Biodiversity Management and Ecosystem Services: Peru Management Guide

Contents

Citation

McQuatters-Gollop, A., Smith, M.A.E. and Parker, J.A., 2020. Biodiversity Management and Ecosystem Services: Peru Management Guide. EO4cultivar Project. UK Space Agency International Partnership Programme.

Acknowledgements

The project team would like to thank the EO4cultivar Peruvian partners for their input and enthusiasm in facilitating the engagement of local organisations with the project. Our thanks go to Dr. Alfonso Orellana Garcia, Dr. Jesús Ormeño and Dr. Marvin Torres at University of Ica and University of San Marcos for their help with fieldwork in the case study areas and to the organisations that contributed to the stakeholder workshop.

EO4cultivar is co-funded by the UKSA International Partnership Programme (IPP) and project partners. IPP uses expertise in space-based solutions, applications and capability to provide a sustainable economic or societal benefit to emerging nations and developing economies. IPP is funded by the Global Challenges Research Fund, a £1.5 billion fund announced by the UK Government, which supports cutting-edge research and innovation on global issues affecting developing countries. The GCRF forms part of the UK's Official Development Assistance (ODA) commitment. Cover image ©EO4cultivar

Biodiversity Management and Ecosystem Services

This guide provides contextual information on the function that biodiversity plays in delivering nature's benefits to humans, also known as 'ecosystem services'. The document, developed by JNCC, demonstrates how the ecosystem service maps produced by Environment Systems for the EO4cultivar project can be used to help inform decision making through the implementation of ecosystem-based management.

What is biodiversity and how does it support society, the economy and ecosystem services?

Biological diversity (bio-diversity) is a term used to describe the variability among living organisms from terrestrial, marine and aquatic ecosystems; this includes diversity within species, between different species and the ecosystems of which they are part[2].

Biodiversity interacts with the abiotic environment at different levels (i.e. soils, minerals, water, atmospheric conditions etc.), all of which differ between locations to create unique ecosystems. 'Ecosystem' describes the dynamic complex of plant, animal and micro-organism communities, and the non-living abiotic environment, functioning as a complete system.

The planet's ecosystems support all life on earth and therefore can be considered to be providing ecosystem goods and services upon which human well-being and the global economy depends. Biodiversity has declined rapidly over the last 50 years, which will affect the provision of many ecosystem services and impact on the benefits that people receive from nature[3].

Peru is a global biodiversity hotspot and is home to more than 20,000 species of animals and more than 5,500 species of plants[5]. Peru is home to 10% of global species and ranks first for fish diversity, second for bird diversity, fourth for amphibian diversity, and fifth for mammal diversity, globally[4]. While biodiversity is increasing in Peru, so is the number of threatened species, with 850 species of plants and animals classed as vulnerable, endangered, or critically endangered[7]. Peru's ecosystems are also diverse and include plains, mountains, coastal Andean foothills, rainforests, dry forests, wetlands, and moors[5]. Thirty of 32 world climates are found in Peru, and temperatures range from below 0˚C in the Andes to 38˚C in the northern Pacific desert[8].

Biodiversity, Ecosystem Resilience and Landscape Connectivity

Biodiverse ecosystems are maintained by functions operating at the species, ecological community and landscape scale. These functions help ecosystems resist negative disturbances, such as invasive species invasions or pest outbreaks, or enables them to quickly recover after a disturbance has taken place, such as following a flood or fire[10]. Ecological traits refer to how an organism interacts with the environment and with other species. These traits vary amongst species in the ecosystem, so the more biodiverse an ecosystem is, the more resilient it is to disturbance, the more likely it will recover from disturbance, and there is greater likelihood the ecosystem will continue providing ecosystem services.

How connected one habitat type is to another similar habitat determines to what degree species can disperse throughout the ecosystem. If there is high connectivity between habitats, species from the surrounding area may disperse easily into the area and colonise it, helping to maintain the community and support the ecosystem function and resilience. In contrast, isolated habitats can have decreased function making them less able to adapt to change and therefore less resilient; meaning the ecosystem services they deliver are also less stable[11]. Whilst connectivity is generally considered to be a positive factor, it can also facilitate the spread of disease and invasion by alien species, which can be a threat to biodiversity.

Adopting a Landscape Approach to Managing Biodiversity and Ecosystem Services

Sustainable and resilient agricultural systems are required to feed the human population, but one of the consequences of agricultural intensification has been landscape simplification and biodiversity loss. Production landscapes often contain only high yield crop monocultures and very little non-crop habitat. This has led to natural habitat areas being greatly reduced and becoming more fragmented.

There are numerous evidence sources showing that the diversity of plants, birds, mammals, and arthropods has drastically declined in agricultural landscapes. In addition to reduced species richness, ecological traits and functional diversity are also declining. There are clear indications that vital ecosystems services such as pollination[12; 13], pest suppression[14; 15] and groundwater recharge[16; 17] in intensified agricultural landscapes are being severely impacted[19].

Multi-functional landscapes are likely to be required in the future to maintain long-term sustainable agricultural productivity, whilst simultaneously supporting biodiversity, ecological function and ecosystem services. To mitigate current trends of biodiversity and ecosystem function loss, actions will be required to alter the landscape structure at scales far larger than individual farms. This will require a context specific and coordinated multi-stakeholder approach to ensure landscape design addresses the multitude of requirements in a sustainable and efficient manner (Table 1). Key tools required to facilitating this approach are landscape mapping and modelling of ecosystem services, such as the outputs developed under EO4cultivar.

Table 1. Relative levels of ecosystem services provided by landscapes under varying levels of management intensity. Potential management goals are reflected in terms of the landscape context. In all cases, preservation or improvement of regulating and maintenance ecosystem services is required to maintain all other services. Adapted from Landis (2017).[19]

Landscape Type	Ecosystem Service Characteristics and Potential Management Goals
Highly Intensified	**Ecosystem services**: High in provisioning services (i.e. food production), often provide low levels of regulating, maintenance or cultural ecosystem services. **Management goal**: Restore ecological integrity to maintain high levels of production and mitigate drivers of negative environmental impacts.
Moderately Intensified	**Ecosystem services**: Often provide a balanced set of services. Whilst production yields may be more modest than intensively managed areas, other ecosystem services such as soil retention, water infiltration and recreational opportunities are relatively higher. **Management goal**: Increase sustainable use and improve overall multifunctionality of the landscape.
Less Intensified	**Ecosystem services**: Production yields are comparatively low, but this is compensated by increases in regulating, maintenance and cultural ecosystem services.

	Management goal: Production in key biodiversity areas or pristine habitats should be avoided to maintain landscape function and resilience. If provisioning services are to be moderately increased this should be done in a manner that maintains current levels of delivery of other ecosystems services; whilst recognising there will be likely trade-offs in terms of losses of these other ecosystem services.

Using Ecosystem Service Modelling to Inform Biodiversity and Ecosystem Service Management

The EO4cultivar project has modelled ecosystem service delivery and produced ecosystem service maps. These can help inform ecosystem-based management interventions that support sustainable management of biodiversity in production landscapes and surrounding areas. The habitat and specific ecosystem service maps can be used to help land managers identify the best locations for improving biodiversity, ecosystems, and the services they provide at a landscape and individual farm scale.

Models utilise multiple datasets at several different scales. When interpreting the maps, users must consider the source data and the scale at which the source data has been captured. A site visit and impact evaluation should take place before any interventions commence.

- ***Habitat map*** – This map has been produced for the area of interest study region, which is located within the Department of La Libertad on the Pacific coast in northwest Peru. The area of interest centres around the Virú watershed and includes wetland, woodland, and scrubland habitats. The habitat map helps provide a baseline of type, extent and distribution of current land uses and different habitat classes and helps to detect change over time. The map can be used to help inform decisions at a landscape and farm level by helping to guide potential sustainable land-use practices that consider natural habitats.

- ***Places with habitat of key importance for biodiversity*** - This map shows areas of natural or semi-natural habitat that are likely to contain high levels of biodiversity. These areas are likely to support ecosystem services such as soil quality and pollination maintenance, food provision, and surface water regulation. These habitats are core components of ecological networks, helping to facilitate gene flow between species populations and increase ecological resilience to environmental disturbances.

