GREEN CLIMATE FUND

GCF DOCUMENTATION PROJECTS

Funding Proposal

2.1 Appendix Agriculture

Feasibility Study

Water Balance

Carbon Balance

Integrated Crop

Management Monitoring

GREEN CLIMATE FUND

FEASIBILITY STUDY

CLIMATE CHANGE: THE NEW EVOLUTIONARY CHALLENGE FOR THE GALAPAGOS ISLANDS

FOOD SYSTEM COMPONENT

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INTRODUCTION

Most island populations, both developed and under-developed, have not achieved food self-sufficiency because of their intrinsic disadvantages: small size, remote location, insularity, susceptibility to disaster, and environmental fragility (Briguglio 1995). These disadvantages are the limited access to natural and social resources, e.g., water, energy, and labor (ONU, 1994) and consequently generate dependence on a narrow range of products and increase import reliance (FAO 2016a). Additionally, transport and communications become a critical issue because a failure in either one may cause uncertainty in the timely supply of agricultural products.

Food security, within the context of the food system, is increasingly important in oceanic islands, such as the Galapagos Islands, because it is being eroded by urbanization and a growing reliance on cheap and often poor-quality imported foods that have little nutritional value. Food security exists "*when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life*" (FAO 1996). Among the numerous driving forces that characterize the state of food security at a local level, the most relevant issues are encapsulated within the concept itself: food availability, food access, food utilization, and food stability (FAO 2006; FAO 2016b). In Galapagos, "food availability", which can be considered as the adequate supply of food and includes variables such as food production, stock levels, and net trade, is sometimes scarce and not capable to sustain the growing local population and the flux of tourist to the islands.

In terms of land, the total extent of the Galapagos Islands is over 799,000 hectares, of which close to 25,000 hectares are designated for agriculture and livestock activities in the defined human use zones, or agricultural areas; however, only 19,010 ha are occupied by agricultural and livestock production units (CGREG 2014). Farmers represents 5.5% of the economically active population at the provincial level. If the comparison is made at the cantonal level, Isabela is the island where 8.8% of the population is dedicated to this activity, followed by San Cristóbal with 7.3% and finally Santa Cruz with 4.3%. Agriculture in the Galapagos is developed in a defined geographic space, under a special political regime, where there are no opportunities for fair competition with imported products that come from the continent, which are highly subsidized and produced with a lower cost of labor and inputs.

The socio-ecological integrity of the Galapagos and its food system are increasingly vulnerable due the constraints described above, illustrated by its "island condition", but are raised by several other forms of human–related pressures such as invasive species, spontaneous development, constrained infrastructure, lack of regulation of imported agricultural products, and changes in the local food consumption preferences, which may alter importation trajectories and compromise conservation on the island. Central to these pressures over the food system within Galapagos are two emergent and synergistic drivers: tourism and climate change.

The rapid growth of tourism is now the main non-climate driver of change in the social, economic, and environmental systems (Taylor, 2006; Watkins and Tapia, 2007, Grenier, 2000). The tourism industry has stimulated a demographic explosion in the last several years, and attracts migrants from the mainland, and in turn has increased the requirement for goods and services to cover basic needs and livelihood standards (Pizzitutti et al., 2016). Official plans (MAGAP, 2013; MAGAP, 2016) and academic studies point out the risk to food insecurity in the islands (Walsh and Mena, 2016) due to local population and tourism exponential growth and lack of infrastructure for more food imports. Moreover, there is evidence of strong nutritional problems in vulnerable populations, which are related to lack of access to local healthy food and consumption patterns.

From the farm labor perspective, in response to the tourist industry and jobs in that sector, Galapagos is undergoing increased rural land abandonment as farmers and/or members of their households, often young adults, seek off-farm employment. The population residing in rural areas has decreased from 42% in 1974 to just 17% in 2010 (INEC, 2010, 1974). This trend has resulted in decreases in local agricultural production, reducing reliance on food produced on the island and decreasing the food security status of local population. As a consequence, the presence of abandoned agricultural plots is more frequently and these lands are likely to become centers of establishment and propagation of invasive plant species such as guava and blackberry (Snell et al. 2002; Jäger et al. 2009) that easily invade neighboring properties including the National Park restricted area.

Climate change already is being considered one of the stressors to the food system of Galapagos. Barrera et al (2019) accounts that 71,1% of farmers report emergent droughts as one of the main challenges for the food system. Weather and climate patterns in the agricultural zones, located in the highlands of Galapagos, are controlled by long term oscillation cycles like El Niño-Southern Oscillation (ENSO) cycle. El Niño, the warm phase of ENSO generates torrential rains in the agricultural areas and la Niña, the cold phase, creates extended drought periods. Scientific analysis predicts erratic conditions of ENSO in the next years with strong and prolonged El Niño. For example, in the period between October 2015 and January 2016, intensive rainfall was recorded with an accumulation of 1,073 mm at the provincial level (INAMHI, 2016). Followed by a period of extreme drought from January to November 2016, which severely affected 56.5% of land for agricultural use (10,740 hectares) according to information provided by the Ministry of Agriculture (MAGAP, 2016), causing economic losses and environmental impact in the agricultural sector, that has been unrecoverable to date.

Moreover, Barrera et al (2019) also report uncertainty of weather conditions as a main challenge that farmers in the Galapagos face, as there is no meteorological or climate early warning system that alert them about dangerous conditions. Additionally, invasive plant species and crop and animal diseases benefit from El Niño like conditions and make it difficult for farmers to eradicate and cultivate land.

In this context, the general objective of the component is to strengthen the food system of Galapagos through the implementation of climate and sustainable resilience measures that reduce the pressure on the ecosystem and consequently to achieve food security. The objectives of this component are: i) Enhance institutional capacity for climate-resilient planning and development; ii) Improve farmers livelihoods and rehabilitate ecosystem services through climate-resilient water and agricultural food productions systems; iii) Improve climate-resilient local value chain or upgraded and more efficient green value chains and increase links to local markets.

1. CHAPTER 1: CLIMATE CHANGE AND THE FOOD SYSTEM IN THE GALAPAGOS ISLANDS

BASELINE: The Food System in the Galapagos Islands

The Galapagos Islands are considered a unique natural laboratory for evolution, generating vast interest from science and conservation, but also from the tourism industry. In this sense, the Galapagos Islands are not only limited in access to resources due to their insular condition, but also its food system is pressured by the tourism industry, which generates short-term and permanent immigration. Food security exists "*when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life*" (FAO, 1996). In the Galapagos, within the food security context, there is a conflict between the well-being of the local population, growing tourism industry, the conservation of their ecosystems, and the risks that climate change implies.

The food system is a complex web of activities involving the production, processing, transport, and consumption (Ericksen 2008). There are several immediate causes and driving forces that characterize the state of food security, within a food system at different scales, the most relevant are considered in the same concept: food availability (the availability of sufficient quantities of food of appropriate quality, supplied through domestic production), access and use of food (Access by individuals to adequate resources -entitlements- for acquiring appropriate foods for a nutritious diet), as well as food stability (To be food secure, a population, household or individual must have access to adequate food at all times. People should not risk losing access to food as a consequence of sudden shocks, e.g. an economic or climatic crisis or cyclical events) (FAO, 2016b, 2006). In this sense, adaptation measures for external shocks, including climate change, will focus on food availability and specifically in the local productive system.

A feature that the Galapagos Islands share with many other oceanic islands is that there are a set of interacting drivers of food system, including the rapid growth of the tourism industry, has become the most important driver of the economy, and its rapid local population growth is also now the main factor of social and environmental change (Taylor, 2006; Grenier, 2000). In this proposal, we focused in one component of the food system "the local food production", which has not been able to keep up with the growth rate to satisfy the growing demand, both local and tourist, due the weakened productive system by institutional factors and biophysical conditions, including climatic impacts. As consequence, dependence on imports from the continent increased, generating a high risk on introduction of invasive species, as well as an increased in the level of GHG emissions due marine and aerial transportation.

Relevant Biophysical Conditions

Water Availability

As a result of the seasonality of the hydroclimatological process, having enough water to sustain human, agricultural, and economic activities has been identified as a major challenge of the Islands. Of the major populated Islands, only San Cristobal has sufficient freshwater sources as it has a series of perennial streams and networks of aquifers which result in water springs and surface water bodies. Santa Cruz and Isabela are dominated by brackish water, characterized by basal aquifers at lower elevations and deep boreholes at higher elevations where water is fresher (Violette *et al.* 2014). Brackish water at lower elevation in Santa Cruz island results from both seawater intrusion and aquifer over-exploitation and it is contaminated with both organic (Liu and d'Ozouville 2013) and inorganic (López and Rueda 2010) matter. At higher elevations, water is less saline since it is extracted from deep boreholes (Violette *et al.* 2014). Floreana on the other hand depends on small-outflow springs that have become depleted over the years (d'Ozouville 2007). Thus, across the islands, the water available to sustain various uses and needs is generally deemed as scarce (d'Ozouville 2007).

While the main inhabited Islands have diverse characteristics, in various cases they share similar problems. For example, across Santa Cruz, San Cristobal, Isabela, and Floreana, the lack of universal coverage (or even the total absence) of water systems forces people to store locally water in tanks (Grube *et al.* 2020). As a result, a significant amount of water is being wasted and lost due to ageing networks, the lack of proper maintenance, leaks, and overflow (Reyes *et al.* 2015).

In Galapagos, water for irrigation is scarce (d'Ozouville 2007, CISPDR 2015), only 30% of the farms have access to irrigation (Table 1) and contains high salinity concentrations making it unsuitable for long term use. This also causes alterations in the soil properties (Mateus *et al.* 2019). In Santa Cruz, there are 8 water sources for irrigation: 1) Los Picachos, 2) Toma del Gallito, 3) Los Guayabillos, 4) Poma Rosa, 5) El Carmen, 6) Salasaca, 7) Cerro mesa, and 8) Finca Sra Marina Salazar. However, there is little understanding of the aquifers' recharge rates, availability, and their status (d'Ozouville *et al.* 2008).

Table 1. Access to Irrigation in the Galapagos

	Access to Irrigation	No access to Irrigation
Island		
Isabela	39%	61%
San Cristobal	27%	73%
Santa Cruz	29%	71%
Farm size		
Small-scale farms	30%	70%
Medium-scale farms	25%	75%
Large-scale farms	34%	66%
Galapagos	30%	70%

In San Cristobal, 17 main springs and the permanent surface water bodies usually sustain human and irrigation demands during the wet season, when conditions remain *normal* and *good*. Also, in general, farmers on this island have built a series of small reservoirs in areas with important perennial springs (Cerro Verde, El Chino, Cerro Gato, El Progreso, El Socavón y La Soledad). Nevertheless, limited water supply from the local water utility company in San Cristobal forces households to store water in roof tanks or cisterns (Grube *et al.* 2020). When dry seasons are intense, or there are poor wet seasons, farmers need to rely on rainfall collection and paid municipal water tanks (CISPDR 2015).

In Isabela, freshwater can be found in natural pools and crevices which are rainfed. However, water with sufficient quality can be just found shallowly since brackish and salty water can already be found just a few meters deep (Violette et al. 2014). In this Island, there is no water distribution system for the agricultural and livestock sectors, so farmers here completely depend on Ministry of Agriculture (MAG) and private water tanks (CISPDR 2015). Floreana Island depends on water tanks due to an absence of a distribution system. As a result, crops are planted just during the rainy season. As a result, these islands typically rely on the continent for supply of both water and food (CISPDR 2015). MAG has proposed irrigation infrastructure incentives for a few areas in the highlands (Los Picachos, Toma del Gallito, Los Guayabilllos, Poma Rosa, El carmen, Salasaca, Cerro mesa, Finca de la Sra. Marina Salazar) in order to improve water availability.

Water Quality and Sanitation

The Galapagos Islands face a double challenge in terms of delivering enough water with sufficient quantity and quality to its growing population. An important problem, related to agriculture and cattle ranching, and in general related to human-induced practices, are the impacts to water quality. In general, the contamination by solid wastes, organic wastes, fertilizers and pesticides, garbage thrown and accumulated, affects the superficial freshwater resource in streams or gullies, and in the waters that drain in the subsoil or in the water table.

Moreover, water sanitation and wastewater treatment are still inadequate in the Islands. Currently, San Cristobal is the only inhabited island in the Galapagos with a municipal wastewater treatment plant (WWTP), however, the WWTP has been shut down since October of 2019 for maintenance and it is expected to be operating by the end of this year. Following a monitoring in these WWTP for three years, it was found that the removal efficiency was 64% of COD and 68% of BOD5 (Grube *et al.* 2020). Removal efficiencies of other key parameters range from about 25%, for ammonium, to about 85%, for turbidity.

These results indicate that although the WWTP in San Cristobal is functioning, it could be optimized to reach removal efficiency of organic matter, nutrients, and suspended solids higher than 85%, which is expected during the biological treatment of domestic effluents (Metcalf and Eddy, 2003). In Santa Cruz and Isabela, water sanitation and wastewater conditions are still very rudimentary. In these islands, since there is no public sewage network nor municipal wastewater treatment plant, households and commercial entities rely on individually based septic systems to treat wastewater (CGREG 2016). In Santa Cruz, for example, by 2010, 97% of households were connected to septic tanks and 1.9% to public sewerage networks (CGREG 2016). In many cases, septic tanks have collapsed allowing the filtration of wastewater into groundwater. Also, in these islands effluents and untreated water is typically discharged directly into the ocean without any treatment. Hence, these effluents affect water quality of oceans and thus may potentially alter biological diversity and composition. This in turn poses a clear growing risk to the economy, food security, public health, and the stability of these fragile biological ecosystems.

Climate altitudinal levels

Altitudinal variation produces drastic biophysical conditions in a relative short range in the agricultural areas of the Galapagos. From 100 meters above sea level, the bioclimate range from semi-arid to semi-humid. When altitude increases humidity increases with a high presence of drizzle and fog, mainly in cold season. These conditions give rise to, different, humid ecosystems favoring the agricultural development of different traditional crops across de gradient (Allauca et al., 2018):

- Tropical (150 to 250 m.a.s.l), crops include musaceous (e.g., banana, edible plantain), coffee, vegetables, fruit trees, pineapple, among others.
- Temperate (251 to 450 m.a.s.l), crops include vegetables, corn, potatoes, grasses, among others.
- Cold (above 451 m.a.s.l): include grasses, potatoes and citrus (less quantity).

From the perspective of agricultural activities, the alternation of warm and cold seasons allows the production of both tropical-weather crops and temperate-weather crops on the same altitudinal level. This contributes to the diversification of agricultural production, which is key to the resilience of the system.

Soils

The soils of the Galápagos Islands span a wide age range on relatively similar parent material and formed under varying moisture conditions on each island. Clear differences in the characteristics and nutrient reserves exist between the young soils of Isabela and older soils of San Cristóbal (Dinter et al. 2020). Agricultural soils are superficial of volcanic origin, young and stony (CGREG, 2016). However, soils are extraordinarily rich in nutrients, which allows agriculture and livestock to develop successfully for most agricultural products (MAG, 2019).

Isabela's agricultural soils are likely easier to cultivate due to their low bulk density, while the coarse texture provides good drainage. These characteristics, along with their high Soil Organic Carbon (SOC) contents, high pH and relative abundance of base cations make the soils of Isabela Island well-suited to agriculture (Figure 1). Many of the soils of San Cristóbal Island are clayey, have low pH values and are largely depleted of their nutrient reserves, which poses challenges to agricultural management. Soils in Santa Cruz island have intermediate conditions that change with elevation.

