the Amazon, which will cause a loss of land fertility. In the mountains, the loss of vegetable cover will influence the rise of albedo. Finally, there will be an increase of evapotranspiration in the coastal zones as a consequence of the rise of temperature.

Peru has a long coastal border that runs along the length of the entire country, and the capital city of Lima is located in it. For this reason, Peru is one of the countries that's most vulnerable to climate change. A change in the sea level is expected to take place on the coast, which will strongly affect the capital city, as well as other coastal cities. The effect will be especially pronounced in the north, where the El Niño events are expected to become more frequent. There will also be shifts in the coastline and the sea's elevation (IPCC 2022: 19), as well as an acidification of the oceans (IPCC 2022: 8). The acidification will cause the redistribution of maritime species (IPCC 2022: 19). The chain of effects will be as follows: Global warming will cause the evaporation of ocean water. This evaporation, together with pollution, will cause the acidification of the oceans, an increase in rains, and changes to the El Niño event, which is also known as El Niño Southern Oscillation (ENSO) due to its worldwide incidence,

Droughts and desertification are expected, among other risks (MINAM 2016: 49). Salinization of underground water (IPCC 2022: 19) is yet another expected outcome. In coastal Peru, the rise of agriculture for the purpose of exportation has resulted in the overexploitation of the aquifers (Sect. 15.3.1), which will lead to the salinification of underground waters.

Agriculture is a crucial activity in the mountains of Peru. 1.4 million people subsist on it, which adds up to 63.9% of all agricultural producers in the country (farming census 2014 cit. MINAM 2014a cit. MINAM 2016). Both the grasslands and Andean forests will suffer the consequences of the rise in temperature. An increase in the frequency of forest fires is expected in these Andean zones (MINAM 2016). The increase in temperature will also affect the elevation at which crops are planted, as well as evapotranspiration. Farmers will need to modify their customs and adapt their types of crop to the new conditions, which also implies an adaptation of the market and the population's eating habits in order to ensure their food security.

Additionally, the effect of the rising temperature will affect the distribution and reproductive cycle of insects, increasing the populations of some key species, such as the white fly and scale insects. Scale insects can alter their reproductive system to adapt to higher temperatures by producing generations of parthenocarpic females. In this way they can greatly accelerate their reproductive speed.

As a consequence of the rising of the crops farming line, there will also be a shrinking of the grasslands. This will affect the carbon balance and the soil structure. Agriculture extracts a large amount of nutrients from the soil, and doesn't supply it with organic matter like grasslands do, so there will be a deterioration of the soil's fertility. There will also be pressure applied on the few Andean forests that remain, leading to deforestation. Finally, it should be kept in mind that overgrazing applies a strong pressure on the soil, modifying it and compacting its structure, while agriculture moves the compacted soil. This creates erosion and a loss of soil in the steeper upper lands.

It should also be considered that farming communities in the mountains distribute their common agricultural lands among their co-owners, while the grazing lands are used communally. This distribution will have to be modified, as otherwise the new agricultural lands will sustain great pressure from being overused by the community, which will affect the physical and chemical quality of the soil. A change in the value of the land should also be expected. As it becomes farming terrain, the communal lands will become private, leading some farming companies to get restructured and to grow in size. This has happened before, for example, when the "year of the quinoa" was declared by the state, leading to a push on its use and an increase on its price. On the one hand, business owners started looking for lands in which to invest, and on the other, the product and demand portfolio of small businesses was modified, causing quinoa to go from a cheap crop used by farmers for their own consumption, to a marketable product, hurting the food security of the population in the process.

The deglaciation that has occurred so far has already modified the course of water sources. Among the risks this produces, there is an increase in the frequency of landslides (MINAM 2016: 49). The loss of wetlands in the Andean highlands, including paramos, will also increase the amount of greenhouse gasses released. This is due to the high amount of accumulated carbon they contain, which will be released as methane when their humidity evaporates and the biome is transformed (Sect. 10.9.1). It's important to remark the importance of the paramo ecosystems due to the high amount of endemic species that inhabit them (Sects. 10.3 and 10.9.2.1).

The future of the Amazon jungle is also less than ideal. The deforestation caused by the transformation of forest into grasslands and agricultural lands are the main cause of greenhouse gas emissions (MINAM 2016: 22). With the effects of the cattle industry, forest fires and droughts, the pressure on the forests will only become larger. Besides climate change, the destruction of the Amazon through overexploitation and logging make the situation worse (Almond et al. 2022: 41). There will also be a loss of amphibians due to agricultural activities (Almond et al. 2022: 41), and a reduction of pollinizer species (IPCC 2022: 15). Together with the higher temperatures, the loss of amphibians will increase the amount of plague insects, which will in turn affect agriculture and the natural vegetation. Additionally, the desertification of the Amazon due to the activities of illegal mining organizations remains a large-scale problem.

Among the socio-economic problems foreseen by the IPCC that are relevant to Peru, we could remark on the extinction of endemic species in focal points of biodiversity, such as the Amazon (IPCC 2022: 14). Food security in the Amazon will be seriously harmed by the rise of temperatures. The production of corn, one of the most extensively planted crops in Peru, and especially in its jungles, will decrease (IPCC 2022: 19).

Peru will also be affected by its current lack of governance, in that the effects of climate change will be worsened and there will be an increase in social conflict (IPCC 2022: 12). There will be a migration of the population affected by climate change (IPCC 2022: 26) that will negatively affect the most impoverished. Considering the existing social inequality in the country, and the large number of impoverished inhabitants, social conflicts will likely be unleashed by these changes.

14.3.2 Positive Consequences of Climate Change

With foresight and good management, some of the good consequences of climatic change can be leveraged to reduce its negative effects. One of these consequences is the increase of water availability caused by deglaciation which, with good planning, could at least have positive effects on agriculture for a relatively long period of time. To this end, water storage systems that allow for the recharging of aquifers will have to be considered, as well as a more adequate distribution of water that prioritizes human consumption and water conservation. The conservation of Andean-Amazonic ecosystems, which help recharge the aquifers, will also be a high priority.

The increase in agricultural spaces that will come with the rising of the farming altitudinal line will bring an opportunity for agricultural development. The use of more environmentally friendly systems will be required for this purpose, ones that limit the environment's deterioration, conserve water, reinforce food security and support the development of the market. A good planning that adapts to each space will be needed to leverage opportunities and reverse the foreseen disaster of climate change.

14.4 Options for Reducing the Effects of Climate Change

Many of the tools for facing climate change are related to the use of traditional agricultural techniques. Among them is the implementation of infiltration ditches for the harvesting of *water*. This technique consists of digging ditches or pits that allow for the recollection of water in upper zones of the land, to be transported through infiltration to the lower areas, where it upwells. This method, also known in other places of the world, is known in the Andes as water planting and harvesting. To achieve the desired result, it's important to be familiar with the route of the underground water flow. Otherwise the water may emerge in unexpected locations, as it follows the path made by cracks in the rocks. Rural communities tend to know these underground routes well, as they are part of the territory they inhabit.

Peat marshes are among the ecosystems that can store large amounts of carbon. Their management and restoration could serve to mitigate the effects of climate change, since they can act as carbon reservoirs (IPCC 2022: 24). The restoration and upkeep of peat marshes and other types of wetlands such as paramos, saltwater wetlands, freshwater wetlands, swamps and highland lakes, are essential to maintaining the flow of water and the storage of carbon. These spaces help preserve the hydric courses by acting as freshwater reserves. The liberation of carbon in the form of methane that occurs as they decay is a large source of greenhouse gas pollution.

Riversides are yet another ecosystem that must be protected in the face of climate change. Among the possible techniques to do this, there's the use of reforestation to decrease the speed of the river's course (IPCC 2022: 25). This would diminish the risk in case of an increase in the water flow, which could cause overflows and landslides. In coastal zones, the restoration and creation of coastal wetlands will help prevent floods and the salinization of freshwater sources (IPCC 2022: 25). The application of this technique requires a good understanding of it, as well as the prevention of the ecosystem. The creation of an excessively educated defence can be counterproductive, as it could impede the ecosystems from functioning adequately and reduce their resilience to climate change and draining. For this reason, it remains important to gather traditional knowledge from the population, who are familiar with the right practices when working in the ecosystem (IPCC 2022: 28).