- ***Places delivering multiple ecosystem service benefits: key areas for biodiversity and surface water regulation –*** This map identifies areas of source scrubland, woodland, and wetland habitats which coincide with areas providing high surface water regulation. The structure and naturalness of the vegetation in these areas provides high biodiversity value whilst the physical characteristics of living organisms combine with the characteristics of the soil, geology and topography and together they provide high levels of surface water regulation.

- ***Opportunities to enhance surface water regulation*** - This map shows sites with cropland, woodland and scrubland land cover where management interventions could be potentially implemented to improve surface water regulation to slow the flow of water runoff into the watercourses.

- ***Ecological network connectivity –woodland, scrubland and wetland ecosystems -*** These three maps show the existing ecological networks for different habitats, within which plant and animal species can move to maintain genetic diversity and sustain viable populations that ensure the maintenance and resilience of the ecosystems. The core network is likely to provide higher levels of ecosystem services, such as the ability to clean water or regulate water runoff, provide natural resources and support human activities of cultural value (e.g. ecotourism). Within the network, habitat restoration interventions are likely to be more effective as propagules, pollinators, seed dispersers and other important species will be available colonise and maintain newly restored areas.

- ***Opportunities to strengthen ecological networks* -** These two maps show places where it should be possible to restore or create new habitat to strengthen the existing ecological networks and enhance biological and genetic diversity. Investing in ecosystem restoration or enhancement in these areas is likely to deliver results quicker, be less labour intensive and less prone to fail and therefore provide a more effective investment of resources.

- ***Opportunities to deliver multiple ecosystem services: ecological connectivity and surface water regulation*** - The map shows places where it should be possible to restore or create new habitat to strengthen the existing wetland or woodland ecological networks to enhance biodiversity, while simultaneously enhancing the level of surface water regulation. Surface water regulation and biodiversity are important ecosystem services in their own right. Identifying places which provide multiple ecosystem services can help inform the decision-making process when prioritising areas for land management action and deliver best value-for-money.

Using Ecosystem Service Maps to Inform Management Decisions

Table 2 provides examples of how the mapped ecosystem service outputs can be used to inform ecosystem-based management measures to help conserve biodiversity and maintain the ecosystem services that support agricultural production.

The modelled outputs can be used to consider other industries that could benefit from ecosystem-based management. For example, wetland restoration could support local fisheries, and woodland enhancement could offer opportunities for agroforestry, or ecotourism. Protected and restored scrubland and woodland also support pollinators and species that offer natural crop pest protection[6].

Earth observation data is a first step to identifying areas for potential restoration or biodiversity enhancement. Areas should be subjected to subsequent feasibility and impact assessments. For example, poorly planned reforestation that converts existing biodiversity rich grassland or wetland habitats may result in a loss of overall ecosystem function across the landscape[20].

Any activities should always consider existing environmental policies and legislation, particularly those relating to nationally and internationally protected areas. These are discussed in the final section of this document.

Table 2 – How to use ecosystem service maps to enhance biodiversity.

Measure type	How to use map	Affiliated management guidance
Enhance and restore natural areas to reduce environmental risk exposure.	Consult habitat map and the map that shows areas of key importance for biodiversity. Use these to identify the habitat types that should be a priority focus for restoration efforts. Consult the maps that show the ability of the land to moderate surface water runoff and the key areas for biodiversity and surface water regulation. Identify areas that provide benefits to both water regulation and biodiversity conservation. Refer to ecological connectivity maps to identify areas where restoration can improve connectivity between fragmented habitat patches. Look at the maps showing opportunities to enhance surface water regulation in the catchment and cross-reference with map showing opportunities to deliver multiple ecosystems services; that being ecological connectivity and surface water regulation. Where possible target areas that benefit key biodiversity areas, improve connectivity and contribute to surface water regulation.	In this context, restoration activities in the upper and mid regions of the catchment can slow water flow through the system and provide benefits, such as reduced flood risk, to a wider area in the lower catchment. More localised and small-scale interventions may provide resilience to flood events at the farm or town level. Options for specific management actions may include: • Conservation of core habitat areas and avoid disturbance of areas supporting ecosystem services. • Reforestation in the upper catchment to slow the flow of water through the watershed. • Preservation of scrubland to act as flood plains • Protection and restoration of forests to combat desertification • Restoration of riparian habitat to slow water flow into main channel • Wetland protection and restoration to provide coastal protection by increasing the ability of the land to store flood waters
Enhancing and maintaining ecosystem resilience and landscape sustainability by improving existing biodiversity in the landscape	Use the habitat map to identify the types of natural habitat that exist within the landscape. Consult the ecological connectivity maps to identify how well connected different natural areas are.	Consider enhancing and protecting ‘natural’ areas. This may be done by creating suitable buffers around field margins as required by some sustainability certification schemes. Global G.A.P. suggest that producers should plan to convert unproductive areas (e.g. low-lying wet areas, woodlands, areas of impoverished soil, etc.) to conservation areas for the encouragement of the natural flora and fauna.

Measure type	How to use map	Affiliated management guidance
	Use the habitat map to identify the types of natural habitat that exist within the landscape. Consult the ecological connectivity maps to identify how well connected different natural areas are. Use the map showing places of high biodiversity importance and opportunities for improving connectivity to identify areas where interventions will enhance ecosystem integrity through improved habitat connectivity. Use this process to draw conclusions on the resilience of different sites and the potential risk of them declining and resulting in the loss of ecosystem service provision.	Consider enhancing and protecting 'natural' areas. This may be done by creating suitable buffers around field margins as required by some sustainability certification schemes. Global G.A.P. suggest that producers should plan to convert unproductive areas (e.g. low-lying wet areas, woodlands, areas of impoverished soil, etc.) to conservation areas for the encouragement of the natural flora and fauna. Identify areas where ecosystem restoration (e.g. saltmarsh and riverine wetland restoration and reforestation of woodland, particularly in gullies) can provide habitat connectivity but also provide shading for irrigation canals to reduce evaporation during high temperatures, improve riverbank stability to reduce sedimentation during rain events, prevent desertification by stabilising soils and retaining water with trees and other vegetation, and enhance coastal protection from saltmarsh vegetation. Strategic planning that enhances connectivity will improve overall habitat extent and improve ecosystem resilience by enabling functional communities to persist within the landscape by reducing habitat fragmentation, increasing ecosystem resilience to disturbances. Interventions may consider the delivery of multiple ecosystem service benefits to ensure maximum impact from investment in activities designed to enhance biodiversity, whilst improving resilience of multifunctional landscapes.

Measure type	How to use map	Affiliated management guidance
Establish biodiverse polycultures to enhance ecosystem services	Use the habitat map and the map showing places of key importance for biodiversity to locate degraded or unproductive land that could be enhanced by establishing low input, organic, marginal land polyculture that has low impact and enhances ecological integrity[21]. Consult ecological connectivity maps and water regulation maps to identify where landscape design could improve ecosystem resilience and deliver multiple ecosystem services.	Matching the right polycultures to available resources and environmental conditions will need systems to be composed of a mixture of suitable species. Species included in this type of management will need to be considered in terms of both their direct commercial value, as well as the value of their ecological function. Farming systems will need to be based on perennial polycultures and may include shade gown coffee, mixed orchard, mixed trees and crop alleys, , mixed crops or pastures[22]. Agroforests can provide a high-quality habitat matrix in fragmented landscapes. Terrace farming supports agrobiodiversity by increasing yields of important crops like potatoes and maize while reducing soil erosion, increasing soil quality, and facilitating adaptation to climate change and extreme weather events by enabling water retention[23]. . Landscape context and configuration are important factors to consider when establishing new ‘biodiversity friendly’ production areas[24].
Restoration of degraded habitats or unproductive land for reduced soil erosion and improved water quality	Consult the soil erosion map to identify areas presenting high risk of soil erosion. Refer to the habitat map to identify existing habitat types in the area of interest, such as areas of degraded woodland, unproductive cropland, or bare ground. Consider opportunities maps and ecological connectivity maps to select habitat types and locations to maximise biodiversity and ecosystem services benefits and enhance the likelihood of restoration persisting in the long term.	Soil erosion maps indicate sources of soil erosion and identify sites for targeting action. Restoration should consider existing habitats and land uses to ensure activities complement existing natural areas and benefit from natural regeneration effects. Working to restore landscape connectivity will enhance the likelihood that regenerated areas persist and adapt to environmental changes. Options for specific management actions • Target restoration on slopes presenting high erosion risk.