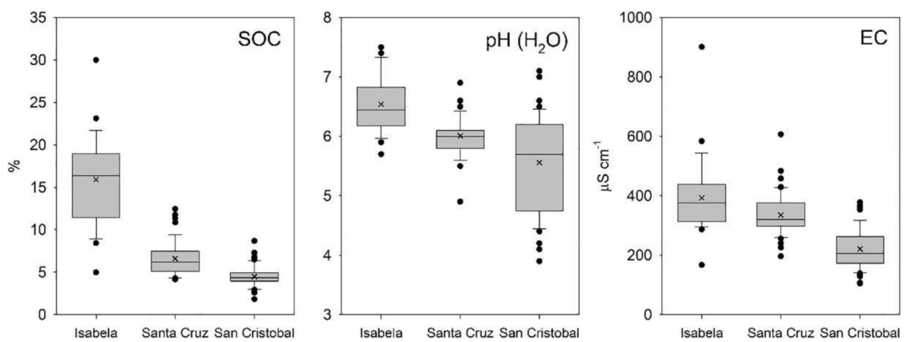

Figure 1. Soil organic carbon (SOC) contents, pH in H2O and electrical conductivity (EC) across islands Isabela, Santa Cruz and San Cristóbal (Dinter el al. 2020)

Barrera et al. (2019) evidenced an accelerated process of soil degradation within the productions systems, caused by intensive processes of land use and inadequate agricultural and livestock practices. Such factors are amplified by the presence of adverse climatic conditions that contribute to the loss of rich carbon soil. Soil management recommendations need to be tailored for each island and within each island considering the diverse spectrum of soil properties (Dinter el al. 2020).

The Food System in Galapagos

There are two distinct sources of food in Galapagos: products imported from the mainland and locally produced. The growing human population in Galapagos, from 18,640 in 2001 to 25,244 in 2015, has increased the demand for food, which has led to most food products being imported from the mainland, generating a cascade of impacts from the abandonment of agricultural lands to the increasing the risk of introducing invasive species to the archipelago.

Inhabitants of the highlands of the Galapagos use their land for three general activities: cattle ranching (bovine, poultry, pork), crop production (permanent and annual crops), and tourism activities. The consumption per capita of vegetables and livestock food in Galapagos is higher than the Ecuador national average: 0.3119 tons/year/person for agricultural products, which include fruits and vegetables; and 0.1319 tons/year/person for livestock products, which include meat, eggs, and milk, while the national average is 0.2825 and 0.0973, respectively. In general, the main consumption rates correspond to residents who meet their basic needs consuming more than 92% of agricultural products and 98% of livestock (Sampedro et al 2019).

Figure 2 illustrates how food demand is connected by local population and tourism growth and the links between important factors, including land abandonment, greenhouses emissions and invasive species. The consumption patterns of both local and tourist populations are changing according to the requirements and preferences, especially of the tourism industry, which has pushed a large flow of imports of agricultural and processed products from the mainland.

Additionally, the agricultural labor force is affected by the opportunities in the tourism industry that offers better remuneration and is perceived as less risky than agricultural life, which leads to an abandonment of agricultural land. The abandonment of the plots is mainly exploited by the occupation of invasive plants that are difficult and expensive to eradicate once they are scattered. In addition to these variables, it is important to emphasize that demographic conditions, such as the structure of the household, and environmental conditions such as humidity and precipitation, are crucial for agricultural development.

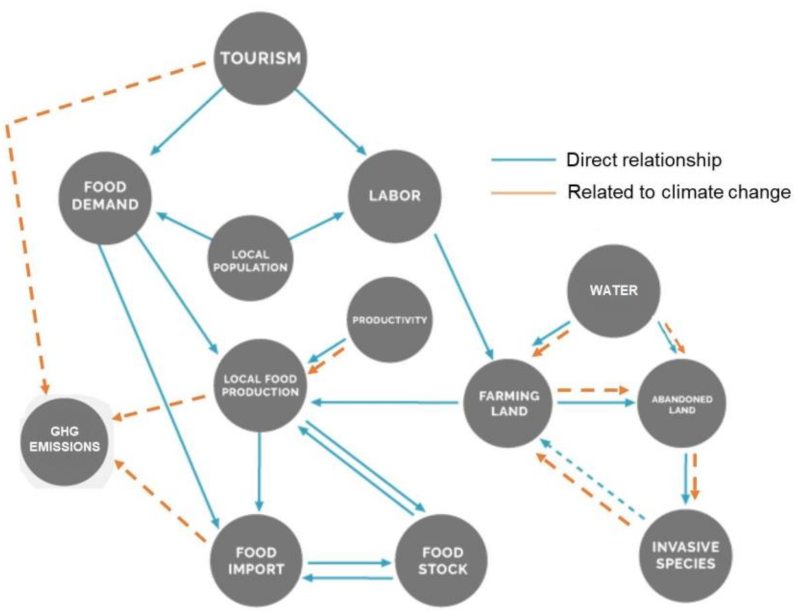

Figure 2. The food system in the Galapagos Island with the connections across components and the relationships with GHG emissions

Since the beginning of the colonization of the Galapagos Islands, agricultural and livestock work have been fundamental for the survival of the families. Agricultural settlers (*colonos*) have introduced a variety of seeds and animals used in continental agriculture and are still present in the Archipelago. Their potential to adapt to the productive conditions of the island, their resilience to climate change and their contribution to the nutritious diet of the population is unknown, causing in many cases the underuse of these species or the removal of these genetic resources. The most common transitory (annual) crops include maize, cassava, watermelon, and tomatoes, but these are reported to represent only about 3% of the agricultural surface area (Laso et al., 2020). The most common permanent (perennial) crops are tree crops such as coffee, banana, and plantain, but also pineapple and sugarcane (CGREG, 2015). Permanent crops cover nearly 12% of the surface area (Laso et al., 2020). Landowners reported that most permanent and transitory crops are grown as monocultures (CGREG, 2015).

Pastures cover about 22% of the land surface area of Galapagos agroecosystems, either cultivated or naturally germinated (Laso et al., 2020). A commonly grown variety is elephant grass (Pennisetum purpureum), which is used as cattle feed but is also considered invasive (Pyšek et al., 2017). Pastures for cattle forage are often combined with forestry practices for tree crops or timber products, an agroecological practice known as silvopastoral (Cruz, Coral, Montúfar, & Baquero, 2007). Trees crop varieties are used in silvopastoral systems/practices often include lemon (Citrus spp.) or guava (Psidium guajava); this last specie is also considered highly invasive, due its rapid advance across ecosystems.

Given the direct influence of agriculture on both the introduction and regulation of introduced species, local government promotes alternative agriculture practices to control the spread of invasive plants to nearby native dominated patches or to the protected lowlands while simultaneously contributing to local food security. (MAG, 2014; Toledo, 2014; Valdivia et al., 2013). Farmers spend a great amount of time and resources clearing their land of invasive plants, which usually proliferate in vacant areas. Land parcels that do not have active land management sometimes become monocultures of invasive plant species, like guava (Psidium-guava) and cedar (Cedrela odorata), which then spread into the adjacent protected areas. In fact, at least 28% of the surface area of the agricultural areas is now covered in invasive plants (Laso et al., 2020). P. guava forests alone, for example, now cover about 20% of agricultural surface area (Laso et al., 2020). Despite its "invasive" label, many cattle ranchers keep a controlled amount of P. guajava as part of their silvopastures because it has proven to be effective in providing moisture, shade, and additional food for their cattle during the dry season.

Models developed by Sampedro et al (2019) link different scenarios of tourism growth: accelerated (exponential), moderate (business as usual), and no growth (zero increase) to set of agricultural variables to create future scenarios. For example, Figure 3 (a) shows land used for agricultural purposes under the three different scenarios of tourism growth, in all cases the amount of land devoted for agriculture (i.e., crops), without any interventions, will decrease, for different reasons, including the expansion of pastures for cattle ranching and lack of labor. Figure 3 (b) shows the relationship of agricultural labor as absorbed by the service sector that tourism industry provides. Without major interventions, the opportunities in the service sector in hotels and restaurants will absorb agricultural labor in different degrees.

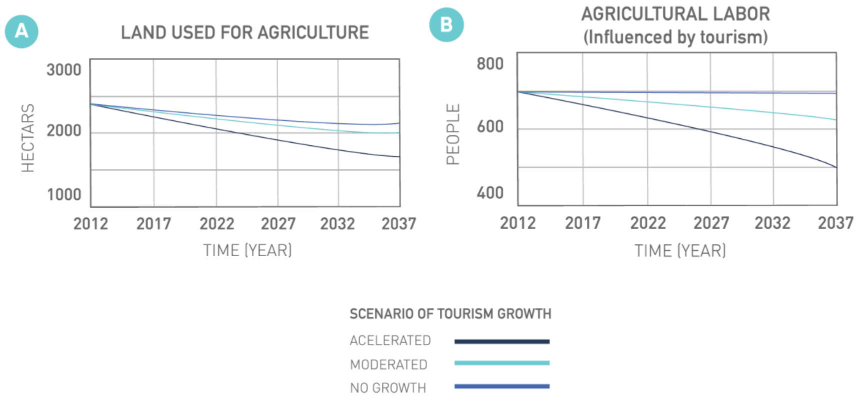

Figure 3. Relationships between tourism growth and local agriculture. Based on Sampedro et al. 2019

On the other hand, in the Galapagos, imports are the largest source of food. The population of the Galapagos Islands depends on imported food through sea and air cargo because local agricultural production is not able to meet the population's demands for agricultural products with a deficit of 47% (Table 2). Sampedro et al (2019) calculates that about 75% of agriculture food supply was transported from the continent in 2017 and this will increase to 95% by 2036 if there are not changes in food policies (Figure 4).

Table 2. Production destination and consumption of local agricultural products (Tons) in Galapagos according to the last agricultural census of 2014

		Production [Tons]
Destination of the production	Self-consumption	581.95
	Market (Traders)	666.84
	Market (Final consumer)	963.75
Total		2,212.54
Consumption of agricultural products (local community)		4,150.01
Difference		-1,937.47 (47%)

Depending on the information source, other author states that around 90% of the food in the Galapagos is imported from the mainland (Guzmán, 2015).

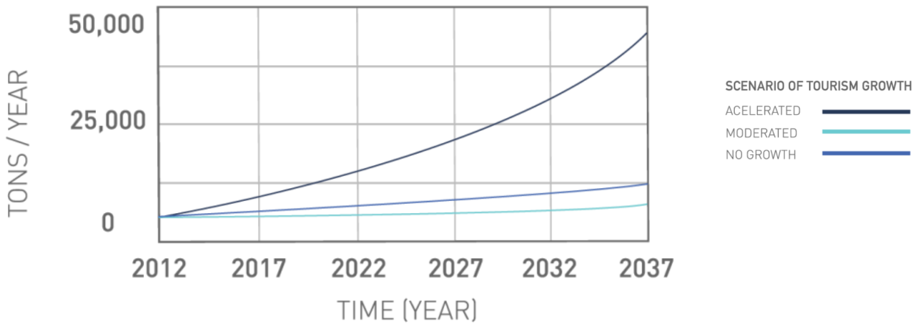

Figure 4. Scenarios of Imported Food (Tons/year)

The Galapagos consumption behavior has a direct impact on social, economic, and environmental systems through the increased use of resources including agricultural products and livestock production. This requires more land, water, and energy resources, and raises the carbon footprint because of food's transportation (Pizzitutti et al. 2016). Consequently, the expenditures for the population and local authorities also increase (Llive 2016).

Additionally, food imports are the most important driver of invasive species arrival in the Galapagos (Cremers, 2002; González et al., 2008). Food imports increase the need for waste management (Buzby & Hyman 2012) and impacts public health (Freire et al. 2014). Thus, analyses of consumption patterns, such as that presented here, provide important information for creating consumption guidelines. The same types of analyses are also necessary for the food supply system. McElroy & Albuquerque (1990) emphasize that mitigating only natural and economic constraints cannot address long-term institutional and structural obstacles to adequate food supply. They concluded that agricultural policy must be integrated into overall economic planning to account for sectoral imbalances, while institutional and information infrastructures must be strengthened (FAO 2017).

Nutritional Impact and Food Insecurity

Galapagos undergoing a nutritional transition, drastic changes in diet and lifestyle that lead to obesity and chronic diseases (Waldrop et al. 2016). There is consistent evidence of the impact of food insecurity in the islands, which is pushed forward by the lack of availability and quality of fresh produce, as well as easy access to industrialized processed and ultraprocessed foods (Freire et al. 2018). In a recent study, most women (55%) reported food insecurity and 60% reported limited availability of fresh produce due to an unreliable food supply shipped from mainland Ecuador (Pera et al. 2019). More important, in Galapagos, there is the prevalence of the dual burden nutritional disease, where: (1) overweight and noncommunicable disease risk factors and (2) undernutrition and infectious disease symptoms are present within individuals and households. In Galapagos, 16% of children, 33% of adults, and 90% in households, food insecurity was positively associated with the risk of dual burden at the household level (Thompson et al. 2020). In terms of water security, in rural areas of Galapagos, being higher income in rural settings is significantly protective of water quality and increasing household size is associated with reduced water access (Nicholas et al. 2020), which can be interpreted as the poor rural households as the most vulnerable for water insecurity.

Although a multicomponent intervention is needed in the Galapagos to solve the nutritional problems (Ocampo 2017), it is clear that the availability of fresh healthy food is strongly needed. There are two complicating and related factors: (a) the growing need for food linked to increase number of tourists and (b) the lack of local agriculture due farm abandonment and uncertainty to farming conditions, including climate change. Assuming that the importation of more food is extremely difficult due the lack of ports, ships, and the excessive financial and environmental costs, it is necessary to improve the local food production and generate a climate resilient farming system.

The Production Sub-system

All four inhabited islands of the Galapagos, Santa Cruz, San Cristobal, Isabela, and Floreana, have a zone in the humid highlands that has been designated for agricultural use (Figure 5). This region extends from what is commonly known as the "transition zone" at about 200 m.a.s.l. to some of the highest points of the islands (~700 m.a.s.l.). The agricultural regions face the south or windward side of the islands, which receive high levels of precipitation during the warm season (January-May) and remain enveloped in clouds during the cool season (June-December) (Itow, 1992). Due to the higher overall humidity and lower average temperatures and solar radiation throughout the year, these areas also record higher productivity and plant diversity when compared to the dryer lowland ecosystems of the Galapagos (Itow, 1992). The continuous influence of atmospheric and climate factors, such as temperature, precipitation, wind and radiation, over highland areas have gradually weathered the islands' volcanic rocks, creating a patchwork of nutrient-rich soils of variable depths and textures (Chiriboga, Fonseca, & Maignan, 2006). The variation of both climatic factors and soils has created the conditions for a highly diversified agricultural matrix in Galapagos with a high diversity of plant and animal species across variable climates.

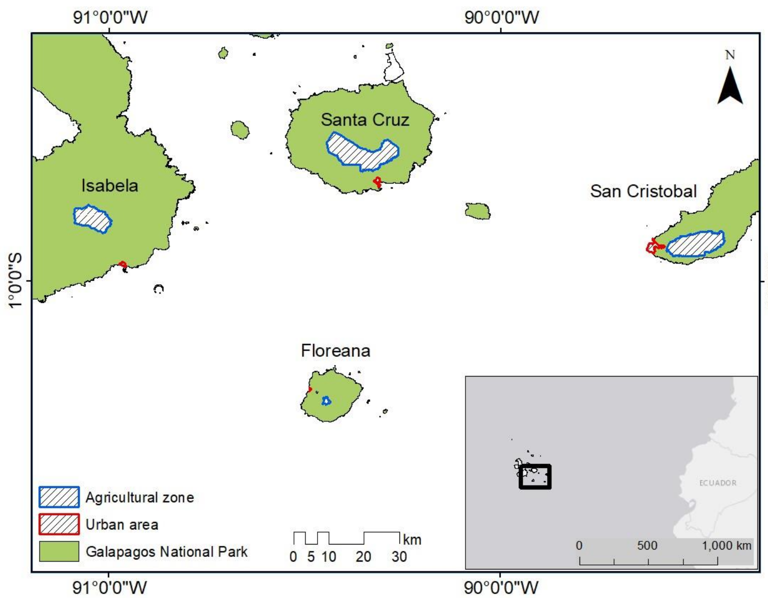

Figure 5. Map of agricultural areas. Galapagos Science Center, 2019.