Well-directed and executed irrigation techniques are also an alternative that may help mitigate the effects of climate change. However, poorly planned irrigation may contribute to the generation of droughts and the salinification of the phreatic layer, especially when using large-scale irrigation, which can affect precipitation patterns (IPCC 2022: 23). For this reason, if irrigation is done without considering ecological factors, such as the correct ecological flow and the recharge of the aquifers, it may end up being harmful instead. Finally, and considering the finite nature of water as a resource, it's important to ensure the recharge of freshwater sources in order to satisfy the population's needs, while preventing its salinization or overflow (IPCC 2022: 26). This is achieved through the correct management of freshwater, taking water flow and water volume into consideration, employing the correct techniques and ensuring its conservation.

With the raising of the agricultural border's altitude, it's likely that high altitude zones and rugged slopes will become cultivation areas. In order to plant in these spaces and avoid the erosion produced by the movement of soils, it will become necessary to employ techniques that make the land less steep. One such technique, used to plant in steep terrains, is the use of agricultural platforms. This is already widely done in the Andes mountains. As detailed in heading 15.3.2, the technique may lessen the soil's erosion when correctly employed.

In zones of the Amazon where the soil has high levels of aluminium due to being constantly washed by rains, and in the paramos, where the soil is very humid (see Sect. 10.5 and Chap. 15), zeolite may be used to improve it. It is composed of highly porous aluminium silicates, with hygroscopic properties. Besides being a habitat for microorganisms, it allows the absorption and storage of water, nutrient absorption and the development of microorganisms. Zeolite is present in volcanic soils as a natural compound, and doesn't alter the environment. It is used on *polluted soils*, such as those contaminated by mining activities in the Amazon.

Many options have been proposed to mitigate the effects of industrial agriculture in the modification and loss of ecosystems. All of them are based on agro-ecological principles such as agroforestation, crop diversification and urban agriculture (IPCC 2022: 24). Besides considering a reduction in the use of agrochemical products, *food security* must be considered and included as part of the proposals in order to ensure the population's access to a balanced nutrition (IPCC 2022: 24). This includes the preservation of agrobiodiversity, the preservation of ecotypes, and that of wild relatives. This is particularly important in Peru, where there is a large amount of wild relatives of common crops like the quinoa, the potato or the mashua (*Tropaeolum tuberosum*), as well as of medicinal plants and wild edible herbs like the *amaranthus*, which haven't been introduced as plants for cultivation. With climate change, eating patterns will have to adapt, as well as the food and agricultural systems. There will be a need to consider food diversification. There will also be changes in the organization of the farming calendar and in the distribution of labour that will require the reconsideration of agricultural systems.

All these sustainable agriculture proposals also take into consideration the adequate use of water, which is essential to prevent its loss, as well as the modification of evapotranspiration, and therefore, a change in microclimates. Much has been said regarding these topics, especially in relation to the northern coast of Peru, where despite the aridity of the land, crops that demand a high amount of water are traditionally cultivated, such as rice, asparagus and, more and more often, avocado. Additionally, since many of these products are cultivated for exportation, the emission of greenhouse gasses produced by transportation must be considered in addition to these crops' high water consumption. Therefore, it's necessary to consider multiple aspects of the agricultural practice besides the cultivation, such as commercialization systems and sustainable food supply chains.

The preservation and correct management of agriculture in the face of climate change remains a priority (IPCC 2022: 24). In the Amazon, agriculture is the source of a large part of the population's protein intake. Ensuring its preservation through the use of healthy water sources, as well as the survival of edible fish species, will be a priority for the food security of the region's inhabitants.

80.1% of Peru's surface is made of lands capable of forestry production, or protected lands. However, forests only contribute to approximately 1% of the national GDP (MINAM 2013a cit. MINAM 2016: 19). In part this is due to the fact that, although there are 17.78 million hectares of permanent production forests, the actual forestry surface established through timber concessions is only 7.4 million hectares (MINAM 2016: 19). Considering the current deforestation of the Amazon, the 2021 Amazon Evaluation Report suggests four key measures: an immediate moratorium of the deforestation and degradation of zones approaching the point of no return; zero deforestation and degradation for 2030; the restoration of terrestrial and aquatic ecosystems; and an inclusive and fair bioeconomy for healthy forests and rivers (Almond et al. 2022: 96). Reforestation and the sustainable management of forests must consider the modifications of species due to climate change and the use of species that are resilient to the climate, to plagues and to forest fires (IPCC 2022: 24). The reframing of the timber industry, the sustainable use of the forest and the restoration of damaged forests are all necessary.

Sustainable cities are those that have green areas that use trees and vegetation to lower their temperature (IPCC 2022: 25). Currently, most of the population lives in cities. This is why ensuring an adequate amount of green areas in cities is one of the best tools to mitigate greenhouse emissions created by motorized vehicles. The amount of green areas a city needs will depend on its amount of emissions. Those cities that can absorb their emissions through urban forests can be considered to be sustainable. However, the state of cities and their regulations regarding green areas are still very underdeveloped.

The country's energy matrix is another priority when thinking of enduring climate change. A correct management and a restructuring towards renewable energy sources could lower the amount of greenhouse emissions. 23.1% of all used energy in Perú from 2014 to 2018 was renewable, while 76.9% was non-renewable (MINAM 2016). The development of solar energy sources and small-scale hydroelectric plants can reduce the vulnerability of rural populations during climate change (IPCC 2022: 26). It should be kept in mind that rural zones make up a large amount of the Peruvian territory.

In conclusion, a holistic focus that involves all sectors is necessary for this task. It will have to include constant monitoring and adjustments to the process in the face of unexpected changes. To that end, the ancestral knowledge of the native inhabitants of the country will fulfil a primordial function.

14.4.1 Bioculturality

Keeping the previous points and proposed alternatives in mind, the term "bioculturality" has been created to refer to the combination of biological and cultural knowledge. Agriculture is a part of local culture, having been developed 10,000–12,000 years ago in several parts of the world simultaneously. It's proposed that there is a connection between cultural, linguistic, biological and agricultural diversity, which is why countries located in the intertropical zone have a higher number of languages and also a wider biodiversity. Domination creates a homogenization of the language, reducing diversity.

The domestication of plants has been a long cultural process that includes the selection of plants and their genetic improvement, first in an empirical way, and later in a more organized and scientific manner. For this reason, many cultivated species are polyploids. Bananas, for example, would not be edible due to their large seeds, which would occupy most of the fruit leaving little space for the pulp, if those plants with triploid fruits hadn't been selected. Those specimens had three genetic bands that impeded the formation of seeds. This is the type of banana that is currently cultivated and multiplied through cloning. Strawberries would also be much smaller if the hexaploid specimens, which are the ones we cultivate now, hadn't been selected (Fig. 14.2).

Anthropic species are those that have been created as a consequence of human activity. Through genetic selection, resistant species with good invasive potential are created. This reduces the genetic diversity of species. Cultivated plants have coevolved with agricultural plants. Therefore, they are anthropic species, adapted to the agricultural fields by an evolutionary process. At the same time, the micro and macroorganisms that live on them, such as tiny algae and soil microorganisms that allow them to subsist, have also evolved.

Fig. 14.2 Agroforestery with banana tree in the tropical forest. (*Author* Ana Sabogal)

The idea of centres of origin of plants has been being developed since the start of the twentieth century, first by Vavilov in 1926, then by Harlan in 1992, and finally by Smith, in 1998. The centres of origin of cultivated plants, where the domestication process of plants started and where wild relatives can still be found, are located in the subtropical zone. The tropical part of the American continent is the centre of origin of multiple cultivated plants such as: squashes (*Cucurbita* spp.), chilis and peppers (*Capsicum* sp.), peanuts (*Archis hypogaea*), pineapples (*Ananas comosus*), sweet potatoes (*Ipomoea batata*), cassavas (*Manihot esculenta*) and avocados (*Persea americana*), among others.