Measure type	How to use map	Affiliated management guidance
		• Wetland and mangrove restoration to improve water filtration and water regulation capacity. • Protect and restore woodland to mitigate desertification by restoring soil quality and retention improving water regulation. Identify crop areas with exposed soil and implement intercrop or cover crop strategies to reduce soil erosion and restore nutrients[25].
Enhance and restore natural areas to improve water regulation and availability	Consult maps showing the ability of the land to moderate surface water runoff and the key areas for biodiversity and surface water regulation. Use these maps in conjunction with the ecological connectivity maps to identify areas where restoration can benefit both biodiversity and increase water regulation through the landscape and facilitate ground water recharge.	Undertake land management to improve interception of rainfall and increase water infiltration into the soil to recharge aquifers. Management options may include: • Plant vegetation to trap condensation in the air and retain it within the hydrological system within the landscape. • Maintain and enhance vegetation around wetlands and irrigation infrastructure to reduce water loss from evaporation. • Maintain and protect natural and semi-natural wetlands.
Increase regulation and maintenance of biodiversity mediated ecosystem services (i.e. pollination* and natural pest control)	Use the habitat map to identify the types of natural habitat that are in proximity to the production area which would benefit from an increase in ecosystem services such as pollination or natural crop pest control. Consult the ecological connectivity maps to identify areas where restoration can facilitate movement of beneficial species through the landscape to improve enhance ecosystem service delivery in areas where pollinators or crop pest predators are unable to access. *This ecosystem service was not specifically mapped. SENCE can be used to produce pollination maps.	It is important to identify the native species that provide these ecosystem services and consider what ecological conditions they require in order to provide the particular functions that are sought. It is critical to consider what amount of biodiversity is required to deliver the desired services and to what extent this is achievable within the bounds of the proposed intervention (i.e. habitat requirements, such as refugia, for beneficial species). As well as the positive benefits, it is important to consider any potential dis-benefits that may be unintentionally realised, such as introduction of pest species or invasive non-native species.

Biodiversity in the La Libertad Region

Five distinctive ecoregions converge in La Libertad: the Pacific coastal desert, the Andean steppe (Serranía esteparia), the equatorial dry forest, the yungas (selva alta) montane forest, and the puna (Figure 1). Each ecoregion hosts multiple habitat types, leading to high biological diversity and high endemism in La Libertad. Altitude, along with associated abiotic factors such as climate and soil type, determine the biodiversity of La Libertad[26].

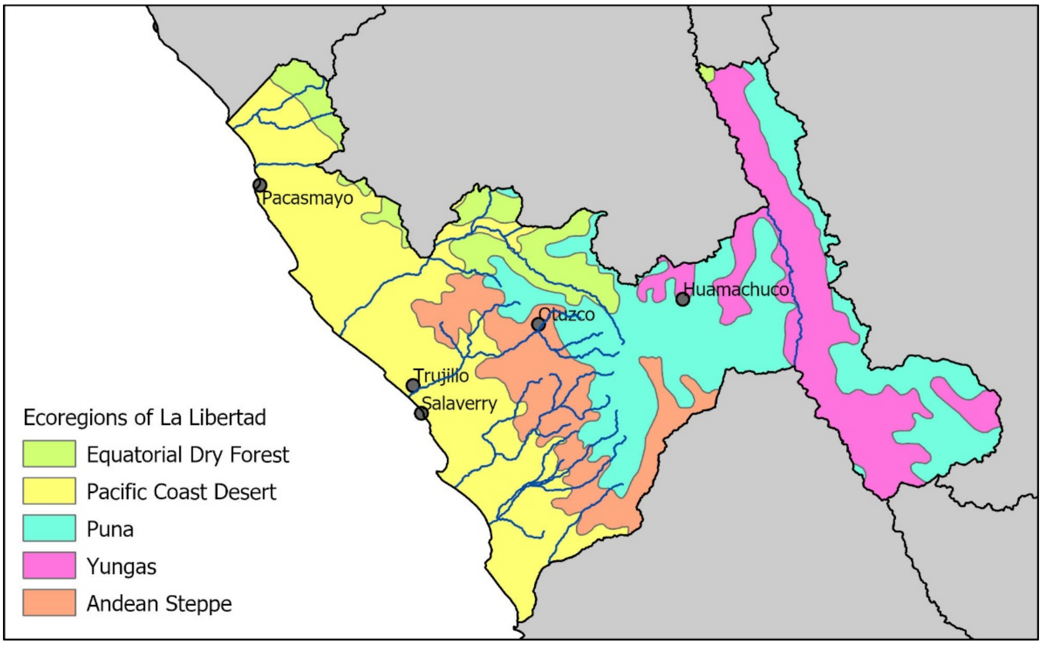

Figure 1: Five ecoregions converge in La Libertad. Data from Ministry of the Environment [27].

The Pacific coastal desert (also called the Sechura desert: Figure 2) reaches from the sea eastward to the Andean steppe[28]. This ecoregion is mostly flat and is formed by coastal dunes, fluvial valleys, and carob forests[28]. The climate is warm in summer and humid in winter, and the region is one of the driest places on Earth[29]. The desert is home to cacti and herbaceous plants such as the chillco and huarango, as well as fox, bats, pigeons, and sand owl[28]. Although mostly arid, a key feature of the desert is the persistent fog which supplies humidity to the lomas[29]. Lomas are plant communities who are entirely reliant on fog for moisture[29] (Figure 2). Unlike the arid regions of the desert, the lomas are species-rich with high rates of endemism (up to 40%) as a result of the geographic isolation of individual lomas communities[29]. Along the Pacific coast, La Libertad has 30 coastal wetland areas which are critical for coastal protection, providing habitat for commercial fish, storing and regulating water flows to mitigate flooding and drought, and capturing carbon[1]. La Libertad's wetlands are also culturally significant; the wetlands of Huanchaco, for example, provide totora reeds (*Scirpus californicus*) used to build caballitos del totora, traditional fishing rafts, which support the artisanal fishing industry, an important subsistence activity[1].

The Andean steppe is located between 1,000 and 3,000 meters above sea level[28]. This region has two well-marked seasons: a dry season (from April to November) and a rainy season (from December to March)[28]. The Andean steppe is semi-arid and covered in xerophytic vegetation such as dry forests, cacti, scrub, and, at higher altitudes, high Andean vegetation which is dominated by grasslands and shrubs such as tarwi (lupines)[30]. The flora in this region is diverse, with species such as chachacomo, capulí, huanarpo, la cantuta (the national flower of Peru), alder, molle, willow, reed, lupine and broom[30; 28]. The bird community contains partridges, raptors and hummingbirds[28], while regional mammals include the Andean fox, the vizcacha, the opossum or muca-muca, the wild cat, the endangered guanaco (Figure 2), and the white-tailed deer[28].

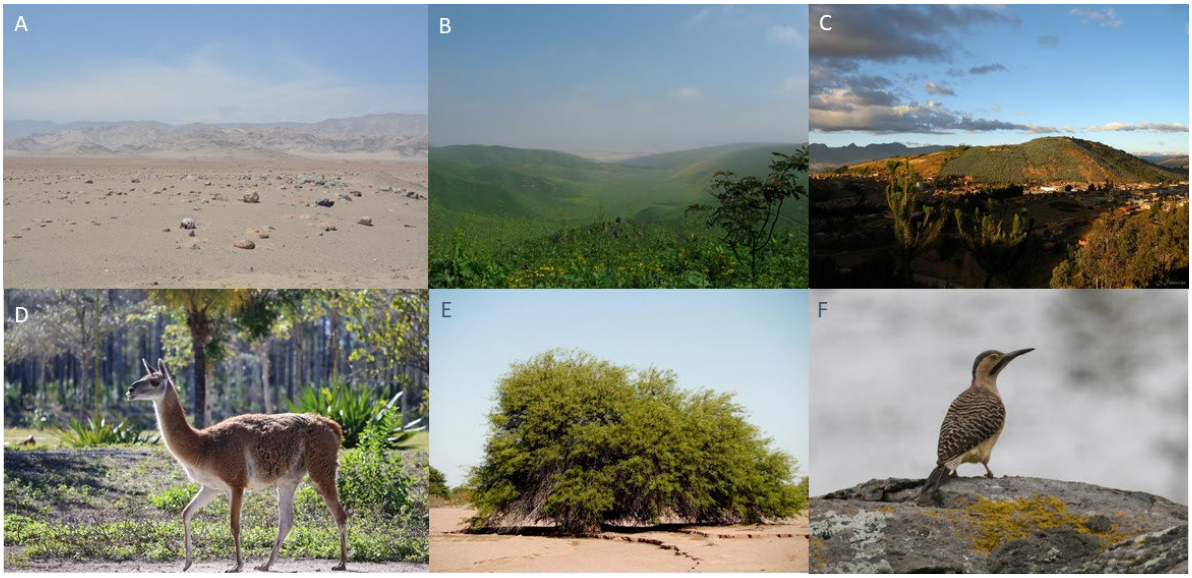

Figure 2: La Libertad is home to diverse habitats and species, from the Pacific coastal desert (A) with its misty lomas (B) and the Andean steppe (C), to guanaco (D), algarrobo trees (E), and Andean flicker (F). Source: Flickr used under Creative Commons License.