Due to these environmental conditions, the highlands of the four inhabited Galapagos islands, Santa Cruz, San Cristobal, Isabela, and Floreana, have been used for agricultural development since the early-19th century. During most of the human history in the archipelago, agriculture was one of the main economic engines and sources of food, and hundreds of alien plant species were intentionally introduced for this purpose (Chiriboga & Maignan, 2006; Guézou, Pozo, & Buddenhagen, 2007; Guézou et al., 2010). Some of these plant species have since become naturalized, some of them becoming productive, others dispersing to other areas within the humid highlands without human aid, and a smaller fraction of them have become invasive threatening the native ecosystems (Guézou et al., 2010; Trueman, Atkinson, Guézou, & Wurm, 2010; Tye, 2006; Watson, Trueman, Tufet, Henderson, & Atkinson, 2009).

Crops

Around 147 introduced crops were reported until 2018, involving more than 341 traditional varieties (vegetables, grains, roots, and tubers, medicinal, fodder and fruit tree) with productive potential and adapted to the island's conditions (Allauca et al., 2018). Regarding the diversity of crops, Allauca et al., (2018) also reported that, at the farm level, the number of crops planted ranges from 1 to 44 species, with an average of 11 crops per farm. 46.6% of farmers cultivate between 1 and 10 species. The analysis by groups according to related crops (Figure 6) shows that the fruit trees are the group with the highest percentage of presence, followed by vegetables. The group with the lowest percentage of presence is the ornamental crops.

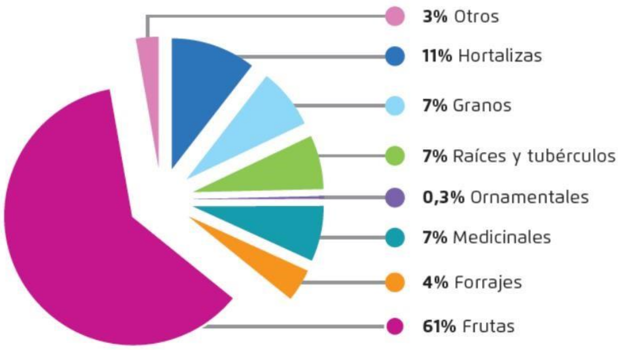

Figure 6. Percentage of crops distributed within farms. Allauca et al. (2018).

In terms of productivity, the crops identified within each farm are categorized based on income-generating potential, the value or use associated with the cultivated species, the productive resources (soil and water) and external factors such as transportation and irrigation infrastructure. In 2019, on the four main islands, at least 23 crop species (Table 3) were reported by farmers as the most widely used species based on the contribution to family income (chard, broccoli, sugar cane, cilantro, coffee, cabbage, bean, banana, lettuce, lemon, maize, sweet corn, orange, tangerine, potatoes, papaya, pineapple, pepper, watermelon, tomato, green beans, cassava). Coffee, pastures, pineapple, tomato, cassava, papaya, orange, banana, maize, platano, and watermelon provide better economic benefits. On Floreana Island, pineapple was the crop that guaranteed family income, while in Isabela and Santa Cruz, Cattle ranching use and the associated pastures reached a higher percentage (Barrera et al., 2019). The coffee is the product with the maximum cost per kilogram ($11) in Galapagos.

Table 3. Current Performance of crops in the Galapagos (Barrera et al, 2019)

Current Performance			
Crops	(Tons/Ha)	Crops	(Tons/Ha)
Lemon	9	Orange	9
Coffee	1	Papaya	14
M-plátano	8.5	Potato	11
M-banana	9	Pepper	6
M-orito	2	Pineapple	14
Cassava	16	Tomato	14
Sugar cane	75	Peanut	1
Beans	1.6	Passion fruit	20

Vegetables	5.5	Aromatics	0.4
Maize	7	Medicinals	0.5
Sweet corn	15	Pasture	11.2
Tangerine	11	Forages	21.8

Seeds

The Census of Agricultural Production Units in 2014 reported that most farmers source their perennial crop seeds directly from their own harvest without any quality criteria. These types of seeds are denominated “common seeds”. The frequent use of common seeds is notable in Galapagos farmers, even in crops of great commercial interest, such as coffee (88%), plantain and banana (99%), and cassava (93%), one of the most widespread transitory crops. For this reason, the use of improved (7%), certified (4%) or hybrid (2%) seeds is still low. In the case of maize crops, 12% of farmers use certified seeds, another 12% use hybrid or improved seed, and the remaining use common seeds. However, 43% of tomato and 45% of watermelon are from certified seeds.

In 2018, the agrobiodiversity study of Allauca et al. (2018) determined how seeds flow into the islands. The study found that the main source seeds are from farmer’s family or own crops, followed by from relatives, neighbors, markets and stores. The same study found that less than 1% of farmers destined growing crops for seeds. Of this percentage, only 26.4% of farmers indicated that they use methods of seed’s conservation (Figure 1.21), including storing store their seeds either in a refrigerator (25.5%), or in jars (23.4%), with insecticide (23.4 %), or in the shade (21.2%).

Livestock

Livestock is defined by FAO as "the activity of raising land animals for food production". Ruminant species (cattle, buffalo, sheep, goats), pigs and poultry, represents 40% of the agricultural production worldwide (FAO, 2019). Livestock production is a vast producer of GHG, cattle (meat and milk) and generates around 5.0 gigatons of CO_2-eq per year at global level, which represents 62% of emissions from livestock activities globally. Pigs emit 0.7 gigatons of CO_2-eq, poultry 0.6 gigatons of CO_2-eq, buffaloes 0.6 gigatons of CO_2-eq and small ruminants 0.4 gigatons of CO_2-eq. The activities that generate GHG emissions in the livestock activity are production, processing, and transport of animal feed (45%), enteric metabolic process (40%) and change in land use (15%). Of the 45% of emissions from production, processing, and transport of animal feed, between 10% and 15% corresponds to the fermentation processes of organic matter (manure and urine) on grasslands. For this reason, there is an international convergence to work in the livestock sector to generate adaptive capacity, by focusing on i) new methods and approaches to assess the adaptation of the sector to Climate Change, as well as the secondary benefits of mitigation and resilience; ii) Improvement of soil carbon and soil health and fertility in grasslands and agricultural land, as well as integrated systems, including water management; iii) Improving nutrient use and manure utilization to achieving sustainable and resilient farming systems; iv) Improvement of livestock management systems; and v) the dimensions of climate change related to socioeconomic aspects, and food and nutrition security in the agricultural sector (UNFCCC, 2017).

In Ecuador, families' livestock production represents 88% of the Agricultural Production Units (Farms) and occupies 41% of the total agricultural land in the country. Beef cattle is the species with the highest presence, registering 4.12 million heads in 2015, pigs occupy the second place with 1.64 million heads (MAE, 2017). The "Third National Communication on Climate Change" prepared in 2017, points out that Ecuador generated 0.081 gigatons of CO2eq in 2012, of which 18.17% is generated by the agricultural sector. The report does not specify the amount of emissions from the livestock sector, but it is mentioned that enteric fermentation is the category with the highest emissions in the sector.

In the case of the Galapagos, cattle farming occupies 58% of the local agro-production area where, according with the last land use and cover classification (Laso et al., 2020), about 15% of livestock area is covered by native forest and 24% is covered by invasive species, of which Psidium-guava is the predominant alien species (70%). In 2014, there were 10,100 heads of cattle distributed in 271 farms. According to the type of farm, 27 farms were dedicated to milk production, 93 farms to meat production and 151 farms have a dual-purpose production (MAG, 2018). However, in 2019 the Bioregulation Agency of Galapagos (ABG) officially registered 10,475 bovine units distributed in 303 farms. 45.75% of the cattle are in Santa Cruz Island.

About 220 heads of cattle (80,088 lb) are slaughtered monthly, of which 91.5% sold in markets (ABG, 2019). Local farms are the only beef suppliers to the consumer in the Galapagos, since this food product is on the list of prohibited entry products due to biosafety and quarantine standards, unless it is processed. However, the entry of frozen tenderloin has been allowed for the tourism sector. Santa Cruz supplies 69% of the total production, San Cristobal 25%, and Isabela contributes 6% (MAG, 2018). At the same time, there are pigs and poultry production that satisfies approximately 84% of the demand of the resident and tourist population.

Demographic Conditions of Farmers

In the Agricultural areas, according to a socioeconomic survey carried out in February 2020 about 81% of the heads of households are men and 19% women. Consistently, within farms, according to the 2014 Agricultural Census and Barrera et al. (2019), 75.24% and 86% of farms are managed by men, respectively. However, despite the fact that women represent only between 8% and 30% (parish level, Figure 7) of the administrators of farms, it is worth mentioning that the data collected by the census does not reflect the real and dynamic roles of women within the farming family environment. As an example, in daily life women are in charge of managing small integral gardens where they produce aromatic and medicinal herbs, which are used for food and home care. Average age of the head of household in the agricultural area is 54 years old for men and 52 years for women.

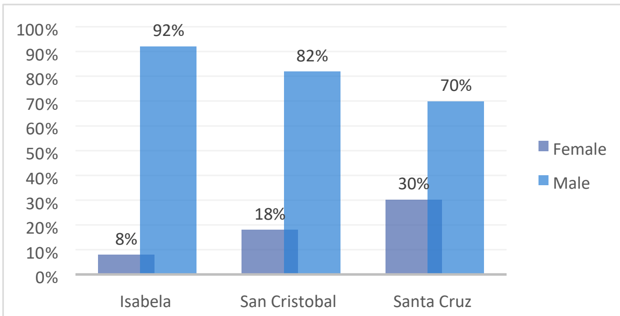

Figure 7. Roles and gender in Galapagos. Source: USFQ survey, 2020

An important factor is "time since settlement" in agricultural areas of Galapagos. The average is 42.25 years, with a minimum of 5 years and a maximum of 83. Age of the head of households and time since settlement indicates a permanent aging population, which is the trend observed currently. In relation to the origin of the heads of households in the agricultural areas, 43.27% are native of the Galapagos, 21.64% come from the province of Loja in the southern highlands of Ecuador, and 9.13% of the Tungurahua province, in the central Andes, the remaining 26% came from other 16 provinces of Ecuador.

Farms and Farming System

The local agro-production system in Galapagos is developed in 755 farms (INEC-CGREG, 2015), which have great potential for the sustainable and resilient management of the ecosystem and provide the population with vegetables, grains, roots and tubers, fruits, aromatic, medicinal plants, and animal protein (dairy, pork, poultry and beef) (Barrera et al., 2019). However, it is estimated that approximately 45.5% (~8700 ha) of the total productive area (~ 19,000 hectares, according to the last agricultural census of 2014) corresponds to land with agricultural and livestock production, while the remaining area is abandoned, covered by native vegetation (21.5%) and infested with invasive plant species (33%) such as *Psidiumguava* (guava), *Syzygium jambos* ("pomarosa"), *Lantana camara* ("supirosa"), *R. niveus* (blackberry), among others (Laso et al., 2020). Of the 755 productive units, 63% are used for family-based agriculture. This type of agriculture is implemented in production units that have an average area of less than 5 hectares and where almost 30% are managed by women (MAG, 2018).

From 755 farms surveyed on the four inhabited islands (Figure 8), located in Santa Cruz (357), followed by San Cristobal (260), Isabela (127), and Floreana (11). There is an increase of farms from 604 in the year 2000 to 755 farms in the year 2014 (CGREG, 2015), indicating a process of farm subdivision since the area for agriculture is fixed and has not increased during this time period.

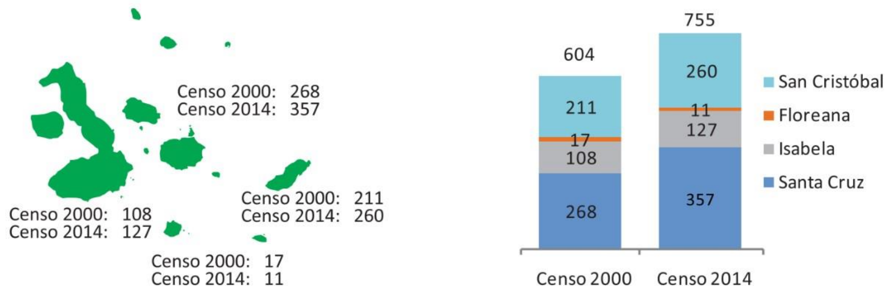

Figure 8. Distribution of Farms in Galapagos islands between 2000 and 2014. Source: Census 2014

The farms are made up of diversified farming and breeding systems, most producers combine crops with livestock, pig farming, and poultry. Thanks to their varied livelihoods, farmers can optimize agricultural income, which is why in Galapagos there are no specialized farmer groups. The raising of hens is common for most farms as a constant source of income.

61% of San Cristobal farms are dedicated to crop production, 17% to livestock and about 7% keep a mix production. In Santa Cruz about 37% of the farms keep a crop production system, while 26% for livestock activities. In Isabela, crop, and livestock production accounts for 37% and 36%, respectively, while about 16% of the farms are dedicated to mix production. Finally, in Floreana about 36% of the farms have mix production, 45% of the agroecosystems are dedicated to crop production, and only 9% produce livestock (Figure 9). The coffee production is centered in San Cristobal (26%) and Santa Crus (74%).

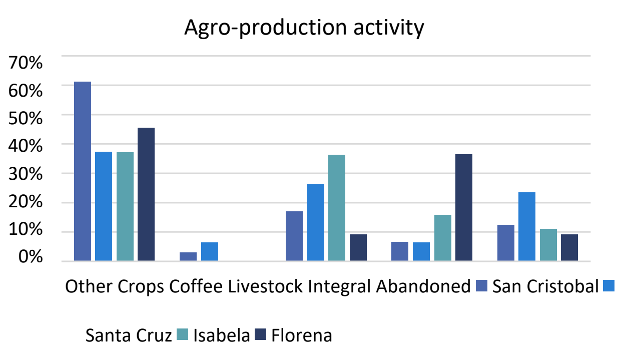

Figure 9. Agro-production activity vs Island. The values are represented in percentage.

Table 4 shows the land use in the agricultural areas in the Galapagos. San Cristobal has the largest area of abandoned farms, representing 46.3% of the total Galapagos agricultural area and 29.5% of the total Island´s agricultural area. Based on 2019 land cover classification using high resolution satellite images (Laso et al., 2020), the agroecosystems in Galapagos show a high landscape heterogeneity, where invasive plants cover most of the surface area (28%), mostly dominated by Psidium-guava (4959 ha). Pastures for raising cattle cover 22% of the agricultural zones and food crops of different kinds cumulatively cover 18% of the surface area. Inside of the agricultural areas, almost 19% of the surface were identified as Native vegetation, mainly located in San Cristobal (2535 ha). About 12% of the agricultural landscape is covered by vegetation that could not be clearly identified as either native or invasive vegetation.