Peru is the centre of origin of many crops. Among them are the 4000 different varieties of potatoes of many types and ecotypes, mostly developed in the mountains due to the altitude and geographic isolation of the ecosystems. An ecotype is a genetic subpopulation that is either phenotypically differentiated, restricted to a separate habitat through species selection, or is a variety created in-place and originating from the location. The Amazon has fundamentally produced timber and ornamental species, such as the anthurium, and multiple species of orchids, such as the canella.

Monocultures present a risk of lowering biodiversity. In Ireland, during 1845, potato crops, which were being widely cultivated through Europe, were lost to the plague. This led to a terrible famine. Wild potatoes were then used to develop genetic improvements (see Chap. 2).

14.4.2 Landscape

Landscape is a cultural construction, which only exists as a result of human interpretation. The coexistence of people in the landscape is a result of human culture, and of a sustainable use of the space. Humans have transformed the landscape throughout history, and in doing so, have woven in it a common history. Agricultural landscapes integrate the use of the space with agricultural production. The cycles of crops mark the rhythm of the population's lives, and the transformation of their products allows them to face the uncertainty of the future. Inhabitants of the mountains have modified the landscape through agriculture by creating farming platforms and terraces (ver 15.3.2). Agriculture has also produced hydrological landscapes, both in the coast, as with the irrigation channels of the Chimú culture and their cultivation lands at the shores of lakes, and in the mountains, as with the irrigated farming platforms built by the Incan culture. Hydrological landscapes and the management of water are directly dependent on power (Budds 2011). One example of these hydraulic landscapes is that of the Tipón terraces. Tipón is located 23 km south of Cusco, and is part of the Incan trail known as Capac Ñan. Besides being used to irrigate the agricultural terraces, the water there formed ceremonial pools that were used for the Inca's ritual baths. It's a masterwork of channels and platforms that carry and distribute water coming from the mountains. Each terrace has a channel that carries the water, moving it from the upper platforms to the lower ones. Finally, in the jungle areas, water is an integral part of the traditional culture as it relates to the fluctuation of rivers. For example, the Naro Mashigenga know these fluctuations and take advantage of the rivers' high-water seasons to fish on the brooks that form as a consequence.

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Chapter 15
Traditional Land-Use Systems and Agrobiodiversity in Peru

15.1 Introduction

Plants and animals have the ability to adapt to different climates and modify their populations to subsist more easily. This is a continuous process of change that includes individuals, populations and communities.

Facilitation is a part of the ecosystem's evolutionary process, which causes changes in the composition of plant communities and in the dominance of species. However, species modify their ecological optimum level, and therefore some may adapt to challenging situations, while others don't (Gross et al. 2010). There are also ecological ranges and differences between the effective niche and the fundamental niche, which depends on competition and can change when the plant's composition or the competition relationships are modified (Smith and Smith 2001).

When human influence of the ecosystem and the consequent migration of species is added to the process, it results in those species modifying their compositions. Additionally, animals and plants react by modifying their morphology, both individually and as a group, as well as their physiology. This allows them to survive under the new conditions.

The history of the use of resources is closely linked to the evolution and adaptation of species, as it defines and shapes the anthropic ecosystems. When agrobiodiversity takes this history into account, it can link the use of resources with the conservation of the environment. Otherwise, it won't be able to contribute to the preservation of resources in the long term.

A. Sabogal, *Ecosystem and Species Adaptations in the Andean-Amazonian Region*, https://doi.org/10.1007/978-3-031-44385-5_15

15.2 Plant Adaptation

15.2.1 Morphology

Plants regulate their temperature through the shape and disposition of their structures, either searching for shade and protecting themselves or exposing themselves to sunlight, depending on their environment. The size and distribution of their leaves is a determining factor in this. The plant's shape and height, and the distribution of each of its organs will depend on the temperature of the environment (see Sect. 8.6). For example, rosette shapes allow plants to be protected from the cold, which is essential in ecosystems like the paramo, while in desert climates, plant shapes with separated nodes allow them a better aeration and help them survive.

But plants also regulate their leave's temperatures through evapotranspiration, as well as through their shape, texture and physiological adaptation. Leaves modify the angle at which they are exposed to the sun throughout the day to regulate their turgidity, with which they can regulate their temperature (Smith and Smith 2001). In zones of extreme temperatures, like deserts and the tropic, plants will hide as a means of defence. In the paramo, plants grow a large part of their structure underground (see Chap. 10); in the tropical forest, leaves are very large and assume an angle of 90° to capture the small amount of solar radiation that reaches the understory (see Chap. 11); and in the deserts, leaves grow forms to reduce their loss of water (see Chap. 12).

The blades of leaves are smooth in rainy tropical climates, and rough in cold, desert areas. Depending on the shape of the leaves' hairs, the rough texture can allow them to form a microclimate that retains humidity, modifying their temperature and the incidence of solar radiation. The colour of the leaves and trunk has a strong influence in this process. Opaque colours reduce the sun's incidence and the loss of water. This is why in the desert and in cold highland climates, plants develop wax, taking on an opaque colour. Together with the wax's protection, this colour reduces the loss of water and keeps the leave's turgency to ensure the necessary rate of photosynthesis. By modifying their turgency, leaves change their amount of solar exposure and the angle at which they are exposed, allowing them to alter their pubescence and the colour of their upper and lower faces. Finally, the plants' temperature will not only depend on the form and size of their leaves, but also their quantity. This is why, under extreme conditions, such as during cold seasons, plants can improve their situation by discarding leaves.

When leaves are subjected to cold weather, such as that of the puna, they may roll up to reduce their exposure (Smith and Smith 2001). By being rolled or turned, the leaf modifies the stomata's position, which also modifies their transpiration. In climates where the night is much colder and there are nightly frosts, rolling up can also help protect the leaves. The plant's temperature may also change considerably depending on their proximity to the ground (Smith and Smith 2001), which is why plants in colder climates are shorter.

The thickness of the leaves and trunks also affect the amount of water that the plants can store, and thus their ability to regulate their temperature. In dryer climates where water is scarce, such as in the seasonally dry forests, this can be crucial. For example, the ceibo (*Ceiba trichistandra*) or the cacti that crown the peaks of hills in these forests, store water and can survive extreme heat conditions (see Chap. 12). Both in the deserts and in the highlands, heat or cold can kill the external cells of the trunks and leaves. These dead cells form a protective layer that impedes desiccation and shields them from the sun or the cold.

A single species may present leaves of different sizes and shapes depending on their location. For long-term populations, the weather creates ecotypes through the selection of the most favourable genes (see Sect. 3.2.2). In warmer and more humid climates, such as in the tropical forest, the leaves below the undergrowth are thin, while cacti and hard-leaved orchids grow over the trees. And in high-altitude zones, the same species will present small, compact leaves when exposed to the wind, or larger leaves and more elongated bodies in sheltered areas. And, as it's well known, the smaller species of potatoes grow at higher altitudes.

The temperature of groups of plants is also regulated by the shape of the group. Plants' growth form tends to be similar to the one assumed by the group of plants in which it grows. In rosette plants, which are common in cold climates, the meristem is protected by the adult leaves, which surround it to ensure its survival. They are also more likely to survive when they grow as a group. Like rosettes, tufty grasses like the ichu (*Jarava ichu*) protect their meristem with all their leaves, and always grow in compact groups. They also accumulate organic matter at the base to harness heat. Cushion plants like the yareta (*Azorella compacta*), which grow in the highlands at altitudes over 4000 masl, are actually tiny trees with reduced trunks that grow close to the ground. The same happens with rosette plants from the paramos. Tiller plants like the highlands grass (*Calamagrostis* sp.) grow in compact groups. They sometimes grow from cracks on the surface of rocks, where organic matter accumulates. They make use of the stone's heat, as well as the accumulated organic matter and water.