The equatorial dry forest ecoregion of La Libertad is part of the wider Tumbesian region which extends from western Ecuador to northwestern Peru. The climate is warm and dry, with a rainy season from January to March[31]. The El Nino-Southern Oscillation plays a key role in bringing precipitation to the ecoregion which promotes seed germination[32]. La Libertad's equatorial dry forest contains parts of the Marañón river valley, where the dry forests range from the valley floor up to 2800 m above sea level[33]. Although the portion of equatorial dry forest in La Libertad is relatively small, it is a biological hotspot for endemic birds[26] with a recent survey counting 120 species of birds, 65 of which are endemic and 21 of which are globally threatened[26; 34]. A notable habitat of the region, huarango, or algarrobo, (*Prosopis pallida*; Figure 2) forest, is one of the world's most endangered forest types[35]. Huarango trees can live for over 1000 years[36], and provide important ecosystem services such as soil stabilisation, combating salinization, soil fertility and moisture enhancement, habitat provision, food for humans, construction material, firewood, and riverine defence during summer floods[1; 37]. Equatorial dry forest vegetation helps control the advance of the Pacific coastal desert and therefore is key to limiting desertification[38]. Additionally, dry forest is an important source of timber and livestock forage food for local populations[1].

The yungas, or selva alta (montane forest; Figure 3), is located in the eastern Andean Amazon region of La Libertad[26], occurring between 800m and 3600m above sea level[39; 40]. The yungas contains multiple types of sub-humid rainforest, including cloud forest, mountain rainforest, and pre-mountain (lower altitude) humid forest[26]. An important feature of La Libertad's yungas is the Marañón Valley, an important biogeographic boundary which limits the distribution of some species[26]. The region has high diversity and endemism. Bird life is particularly rich, with over 300 species found in the yungas, 30 of which are endemic[26]. The unique and varied biogeography allows highland bird species such as to co-exist alongside temperate species[26]. The spectacled bear (*Tremarctos ornatus*; Figure 3), listed as vulnerable on IUCN's Red List, is South America's only bear species and lives in La Libertad's yungas[41].

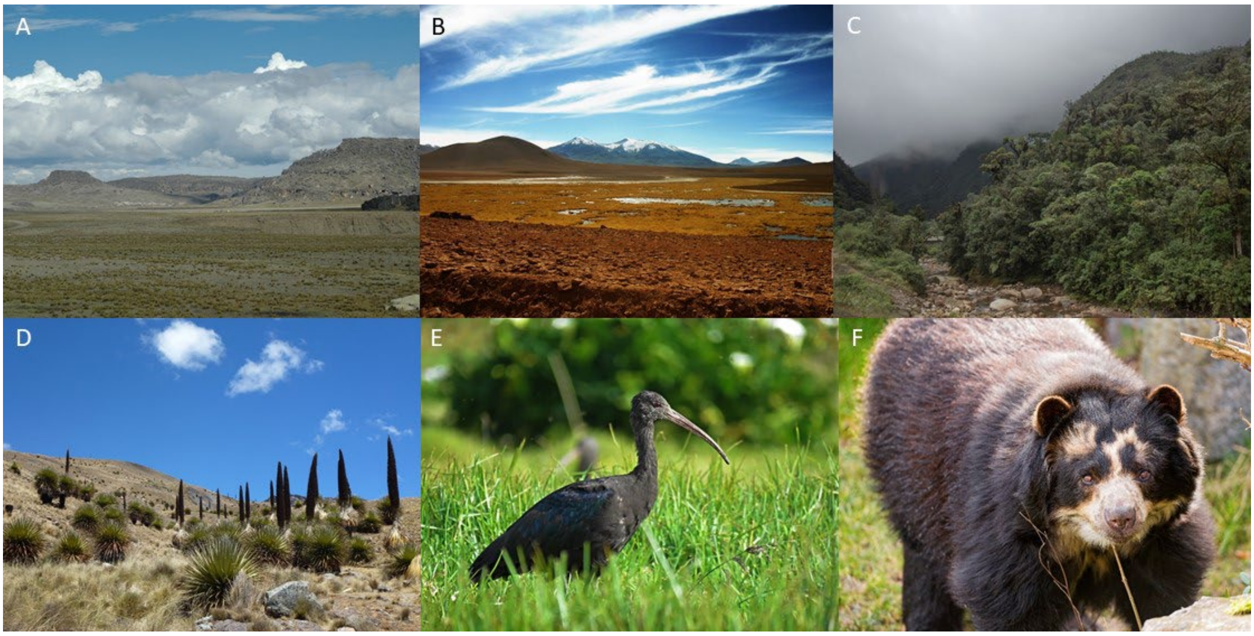

Figure 3: La Libertad's puna (A,B) and yungas (C) ecosystems support species such as the Queen of the Andes (D), the puna ibis (E), and the spectacled bear (F). Source: Flickr used under Creative Commons License.

The puna region (Figure 3) begins at 3,800 meters above sea level and is characterised by bofedales (wetlands), tolares (dominated by *Lepidophyllum quadrangulare*), and grassy plains[42; 43]. Some isolated areas contain queñual (*Polylepis* sp.) and kolle forests, which are in danger of extinction due to logging[28]. The climate is cold, with frequent frosts and variable temperatures, which can reach 40 ° C during the day and descend abruptly during the night[28]. The Puna region is the habitat of the Queen of the Andes (*Puya raimondii*), also called titanka or keshke[44; 43]. The Queen of the Andes (Figure 3) is a bromeliad which, once it achieves an age of one hundred years, blooms only once, producing more than 20 thousand flowers containing ten million seeds, and then dies[44; 28]. The Queen is ecologically important, acting as a habitat and food source for several bird species[45]. Puna fauna is diverse and contains many endemic species. The vicuña, the skunk (*Conepatus chinga*), the Andean fox (*Pseudalopex culpaeus*), the poronccoy or wild guinea pig (*Cavia tschudii*), Andean deer (*Hippocamelus antisensis*), gray deer (*Odocoileus virginianus*), and vizcacha (*Lagidium peruanum)* live in the puna sub-habitats. Predators of the puna include three species of cat (*Felis concolor, Oncifelis colocolo, Oreailurus jacobita*). The puna is also home to many species of birds including partridges , Andean goose (*Chloephaga melanoptera*), and gargacha flicker (*Colaptes rupicola*; Figure 2)[43].

The importance of agrobiodiversity in La Libertad

La Libertad is rich in agricultural biodiversity, or 'agrobiodiversity'[1]. Agrobiodiversity refers to the ecosystems, plants, and animals used for agriculture and is a result of both natural selection and historical human intervention[1]. Agrobiodiversity supports ecosystem services such as nutrient cycling, water retention, soil health, pollination, and is important in supporting the adaptation of commercial species and ecosystems to climate change[1].

The conservation of agrobiodiversity is a food security priority for Peru[4] and since the 2000s, there has been increasing progress regarding laws, strategies, and action plans to sustainably use Peru's native agrobiodiversity[6]. Agrobiodiversity zones have been established to increase agrobiodiversity knowledge and conserve sites with high genetic diversity of important agricultural species[5]. Various government support schemes to conserve agrobiodiversity now exist including ValBio, which facilitates stakeholder collaboration and funds research into valuing native biodiversity[9], and GENESPERU, which facilitates access to genetic resources and benefits sharing[6]. Payments for Agrobiodiversity Conservation Services (PACS) is a competitive grant scheme which supports communities to increase crop biodiversity. PACS have been incorporated into the MINAM Peruvian Ministry of Environment annual work plan in order to promote the adoption of these incentives. PACS contracts have been used to incentivise conservation and sustainable use of five native quinoa species at risk of extinction in a project involving six communities in southern Peru[6].