Table 4. Land use in 2014 and 2019 in the Galapagos

Land Cover Class	Land Cover 2014 (Agricultural Census)		Land Cover 2019 (Laso et al., 2020)			
	Active farms		Active farms		Active and abandoned farms	
	Ha	%	Ha	%	Ha	%
Permanent crops	1,517	8	3,171	16	3,913	15
Transitory crops	330	2	587	3	698	3
Pastures	11,126	59	5,117	26	5,618	22
Invasive species	934	5	4,964	25	7,080	28
Pioneer and forest	4,622	24	5,479	28	7,630	30
Other Uses	482	3	169	1	307	1
Total	19,010	100	19,488	100	25,246	100

Table 5 shows the extent of invasive species in the agricultural areas of the Galapagos. Currently, invasive species cover the largest fraction of the non-active farms ranging from 33.86% in Santa Cruz to 76.19% in Isabela (Laso et al., 2020), being *Psidium guajava* the alien plant with most presence in the area (on average, covers 55%). On the other hand, native vegetation (native forest and pioneers), on average, covers 29% of these areas, where San Cristobal is the only island with a significant cover of native vegetation (42%).

Table 5. Extent of Invasive Species in the Galapagos

Island	Invasive Species 2014 (Agricultural Census)	Invasive Species 2019 (Laso et al 2020)
	Average at the farm level	Average at the farm level
San Cristobal	46.33%	44.04%
Santa Cruz	29.66%	33.86%
Isabela	23.49%	68.47%
Floreana	0.51%	76.19%

Food Value Chain

Food availability in the Galapagos depends largely to the extent on food and agriculture inputs (e.g., labor) imported from the mainland, despite recent regulations promoting the local production. However, imports facilitate the introduction of pests and invasive species, imbalance in competitiveness, and consequently affecting the profitability of local production (Viteri and Vergara, 2017), decreasing the resilience to external shocks, including climate change. Based on data from the 2014 Agricultural Census, Granda (2017) shows that local agricultural production in 2014 was 7,085 MT/year, while the entry of products from the mainland was 19,066 MT/year (MAG, 2018). According to Guzmán (2017), only tomato and cabbage had a local supply greater than the products coming from the mainland in 2009 (Figure 10), from the local production 2,939 MT/year corresponds to permanent (81%) and short-cycle (19%) crops. In 2019, Barrera et al. (2019) reported that the crop production increased to 5,359 MT/year, where the 84.8% (4,545 MT/year) of the production in destined for sale in the local markets, the remaining for family consumption. In the cattle production, 65% of the farms are dedicated to meat production and 35% to milk production.

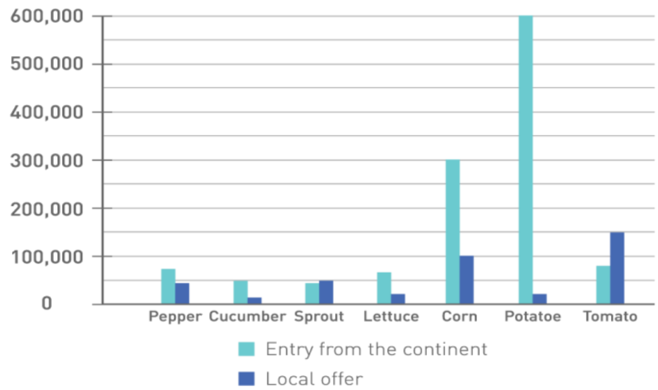

Figure 10. Local production and entry of mainland agricultural production in Galapagos in

In the Galapagos there is an “intermediary system”, which does not differentiate between local and imported foods, which means that everything is sold at the same price, depending on perceived quality, decreasing local product profitability. The diminished returns from selling local produce at markets are driving many landowners to seek a future in the tourism industry and therefore abandon agriculture. On the other hand, local meat production supplies 100% of the local and tourist demand for “fresh meat” due to the laws that prohibit the import of fresh meat to the islands, strengthening this sector. In terms of processed meats (smoked, frozen, among others), local production supplies almost 68% of the demand of the locals and the tourism industry (Espinoza, 2017).

The tourism industry, especially cruise-based tourism, has autonomous supply channels from the continent with suppliers that guarantee quality and availability. Likewise, the supply from the continent of "ready-to-eat” causes poultry farmers to work under its capacity (CGREG, 2020). On the other hand, 38% of the demand for fresh vegetables and fruits is covered by imports, and most dry food products (cereals and processed foods) are also imported, bringing the total percentage of imported supplies to close to 75%. Therefore, the province is a net food importer that is an indicator of its level of food insecurity. (Hoering, 2013).

There are links (chains) between in the wider economy of the islands through the service industry (Figure 11). In this process, there are also leaks of different types of capital, which allows resources to scape to suppliers who are located outside the area (CEPAL, 2002). In Galapagos, there is a weak articulation within the tourism chain, strong dependence on intermediaries and imported inputs from the continent, with strong potential for leaks in the system, and leakages of profits, services, utilities, and other to mainland, which impacts the local economy.

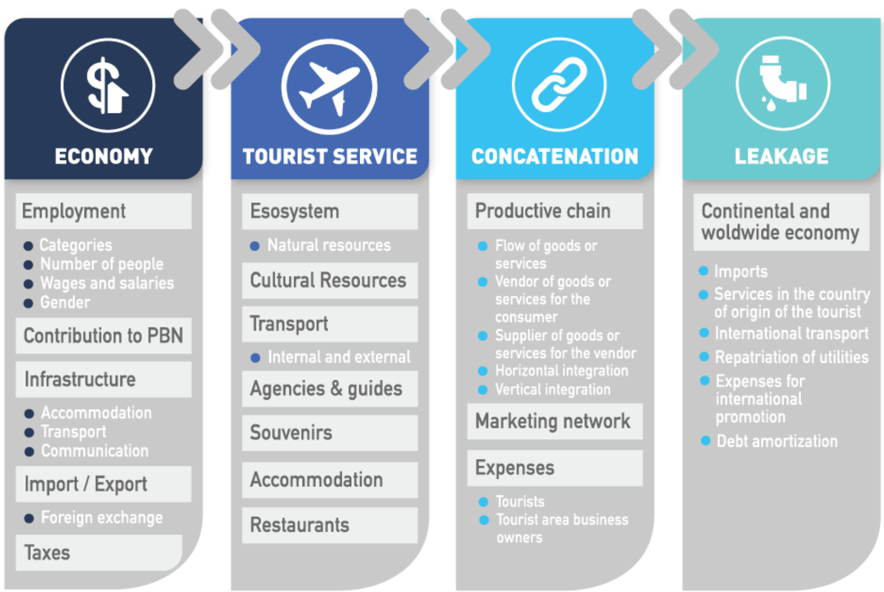

Figure 11. Links of the Galapagos Tourism Chain. Adapted from CEPAL, 2014.

The promotion of the local agricultural system is, therefore, a fundamental link to strengthen the food chain, in addition, to developing adaptive agricultural systems in the face of climate change. The destinations of its products are multiple: most are fresh products, consumed by families or sold as raw materials within the local environment. The predominant forms of sale are fairs and markets (especially merchants and intermediaries) and wholesale supply centers (Figure 12). According to FAO (2014), the basic Food Value Chain (FVC) "is made up of actors in the value chain who produce or buy products at the initial level, add value to these products and then sell them at the next level. These actors perform four functions: production (agriculture, fishing, forestry and agroforestry), association, processing, and distribution (wholesale and retail)".

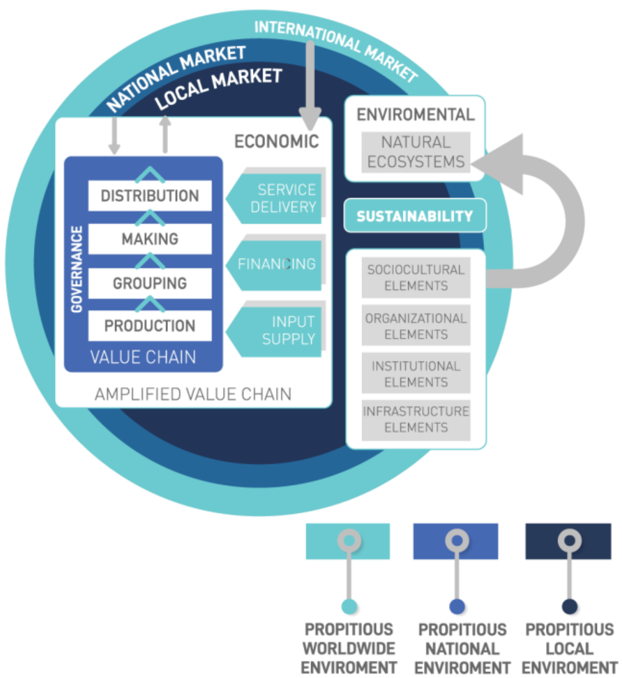

Figure 12. The sustainable food value chain development framework-FVC, Adapted from FAO, 2015

For the Galapagos Archipelago, its food vale chain generally has the same framework as those indicated in Figure 12. According to the Government Council of Galapagos (CGREG, 2020), the main problem of the “food system” in the Galapagos is that it depends on the importation of agricultural products, weakening local production. Problems are related to the difficulties of local agriculture to enter the food value chain. For example, the differences in production costs between the mainland and the islands, regular availability (lack of supply) and limited access of healthy and fresh foods, vulnerability to transportation issues make it difficult for local products to be competitive in local markets. Institutional frameworks, such as transportation subsides for products from mainland, which promote the importation of food are negative factors for local production (Viteri and Vergara, 2017). In addition, local agriculture is also impacted by to the low degree of association among producers and lack of efficient technologies.

In the Galapagos Islands, producers are grouped through unions, associations, and cooperatives. According to data from the SPMSPC (National Secretary for People, Social Movements and Citizen Participation) in 2012, 41% of active social groups were in San

Cristobal, 67% in Santa Cruz and 46% in Isabela. The Institute of Popular and Solidarity Economy, also registered in 2015 a total of 13 community organizations, associations, cooperatives, and integration organizations (CGREG, 2020). Coffee production has been promoted by a cooperative COPGALACAF, which encompass coffee farmers from the 4 inhabited islands and have strong relationships with the community.

Farmers interact with companies through verbal or written contracts. Thus, local suppliers contracted through the formal Public Procurement System represented only 7.5% in 2015 (CGREG 2016). The economic activity "transport and storage" represented 17.9% of the GDP (Gross Domestic Product) in 2010 since most of the products consumed on the islands are brought from the mainland (CGREG, 2020), while, in 2017 this activity contributed 11.8% of the annual income generated by branch of activity (INEC, 2017).

The distribution of goods within the island or inter-islands is done through motorized vehicles or vessels, which causes an energy dependence on the continent, which entails impacts such as the latent risk in the maritime space due to possible fuel spills (CGREG 2016). Most institutions that supply physical inputs such as seeds and packaging materials, or financial or non-financial services such as loans, insurance, transportation, laboratory analysis, fumigation, information, and marketing studies, are 25 public institutions (CGREG 2016).

Current Situation of the main local products

Global trends in agriculture are applicable in the Galapagos as well. Most agricultural lands (58.9%) are extensive pastures for **cattle ranching** which employ few or no technologies for optimizing resource use. About 224 cattle (equivalent to 80,088 pounds of meat) are slaughtered every month across the entire province and over 91% of the meat is sold on the local market. Santa Cruz supplies 69% of the total meat sales, while San Cristobal provides 25%, and Isabela contributes the remaining 6% (MAG, 2018). Furthermore, local pig and poultry production satisfies approximately 84% of the demand of the resident and tourist populations. Importing unprocessed meat into the Galapagos is prohibited by law due to biosafety and quarantine standards, so local farms are usually the only beef suppliers for local consumption. However, the entry of frozen tenderloin has been allowed for the tourism sector because tourists demand a greater quantity of quality products than what local markets can provide.

As the booming tourism industry has provided Galapagos residents with greater spending power, their consumption patterns and dietary habits have changed. There is an increased demand for animal protein, causing the rate of meat consumption in Galapagos to increase every year. Despite current production levels, satisfying the demand of local markets in terms of quantity and quality of meat products remains a challenge for Galapagos cattle ranchers.

In 2019, the Centro Integral de Faenamiento (CIF, Integral Center for Meat Processing) is created, as a public company from the local governments but with financial and administrative autonomy, to generate services of meat pre- and post-processing, within a strong environmental and administrative regulatory framework and quality control across the whole process. CIF can process up to 200 cattle heads, 80 pigs and 20,000 chickens per month and it is the only institution in the Galapagos approved for these tasks.

Main meat consumers are local residents (28%), tour boats (24%), hotels (23%), restaurants (25%) (EPSIF, 2020). In the last months, due the COVID19 pandemic, and the economic stress caused, there has been a considerable decline in meat consumption and a significant drop in prices and consecuently, possible impacts in nutrition.

Another staple crop for Galapagos agriculture is **coffee** growing. Coffee production in Galapagos has been part of Galapagos human history for 151 years. In recent years, Galapagos coffee has been marketed as a premium gourmet product with global recognition. The organoleptic characteristics of Galapagos coffee originates from a combination of factors, including, 1) a diversity of microclimates, 2) nutrient-rich soils in Galapagos highlands, 3) synergies with fruit and forest trees that give an aromatic touch to the coffee bean, and 4) a diversity of planted coffee varieties within each farm (Within each farm we find multiple coffee varieties, including Bourbón, Típica, Caturra, Catimoro, Villalobo).

Like the agricultural sector in general, coffee growing has declined dramatically since the 80s. Coffee production has declined dramatically due to: i) high production costs, ii) aggressive importation of coffee from the mainland, and iii) a variable sales market. By 2014 the area sown with coffee had been reduced to 723 hectares, a 57% drop since 2000 (CGREG, 2014).

a) High production costs: Coffee plantations require permanent labor to care of the coffee plants, from sowing, maintaining adequate plant nutrition, managing agricultural pests, harvesting ripe beans, and performing wet and dry processing of the coffee beans to obtain product fit for self-consumption and market sale.

b) Coffee imports: It is estimated that 80% of the demand for ground coffee is supplied by imported brands rather than local production. This dependence on imported goods has caused a decline in prices of local coffee, an increased incidence of introduced agricultural pests, and economic concentration with product importers.

c) Variable sale market: Galapagos coffee is attractive to the international market. For example, in 2006 a metric quintal was sold at an average $55 (Chiriboga & Maignan, 2006), and by 2016 average price had reached $350 per metric quintal (MAGAP, 2016). Today, Galapagos coffee is listed as one of the most exotic and expensive varieties in the world (London Evening Standard; 2015). However, intermediation has not allowed Galapagos farmers to receive fair prices for their coffee.

Currently, farmers are re-planting a considerable surface area with coffee because they perceive it as an opportunity to market their coffee with the certificate of designation of origin for Galapagos coffee. This certificate is issued by the Ecuadorian Institute of Intellectual Property (current National Service of Intellectual Rights) to process ground coffee and sell it in the local market at a fair price. However, local coffee processing practices and infrastructure have to be significantly improved in Galapagos before farmers can reliably obtain quality coffee for the local market.

There are ongoing efforts to improve coffee production processes in Isabela, San Cristobal, and Santa Cruz. However, farmers still lack the technology and the expertise to obtain a highquality product.

CLIMATE RATIONAL

This section is a summary of a larger study located in Appendix 1, which contains details about climate trends, future scenarios, and implications.

The Galapagos climate is a product of the interaction of oceanic currents surrounding the islands and the winds from the southeast (Trueman and D'Ozouville, 2010). The influence of currents and winds is governed by interactions of the Inter-Tropical Convergence Zone (ITCZ) and the El Niño Southern Oscillation (ENSO) (Houvenaghel & Houvenaghel, 1974; Sachs and Ladd, 2010). Specifically, the ITCZ migration influences the main bi-seasonal characteristics of currents and winds of the Islands, whereas ENSO regulates yearly decadal fluctuations (Hamann, 1979, 1985; Hartten and Gage, 2000). For most of the year, the ITCZ is located north of the archipelago and the southeast trade winds blow across the Galapagos, bringing cooled air from over the cold upwelled waters of the south pole. When the ITCZ migrates southwards closer to the Galapagos, the trade winds are reduced and warmer ocean currents from the north arrive to the archipelago (Alpert, 1946).