Both the form and the internal anatomy of plants are a result of their adaptations. The succulent stem that's characteristic of the desert and highland plants, or the succulent leaves present in desert ecosystems, are an evolution of the secondary xylem for the production of lignin. The acaulescent rosettes that grow close to the ground protect the plant and the group from the cold and frost. Species such as those from the astracea family, which are common in the Andean highlands, and the campanulaceae, show pedomorphosis to preserve the xylem's youthful characteristics (neoteny), as well as perforations in the xylem vessels, which allow for a better circulation of sap to the leaves (Carlquist 2008 cit. Sabogal 2014). Some caulescent rosettes can also be found in the puna, like the Raimondi puya (*Puya raimondii*), which grows in the southern Andes of Peru. This plant has developed a wide pedestal that is formed by the thickening of the stem. The puya is an endemic species from southern Peru. Botanically it is classified as a monocarpic caulescent rosette, which blossoms a single time and then dies to give its nutrients to the new seeds.

With the low temperatures, there is also a reduction of photosynthesis. However, if the temperature remains stable, the photosynthesis rate is also maintained. The dehydration of plants is also lowered with the reduction of evapotranspiration. Changes in temperature raise the leaves' turgency, which makes them expel water. The water surrounds the plants and produces energy when freezing, creating a protective layer for the group. In this way, the plants' dehydration is reduced. The grey, opaque colour of the dead cells also protects them by reducing evaporation.

Organic matter is crucial, not just for sustaining the flora and fauna and for reducing erosion, but also for maintaining the soil's temperature. Plants in cold zones like the puna protect over a third of their structure underground to ensure their survival. Growing in groups also allows them to survive through the coldest seasons. The temperature's stability is reinforced by the water that the organic matter keeps around the plant. In the puna, plants are compact and close to the ground to preserve the group's heat and avoid the highland's cold, which could cause their desiccation. While plants grow smaller as the altitude gets higher, animals get larger in order to accumulate fat in the form of a thick layer, for insulation.

Small leaves are characteristic of plants from the desert and the puna. While in the puna plants are covered in hairs, in the desert they grow thorns. This can be seen in the differences between desert cacti and puna cacti. Both in the desert and in the puna, there is constant wind that dissipates humidity and dries the air. For this reason, the size of leaves is related to the density of their stomata. In both environments, there is a reduction of the amount and density of stomata to reduce evaporation. In the tropical forest, on the other hand, there is a higher amount and density of stomata. This is a way to regulate the plant's temperature, since by eliminating overheated water from the leaf, new, colder water can be absorbed. This is only possible in ecosystems where water is not scarce.

In highland ecosystems, where there is little carbon dioxide and the stomata's function is not as crucial, vascular plants' protection from desiccation and cold is related to their abundant production of lignin (Wilkinson 2009, cit. Sabogal 2014). For example, one of the arboreal species that reaches the tallest heights in the highlands is the polylepis (*Polylepis incana*), which covers its trunk with dead cells that protect it from the cold, like a coat. Another strategy is the reduction of the plant's size to shelter itself (Fig. 15.1).

In cold zones, the red, purple or blue colouration of flowers is another important adaptation that allows them to store what little heat they can get. For example, the fuchsia flower has a combination of red and purple petals. The colours of flowers and leaves play an important role in heat conservation. While in the deserts most flowers are white to reduce evaporation, in the puna they are red to retain heat. However, in the tropical forest colouration has a less crucial role, and is more dependent on the soil's strata. The size of leaves is more important, and is adapted to ensure photosynthesis, since access to water is not a limitation.

Fig. 15.1 *Polylepis weberbaueri*, Lampa. Peru. (*Author* Ana Sabogal)

15.2.2 Physiology

All living beings are, in great measure, composed of water, and in the case of plants it makes up 80% of their matter. The volume that water occupies depends on its physical state. Frozen water takes up more space than liquid water. For this reason, plants expel water from their tissues to their intercellular spaces before it freezes. However, if there's an excess of water being expelled from the cells, salts get concentrated, proteins are precipitated, the cells collapse and the plant dies from dehydration. For this reason, the accumulation and regulation of water is essential for plants adapted to the cold weather and to droughts. The temperature and amount of expelled water are directly correlated to evapotranspiration, which in turn is dependent on a series of physiological and morphological factors. As explained in the heading 15.2.2, the amount and distribution of stomata, as well as the size and angle of the leaves, are some of these morphological factors.

Plants expel water during the early morning to raise the temperature around the leaves and endure the frosts. The temperature at which this happens is called the dew point. In this way, plants from the highlands or deserts avoid the desiccation of their leaves due to the low humidity caused by the winds and low air density.

Additionally, the leaves of rosette plants can produce a small nastic movement when modifying their turgency, which increases the temperature around the apical bud.

The water content of young leaves is greater than that of older leaves, which is why they can't endure the cold unless they are covered in wax or hairs, or unless they raise the content of sugar, starch or pectin substances they produce. Resistant species produce a higher amount of these substances to hold back the freezing temperatures. Plants concentrate photosynthates in their buds to protect them. This lowers their freezing temperature by increasing their sugar content. The higher the sacarose content of the leaves, the more resistant the plant will be. Other chemical substances like fats or resins also help modify the freezing point in cold ecosystems. This is why so many medicinal and aromatic plants can be found in the highlands and deserts, where water is a limiting condition. Many plants from these ecosystems accumulate pectin at the base of their leaves to protect the buds and avoid evaporation.

As the altitude increases, the concentration of oxygen and of carbon dioxide diminishes. This affects the speed of photosynthesis, and therefore, the speed at which plants grow. The opposite occurs in the undergrowth of rainy tropical forest ecosystems, where there is little ventilation and the carbon dioxide emitted by animals gets concentrated. In these spaces, the oxygen released by plants is quickly used up by mammals, which limits the number of mammals that the ecosystem can support.

Potassium ion plays a fundamental role in the opening and closing of stomata, as well as in the expansion of cells during the xylem differentiation, which determines the plant's resistance to frosts. Additionally, potassium ion is essential to cell division and growth. It is responsible for the elongation of the vascular cambium cells. Calcium, on the other hand, determines the lignification of the cellular wall. These two elements, present in the soil, play an important role in the adaptation of plants to limiting conditions.

However, the type of photosynthesis these plants use is maybe their most important adaptation. There are three main types of photosynthesis used by plants: C_3 photosynthesis, which is the most common in highland ecosystems; C_4 photosynthesis, which is more common in grasslands, and CAM photosynthesis, which is more common in deserts. In the rainy tropical forest environments, C_4 and C_3 photosynthesis can be found. C_4 plants have a higher resistance to high temperatures, and can be found in areas of lower humidity, like the canopies of trees. C_4 plants also predominate in warm grasslands.

The number of vacuoles in plants is crucial in highland ecosystems, in deserts and in ecosystems polluted with metals. Vacuoles can accumulate salt, water or metals, allowing the plant to grow.

In Andean zones, the variation of diurnal and nocturnal temperatures can make the plants' survival difficult, as it requires a combination of resistance to frosts and an effective diurnal photosynthesis. Plants in these locations are adapted to endure and benefit from high levels of radiation. During the colder hours of the night, the plants reduce their respiration, which sometimes leads to an oxidative stress that can affect them.

The plant's roots regulate their intake of nutrients, and are essential to allow plants to adapt to the ecosystem. In extreme environments, the roots of plants show microbial symbiosis to ensure their absorption of nutrients. Without them, the plants wouldn't be able to survive. The organic matter raises the plant's temperature due to both its colour and its augmentation of the microorganisms' activity, creating a microclimate. The importance of the root and its proportion to the rest of the plant will depend on its need for protection. In desert and cold climates, where the soil has limiting factors, the root's proportion increases.

In plants that are resistant to the cold, the root's increase in leucoplasts ensures an accumulation of glucose and starch, which can be transformed into fats and oils to reduce the freezing temperature. While fats protect from the cold temperature, sugar protects the plants from frosts. The presence of Andean tubers adapted to the highland climates is explained by the plants' adaptive accumulation of starch in the root.