In La Libertad, agrobiodiversity provides food, fiber, fuel, animal feed, and medicines and supports other ecosystem services important to farming such as water regulation and soil health[1]. The Catalog of Ancestral Potato Varieties from Chugay was created in recognition of the important role of agrobiodiversity in the La Libertad Department. The catalog provides comprehensive information on over 100 types of native potato and is a demonstration of the valuable scientific knowledge held in La Libertad's farming communities[18].

Biodiversity and Ecosystem Services

Biodiversity plays a significant role in directly providing goods and services, as well as regulating and maintaining ecosystem properties that underpin the delivery of ecosystem services. Conservation management of biodiversity is vital to the ongoing sustainability of agricultural production globally[46] as multi-functional production landscapes often rely upon natural areas within the surrounding landscape as a source of soil fertility, natural crop pest control, maintaining the water supply and reducing risk posed by environmental hazards, such as flooding[3]. Other ecosystem services that are provided, maintained or regulated by biodiversity include:

- ***Soil formation and fertility***
  Soil formation and fertility is an essential component of a productive ecosystem, providing essential nutrients for soil grown produce. More than 99% of total worldwide food supply is produced on land. Diverse soil biota facilitates the formation of fertile soils and improves crop production. One square metre of soil frequently supports around 200,000 invertebrates and billions of microorganisms[47].

- ***Harvest of food and pharmaceuticals from wild natural resources***
  Each year around US$90 billion of food and related products are harvested from the world's forests and used by approximately 300 million people worldwide[47]. Up to 50% of the approved pharmaceuticals developed are directly or indirectly derived from natural resources[48].

- ***Biomass and recycling of organic wastes***
  Nearly 50% of the total photosynthetic production on land is used by humans, including managed forests and agricultural production. Agriculture and other human uses of ecosystems produces 38 billion metric tonnes of organic waste globally each year. These waste products are recycled by a variety of decomposer organisms that reprocess nutrients and makes them available for future primary production[47].

- ***Nitrogen fixation***
  Nitrogen fixation is essential for plant growth and without it biomass production is limited. Biological nitrogen fixation occurs naturally through nitrogen fixing plants and microbes and is often used as an alternative to chemical nitrogen fertiliser[47].

- ***Greenhouse gas sequestering***
  Sequestration of carbon dioxide by trees and other natural vegetation mitigates against increased global warming. Unmitigated rising temperatures and resultant changes in global rainfall patterns are likely to alter crop production. Working with natural solutions to mitigate the impacts of global warming are essential to the sustainability of agricultural crop production. Forested areas near to crops can also contribute to nitrogen fixation and increase soil fertility[47].

- ***Bioremediation of chemical pollution***
  Microbes and plants can degrade contaminant materials (i.e. chemicals and heavy metals) in soils and act as a biological decontamination process. This can occur naturally or be artificially enhanced to treat polluted sites and filter hazardous waste from water. The presence of a greater number of microorganisms in the soil ecosystem provides greater bioremediation potential. These complex processes are dependent on environmental conditions and can be limited if high levels of toxicity occur. It is important to note any bioengineering must be subjected to biosafety procedures to avoid health or environmental hazards[49].

- ***Genetic resources and biotechnology***
  Commercial crops possess a narrow genetic base, making them vulnerable if changes in environmental conditions do not suit their biological requirements. Induced variation techniques are becoming more important to provide new genetic varieties that have traits that will enable food crop plants to adapt to environmental change. Due to the global loss of biodiversity in natural ecosystems, genetic resources are being drastically eroded and this inhibits the potential of future biotechnology advances. This reduces potential for human food systems to adapt to new socio-economic and environmental conditions[50]. High agrobiodiversity, such as that found in La Libertad, provides genetic raw material for the improvement of new plant and animal varieties, which increases food security as well as the resilience of the agricultural industry[1].

- ***Pollination***
  Pollinators such as bees, butterflies, birds and bats contribute to the maintenance, diversity and productivity of agricultural and natural ecosystems. Pollinator diversity depends on ecosystems that are rich in diverse vegetation. Even self-pollinated crops, such as rice and potatoes, rely on animal-pollinated wild relatives to provide the genetic diversity that is essential for crop improvement and resilience to disease[3].

- ***Wildlife and ecotourism***
  Approximately 4.4 million international tourists visited Peru in 2018[51], resulting in revenue of an estimated $US5 billion for Peru's economy[52]. Approximately 19% of international tourists cite birdwatching as their reason for visiting Peru[53], which makes a contribution of nearly $US1 billion to Peru's economy in 2018. Tourism is increasing in La Libertad, particularly in the Calipuy protected areas and the archaeological sites along the Moche Route[1].

Pressures Affecting Biodiversity

As the human population increases biodiversity faces growing pressures from human activity across the globe, including habitat conversion and degradation, habitat fragmentation, over harvesting of natural resources and suffering impacts from pollution. Recent global biodiversity assessments conducted by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) highlights the threat posed by a continued decline in global biodiversity, key findings include[54]:

- Globally, local varieties and breeds of domesticated plants and animals are disappearing. This loss of diversity, including genetic diversity, poses a serious risk to global food security by undermining the resilience of many agricultural systems to threats such as pests, pathogens and climate change.
- Human-induced changes are creating conditions driving rapid biological evolution, with effects being seen in only a few years, or even quicker. The consequences can be positive or negative for biodiversity and ecosystems, but create uncertainty about the sustainability of species, ecosystem functions and the future delivery of nature's contributions to people (ecosystem services).
- Nature across most of the globe has now been significantly altered by multiple human drivers, with the great majority of indicators of ecosystems and biodiversity showing rapid decline.

Peru's Convention on Biological Diversity country profile highlights several high-profile threats to national biodiversity. These include deforestation, climate change, mining, coastal erosion, and agricultural development. These pressures contribute to habitat degradation, changes in land use, over consumption of natural resources, and negative impacts on ecosystem services. The combination of these factors is likely to heighten the impacts of climate change[5; 55].

Natural ecosystems in Peru have been largely transformed for agriculture, with the expansion of the agricultural frontier accounting for up to 90% of deforestation[6; 55]. For example, due to overgrazing and conversion to agricultural land, the area of unique lomas ecosystem has decreased by 90%, resulting in degradation of the soil, reduced ability to retain fog for moisture, and drought[56].

Pressures Affecting Biodiversity in the La Libertad Region

Deforestation has impacted all ecoregions of La Libertad. The logging of forests for firewood and wood is a major pressure on the equatorial dry forest and yungas, while encroachment of farmland is a threat in the puna and yungas[26]. In addition to logging, forest is lost through poor land management practices (such as burning of woodlands and grasslands) and the encroachment of farmland, which can lead to desertification[38; 1]. Important drivers of deforestation include the absences of property rights and the lack of land use planning, the low market value of forest land compared to other land uses, unsustainable production policies, and infrastructure construction[1]. Deforestation in the upper catchment also leads to soil erosion, which affects water retention and sedimentation downstream [1].

Agriculture in La Libertad is vulnerable to a range of pressures. Monoculture systems are less resilient than polyculture to pests and disease and require high levels of pesticide and fertiliser use. These agrochemicals can contaminate water sources and degrade biodiversity, reducing resilience and resulting in the loss of the ecosystem's natural ability to regulate pests and diseases[1].

Natural areas around farms, such as shelterbelts and other vegetated zones, are critical for maintaining important ecosystem services, such as shelter from wind and improving water infiltration into soils. Agriculture practices can lead to alterations of the watershed and soils, which may impact upon sustainability of farming. Along Peru's coast, the cultivation of water-intensive crops is resulting in soil salinization[4], which can reduce crop yield[57]. In addition, La Libertad's valleys are becoming salinized due to improper management of agricultural irrigation systems and the falling water table, with the Chicama, Jequetepeque and Chao valleys most affected[1].

The mining industry is placing pressure on La Libertad's species and habitats, particularly in the punas and yungas[26]. Habitat loss, particularly in forests, leads to increased pollution in watercourses[1]. These impacts are resulting in reduced biodiversity and even extinctions, with amphibians, for example, showing decreased species richness in areas undergoing mineral extraction[58].

Coastal wetland systems are disappearing as their soils are extracted for agricultural use[1],reducing the ability of the landscape to regulate water retention, which can result in flooding in coastal regions. Coastal erosion is causing decreased functioning of beach ecosystems and vulnerability of the coastline, particularly in Trujillo province[1]. Biological communities in affected coastal regions show signs of stress, such as reduced diversity[59].