The seasonality of the ITCZ combined with the topography of the archipelago results in two seasons: a warm, rainy season (January to May) and a cool, dry season (June to December) (Colinvaux, 1972; Hamann, 1979; Itow, 2003). During the warm, rainy season, evaporation due to high Sea Surface Temperature (SST) leads to orographic rainfall that increases with altitude; thus, the lowlands only receive a marginal amount of rainfall and stay dry while the highlands become significantly humid (Hamann, 1979; Snell and Rea, 1999; Trueman and D'Ozouville, 2010). Each island's size, altitude and exposure to wind determines the amount and seasonality of rainfall received. Furthermore, during the cool, dry season the air is lowered in temperature by the ocean surface and is trapped below masses of warmer air, creating condensation. Condensation occurs above 250 m altitude and creates heavy mists and drizzle that are blown inland from the ocean, shifted upwards by the mountains, and consequently cooled, resulting in more intense rainfall in the highlands (Hamann, 1979; Sachs and Ladd, 2010; Trueman and D'Ozouville, 2010).

Recurring Climate Patterns in the Eastern Pacific Ocean

The Tropical Eastern Pacific (TEP) exhibits inter-annual SST variability that is dominated by the ENSO cycles (Wang and Fiedler, 2006). El Niño (warm phase) events are characterized by high SST, a lack of west-to-east thermal gradient across the surface of the Pacific and a weakening of the easterly trade winds (Snell and Rea, 1999). El Niño (warm phase) effects in the Galapagos include high air temperatures, sustained high SST, increased rainfall, and a longer than usual warm season, whereas La Niña (cold phase) events result in abnormally cold conditions and drought (Sachs and Ladd, 2010). Past strong el Niño events

(1975-76, 1982-3, 1993-4 and 1997-8) (Martin et al., 2017; Trueman and D'Ozouville, 2010) triggered dramatic effects on both marine and terrestrial ecosystems (Snell and Rea, 1999). The most catastrophic El Niño (1982-3) decimated populations of endemic species, such as the Galapagos penguins (Spheniscus mendiculus) and some of these species are still recovering (Laurie, 1984; Robinson and del Pino, 1985; Trillmich and Limberger, 1985). Coral reefs suffered intensely during this period, with 98% of corals being wiped out by coral bleaching (Glynn, 1994, 1990; Lessios et al., 1983; Robinson, 1985) followed by a significant decrease in marine species diversity (Edgar et al., 2010; Stein Grove, 1985). During El Niño events the bottom of the food chain is also impacted by ENSO, as phytoplankton concentrations can decrease substantially (33-46%) as a result of high temperatures in the archipelago, leading to community-level reductions in biomass (Wolff et al., 2012).

The impact of ENSO events also extends to terrestrial ecosystems and communities. Heavy rainfalls characteristic of El Niño can trigger massive increases in herbaceous plants, which can then stimulate increased abundances of exotic invasive species and vines (Larrea and Di Carlo, 2011). Over-flooding can also result in increased mortality for resident species, such as for arboreal plants (Aldaz and Tye, 1999; Tye and Aldaz, 1999) that have trunks smothered by vines (Hamann, 1985; Tye and Aldaz, 1999) and giant tortoises that die due to injury or drowning in flooded ravines (Marquez et al., 2008). Land birds (e.g. finches) can also be negatively affected by El Niño events due as to the intensity of perturbations and because high rainfall triggers more intense parasitism (Dudaniec et al., 2007; Fessl and Tebbich, 2002; Grant et al., 2000). Despite the occurrence of ENSO events in the Galapagos for thousands of years, strong El Niño events are unusual. However, evidence suggests that El Niño events have increased in intensity and frequency over the last two decades due to warmer SSTs (Conroy et al., 2010, 2008; Rustic et al., 2015; Thompson et al., 2018).

Current and Temporal and spatial climatic trends

In Galapagos there are five active weather stations, which are managed by the Ecuadorian National Meteorological and Hydrological Institute (INAMHI, by its acronym in Spanish) and they are split as follows: 4 principal climatological station and 1 precipitation-only station (Figure 1). In order to assess recent past climatological trends, we obtained observations from the four-station located in both San Cristobal and Santa Cruz islands since they have been registering data over longer periods of time (30 years or more; see Figure 1 for their locations). It is important to note that from these, three stations M0192, M0191, and M0221 provide both precipitation and air temperature readings whereas M0508 records only rainfall. The coastal stations in both islands are located at 6 meters above sea level and the highland stations are located at 194 and 300 m.a.s.l in Santa Cruz and San Cristobal, respectively. Conversely, the station at Isabela (M0194) just started its readings in 2002 and the recorded data is only available until 2004. It is also important to mention that the lack of enough meteorological observations combined with the complex topography and habitat diversity in the islands impede us to follow traditional extrapolation exercises.

Next, we enrich the meteorological records from INAMHI by including available satellite observations as well as climatological reanalysis products. As such, we first evaluate how satellite products describe temperature and precipitation patterns in the Islands. For this we use CHIRPS and MODIS products for precipitation and temperature analysis, accordingly. We then also evaluate how ERA5 describes these key variables.

Mean air temperature has increased by ~0.6ºC since the late 1980s in both lowland and highland regions, as suggested by data from the National Meteorological and Hydrological Institute (INAMHI) climatological stations on the islands of Santa Cruz and San Cristobal, Ecuador. This increase in mean air temperature is higher during the warm/wet (Jan-May) season on the coast in the cool/dry season (Jun-Dec). In contrast to this increasing trend in mean air temperature, precipitation records from 1981 to 2017 suggest a decreasing trend across the archipelago, particularly in arid coastal areas. Critically, the first two decades of this century are on average ~45% drier than those during the decade of 1981-2000 (Appendix 1). Despite this overall decreasing trend in precipitation in the archipelago, records from 2002 to 2017 suggest the precipitation pattern does not change significantly in the coastal region of Santa Cruz and San Cristobal islands, supporting that ENSO events, particularly those from 1982/1983 and 1997/1998, have influenced the timeseries and prevented a clear interpretation of climatic trends. Although records from the islands of Santa Cruz and San Cristobal are essential in understanding climatic patterns, their variation to island topology and exposure to oceanographic and climatic variables highlights the need to establish several more climatic stations in this region in order to understand climate variability throughout the entire archipelago.

The regional relationships between elevation and key climatological variables was evaluated using the CHELSA estimates (Karger et al., 2017) from the last 34 years (1979 to 2013) that cover the entire extent of the Galapagos Islands. These patterns of precipitation and air temperature demonstrate spatial variability, particularly with elevation. Data from this time series shows that annual precipitation ranges from 557 mm to 1324 mm following a clear positive trend along the elevation gradient. The upper section (areas above 368 m a.s.l.) of the islands received, over this time period, a mean annual rainfall of 909 mm whereas areas below 51 m a.s.l. are exposed to an annual rainfall of 749 mm (or about 18% less, Figure 6a). Furthermore, mean air temperature of the islands, from 1979 to 2013, averaged 22 °C with an adiabatic lapse rate of 0,55 °C per 100 meters. The thermal amplitude spans from a mean air condition of 24°C at sea level to as cold as 15°C at 1600 m a.s.l. at the mountain summits of Santa Cruz, San Cristobal or Isabela (see Appendix 1).

Within the GMR, SST for the period 2002-2018 shows a clear warming trend. Data from MODIS inter annual variability shows an increase in diurnal and nocturnal SST at a rate of 0.06 °C year, a finding that agrees with other reports suggesting that the equatorial Pacific has warmed 0.4º-0.8º over the last 40 years (IPCC, 2007), and that greater increases in SST are expected in this region due to greenhouse warming (Cai et al., 2018, 2015). However, due to the prevailing oceanic currents having differences depending on the region of the Galapagos Islands being examined, SST anomalies for the GMR have contrasting patterns. For the period 2002 to 2018, the far-northern and northern bioregions have received the highest warming (up to 2.3°C increase), whereas the western bioregion have received the highest cooling (-5.7°C decrease). Coastal areas around Floreana, Española, and San Cristóbal have also shown increased SST anomalies.

Future Scenarios

The Climate Model Intercomparison Project (CMIP5) simulates a historical and future broad warming in the Eastern Pacific over the past century (Coats and Karnauskas, 2017). However, small-scale temporal and spatial variability may be dominated by natural fluctuations in the climate system or with phenomena such as El Niño. Nonetheless, for the Galapagos Islands, Global Circulation Models (GCMs) generally project warmer and wetter future conditions, consistent with current observations (Liu et al., 2013; Rial et al., 2017; Sachs and Ladd, 2010).

In order to understand the potential impact of climate change in the Galapagos Islands we examined temperature and precipitation from: (i) the official estimates of the Ecuadorian Ministry of Environment (MAE) to downscale climate projections from four selected CMIP5 models at 10 km of resolution (CSIRO-Mk3-6-0, GISS-E2-R, IPSL-CM5A-MR, MIROCESM) (MAE, 2017) and (ii) climate outputs from the CHELSA project (Karger et al. 2017)

In general, the MAE and CHELSA projections suggest a consistent future warming trend as well as wetter conditions across the Galapagos Islands (see Appendix 1). In general, the multi-model ensemble projects an increase in mean annual precipitation between 30% and 45% across the Islands by 2050; thus, suggesting a wetter future. Spatially, projected increases in annual rainfall is accentuated on the east side of the Islands. As of temperature, we find that the ensemble of climate projections estimates increases between 1.4 and 1.9 °C by the 2050-time horizon fro RCP 4.5 and RCP 8.5, respectively.

Yet, the specific magnitude of the projected changes differs across projects, scenarios, and decades. Conservative estimations (RCP 4.5) project an increase in mean annual temperatures of just about 0.5°C for the next two decades (for both MAE and CHELSA projections, when compared with the historical reference period) (Figure 13). Also, the most extreme climate projections (RCP 8.5) suggest that temperatures may increase up to 2.5°C in the 2040-2060 decades. These extreme future conditions are typically simulated by the MAE exercise. In contrast, CHELSA projections estimate a maximum temperature increase of just about 1.8°C by such time period. Also, as expected RCP 8.5 scenarios lead to more warming levels than RCP 4.5; this difference would be accentuated during the 2040-2060 decades.

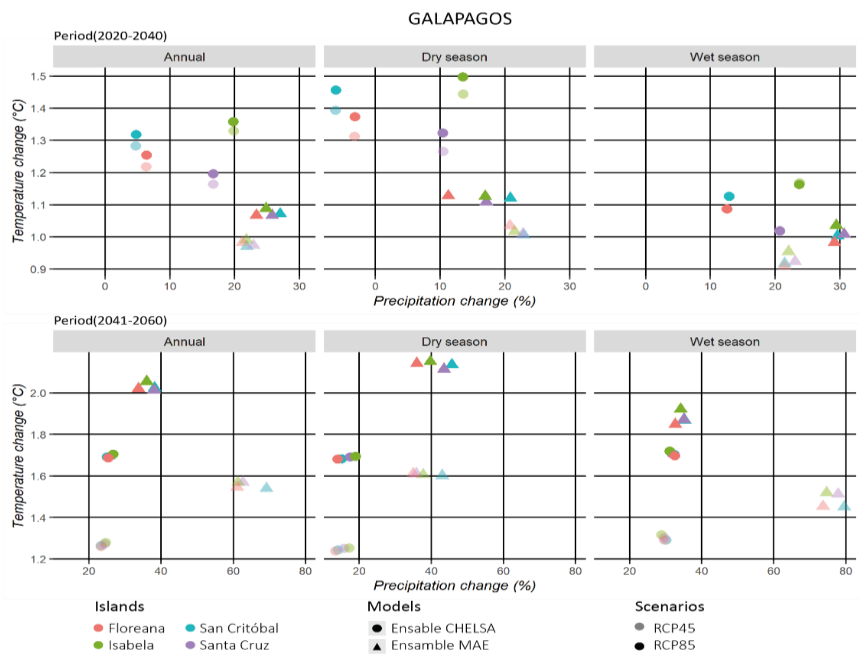

Figure 13. Mean absolute temperature and proportional precipitation changes on Galapagos Archipelago in the period 2020-2060 according to the different median of the ensemble of projections of MAE downscaling efforts and the CHELSEA project. Reference period is 1981-2005 for the MAE projection and 1979-2013 for the CHELSA outputs.

Similar to temperature, precipitation projections also differ across models. We find that mean annual precipitation over the next two decades would increase between 5% and about 25% across all the Islands. In general MAE projections seem to be more at the higher end of these estimates, whereas CHELSA precipitation increases seem to be more conservative. This pattern seems to result from an intensification of the wet seasons as relative increases in this season augment accordingly to those annual estimate (in contrast to the dry season where some scenarios even project a precipitation reduction). Then for the decades between 2040 and 2060, precipitation may increase even more. Our climate projections suggest that rainfall in the Galapagos may increase between 20 and 70%. Similarly, MAE projections generally estimate a wetter future, which is particularly noted for RCP 4.5 scenarios rather than RCP 8.5. According to these subsets of projections, by the end of the century mean wet season conditions may intensify by up to 80%.

The extreme weather precipitation and temperature conditions detected by the models through the 90th and 10th percentile estimates shows that magnitudes of extreme wet anomalies increase between 60% and 85% for the period 2040-2060 under RCP 4.5 and RCP 8.5, respectively. This is specially observed in the western side of the Archipelago (e.g. Isabela Islands). As of extreme dry conditions, we found that in general there is a reduction in about 10% in rainfall quantities (Figure 14). Thus, these climate projections suggest more severe extreme wet conditions across the islands along with less severe drought events. Yet, despite identifying these extreme scenarios, none of these results have shown similar values compared to historical values related to recent ENSO extreme events.

Finally, temperature anomalies indicate that for the lower percentiles, temperature increases range from 1°C and 1.5°C. In the case of the upper percentiles, the estimations show an increase in temperature between 1.5°C and 2.5°C. These results in turn suggest the occurrence of more often abnormally hot conditions which could then translate into heatwaves. Also, we acknowledge the existence of other more sophisticated techniques and metrics to calculate extreme precipitation and temperature characteristics, yet here we expect to show an initial overview of these type of hydrometeorological conditions.

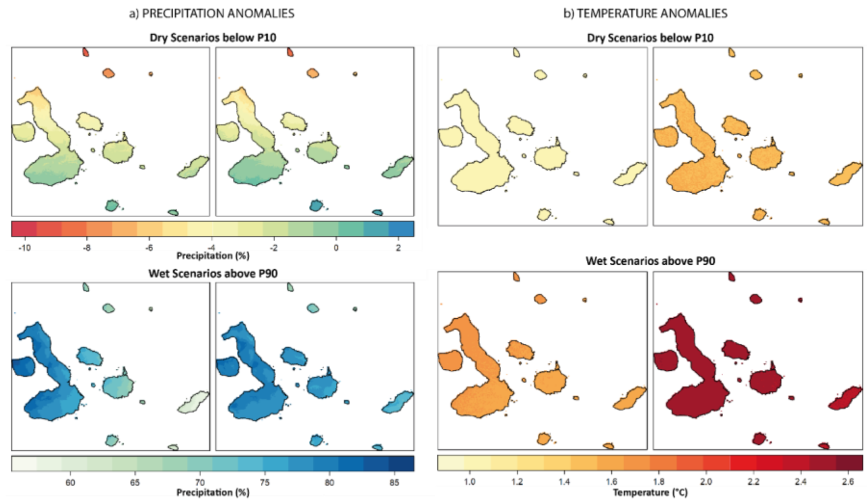

Figure 14. Spatial distribution of the a) precipitation and b) temperature anomalies of the CHELSA project in the period 2040-2060 for dry scenarios below percentile10 and wet scenarios above percentile90.