15.3 Agrobiodiversity and the Use of Resources

This heading goes over the agrobiodiversity of each of Peru's regions: the coast, the mountains and the tropical forest. It is complemented by another heading from Chap. 2 (Sect. 2.3.1), where the use of resources is discussed.

15.3.1 Coast

The Peruvian coast is a large desert that's crossed by rivers flowing from the mountains, which supply it with great amounts of water rich in nutrients during the summer. Throughout history, these valleys have been used for farming by many different coastal cultures, such as the Paracas people, who occupied the area south of current-day Lima. Besides developing irrigation canals to distribute water to the richer lands, the Paracas applied a form of agriculture that used sunken fields called *wachaques* in order to reach the humid soil, which lies several meters underground. To provide fertilization for the sandy terrain, a fish was buried with the seeds on its mouth. As the fish decomposed, the seeds would absorb its nutrients. This technique allowed the cultivation of many native crops, such as large lima beans, maize, beans and trees like the lucuma and pacay (*Inga feuillei*).

In 1589, during colonial times, the auction of community lands that exceeded the minimum needed for farming by their co-proprietors was decreed. In this way, landowners, or hacendados, purchased these lands from farmers. At the time, the right to irrigation was related to the amount of land owned, so those who owned more land had more claim over the water. At the same time, taxes were also paid according to the amount of land owned. Due to this, many communities lost their lands, since

Fig. 15.2 Church in the Zaña community. (*Author* Ana Sabogal)

they couldn't pay their taxes. This led to a concentration of lands (Gonzales 2016: 37).

One case where this happened was the Santiago de Miraflores de Zaña community, founded by order of the king in 1563. It was located in the province of Lambayeque, in northern Peru (Gonzales 2016: 37). Through the creation of the native reservations in 1569, the owners acquired native Peruvian labour, and later, African slaves to work the fields. An opulent sugar plantation was created, where a local elite developed, with a strong presence from the Jesuit church. The space was highly developed, and used so much by the church that seven temples were built. However, it was flooded during the El Niño events of 1720 and 1728, and the town was left in ruins (Fig. 15.2).

The history of Peru has been woven around its natural resources (see Sects. 2.2 and 2.3). The boom of guano, from 1840 to 1870, led to the War of the Pacific, which was fought from 1879 to 1884 over control of guano and saltpetre. Most of the earnings from the sale of guano were meant for foreign parties. Then there was the boom of rubber, from 1879 to 1912, which resurged from 1942 to 1945. The construction of the railroad in 1870 in Northern Peru was a response to the cultivation and need for transportation of sugarcane, since it was there that most of the crops were concentrated. This led to the formation of the aristocratic Republic, which existed from 1899 to 1919. It was an elite group of landowners with economical resources that focused on innovation and technology, modernizing the agricultural and mining industries for exportation, and establishing relations abroad.

Natural resources are also linked to the availability of labour, which was scarce at the time, especially during the times of harvest. The abolition of slavery in Peru in 1821 was a response to the liberalization of the workforce and the reduction of costs. Landowners received payments from the government for the liberation of each slave, which was greatly profitable to them. Slaves were replaced by farmers of Chinese origin, most of whom worked in plantations in the coast, under poor living conditions. This led to the rebellion of a group of these Chinese "*culis*", who killed the owner of the Pucalá hacienda in northern Peru. Meanwhile, in the Cayalti hacienda, six suicides were reported, 5 of them by opium overdose (Gonzales 2016). While the German doctor Ernst Middendorf was living in Peru (1885–1888), he visited the northern plantations and recommended the implementation of bathrooms and showers to prevent the propagation of diseases such as tuberculosis, measles, the bubonic pest, and others (Gonzales 2016). The Chinese workforce was partially replaced by Japanese workers from 1880 to 1933, so that from 1898 to 1923, 17,764 Japanese workers were brought to Peru, most of them to work in plantations.

Later, in the twentieth century, workers from the great northern plantations were no longer slaves, but would be put through a system intended to make them go into debt with the landowners. They were only permitted to make purchases from stores that were part of the plantations, where prices were exorbitantly high, and would be forced to take loans to do so. Sometimes they would also be given tokens to spend at these stores instead of part of their salaries (Gonzales 2016). Once they received their salaries, they would realize it wasn't enough to pay their loans, and would become dependent on receiving the next salary to clear their debts. This system was called "*enganche*", or "hook", as the workers couldn't leave the plantations due to their accumulated debt. The stores were run by the employers of the worked called "*enganchadores*", and landowners would supply them with opium to sell (Gonzales 2016).

The lack of available labour at the time made the management of the workforce an important obstacle, leading landowners from the coast and from the mountains to create alliances (Gonzales 2016). During times of harvest, workers were taken from the mountain regions to plantations in the coast, and the same workers were taken to the mines at times when there was no harvest to be done in the mountains (Gonzales 2016). Since the start of the twentieth century, many native Peruvians were hooked and put to work periodically in the plantations. Many of the *enganchadores* were landowners from the mountain regions, who would send their workers to the coast during the mountain's drought seasons. In exchange, the *enganchadores* would receive 20% of the workers' salaries. The few workers who would try to escape were chased and brought back. Since the middle of the twentieth century, the plantations of the Lambayeque valley had put together crews that patrolled the mountains in search for fugitives, who were then taken back to the coast to continue working in plantations (Gonzales 2016).

At the start of the twentieth century, Casa Grande and Cartavio were the two largest sugar plantations in the world, and both were located in the northern coast of Peru. Cartavio was so large, that it had its own internal rail to transport the harvest (Gonzales 2016). In 1930, the workers organized and began major protests, which led to the Trujillo revolution of 1930. Workers from several northern plantations participated, including the Casa Grande, Laredo and Cartavio plantations. Some changes were achieved, such as the implementation of medical controls to avoid the spread of tuberculosis, measles and the bubonic plague; and access to education for children up to the age of 12, after which they would be sent to work in the plantations (Gonzales 2016). Eventually, the protests led to the Agrarian Reform of 1969, in which the lands were expropriated by the government and distributed among workers. In the northern coast, agricultural cooperatives were formed, and in the mountains, communities based on the old plantations that used the previous organizational structure.

Currently, there is a new concentration of lands in the coast that has led to a type of agriculture meant for exportation, called agro-exportation. This has taken place despite the lack of water and the limitations of the salty, arid soil. The coast of Peru has been a significant agricultural zone throughout its history, from being used to plant cereals during the colonial era, to cotton and sugar in later times, and even being the location of one of the largest sugar plantations in the world. This is why the region has been so dependent on labour, from African slaves to Chinese *culis*, and later to the indigenous population from the mountains. It has been the stage for many social injustices.

Although according to the national map of major land use Peru's agricultural surface is only 5.92% (due to the terrain's characteristics), cultivation is currently practised in 30.1% of the national territory, 11.5% of which corresponds to the coast (INEI 2012). Coastal agriculture is mostly developed in the valleys that receive water during the mountain's rainy season. The use of modern irrigation technique and the construction of dams has allowed the agricultural boundaries to be expanded. The number of cultivated hectares in the coast has increased by almost one million from 1994 to 2012. Meanwhile, the area of drylands has increased 9.5% on a national scale (INEI 2012).

Throughout the twentieth century, the main traditional crops in the coast have been sugarcane, rice, cotton and starchy maize. Today, exportation agriculture and the reconcentration of lands have led to a diversification of the crops.