In addition to direct anthropogenic pressures, climate change is altering La Libertad's ecosystems, the biological diversity that is contained in them, and the ecosystem services they provide. With an increase in temperature of 1.5˚C 30% of La Libertad's species are predicted to be at increased risk of extinction[1]. In La Libertad, climate change is expected to reduce water availability as glaciers retreat, altering the montane and downstream ecosystems which depend on this water source. Desertification and soil erosion will increase with the higher temperatures and changing water supply. Coastal wetlands will decrease in area due to sea level rise. Native biodiversity, including agrobiodiversity, will be lost for the species and habitats unable to adapt to rising temperatures[1]. As the temperature increases and water availability decreases in La Libertad, the productivity of important crops such as cereals will be reduced. Together these climate-driven changes will, in turn, compromise the delivery of ecosystem services such as coastal protection, food and material provision, water regulation, and soil stability[1].

Existing Policies for Managing Biodiversity and Ecosystem Services

The outputs of the EO4cultivar project provide tools and ideas as to how individual practitioners can consider biodiversity and ecosystem services in the context of specific sites and the wider landscape. This is particularly valuable when considering how sustainable practices at the farm level can collectively contribute to wider strategic objectives for biodiversity.

National Biodiversity Targets

National Biodiversity Strategies and Action Plans (NBSAPs) are required by the Convention on Biological Diversity to translate its global targets into national action. Peru submitted its NBSAP in 2015, which contains an action plan to 2018 and targets for 2021[55].

There are some key national targets that could be considered in the context of the EO4cultivar project outputs. Individual and collective interventions between and amongst sectors could have a marked positive impact on Peru's ambitious targets, which include:

- At least **17% of Peru's land area and 10% of its marine environment will be sustainably and effectively managed** to conserve biodiversity
- Peru will have at least **15 conservation plans for threatened species**
- Peru will develop at least **10 conservation programs that conserve and sustainably use the genetic diversity of native species**
- **Five ecosystem services will be valued**, ensuring the integrity of ecosystems and respect for indigenous people
- **Access to and distribution of benefits from genetic resources will be distributed** according to the Nagoya Protocol
- **Awareness and appreciation of the importance of biodiversity to development and national welfare will increase by 20%** among Peruvians
- The **rate of degradation of ecosystems will be reduced by 5%**, with an emphasis on forests and fragile ecosystems
- **Control and regulation of threatened and invasive alien species will be increased**
- **Institutional capacities will be strengthened** at all levels of government for effective and efficient management of biological diversity.
- **Biodiversity knowledge will have increased**, through the integration of technological development and innovation with traditional knowledge related to the conservation and sustainable use of biodiversity
- **Peru will have generated new knowledge about the genetic wealth or diversity**, **including spatial distribution, of ten native or naturalized species**, in collaboration with local and indigenous people, with consideration of the fair and equitable distribution of benefits
- The protection, maintenance, and recovery of **traditional knowledge and techniques of indigenous peoples and local populations related to biological diversity will be improved**
- **The decentralized governance of biological diversity will be strengthened** under a participatory, intercultural, gender and social inclusion approach, in coordination with the levels of national, regional and local government, within the framework of international treaties

National mechanisms to promote and protect biodiversity

Public investment in biodiversity and ecosystem services

Peru's Ministry of the Environment and the Ministry of Economy and Finance have published a set of guidelines for formulating public investment projects in biodiversity and ecosystem services[60]. The Ministry of the Environment also supports the application of ecosystem-based adaptation (EBA). EBA uses biodiversity and ecosystem services to help people adapt to the impacts of climate change. EBA explicitly considers the socio-economic benefits of climate change adaptation when managing natural resources and biodiversity by:

- using information on the effects of climate change to inform decisions
- analysing the cause-effects relationships of climate change

- examining the costs and benefits of different adaptation measures
- monitoring the effects of adaptation[1]

In 2016 the Peruvian government approved the Law on Compensation Mechanisms for Ecosystem Services which promotes payments for ecosystem services through voluntary agreements that establish actions for conservation, recovery and sustainable use of ecosystems[4; 61]. The scheme applies to, for example, farmers who change to more sustainable agricultural practices, thereby increasing biodiversity, managing soil erosion and increasing water retention, which enables other users to benefit from the enhanced ecosystem services.

International partnerships

Corporate responsibility projects are an additional mechanism used in Peru to protect and promote native biodiversity. For example, Barfoots Peru, a large-scale agricultural producer has established community projects in Ica, Peru, which focus on wildlife restoration and conservation[62]. In partnership with Kew Botanical Gardens (UK) and Sainsbury's supermarkets (UK), the program focuses on carefully managing local biodiversity to maintain resilience to disease and increase soil fertility. The programme's goal is to integrate native biodiversity into high-volume production landscapes and in the process deliver ecosystem services such as improved water conservation, pollination, carbon capture, erosion control, worker nutrition, and wellbeing[63]. The programme has also worked with Peruvian agro-industries such as Agrícola Chapi and Agrokasa to establish the first Native Plant Research and Conservation Center in Peru whose objective is to develop a native seed management scheme and propagation protocols for rare native plants[63].

International NGOs play a role in conservation of Peru's native biodiversity. Reforest Action and Progreso are collaborating with 1500 local families to plant 500,000 trees in the Piura region. The aim of this project is to restore local dry forests to halt desertification. The restored forests will restore biodiversity and help limit soil erosion, while also providing a source of income for local residents through sustainable harvesting for firewood and timber sales[64].

Protected areas

Protected areas are one of the most effective conservation strategies for protecting ecosystems and species[8]. Protected areas currently cover 17% of Peru, including 10 protected areas in the marine and coastal environment[5]. The Calipuy National Reserve and National Sanctuary protected areas of La Libertad are approximately 70,000 hectares in size and include a range of habitats, from desert to plains to mountain slopes[65].

Regional Strategy of Biological Diversity and Action Plan for La Libertad 2019-2020

The Regional Strategy of Biological Diversity and Action Plan for La Libertad harmonises existing regional priorities for biodiversity conservation with national priorities such as Peru's NBSAP. An important goal of the strategy is to manage biodiversity in order to mitigate and adapt to climate change[1]. The vision of the strategy is

"By 2022, the effective management of biological diversity in the La Libertad Region has been consolidated through conservation and sustainable use, identifying the opportunities that its management entails to minimize the threats and pressures on the services it provides, in such a way as to ensure the satisfaction of the well-being of current and future generations, based on its revaluation and strengthening of the institutional framework with an ecosystem approach".

There are some key regional actions that could be considered in the context of the EO4cultivar project outputs. Individual and collective interventions between and amongst sectors could have a marked positive impact on La Libertad's ambitious goals, which include:

- **Increase the spatial area of protected areas**
- **Implement plans for the management of prioritised ecosystems**
- **Strengthen natural protected areas** in La Libertad
- **Identify the main sources of pressures and threats** that contribute to the loss of biological diversity
- **Strength the surveillance, control and monitoring mechanisms** for the conservation and sustainable use of biological diversity
- **Identify potential opportunities** of biological diversity and sustainable use **for the promotion of bio-trade and bio-business products**
- **Promote compensation mechanisms for ecosystem services**
- **Implement a research program for the conservation of wildlife populations**, directing research efforts on endemic and threatened species
- **Implement and strengthen an informatics platform with biodiversity information**, for the effective exchange of data
- **Promote the strengthening of the capacities of institutions related to the conservation and sustainable use of biological diversity** for its adequate and effective management
- **Promote the development of mechanisms for the mobilization of public and private financial resources** for the conservation and sustainable use of biological diversity
- **Promote the formulation and implementation of regional public investment projects** in the field of biological diversity
- **Develop a Regional Environmental Education Action Plan** with emphasis on the promotion of biological diversity in formal and non-formal environments

References

[1]Gobierno regional La Libertad (2019) 'Estrategia Regional de Diversidad Bioloógica La Libertad: Plan de acción 2019-2022'. *Available at:* http://sial.segat.gob.pe/documentos/estrategia-regional-diversidad-biologica-plan-accion-libertad-2019

[2]Convention on Biological Diversity 'Convention, Sustaining Life on Earth'. [Online]. *Available at:* https://www.cbd.int/convention/guide (Accessed: 14 May 2020).