The eastern Pacific is expected to have increased SSTs due to greenhouse warming, suggesting an increase in ENSO frequency and intensity (Cai et al., 2018, 2015). The dynamic downscaling of the impact of climate change on the ocean circulation dynamics in the Galapagos Islands projects an increase of a near 2°C rising trend in SST anomaly in the El Niño 3.4 region for the period 2001–2050 (Liu et al., 2013). The observed warming trends in the dynamic model show that the entire Galápagos region is significantly affected by global climate change, yet the degree of exposition is not homogeneous across the archipelago. The upwelling region to the west of Isabela Island shows relatively slower warming trends compared to the eastern Galápagos region.

The observed negative effects of El Niño indicate that an interaction between climate change and ENSO could pose a grave threat to the Galapagos Islands. The coupled impacts of both stressors could profoundly impact previously affected ecosystems and species (Boersma and Rebstock, 2014; Salazar and Denkinger, 2010), augment colonization dynamics of invasive exotic species (Ellis-Soto et al., 2017), disrupt ecological processes such as ocean productivity (Sachs and Ladd, 2010) and fishing resources (Castrejón and Charles, 2020), and change water regulation capacity through the altering of soil organic carbon stocks (Rial et al., 2017). Lastly, upward trends in sea levels are projected to continue throughout the twenty-first century (Nerem et al., 2018) and the sea level in the Galapagos has been slowly rising (~10 cm since 1985). Sea level rise in the Galapagos Islands could increase the risk of coastal flooding and impact tourism and infrastructure, along with reducing marine and terrestrial habitat such as shallow reefs, mangroves, and nesting sites for marine iguanas and turtles.

The observed trends and future projections discussed above indicate a progressive divergence of current climate conditions in the Galapagos Islands from past confidence intervals characterized for climatic variables in this region. Continued increases in sea surface and air temperature coupled with more intense and erratic ENSO events may lead to a climate system in the Galapagos Islands with increased seasonality and stronger spatial heterogeneity (Wolff, 2010).

The discrepancies between the historical observations and future modeling in precipitation show a high degree of uncertainty and also show the influence of the climatic variability in the analyzed data. Therefore, adaptation decisions must be made to ensure that practices are robust enough to respond to both conditions: wetter and drier scenarios, which can be possible with drastic shifts in Galapagos.

Impact of Climate Change for the Hydrological and Agricultural Systems

Climate change is key within the food systems dynamics because, in agricultural areas, climate control much of the natural resource base, including the availability of water into the agricultural subsystem and the cascading effects into the humidity of soils, rainfall and invasive species. In the marine reserve, ocean warming is linked to decrease in fisheries. In general, climate change impacts work in synergism with other endogenous factors (e.g., local population growth, policies, etc.) and other exogenous drivers (e.g, tourism growth, imported products, etc.) to stress a food production system.

This pattern of supply and demand for food that occurs in the Galapagos, is similar to what occurs in small island developing states (FAO, 2014). In this context, by strengthening the food system of the Galapagos Islands, the aim is to establish the bases for the construction of an island climate resilient model that is economically, socially, and environmentally sustainable in a context of food security and climate change.

Water Deficit

A water balance describes the flow of water which enter and leave a system (i.e. the way by which precipitation compares with runoff and evapotranspiration fluxes). This proposal has generated a water balance for Santa Cruz, San Cristobal and Isabela Islands using a Water Evaluation and Planning System (WEAP) model as our main tool, see Appendix 2 for details. Briefly, for the Galapagos Islands the model is set up by using a range of available data, which includes climatological data from the ERA5 reanalysis effort as well as direct observations from available meteorological stations, soil parameters (A Pryet, 2011) as well as a Digital Elevation Model (Lehner et al., 2008) at 3 arc-second spatial resolution. This model generates as output the following variables: evapotranspiration, surface runoff, subsurface flow, base flow, and changes in soil humidity.

This balance cannot be validated by observed flows because of the lack of discharge information. This is the reason why one of the proposed practices/activities include a monitoring system of discharges in the islands. intend to build a robust balance by evaluating the different flows such as the aquifer recharge flow and identify specific zones to be intervene because of their hydric importance. This balance can be a guide to know if the model represents in a good way the fluxes in the ground (Figure 15). Also, the hydrological model was set up in a way that makes easy the input of new variables such as climatic and hydrological values for future projects.

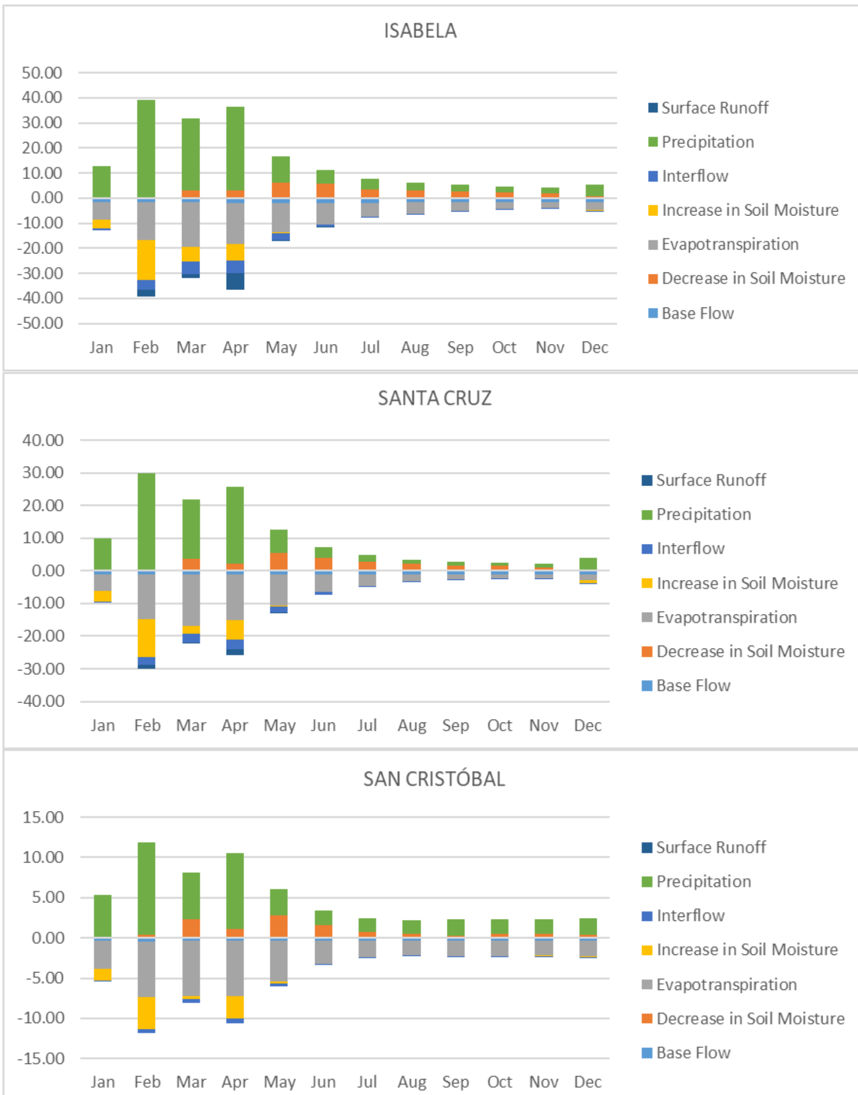

Figure 15. Hydrological balance in Isabela, Santa Cruz, and San Cristobal islands

This modeled water balance shown here depicts the mean average flow for two time periods: 1981-2000 and 2001-2019. The first period represents a wet one where El Niño events (19821983 and 1997-1998) where relevant and cause vast damage in native ecosystem and anthropogenic infrastructure in the region. Conversely, the most recent period represents one with more apparent dryness and characterized by the presence of La Niña events. The results showing a notable decrease surface flow between these historical baselines (Figure 16), mainly in the wet season. The flow variability in the dry season is not significant in the two periods.

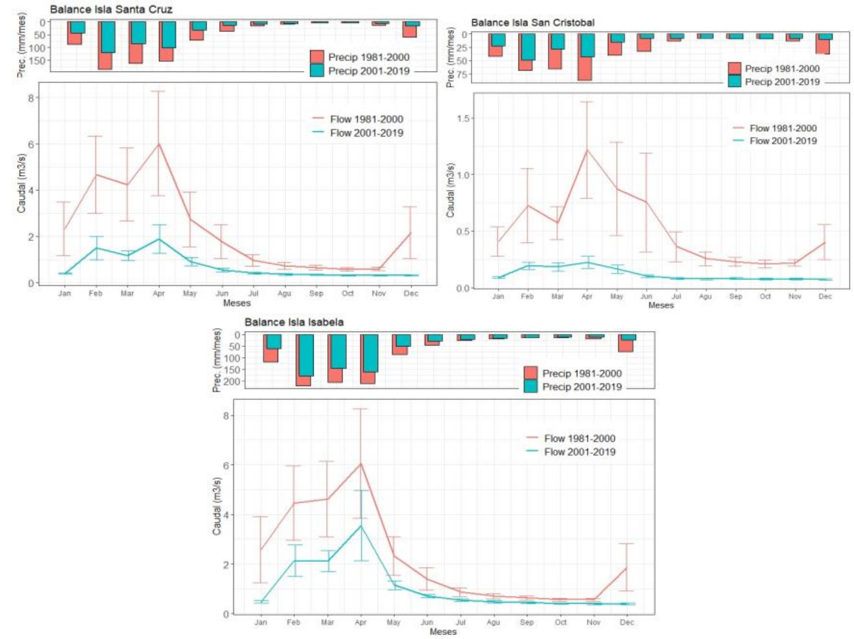

Figure 16. Water balance for the Galapagos Islands - Historical Conditions (precipitation and surface flow). Bars represent standard error.

Figure 17 shows one of the results of a climatic sensitivity analysis for the three islands. This study captured the elasticity of the system (and thus, the key output variables) to a range of climatic scenarios. The proposal built 48 scenarios which represent combinations of modifications in precipitation and temperatures historical records. So historical precipitation is modified in 10% intervals of change from -50% up to 200% whereas temperature modifications represent increases in the historical series from +0.5°C up to +3°C. This approach permits us to understand the elasticity of the chosen variables of analyses when they are subject to levels of stress.

Results from the water balance, consistent with farmers' observations that show a decrease of the precipitation and superficial water flow in the agricultural areas, across the three islands, from the first period (1981-2000) to the second period (2001-2019). More specifically, there is also a significant decrease of precipitation and superficial water flow in the wet season, which indicate of strong risk of water stress year around with consequent impact of plants and animals.

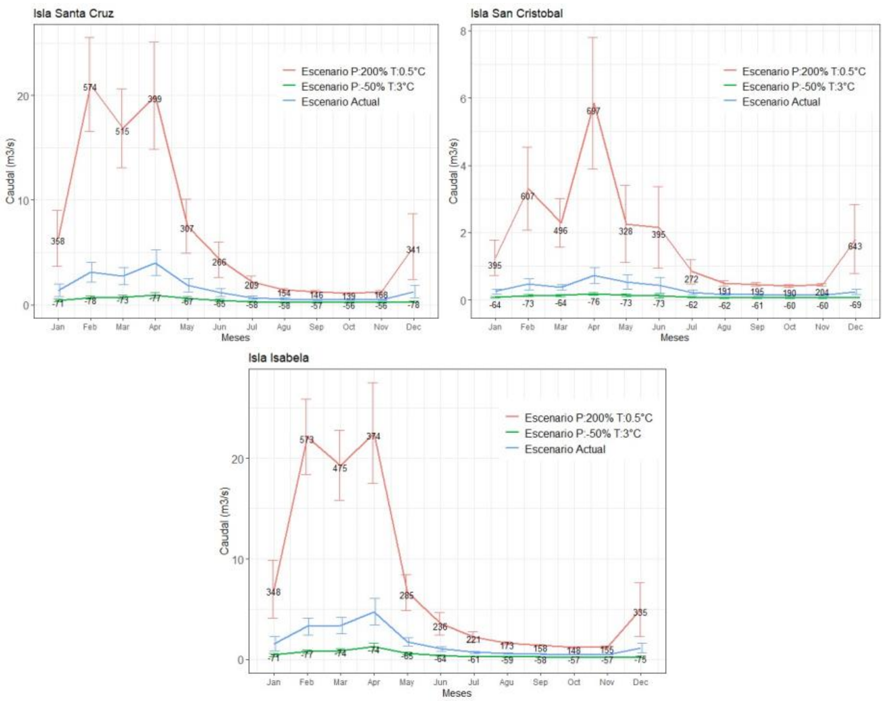

Figure 17. Example of water balance sensitivity analysis for the Galapagos Islands under extreme conditions. The numbers show the percentage of change and the bars the standard error.

Crop losses and Yield reduction

In terms of the effects of climate change in water availability and their consequences in the productive systems, the study shows different types of crops and its water demand. The actual evapotranspiration (ETA) value is an output of the WEAP model that is based in crop coefficients (Kc) methodology (Allen et al., 2006) and potential evapotranspiration (PET) calculated by the Penman-Montheith method (Monteith, 1985). Crop coefficient values had to be corrected because of the type of climate in Galápagos. These corrections are based on the relative humidity, precipitation depth and wind velocity. The process shows an increase in the crop coefficient values and therefore in the evapotranspiration values. Results show a considerable difference between water supply and demand, Table 6 illustrates it for the month of October (dryer month), which show higher demands of water for all crops modeled.

Table 6. Water demand by crop in October

CROPS	Eto (WEAP)	Modified crop coeficient Kc			Crop evapotranspiration daily demand (m3/ha)			Daily water supplyOctober (m3/ha)			Daily water demandOctober (m3/ha)		
	mm/day	Crop season			Crop season			Scenario			Scenario		
		Initial	Develop	Late	Initial	Develop	Late	Dry	Mod	Wet	Dry	Mod	Wet
Alfalfa	3.70	0.40	1.22	1.17	14.80	44.40	43.3				42.2	40.6	39.2
Porotón	3.70	0.40	1.03	0.63	14.80	37.00	23.1				34.8	33.2	31.8
Morera	3.70	0.40	1.03	0.63	14.80	37.00	23.1				34.8	33.2	31.8
Leucaena	3.70	0.40	1.03	0.63	14.80	37.00	23.1				34.8	33.2	31.8
Café	3.70	0.90	0.99	0.99	33.30	35.15	36.7				32.9	31.3	29.9
Pasto Gramínealeguminosa	3.70	0.40	1.08	0.88	14.80	38.85	32.4				36.6	35.0	33.6
Cedro	3.70	0.50	1.14	0.69	18.50	40.70	25.6				38.5	36.9	35.5
Maíz	3.70	0.40	0.84	0.74	14.80	29.60	27.2				27.4	25.8	24.4
Fréjol	3.70	0.40	1.20	0.40	14.80	42.55	14.6				40.3	38.7	37.3
Cítricos	3.70	0.50	0.54	0.49	18.50	16.65	18.2				14.4	12.8	11.4
Aguacate	3.70	0.60	0.92	0.82	22.20	31.45	30.3	2.2	3.77	5.19	29.2	27.6	26.2
Sandía	3.70	0.45	0.78	0.78	16.65	27.75	28.6				25.5	23.9	22.5
Yuca	3.70	0.30	1.13	0.53	11.10	40.70	19.7				38.5	36.9	35.5
Papa	3.70	0.00	1.17	0.67	0.00	42.55	24.9				40.3	38.7	37.3
Tomate	3.70	1.15	0.92	0.62	42.55	33.30	23.0				31.1	29.5	28.1
Pimiento	3.70	0.60	1.03	0.78	22.20	37.00	28.7				34.8	33.2	31.8
Banana	3.70	1.00	1.29	1.19	37.00	44.40	44.1				42.2	40.6	39.2
Maracuya	3.70	0.55	0.99	0.74	20.35	33.30	27.3				31.1	29.5	28.1
Pina	3.70	0.50	0.32	0.32	18.50	11.10	11.9				8.9	7.3	5.9
Cana de azucar	3.70	0.40	1.34	0.84	14.80	46.25	31.0				44.0	42.4	41.0
Papaya	3.70	0.50	1.19	1.09	18.50	40.70	40.2				38.5	36.9	35.5
Mani	3.70		1.22	0.67	0.00	42.55	24.6				40.3	38.7	37.3

Table 7 shows the threshold temperature and rainfall requirement of the main groups of crops cultivated in the islands. Responses to temperature and water requirement differ among crop species throughout their life cycle (Hatfield and Prueger, 2015). Increases of temperature significantly impact productivity of vegetables, grains, ornamentals and some roots and tubers crops. While the reduction of precipitation can mainly impact pastures and fruit trees. On the other hand, the occurrence of heavy rains and increased precipitation influences the occupation and possible expansion of invasive plants that threaten local agricultural productivity and are responsible for the degradation of critical habitats and ecosystems in the protected areas located in the upper and humid parts of the island (FIC-LAVOLA-UTPL, 2019).