The Tangüis variety of cotton is selected in Peru, this variety is resistant to the fungi (*Verticillium alboatrum*). Tanguis was a gut quality cotton with a long fibre. In Peru, cotton has been an important part of the history of agriculture. The *Gossypium barbadense* cotton is the one that has its centre of origin in Peru. It presents several colours, ranging from purple to crimson, and was widely used by Pre-Columbian cultures from Peru's coast. Because of the absence of rain in the coast, cotton doesn't get stained, which improves its quality. It is also a species that doesn't require much water. On average, it uses between 4500 and 6500 m^3/ha during a vegetative period of 140–180 days. Its optimal soil pH is saline, from 6.1 to 7.8. It's cultivated in a total of 85,000 to 10,000 has, and its production gives jobs to approximately 20,000 families (8% of the economically active population) (MINAGRI, SENAHMI 2023a). Although there have been issues with the cotton fungi (*Verticillium alboatrum*), which led to the banning of ratooning, the sandy soil helps drain the plant, reducing the plague's incidence. Ica is the department with the highest cotton production (64.6%), followed by Lima (12.1%). Currently, the Tangüis and Pima cottons (*Gossypium barbadense*) are the main types being cultivated (MINAGRI, SENAHMI 2023a). The Tangüis variety was developed in Peru to resist the cotton fungus, which at the time had already ruined a large part of the crops. This variety is characterized by its large, high-quality fibres.

Sugarcane (*Saccharum officinarum*) is a plant of quick growth that requires a very large amount of water: from 28,000 to 32,000 m^3/ha. It originates in India, and has a vegetative period of 5–6 years. The first harvest takes place after its first year, at which point it is cut to allow it to regrow. Currently, it's mainly cultivated in the La Libertad department (42.93%), followed by Lambayeque (35.88%). It's cultivated in the coast despite its high water requirements due to the sandy, slightly salty soil of the zone. This is beneficial for the plant, as it requires a well-drained soil to prevent fungi, and needs a soil pH of 6.5, though it can tolerate a pH of up to 8.5 (MINAGRI, SENAHMI 2023c).

There has been a recent concentration of lands in the coast, which is being used to develop agriculture meant for exportation. Lime, mango, banana and avocado are cultivated on the northern coast; grape, cranberry, avocado and asparagus on the central coast; and olives, grapes and asparagus on the southern coast. In many cases, these crops are meant for foreign markets. Some of these plants, like the asparagus and avocado, require large amounts of water, and so it's sometimes said that Peru "exports water from the desert", which is an absurd paradox in the face of the coming climate change.

Until a few decades ago, asparagus was not a common crop in Peru. Since its introduction, it has been moderately incorporated into the gourmet cuisine market. However, its cultivation is mostly meant for exportation. The asparagus (*Asparragus officinalis*) originates in Asia Minor. It has a cultivation period of 300–360 days, and can be harvested for 8–10 years. In Peru, it is mostly farmed in the south of Ica (42.24%) and the north of La Libertad (41.76%). The crop demands a high amount of water, requiring 15,500 m^3/ha per campaign. It's cultivated in the coast because it needs a sandy-loam soil with a saline pH of between 7.5 and 8 (MINAGRI, SENAHMI 2023b). The sand helps the cultivation of white asparagus by covering the shoots.

In northern Peru, communities such as the Yaguay Negro or the Quebrada Bocapan settlement practice riverbed agriculture, using the humidity left behind by the river during the high water seasons to plant temporary crops. To this end, the soil is transported from the borders to the riverbed, and is then washed away by the river during the next rainy season. In this way the soil gets renewed every year. Nowadays, boreholes are also used to extract water for irrigation (Fig. 15.3).

In some parts of the southern coast, such as the Atiquipa hills, where the Andes rise steeply, terrace or Andean agriculture is still practised. It is used to harness the

Fig 15.3 Riverbed agriculture, sweet potato crop, Piura. (*Author* Ana Sabogal)

humidity brought by the ocean breeze, which is caught by the mountains due to the rain shadow phenomenon (see Sect. 15.4.2).

15.3.2 Mountains

All mountain ecosystems in the world share some common characteristics, such as a high altitude, sloped terrains, and an ecological isolation that makes the ecosystems fragile. This also leads to similarities in the anthropic mountainous ecosystems, such as transhumance, migration, the use of several altitudinal levels and the presence of resource mining.

The Andes is 7200 km long, goes through 7 countries, and is populated by more than 30 million inhabitants. Just in the Peruvian territory, the mountain range is 1800 km long (Tapia 1996: 17). As mentioned in previous chapters, the mountains of Peru contain many ecosystems and communities, which makes it hard to describe the area in general terms. In most cases, when talking of the mountain regions, sources refer to the central mountains, and to the quechua culture that inhabits them. The aymara culture, which dominates the southern mountains of Peru, is rarely discussed, much less the northern mountain areas.

Regarding its ecological characteristics, there are geographic factors that determine the region's climate, such as its latitude, longitude and solar incidence due to the inclination of the earth's axis. Solar radiation is also influenced by the altitude, making it more intense. On the other hand, humidity depends on the temperature and wind conditions, and is also affected by the position and size of the mountains and slopes. The speed of the wind is altered by the presence of surrounding mountains. Relative humidity, then, depends on the temperature. Air density depends on the humidity, altitude, latitude and temperature.

In this way, the high altitude produces a series of modifications that determine the climatic characteristics. At higher altitudes, gravity decreases, which produces a lower particle cohesion, reducing air pressure and oxygen density and increasing solar radiation. The reduction of air pressure lowers the air temperature, creating nocturnal frosts despite the lands being located in a subtropical area.

Mountains create two well-known geographical phenomena: rain shadows and thermal inversion. The rain shadow phenomenon is produced when winds carrying humidity are stopped by tall, wide mountains. As the wind collides against the mountain's surface, the humidity precipitates in the form of rain, allowing vegetation to grow on one side of the mountain, and creating a desert landscape on the other. Thermal inversion, on the other hand, is the difference in temperature that occurs in regions enclosed by mountains. During the night, the air closest to the ground gets colder while the warmer air rises, leaving warmer air at the bottom of the valley. During the day, the cold air gets warm and rises, getting temporarily trapped under the cold air since, due to the presence of the mountains, there is no wind or air circulation.

The mountain region has very few areas that are agriculturally productive. Except for its valleys, the land can't be farmed, as its soil has a very low pH, the terrain is sloped, and there is a strong risk of frosts. This has led to the development of several agricultural techniques that has allowed it to be used throughout history. There have been several proposals for the classification of the mountain's agricultural spaces, from purely ecological methods to those that focus on the land's use. One useful proposal is that of Tapia (1996), which classifies the environmental factors as either fixed or non-fixed variables. Although this classification method was created several years ago, it still proposes valuable elements that are useful for the analysis. Fixed factors are those that can't be modified, such as the territory's weather, inclination and precipitation, while variable factors are those that can be modified, such as the cultivation method or the chosen types of crops. Variables such as the latitude, the specific basin that's used, and orientation, are unmodifiable, and therefore fixed variables. Meanwhile, the chosen latitude and altitude, which define the temperature and precipitation; and the hydrological balance, which defines the agricultural production, are part of the second group of variables that are modifiable by humans. Also in this group are the soil, humidity and slope of the land. Finally, the population's perception and language, the land use and the weather, are also taken into account (Tapia 1996: 77–78).

One of the characteristics that make classification difficult is the subdivision of spaces due to the modification of slopes, which creates different agro-ecological zones in micro-spaces (Tapia 1996: 78). This has led to the creation of complex agricultural systems like terraces, waru-warus, qochas or the use of lakes' borders. These are explained below.

Terrace agriculture modifies the microclimatic conditions. The microclimate changes at every level of the platform depending on the size of each terrace and its inclination. Using terraces lowers the risk posed by frosts, hailstorms, floods and droughts by modifying the inclination angle of each terrace, which allows it to increase the surface that gets exposed to the sun. Terraces can also reduce the slope angle, and therefore the level of erosion. In this way, by changing the depth and orientation of each separate terrace, a variation in the incidence of solar radiation is produced, which also changes the humidity, temperature and amount of shade.

Terraces or as they are better known, *Andenes*, have been widely used in many mountainous environments. There are four types of terraces in the world:

- Terraces on mountainous or rugged terrains, which may present irrigation systems (Mediterranean region, Himalayas, Andes and Mesoamerica).
- Terraces on wet terrains, such as those from Southeast Asia.
- Raised field terraces, used in arid or semi-arid zones.
- Terraces from the Northeast of Europe (Sandor 2006 cit. Llosa 2019).
- In Peru we can observe:
- Natural terraces: those with no human intervention.
- Terraces with minimal human intervention: in zones where the conditions of the mountain allow it, straw and branches are piled up to reduce the slope and avoid erosion. With the coming rain, soil slides down and accumulates in these spaces, forming terraces.
- Stone wall terraces: Complex terraces built with walls of stone that surround a flat area, allowing for cultivation (Santillana 1999).