[3]IPBES (2016) *The assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on pollinators, pollination and food production.* Bonn, Germany: Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. 552 pp. *Available at:* https://doi.org/10.5281/zenodo.3402856.

[4]Alova, G. *et. al.* (2018) *Mainstreaming biodiversity and development in Peru: Insights and lessons learned.* Paris: OECD Pulishing. 71 pp. *Available at:* https://doi.org/10.1787/2933d7d2-en.

[5]Convention on Biological Diversity 'Peru Country Profile'. [Online]. *Available at:* https://www.cbd.int/countries/profile/?country=pe (Accessed: 20 November 2020).

[6]Bioversity International (2017) *Mainstreaming agrobiodiversity in sustainable food systems: Scientific foundations for an agrobiodiversity index.* Rome, Italy: Bioversity International. 180 pp. *Available at:* https://www.bioversityinternational.org/mainstreaming-agrobiodiversity/.

[7]IUCN Red List of Threatened Species 'Threatened species of Peru'. [Online]. *Available at:* https://www.iucnredlist.org/search?landRegions=PE&searchType=species (Accessed: Accessed 20 November 2020).

[8]Shanee, S. *et. al.* (2017) 'Protected area coverage of threatened vertebrates and ecoregions in Peru: Comparison of communal, private and state reserves'. *J Environ Manage*, 202 (Pt 1), pp. 12-20. *Available https://pubmed.ncbi.nlm.nih.gov/28715677/*

[9]Programas de Ciencia Tecnología e Innovación (2016) *Programa Nacional Transversal de Valorización de la Biodiversidad 2015-2021. Available at:* https://portal.concytec.gob.pe/images/publicaciones/libro_biodiversidad_valbio_oct.pdf.

[10]Oliver, T. H. *et. al.* (2015) 'Biodiversity and Resilience of Ecosystem Functions'. *Trends in Ecology & Evolution*, 30 (11), pp. 673-684. *Available at:* http://www.sciencedirect.com/science/article/pii/S0169534715002189

[11]Correa Ayram, C. A. *et. al.* (2015) 'Habitat connectivity in biodiversity conservation: A review of recent studies and applications'. *Progress in Physical Geography: Earth and Environment*, 40 (1), pp. 7-37. *Available at:* https://doi.org/10.1177/0309133315598713

[12]Kremen, C. *et. al.* (2002) 'Crop pollination from native bees at risk from agricultural intensification'. *Proceedings of the National Academy of Sciences*, 99 (26), pp. 16812-16816. *Available at:* https://www.pnas.org/content/pnas/99/26/16812.full.pdf

[13]Potts, S. G. *et. al.* (2010) 'Global pollinator declines: trends, impacts and drivers'. *Trends in Ecology & Evolution*, 25 (6), pp. 345-353. *Available at:* http://www.sciencedirect.com/science/article/pii/S0169534710000364

[14]Bianchi, F. J. J. A. *et. al.* (2006) 'Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control'. *Proceedings of the*

Royal Society B: Biological Sciences, 273 (1595), pp. 1715-1727. *Available at:* https://royalsocietypublishing.org/doi/abs/10.1098/rspb.2006.3530

[15]Gardiner, M. M. *et. al.* (2009) 'Landscape diversity enhances biological control of an introduced crop pest in the north-central USA'. *Ecol Appl*, 19 (1), pp. 143-154. *Available at:* https://pubmed.ncbi.nlm.nih.gov/19323179/

[16]Scanlon, B. R. *et. al.* (2012) 'Groundwater depletion and sustainability of irrigation in the US High Plains and Central Valley'. *Proceedings of the National Academy of Sciences*, 109 (24), pp. 9320-9325. *Available at:* https://www.pnas.org/content/pnas/109/24/9320.full.pdf

[17]Wada, Y. *et. al.* (2010) 'Global depletion of groundwater resources'. *Geophysical Research Letters*, 37 (20), *Available at:* https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2010GL044571

[18]Centro Internacional de la Papa (CIP); Asociacion Pataz; Instituto Nacional de Innovacion Agraria (INIA) (2015) *Catalogo de variedades de papa nativa de Chugay, La Libertad - Peru.* Lima, Peru: Centro Internacional de la Papa (CIP). 199 pp. *Available at:* https://cgspace.cgiar.org/handle/10568/69083

[19]Landis, D. A. (2017) 'Designing agricultural landscapes for biodiversity-based ecosystem services'. *Basic and Applied Ecology*, 18 pp. 1-12. *Available at:* http://www.sciencedirect.com/science/article/pii/S1439179116300950

[20]Nosetto, M. D. *et. al.* (2005) 'Land-use change and water losses: the case of grassland afforestation across a soil textural gradient in central Argentina'. *Global Change Biology*, 11 (7), pp. 1101-1117. *Available at:* https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1365-2486.2005.00975.x

[21]Rural Industries Research and Development Corporation (2001) *Polyculture Production - Principles, Benefits and Risks of Multiple Cropping Land Management Systems for Australia. Available at:* https://www.agrifutures.com.au/wp-content/uploads/publications/01-034.pdf (Accessed: Accessed 13 July 2020).

[22]Lefroy, E. C. (2001) 'Applying ecological principles to the re-design of agricultural landscapes', *Science and technology: delivering results for agriculture? 10th Agronomy Conference: 29 January-1 February 2001*. Hobart, Tasmania, Australia.

[23]Tambet, H. *et. al.* (in press) 'Climate Adaptation and Conservation Agriculture Among Peruvian Farmers'. *American Journal of Agricultural Economics*, *Available at:* https://www.researchgate.net/publication/329717578_Climate_Adaptation_and_Conservation_Agriculture_Among_Peruvian_Farmers

[24]Perfecto, I. *et. al.* (2002) 'Quality of Agroecological Matrix in a Tropical Montane Landscape: Ants in Coffee Plantations in Southern Mexico'. *Conservation Biology*, 16 (1), pp. 174-182. *Available at:* https://conbio.onlinelibrary.wiley.com/doi/abs/10.1046/j.1523-1739.2002.99536.x

[25]Magdoff, F. *et. al.* (2010) *Building Soils for Better Crops.* USA: Sustainable Agriculture Research and Education (SARE). 294 pp. *Available at:* https://www.sare.org/resources/building-soils-for-better-crops-3rd-edition/

[26]Núñez-Zapata, J. *et. al.* (2016) 'A compilation of the birds of La Libertad Region, Peru'. *Revista Mexicana de Biodiversidad*, 87 (1), pp. 200-215. *Available at:* http://www.sciencedirect.com/science/article/pii/S1870345316000270

[27]Minesterio de Ambiente 'Intercambio de Datos'. [Online]. *Available at:* https://geoservidor.minam.gob.pe/recursos/intercambio-de-datos/ (Accessed: 30 November 2020).

[28]iPeru 'Flora y Fauna de La Libertad'. [Online]. *Available at:* https://www.iperu.org/flora-y-fauna-de-la-libertad-peru (Accessed: 24 November 2020).

[29]Dillon, M. O. (2005) *Solanaceae of the lomas formations of coastal Peru and Chile. A festschrift for William G. D'Arcy: the legacy of a taxonomist* 131– 155 pp. *Available at:* https://www.researchgate.net/publication/265225534_THE_SOLANACEAE_OF_THE_LOMAS_FORMATIONS_OF_COASTAL_PERU_AND_CHILE.

[30]Brack, A. *et. al.* (2008) 'Serrania Esteparia', *Enciclopedia Ecologia del Peru.* https://www.peruecologico.com.pe/ecorregion_serrania_1.htm (Accessed 24 November 2020)

[31]WWF 'Southwestern Ecuador and Northwestern Peru'. [Online]. *Available at:* https://www.worldwildlife.org/ecoregions/nt0232 (Accessed: 26 November 2020).

[32]Whaley, O. Q. *et. al.* (2010) 'An ecosystem approach to restoration and sustainable management of dry forest in southern Peru'. *Kew Bulletin*, 65 (4), pp. 613-641. *Available at:* https://doi.org/10.1007/s12225-010-9235-y

[33]Brack, A. *et. al.* (2008) ' El Bosque Seco Ecuatorial', *Enciclopedia Ecologia del Peru.* https://www.peruecologico.com.pe/lib_c7_t01.htm (Accessed 24 November 2020)
[34]Peru North (2020) 'Dry Forest'. [Online]. *Available at:* https://www.perunorth.com/dry-forest (Accessed: Accessed 25 November 2020).