Table 7. Temperature thresholds and rainfall requirement of the main groups of crops cultivated in Galapagos (INIAP, 2019).

Crop	Weather	Minimum Temperature °C	Maximum Temperature °C	Precipitation mm/cycle
Vegetables	Tempered	10	22	400
Grains	Tempered	12	24	400
Tree Fruits	Warm	18	30	1000
Roots and tubers	Cold	6	18	700
Roots and tubers	Warm	12	30	700
Medicinal and aromatic	Tempered	10	24	500
Grassland and forages	Warm	15	28	1000
Ornamental		5-8	28-30	600

The adverse effects of the climate variability and climate change have a high impact on the agricultural sector and have become increasingly evident in recent years. These impacts are linked to. The major events experienced by the agricultural sector in Galapagos are described below:

- *1997/98 ENSO (El Niño event):* during this period surface temperature and rainfall increased drastically over much of the Pacific. Farmers reported losses of 100% of total harvest of crops such as plantains, banana, cassava, and vegetables due to excess water.

- *2016 ENSO (La Niña event/Drought):* it was a period of extreme drought from January to November 2016, which severely affected 56.5% of land for agricultural use (10,740 hectares) according to information provided by the National Agrarian Authority (MAGAP, 2016), causing economic losses and environmental in the agricultural sector, unrecoverable to date in Galapagos. As a result, 45.9% of the grassland were affected, as well as 49.7% and 74% of the short-cycle and perennial crop land, respectively. It is estimated that the loss of the agricultural and livestock sector was over USD 15 million, with the most affected products being cassava, maize, tomato, banana, melon, orange, as well as milk production. All these items are part of the basic food basket and provide a nutritional balance for the population. Additionally, the reduction in milk (55.9%) and beef production threatens quarantine policies that have already been established in this territory to prevent the entry of bovine diseases and boost the local dairy products industry (MAG, 2018).

Invasive Species Expansion

The large majority of invasive plant species are also found in the humid highlands, where agricultural lands are established, and biotic conditions are more suitable for invasion. Currently, these biotic conditions are changing due to shifts in climate conditions and have become more favorable for the spread of invasive plants (Watson et al. 2009).

Many invasive species are pre-adapted to take advantage of disturbed areas (e.g. native ecosystems and agroecosystems stressed by climate change) mainly by extreme events such as ENSO, creating new opportunities for introduced species to establish and thrive (Beaury et al. 2020, Shackleton et al. 2020). For example, the Cuban cedar (*Cedrela odorata*) was planted vegetatively but after the El Niño events in 1982/83, it started to sexually reproduce and populations proliferated on Santa Cruz. Another clear example is the case of the guava (*Psidium guajava*) and blackberry (*Rubus niveus*) invasions, the most highly invasive plants in Galapagos (Jäger et al. 2009, Jäger et al. 2015, Rivas-Torres et al. 2018). Preliminary evidence suggest that guava is drought and shade tolerant, resistant to temporary waterlogging, grows well in a wide range of soil pH and has the capacity to intercept fog water via stemflow (Walsh et al. 2008, Takahashi et al. 2011). These characteristics, coupled with the high rainfall and several droughts associated with El Niño and La Niña respectively, is expected to facilitate the spread of guava and blackberry after dieback of native species (e.g. *Scalesia spp*.) and the degradation of agroecosystems in Galapagos (Tye 2006, Jäger et al. 2009, Schmitt et al. 2018, Laso et al. 2020).

The results of dispersion analysis of invasive species in Galapagos, mainly focused on *Psidium guajava* (see Appendix 2.1) show that there is a positive correlation between guava growth and factors associated with water availability (precipitation, humidity, and soil moisture). Thus, access to water plays an important role in the interaction between native and invasive species (Guo et al., 2020), where introduced plants have shown to be better competitors than native plants. For this analysis, higher values of precipitation, humidity (wet index) and soil moisture represent better conditions for guava growth and spread. This means that when resources increase (high soil water storage), it will increase probability of the invasion success of guava into a native plant community/abandoned agricultural lands and its presence will not be affected by water scarcity due to its drought tolerance (Binggeli et al., 1998; Schmitt, 2018). According to the analysis, 15.7% of the entire study area was occupied by *Psidium guajava* in 2018, which will increase to 23.16% by 2030 under a BAU scenario. If restoration and rehabilitation activities were implemented in both protected and agricultural areas, this increase could be reduced between 16% and 18% under program implementation scenario.

Future Scenarios in Relation to Water Availability in the Agricultural Areas

As Appendix 1 indicates, precipitation measurements show a drying trend across the Islands. This trend is particularly noted in the coastal-arid zones of the Islands. Indeed, we find that the first two decades of this century are in average 45% drier than the decade 1981-2000. In the agricultural areas, the study points out a diverse set of responses. In San Cristobal just the first decade of this century has been unusually dry (50% drier) and in Santa Cruz, precipitation has decreased in about 10% over the last two decades.

It is important to also note that the orographic characteristics of the islands distinguish between coastal and highlands sub-climates. The agricultural area, for example, exhibits important humidity as well as drizzles during the cold season. Our results find that in average, the drizzles or garúas contribute to about 30% of the cold-season rainfall over the highlands. As of temperature, observations estimate that mean annual values have increased by ~0.6°C over the last four decades across the Islands. **This research suggests that by the midcentury**

mean annual temperature is expected to rise by ~1.1 and over 2.0°C when compared to the historical baselines. These changes will be more acute during the dry season. Thus, subregional as well as seasonal differentiations should also be considered when refining past and future hydroclimatic conditions in the Islands.

This section shows the results of a land-hydrological model. Figure 18, which show how surface "stream flow" affected by climate change. This is done by utilizing mean annual hydrological results of our sensitivity analysis, which are then plotted in surface response maps (showing the increases in temperature and precipitation, and their resulting output variable, stream flow) against the CMIP5 climate projections. For reference, the study also delineated the hydroclimatic conditions of El Niño 1982-1983, 1997-1998 and the dry conditions of 2015-2016. The first two periods of El Niño caused important damages and losses in the Islands as result of severe floods. The recent dry conditions led to local authorities to decree a regional state of emergency due to severe impacts that droughts caused on society, see Figure 18 below.

The proposal first shows that none of the projected climate scenarios estimate the mean annual conditions of 2015-2016 (drought) would not be repeated (or intensified) in the upcoming decades. While this result may provide a sense of robustness and certainty of Galapagos water systems, it is important to highlight the general wetting tendency of existing GCMs once again in the Islands; this in turn contradicts recent drying observed trends, as discussed above. Also highlights the current vulnerability to droughts of the Galapagos productive systems.

Additionally, this proposal presents the results of streamflow, with projections of land use change in agricultural areas (Table 8). Agricultural areas have been modeled in detail in Sampedro et al 2018 and in this feasibility study we create three scenarios of land change, and related to the land management options, including strategies for land use adaptation to climate change.

Table 8. Land Use Scenarios used to model the impacts of the climate change resilient strategies on streamflow.

Land Use Scenario Year 2035 (based on Sampedro et al 2018)	**Scenario Description**
Business as Usual (BAU)	• ~50% of agricultural area covered by pastures • Decrease ~10% of crop area • ~28% of area covered by invasive species • Loss of ~90% of area covered by native vegetation
Land Abandonment Scenario	• ~40% of area covered by invasive species • Loss of 90% of area covered by native species • 10% reduction of productive areas (pasture + crops)

Climate Change Resilience Scenario	• Native vegetation within agricultural areas is conserved • There is an increase of 5% area covered by agriculture and cattle ranching (crops and pastures) with climate resilience practices including silvopastoral practices, integrated soil management, and conservation of key hydro-ecological areas. • Reduction to 26% of area covered by invasive species

Results show the water availability (streamflow) increase by almost the double under a scenario of Climate Change Resilience. Moreover, BAU and land abandonment scenarios put GCMs results close to conditions of drought as the experienced in the Galapagos (Figure 18, red line). Climate Change Resilience scenario move away from those drought conditions.

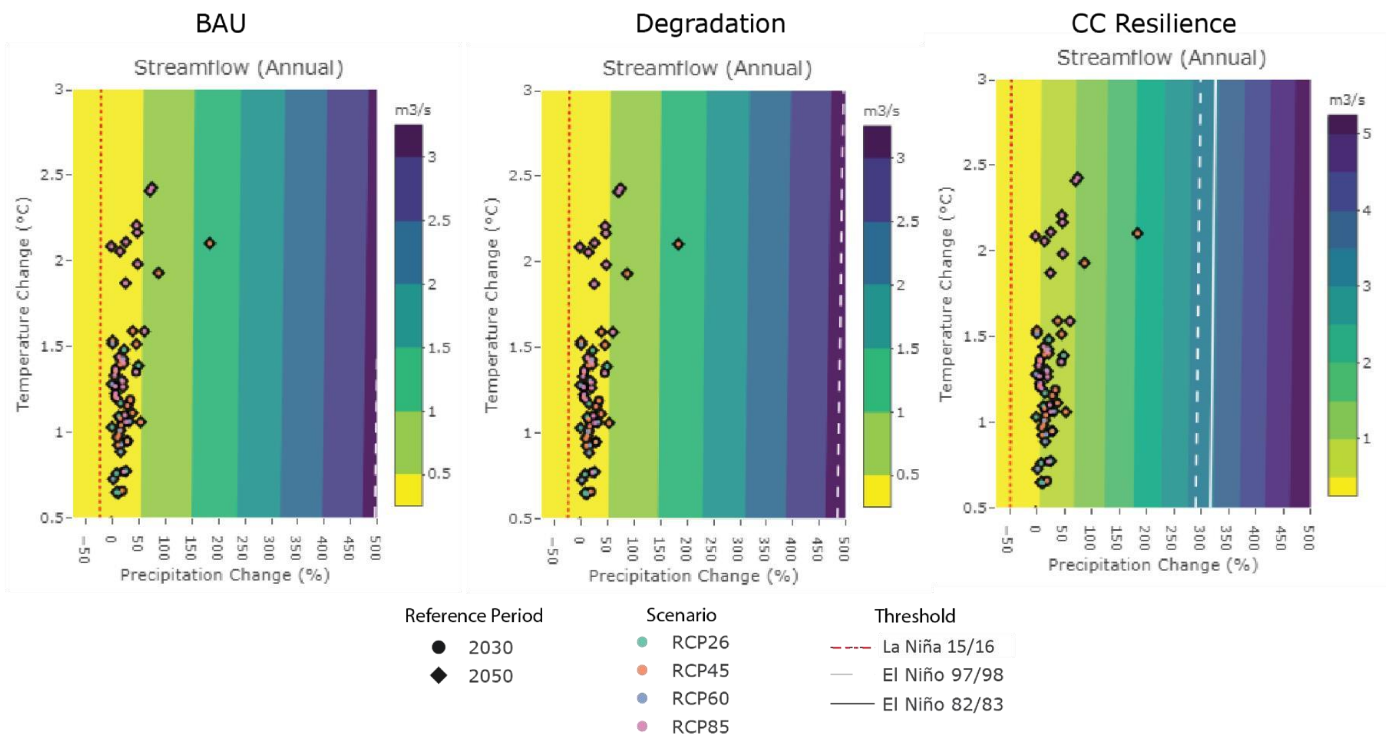

Figure 18. Surface response maps for the sensitivity analysis of mean annual conditions of streamflow to changes in precipitation and temperature. Colors represent the mean annual hydrological output when combinations of temperature and precipitation are run, for three different land use management scenarios.

INIAP (Instituto Nacional de Investigaciones Agropecuarias) has generated a dataset of crop tolerance to temperature and precipitation for different agricultural products in the Galapagos Islands (Table 6). We have taken these tolerances to create agricultural product suitability according to our climate change scenarios explain in Appendix 1. Figure 19 to Figure 21 show the results.

Models used in this study show how agricultural products or crops will be drastically affected. Grains and vegetables across all seasons will be strongly affected with temperature change, but more importantly affected by rainfall decrease, especially during the dry season. This is probably the most important implication of climate change in the agricultural products. Pastures will be seriously affected by the decrease precipitation, especially during the dry season. Fruit trees and roots and tubers are cultivars that will have higher tolerance to climate change, although affected in minor degree.

It is expected that with climate resilient activities and sub-activities, described below in Chapter 2, there will be an improvement of the conditions, for example, in terms of productivity, crops will increase productive within the first year of the project. Table 9 shows a comparison of performance with current practices versus estimated future performance with resilient practices, in Tons/Hectare. **Future performance is estimated for 24 crops used in the agricultural areas of Galapagos. In all cases, there are improvements that range from 2.6 to 69.6%, including pasture, cassava, peanut, and others with the highest improvement in productivity.**

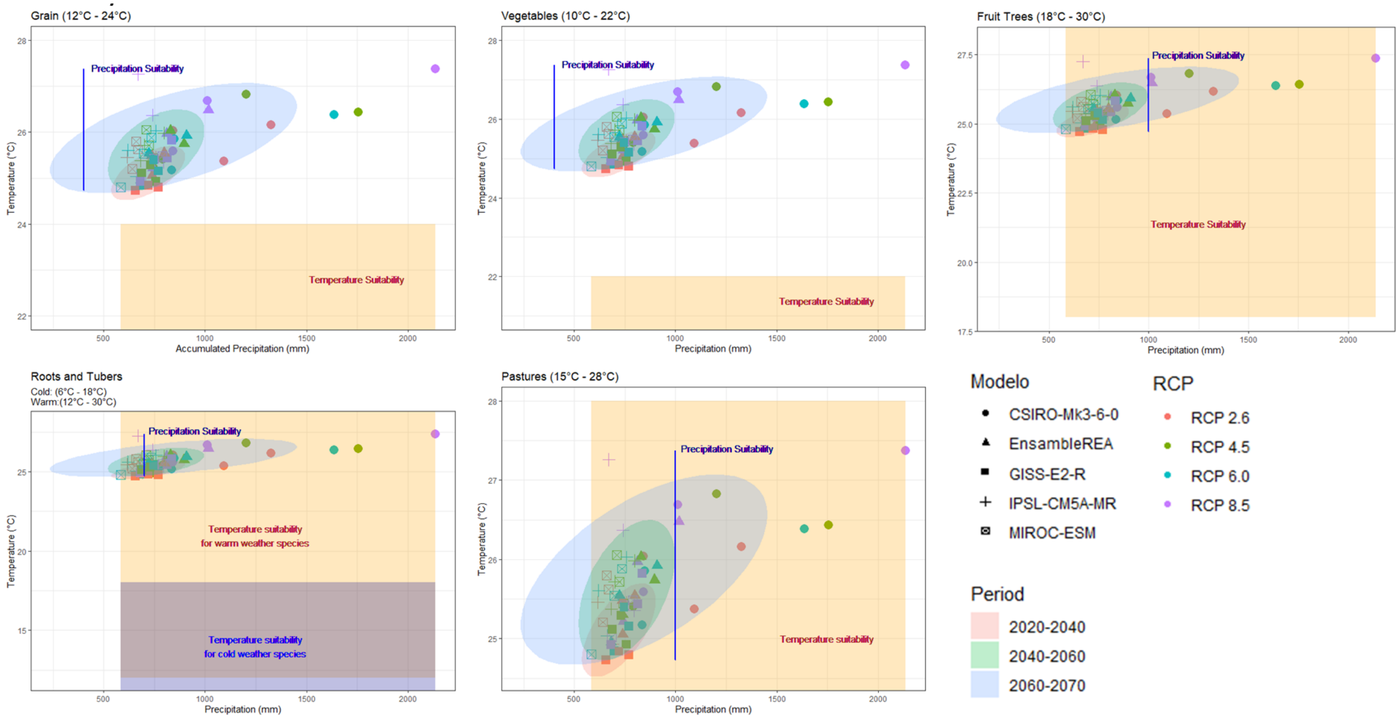

Figure 19. Precipitation and temporal suitability, all months of the year, for grains, vegetables, fruit trees, roots and tubers, and pastures, for different climate scenarios RCP 2.6, 4.5, 6.0, 8.5 and different periods 2020-2040, 2040-2060, 2060-2070