Complex terraces are built by transporting stones to build trapezoidal walls that stop erosion. The terrace's ground is built up by placing large stones at the structure's base, which allows for adequate drainage, and then filling it up with sandy soil, then placing fertile soil on the surface. To move from one terrace to the other, stone ledges were placed forming steps. Crop rotation was practised when using complex terraces in order to maintain the soil's fertility. Each terrace also has irrigation canals that transport nutrients to the soil.

Waru-warus were systems used by the Pucará culture, and which are still used to this day. They are raised fields crossed by water canals, built on floodable terrains where water can be transported. They are used for the planting of potatoes, tubers and grasses from the Andean highlands. The water tempers the space's temperature, creating a small micro-climate by releasing heat when it cools down or freezes. This technique is still being practised.

Cultivation on the edges of qochas, or lakes, was also carried out in southern Peru in order to make use of the micro-climate created by the highland lakes. To do this, raised fields were built on the lake's edges, with ditches that were filled with water. The crops were planted along the lake's dry borders. The Pucará people also planted next to the lakes during the dry season. In this way, once the rainy season started, algae would grow in the land, which would then be used as fertilizer for the crops during the dry season.

Another technique used both in Cusco and in Mollebamba (Apurimac) is the cultivation in qochas. This involved the construction of small reservoirs made of stone and dirt, located on depressions of the terrain. They would be used to accumulate water, which was then guided through collecting ditches. The system also used drainage ditches in lower parts of the land to prevent disasters (MINAM 2023).

Agriculture in the mountains is defined by the presence of an accidented topography, the fragmentation of property, dryland agriculture, the simultaneous use of different agro-ecological zones, and extensive cattle raising (Tapia 1996: 34). This type of agriculture uses traditional technology, and consumes very few resources (Tapia 1996: 37).

Currently, agriculture in the area is limited by a series of factors derived from the nature of the land. Among them are: erosion, the occurrence of frosts, a lack of available workers due to migration, water scarcity and the lack of water retention during rainy seasons, when the rivers' volumes increase and sweep the ground, creating landslides. Additionally, agriculture is far from being technified due to the subdivision of lands and the very sloped terrain. This could and should be used to highlight the value of smaller, local crops for domestic use, for exportation or for the gourmet market. However, there are some limitations that make this difficult. For example, there is no certified seed for the development of these crops. And while the use of organic fertilizers has started to be promoted more and more, very few apply these techniques, since most only plant for their own use and for the local market. In many cases, organic agriculture without the use of many resources is practised, but it's mostly done due to a lack of capital rather than by choice.

15.3.3 Tropical Forest

The Amazonian region we denominate tropical forest is an area dominated by rainy tropical ecosystems. It can be clearly separated into a high tropical forest zone, which shows pronounced slopes, and a low tropical forest zone, which is mostly flat.

These are spaces with a high level of biodiversity and biological cycles in which the ground offers mostly support rather than sustenance. Nutrients get decomposed by microorganisms at a high speed and are quickly passed to the next trophic chain. Soils in the tropical forest are very infertile. On the one hand, high tropical forest grounds are sloped and are washed often by rains that drain to the foot of the hills, making them poor and sandy-clayey. Mainly bushy species such as coffee, cocoa, coca and tea can flourish there. On the other hand, low tropical forest soils are also washed, clayey and have low pH levels, as well as high amounts of aluminium. When the ground is left clear of plants, the biological cycles get interrupted and rainwater washes the soil away, both at the surface level and in deeper parts of the ground. All this leads to a very low fertility.

Traditional tropical forest agriculture used to be migratory and extensive. populations would combine agriculture with plant scavenging, fishing and the hunting of forest animals. In this way, they would allow the soil to recover at a natural pace. Dourojeani (2009: 374) postulates that the natural recovery of the forest requires at least 50 years. Agriculture was done through a system known as slashing, felling and burning, which also included a fallowing to recover the cut-down areas. In zones adjacent to Brazil, trunks were used to fertilize the soil. They were carbonized and buried so that they would compost the ground more slowly and produce a better harvest. Additionally, the productive systems made use of the seasonal stages of fishing and hunting. The populations had a good knowledge of the seasonal qualities of plants, animals and fishes. For example, Rodríguez Achung (2016) describes in detail the harnessing of resources during the fishing season by the Naro-Machigenga people.

Currently, despite attempts with different production systems, monocultures are still dominant in the tropical forest, since they are practised by large companies that export products such as oil palm, coffee and tea. Monocultures quickly reduce the land's fertility and modify the ecosystems drastically. Other production forms like polycultures include agroforestal systems that combine agriculture with forestry by working on all three strata: the arboreal stratum, with trees like the cedar and mahogany; the shrub stratum, with plants like the banana, coffee, tea, cocoa, achiote and coca; and the low stratum, with plants like maize and beans. These production systems are much better adapted to the space, since they also include a use for the low grounds and reduce the erosion by preventing the absence of plants between the grooves used by traditional agriculture.

Agroforestal systems have been used in many other parts of the world, but they have not been used in the Amazon traditionally, nor have they been fully accepted in the area, despite great efforts and investments to incorporate them. This is largely due to the time demand of managing the parcels, and the fact that the systems are less mechanized.

Among the different agricultural plans proposed by international cooperatives and by the state, are the cultivation of bananas, which can help ensure food security; coffee and tea, which are planted in the limits between the tropical forest and mountain regions; cocoa for the lower tropical forest; and some fruit trees like the camu-camu (*Myrciaria dubia*), papaya (*Carica Papaya*), avocado (*Persea americicana*) and chestnut (*Bertholletia excelsa*), as well as timber trees like cedar (*Cedrela odorata*), mahogany (*Swietenia macrophylla*) and ishpingo (*Amburana cearensis*), among many others. From the medium stratum crops, the most embraced have been bananas, coffee, cocoa, achiote, tea and coca; and from the medium stratum, maze and beans. There is, however, a lack of saplings and certified seeds, which makes it difficult to cultivate local species and makes the planting process longer, as it forces farmers to make their own seedlings, which lack the necessary quality.

Besides agroforestry, which has the advantage of producing escalated harvests throughout the whole year; and polycultures, which ensure all of the ground's coverage and prevent erosion; there are the agrosilvopastoral systems, which use part of the trees and crops for the raising of bovine cattle intended for meat production. This improves the food security and the diet of migrant settlers, who don't have access to the forest and don't practice traditional hunting. These systems integrate the vegetal strata with cattle raising, and require a constant alternation of the low-strata crops, since, as mentioned before, the soil in the area is poor and gets quickly expended. In the high tropical forest zones, the planting of low-strata crops requires using contour furrows to prevent erosion, as well as a reduced tillage of the soil. Other techniques that help maintain the soil's quality are compostage and the use of green fertilizers, which is appropriate for these areas, where decomposition and the biological cycles of the ecosystem happen very quickly.

Despite not being a local crop, coffee has been adopted easily by the tropical forest population, leading Peru to produce and export a great amount of organic coffee. The most appropriate ecological floor for coffee is at an altitude of 900–1800 masl, in the high jungle. Its combination with the planting of forest trees is notable, as the shade improves the coffee's quality by slowing its growth and allowing the development of aroma. Additionally, the excessive use of nitrogenized fertilization accelerates its growth and deteriorates the grain's quality, making its organic cultivation more valuable. One of the few disadvantages of the crop is that the excessive rain stains the grain, and can develop a fungus known as roya (*Hemileia vastatrix*). Currently, Peru produces very large amounts of coffee and also exports its organic varieties. This is also the case for bananas, which also aren't native to South America. Almost all bananas exported from Peru are organic.