[35]Bos, T. (2015) *Trees in the desert: A suitability assessment for a future community forestry and reforestation project in the department of La Libertad, Peru.* University of Applied Sciences Van Hall Larenstein Velp. *Available at:* https://hbo-kennisbank.nl/details/samhao:oai:www.greeni.nl:VBS:2:140926

[36]Beresford-Jones, D. G. *et. al.* (2009) 'The role of *Prosopis* in ecological and landscape change in the Samaca Basin, Lower Ica Valley, South Coast Peru, from the early horizon to the late intermediate period'. *Latin American Antiquity*, 20 (2), pp. 303-332. *Available at:* http://www.jstor.org/stable/40650197

[37]Society for Ecological Restoration 'Restoration of the Prosopis pallida (Huarango) Southern Dry Forest'. [Online]. *Available at:* https://www.ser-rrc.org/project/peru-restoration-of-the-prosopis-pallida-huarango-southern-dry-forest/ (Accessed: Accessed 26 November 2020).

[38]Cuba Salerno, A. B. *et. al.* (1998) 'Proyecto Algarrobo'. *Seminario Internacional "Bosques Secos y Desertificación*. Lima-Perú.: Instituto Nacional de Recursos Naturales. *Available at:* https://agris.fao.org/agris-search/search.do?recordID=PE1997104228.
[39]CDC-UNALM y TNC (2006) *Planificación para la Conservación Ecoregional de las Yungas Peruanas: Conservando la Diversidad Natural de la Selva Alta del Perú.* Lima, Perú: Informe Final.

[40]Dinerstein, E. (1995) *An assessment of the conservation status of the terrestrial ecoregions of Latin America and the Caribbean.* Washington, DC: WWF and World Bank. 135 pp. *Available at:* http://invenio.unidep.org/invenio//record/671/.

[41]IUCN Red List of Threatened Species 'Spectacled bear'. [Online]. *Available at:* https://www.iucnredlist.org/species/22066/123792952 (Accessed: Accessed 20 November 2020).

[42]Brack, A. *et. al.* (2008) 'Las Comunidades Vegetales', *Enciclopedia Ecologia del Peru.* https://www.peruecologico.com.pe/lib_c10_t02.htm (Accessed 24 November 2020)

[43]Ministerio del Ambiente (2010) *Cuarto Informe Nacional Sobre La Aplicación del Convenio de Diversidad Biologica – Anos 2006-2009. Available at:* http://www.minam.gob.pe/diversidadbiologica/wp-content/uploads/sites/21/2013/10/Cuarto-Informe_Convenio-de-Diversidad-Biologica.pdf (Accessed 1 December 2020).

[44]Brack, A. *et. al.* (2008) 'La Ccara o Titanca en el Ambiente Andino', *Enciclopedia Ecologia del Peru.* https://www.peruecologico.com.pe/lib_c10_t03.htm (Accessed 24 November 2020)

[45]Brack, A. *et. al.* (2008) 'La Fauna de los Ambientes Terrestres', *Enciclopedia Ecologia del Peru.* https://www.peruecologico.com.pe/lib_c10_t06.htm (Accessed 24 November 2020)

[46]Dawson, I. K. (2019) *Contributions of biodiversity to the sustainable intensification of food production – Thematic study for The State of the World's Biodiversity for Food and Agriculture.* Italy: FAO. *Available at:* http://oar.icrisat.org/11207/ (Accessed 11 May 2020).

[47]Pimentel, D. *et. al.* (1997) 'Economic and Environmental Benefits of Biodiversity'. *BioScience*, 47 (11), pp. 747-757. *Available at:* https://doi.org/10.2307/1313097

[48]Veeresham, C. (2012) 'Natural products derived from plants as a source of drugs'. *Journal of Advanced Pharmaceutical Technology & Research*, 3 (4), pp. 200-201. *Available at:* https://doi.org/10.4103/2231-4040.104709

[49]Ojuederie, O. B. *et. al.* (2017) 'Microbial and Plant-Assisted Bioremediation of Heavy Metal Polluted Environments: A Review'. *International Journal of Environmental Research and Public Health*, 14 (12), pp. 1504. *Available at:* https://www.mdpi.com/1660-4601/14/12/1504

[50]UNFAO / UNIAEA 'Plant Biodiversity and Genetic Resources Programme'. [Online]. *Available at:* https://www.iaea.org/topics/plant-biodiversity-and-genetic-resources (Accessed: 11 May 2020).

[51]World Bank 'International Tourism, number of arrivals – Peru'. [Online]. *Available at:* https://data.worldbank.org/indicator/ST.INT.ARVL?end=2018&locations=PE&start=2017 (Accessed: 30 November 2020).

[52]CEIC 'Peru Tourism Revenue Growth 1996 – 2018.'. [Online]. *Available at:* https://www.ceicdata.com/en/indicator/peru/tourism-revenue (Accessed: 30 Nov 2020).

[53]Puhakka, L. *et. al.* (2011) 'Bird Diversity, Birdwatching Tourism and Conservation in Peru: A Geographic Analysis'. *PLOS ONE*, 6 (11), pp. e26786. *Available at:* https://doi.org/10.1371/journal.pone.0026786

[54]IPBES (2019) *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.* Bonn, Germany: IPBES secretariat. *Available at:* https://ipbes.net/global-assessment (Accessed 14 May 2020).

[55]Ministerio del Ambiente (2014) *La Estrategia Nacional de Diversidad Biológica al 2021 y su Plan de Acción 2014-2018. Available at:* https://sinia.minam.gob.pe/documentos/estrategia-nacional-diversidad-biologica-2021-plan-accion-2014-2018 (Accessed 30 November 2020).

[56]UNESCO 'The coastal lomas system of Peru'. [Online]. *Available at:* https://whc.unesco.org/en/tentativelists/6424/ (Accessed: 27 November 2020).

[57]Szabados, L. *et. al.* (2011) 'Chapter 4 - Plants in Extreme Environments: Importance of Protective Compounds in Stress Tolerance', in Turkan, I. (ed.) *Advances in Botanical Research.* Academic Press, pp. 105-150. http://www.sciencedirect.com/science/article/pii/B9780123876928000047

[58]Aguilar, C. *et. al.* (2012) 'Andean amphibians and the studies of environmental impact in mining concessions of Peru'. *Alytes*, 29 (1-4), pp. 88-102. *Available at:* https://www.scopus.com/inward/record.uri?eid=2-s2.0-84865261982&partnerID=40&md5=abdf8a87eb7e92c4f37bfed572385bf5

[59]Padilla, A. G. *et. al.* (2014) 'Impacto ambiental generado por erosión costera en la zona litoral de Buenos Aires Norte, distrito de Víctor Larco Herrera, La Libertad, Perú', *REBIOL 2013*. Peru.

[60]Ministerio de Economía y Finanzas y Ministerio del Ambiente (2015) *Lineamientos para la formulación de proyectos de inversión pública en diversidad biológica y servicios ecosistémicos. Available at:* https://www.mef.gob.pe/contenidos/inv_publica/docs/instrumentos_metod/ambiente/Lineamientos-para-la-formulacion-de-PIP-en-DB-y-SE.pdf

[61]Ministerio del Ambiente 'Mecanismos de Retribución por Servicios Ecosistémicos'. [Online]. *Available at:* https://serviciosecosistemicos.minam.gob.pe/ (Accessed: 2 December 2020).

[62]Barfoots 'Conserving agriculture in Peru'. [Online]. *Available at:* https://www.barfoots.com/sustainability (Accessed: 30 November 2020).

[63]Whaley, O. (2016) 'Sustaining life and agriculture in the Peruvian desert'. *Kew Royal Botanic Gardens,* Kew Royal Botanic Gardens. [Online]. *Available at:* https://www.kew.org/read-and-watch/sustaining-life-peruvian-desert (Accessed: 30 November 2020).

[64]Reforest'Action 'Discover our new reforestation project in Peru!'. Reforest'Action. [Online]. *Available at:* https://www.reforestaction.com/en/blog/discover-our-new-reforestation-project-peru (Accessed: 10 December 2020).

[65]Parks Watch 'Calipuy National Reserve and National Sanctuary Biodiversity'. [Online]. *Available at:* http://www.parkswatch.org/parkprofile.php?l=eng&country=per&park=canr&page=bio (Accessed: 26 November 2020).