There are a series of limiting factors that make developing agriculture in the tropical forest difficult, besides the agronomic constraints. One of them is the issue of land ownership, which in many cases is not officialized, making it difficult for landowners to access bank credits. There are also land invasions and the traffic of lands. All this has made it a priority for the World Bank to regularize the physical and legal state of the terrains through their Land Titling Program.

Currently, most of the tropical forest population somehow connects their production system to a city, usually through members of an extensive family. The young adult relatives usually work in the city, while the children and elderly remain in the rural areas (Sabogal 2021). The distance to the markets and the lack of minor commercial areas for purchasing low harvest volumes, means that many farmers choose to plant crops with a safer demand, these being commodity products and expansive crops such as coffee, tea, and oil palm. These are products with prices that are regulated globally, for which there is no negotiation margin on the part of small and medium farmers. This doesn't help develop food security, which is already very low in both the high tropical forest and low tropical forest regions.

15.4 Alteration of the Ecosystem

15.4.1 Agriculture

Agriculture is one of the activities that is most linked to the population, and that at the same time produces changes in both the landscape and the ecosystem. This is especially true when dealing with intensive agriculture with a significant use of products in non-traditional spaces. The farming sector contributes to approximately 5.3% of the GNP, and includes agricultural, cattle-related, hunting and forestry activities (Farming census cit. MINAM 2016: 18).

In Peru, small-scale agriculture is mostly carried out in the mountain regions, but not exclusively. It shows a series of common characteristics, including spatial heterogeneity, the use of diverse altitudinal levels, the use of familial labour, a non-monetary economy, extreme poverty, high levels of uncertainty and low productivity (FAO 2017). The highest earnings come from the gathering and commercialization of agricultural products. However, small-scale agriculture produces 70% of the crops that form the national food basket (Chamber of Commerce of Lima 2017 cit Diario Gestión).

Considering the low profitability of agriculture, many measures related to commercialization and the market have been proposed. One of the main problems is the difficulty of offering the products in the markets at a fair price. A large part of the earnings are kept by merchants due to the difficulty of accessing the production territories.

Irrigation infrastructure has also been improved, especially in the coast. In the mountain region, research and dissemination of information regarding traditional water distribution systems has been done, including the planting and harvesting of water. This traditional technique consists of creating small reservoirs that allow for the draining and upwelling of water in lower areas of the terrain. It's a complex technique, which requires knowledge of the location and the paths of cracks on the terrain's rocks. In many communities, this kind of knowledge forms part of the traditional wisdom that is passed on.

The food basket has also been modified in the coast, going from the cultivation of rice and sugarcane, which require large amounts of water, to less demanding crops. There is work being done on the development of organic crops and the biological control of exportation products, as well as the development of improved seedlings. The value chains of some products have been improved, such as those of the cocoa and coffee crops from Peru's jungles, leading to the creation of new markets. In order to achieve fair prices, work has been done to create markets for organic products, and to implement a green label system. These are some of the many efforts made to achieve a competitive agriculture, not just in terms of the market, but also for the needs of agricultural workers and of the country, in order to reduce the current societal divide.

15.4.2 Cattle Farming

Cattle farming in Peru is practised in all three of its regions. It has been especially significant in the mountain region, where stock farming lands are located. 13.94% of Peru's lands are, by nature, suitable for grazing (ONERN 1985). Also, of all grazing lands, more than 90% have a low carrying capacity (Tapia 1996; 36). In the central Andes, lands have an approximate capacity of 1–2 livestock/ha/year, while in the dry puna and the janca zones their capacity is 1 alpaca for every 2–3 hectares (Tapia 1996; 36). For this reason, livestock farming on the mountains is fundamentally extensive, both in the highland grasses and in the paramo (Tapia 1996; 36). Dairy farming is developed in the quechua zone, where alfalfa is cultivated, and uses agricultural leftovers. Production in these zones is both extensive and intensive (Tapia 1996; 36). In the suni zone, bovine, ovine and camelid cattle are raised, and in the puna zone, alpacas are also raised (Tapia 1996; 36). Livestock farming in the tropical forest also extensive, and meant for the production of meat. Zebu cattle are raised there.

The history of cattle farming in the coast region involved an important boom to the north of the city of Lambayeque during the nineteenth century, where the production of leather, soap and other derivatives of bovine cattle was practised, even surpassing the production of sugarcane (Gonzales 2016). In the twentieth century, it was focused on the fattening of cattle from the mountain regions in times of drought, when their original owners couldn't feed them. They would be sold at a low price, and taken to the coast to be fattened with maize leaves and then resold at a higher price.

Due to a reduction in humidity during the pleistocene intervals, grasslands expanded on the southern Amazon basin, replacing the tropical forest (Van der Hammen 1974). In the mountain region, grasslands are burned during times of drought to allow the grasses to sprout again, creating a food supply for the cattle. It's a widely extended practice in the paramo. The expansion of grasslands below the forest line is a consequence of these burnings and grazing (Verweij and Beukema 1992).

During the times of drought, plants hold a higher concentration of nitrogen due to their lower water content. Plant's palatability increases in these periods (White 1976 cit. Young and Smith 2008) because of their higher nitrogen content (Young and Smith 2008). The smaller the plant, the more it will be affected by these hydric stresses, making them more preferable to insects. Additionally, these plants are one of the few food options during these periods (Young and Smith 2008).

There are many improvements related to cattle farming in Peru, yet to be achieved. Among them are the introduction of races of animals with a better conversion, the use of artificial insemination practices, the improvement of the native cattle, the vaccination and veterinary control and the use of balanced food. As previously mentioned, both in the coast and mountain regions cattle raising is done extensively and with little to no technical intervention.

15.5 Agroecology

Agroecology is a valid option for spaces where ecosystems are still preserved and where pollution could be easily displaced, as is the case with aquatic ecosystems or those that have been largely eroded, like a large part of the Peruvian territory. But agroecology goes beyond just the reproduction of natural ecosystems. It is a science that studies agro-ecosystems and includes their ecological, cultural and economic aspects. It also analyses the food systems in order to propose ecologically and socially sustainable forms of developing it.

Agroecology is an agricultural technique that considers agrarian systems as ecological ones, and therefore respects their exosystemic functions, such as the trophic chain and biochemical cycles. To this end, it attempts to reproduce the conditions of existing natural ecosystems, like the use of three stratum: the arboreal stratum, the bush stratum and the herbaceous stratum. This is done in order to keep the soil covered, minimize the tilling to reduce erosion and use biological controls to maintain a trophic chain. It attempts to do this using the minimum necessary number of external products to keep genetic diversity intact and ensure the cycling of nutrients.

In this way, agroecology proposes some agronomic practices, such as the use of allelopathic plants to eliminate weeds. The chemical substances that are produced can be eliminated through the soil, or they can be volatile substances that eliminate the undesired plants, like growth inhibitors and toxins. In this way, the allelopathic plants impede the growth of weeds and eliminate competition through the use of chemical substances.

Regarding the soil, agroecology considers the adequate functioning and reproduction of its flora and fauna using organic matter, compost and guano. It also takes into account the cycling of nutrients from the deeper stratum of the soil. It also focuses on fostering natural pollinators through the planting of flowers to attract insects and by releasing attractor substances to encourage their presence.

As for biological control, this is the concept of insects eating other insects, but also of plants emitting volatile substances to communicate the presence of insects to the group so that they are repelled. This system is harnessed by agroecology.

In this way, agroecology uses a series of agricultural practices that allow the ecosystem to function correctly. Among these practices is the quick occupation of the space by plants. To do this, a high density of seeds is used, followed by an early selective harvest. This practice is used especially for the planting of vegetables.

In general, a series of production systems are proposed, which are temporally diverse and occupy diverse stratum of the ecosystem, ensuring the use of both the ground and aerial spaces, for example, the agroforestry and agrosilvopastoral systems (see Sect. 15.3.3). All used agronomical practices consider polycultures to be of great importance. These can be managed through a temporal and spatial rotation of the crops, or using furrows that go against the slope, called contour furrows.

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