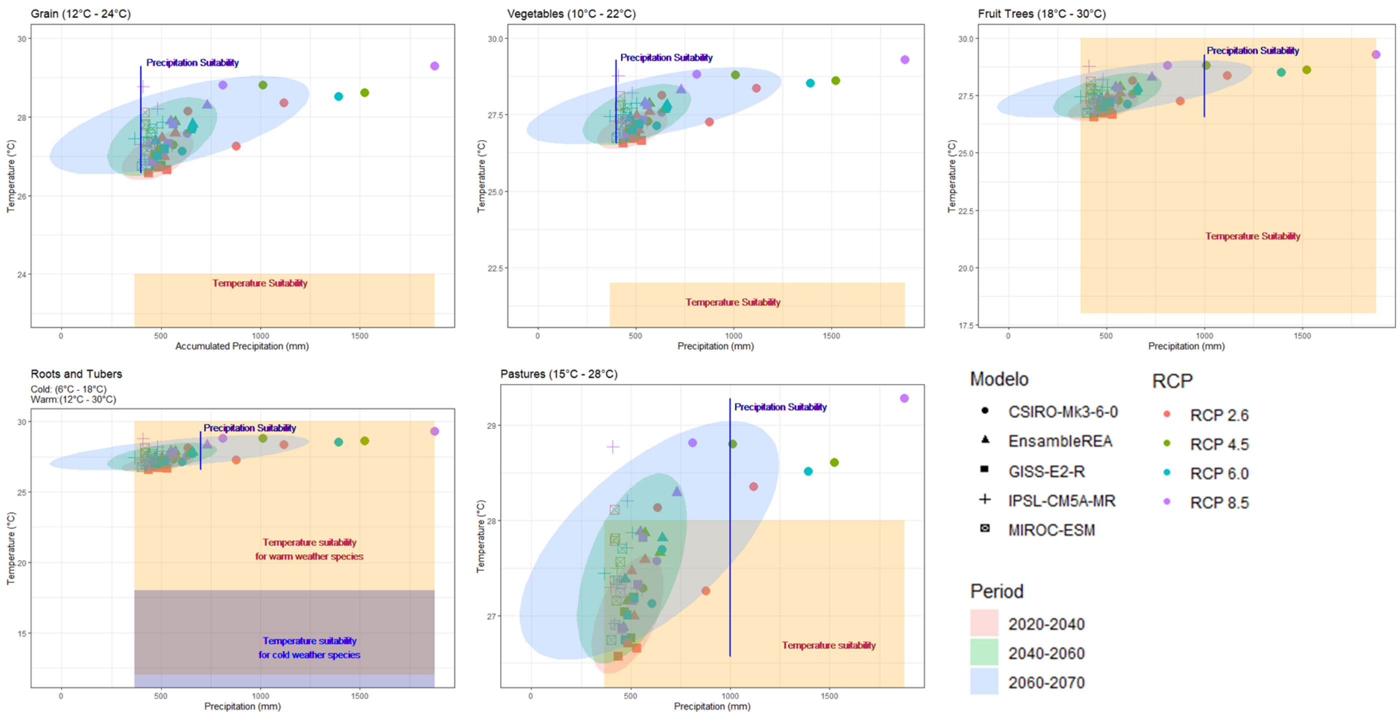

Figure 20. Precipitation and temporal suitability, rainy season (January to April) for grains, vegetables, fruit trees, roots and tubers, and pastures, for different climate scenarios RCP 2.6, 4.5, 6.0, 8.5 and different periods 2020-2040, 2040-2060, 2060-2070

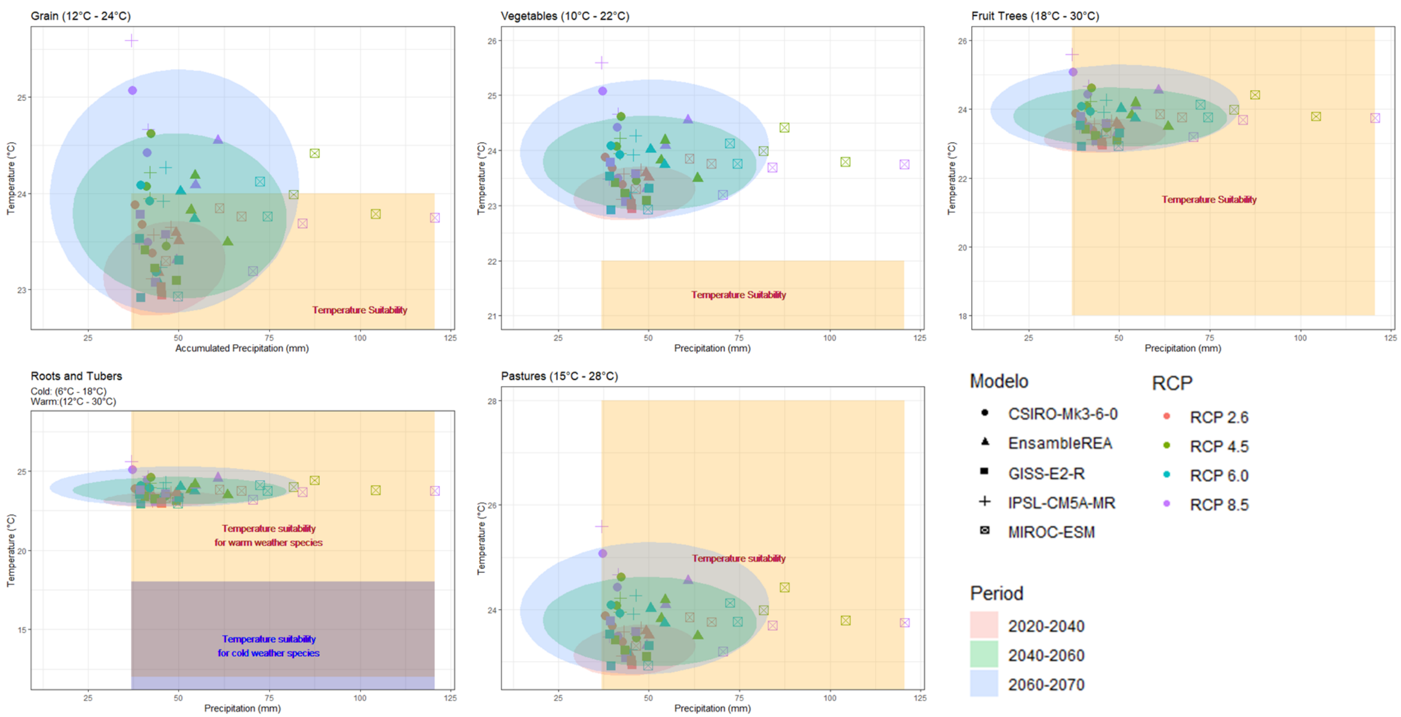

Figure 21. Precipitation and temporal suitability, for the dry season (August to November) for grains, vegetables, fruit trees, roots and tubers, and pastures, for different climate scenarios RCP 2.6, 4.5, 6.0, 8.5 and different periods 2020-2040, 2040-2060, 2060-2070

Table 9. Estimated Impact of project activities in a year of project

performance with current practices *vs* estimated future performance with resilient practices (Tons/Hectare)					
CULTIVOS	Current Practices	Climate Resilient Practices	CULTIVOS	Current Practices	Climate Resilient Practices
Limón	9	9.6	Naranjas	9	11
Café	1	1.2	Papaya	14	15
M-plátano	8.5	10	Papa	11	16
M-banano	9	11	Pimiento	6	7.5
M-orito	2	4	Piña	14	15.5
Yuca	16	33	Tomate	14	15
Caña	75	77	Maní	1	2
Fréjol	1.6	2.2	Maracuyá	20	30
Hortalizas	5.5	6.5	Aromáticas	0.4	0.6
Maíz – choclo	7	11	Medicinales	0.5	0.75
Maíz – ensilaje	15	22	Pastos	11.2	19
Mandarina	11	12	Forrajes	21.8	33.2

Farmers Perceptions about Climate Change

In a socioeconomic survey carried out in February 2020, 196 farms' households were interviewed about socioeconomic, environmental and climate change, as related to the agricultural activity. A vast number of farmers, 98%, reported climate change as a change already present in their farms, which is consistent with climatic historical observations and climate modeling. Of those farmers, 41.5% already report negative effects in their production (Table 10). There are relatively minor differences across island and farm sizes.

Table 10. Farmers reporting negative effects of climate change in their farms.

	Yes	**No**
Island		
Isabela	41%	59%
San Cristobal	39%	61%
Santa Cruz	45%	55%
Farm size		
Small-scale farms	37%	62.67%
Medium-scale farms	43%	57.14%
Large-scale farms	45%	54.93%
Total	**41.54%**	**58.46%**

In terms of negative events suffered as result of climate change, farmers report a diversity of types, being droughts the type of climatic events that have caused more damage (Figure 22).

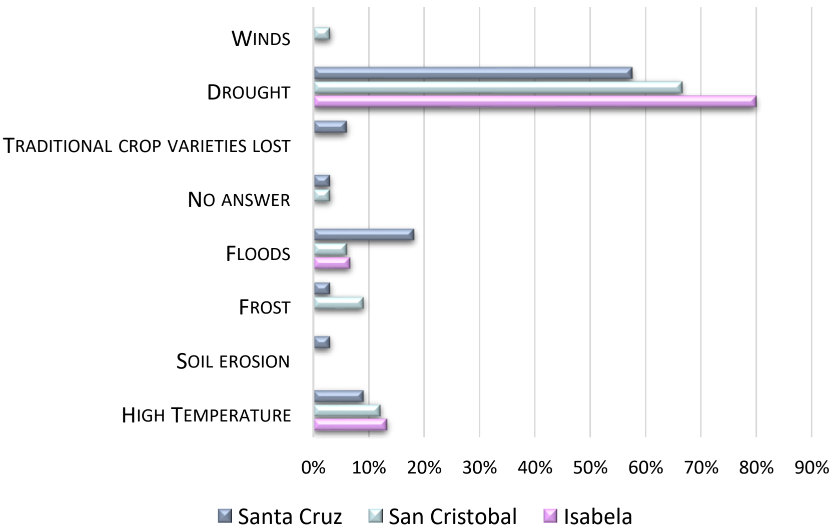

Figure 22. Main Climate Change events that affect production in Galapagos in 2019

Vulnerability and adaptive capacity communities - farmers

As ecosystem and terrestrial ecosystems, water availability, crops, livestock, and land become affected by climate change as explained in the previous sections, **direct impacts will be felt within the human society, from both economic and quality of life perspectives.** The three primary economic sectors of Galapagos (tourism, fisheries, and agriculture) depend upon the natural resources and current climatic conditions. In 2016, a severe drought generated losses for the agricultural sector by more than USD 15 million (MAG, 2018), affecting products associated to the basic food basket (BFB), accounting for the nutritional balance of the resident population and tourists. All of this will have negative economic repercussions within Galapagos society and potentially for Ecuador. The current conditions in the communities of Galapagos, including poor healthcare, sanitation, water quality, and little to no urban planning, will exacerbate these risks and make farmers and fishermen vulnerable to climate change.

The population of the Galapagos Islands depends nearly exclusively on imported food through sea and air cargo because local agricultural production is not able to meet the population's demands for agricultural products with a deficit of 47% (Table 2 previous section). Sampedro et al (2019) calculates that about 75% of agriculture food supply was transported from the continent in 2017 and this will increase to 95% by 2036 if there are not changes in food policies. Galapagos undergoing a nutritional transition, drastic changes in diet and lifestyle that lead to obesity and chronic diseases (Waldrop et al. 2016). There is consistent evidence of the impact of food insecurity in the islands, which is pushed forward by the lack of availability and quality of fresh produce, as well as easy access to industrialized processed and ultra-processed foods (Freire et al. 2018). In a recent study, most women (55%) reported food insecurity and 60% reported limited availability of fresh produce due to an unreliable food supply shipped from mainland Ecuador (Pera et al. 2019). More important, in Galapagos, there is the prevalence of the dual burden nutritional disease, where: (1) overweight and noncommunicable disease risk factors and (2) undernutrition and infectious disease symptoms are present within individuals and households. In Galapagos, 16% of children, 33% of adults, and 90% in households, food insecurity was positively associated with the risk of dual burden at the household level (Thompson et al. 2020).

Although the conditions of poverty are not extreme like other provinces of the Ecuadorian continent, 10.4% of people in Galapagos live below 50% of the average income. 51.3% of the population is in poverty due to unsatisfied basic needs (INEC-CGREG, 2015). The gross employment rate is 74.5% (INEC, 2017). 85% of economic activity depends directly or indirectly on tourism. Galápagos had 275,000 tourists in 2019, and there was a 75% decrease in 2020.

All these conditions mean that these communities, fishermen and farmers have less capacity to face the current and future impacts of climate change.

Previous and ongoing Climate Change Processes in Galápagos

The proposal is aligned and will contribute to compliance with the Constitution of Ecuador (Articles 3,14,66, 389, 411, 413, 414, 415), the National Development Plan 2017-2021 (Objective 3, policy 3.4).

The actions of this component support the achievement of the guidelines of the National Climate Change Strategy 2012 - 2025 (State Policy -Executive Decree 495, 2010) in both adaptation (create and strengthen the capacity of social, economic, and environmental systems to deal with the impacts of climate change) and mitigation (create favorable conditions for the adoption of measures that reduce GHG emissions and increase carbon sinks in strategic sectors) pathways. In particular, the activities proposed in this component will support the sectors prioritized by the ENCC are: Food sovereignty, agriculture, livestock, aquaculture and fishing, Water heritage and Natural heritage.

The proposal contributes directly to the Ecuadorian NDC. In adaptation, it will contribute to the following measures and goals:

- Natural Heritage: improvement of the public policy instrument for natural heritage including ACC, implementation of sustainable practices for the use of natural resources in areas of influence.
- Water Heritage: incorporation of climate change criteria and national and sectoral strategies and plans of the water sector, inclusion of climate change variables in technical feasibility and in the regulation and control of water resources and control of water resources. and implementation of its management plans to ensure, in the future, water in quantity and quality; and design and implementation of actions that contribute to increasing the adaptive capacity of hydraulic infrastructure (existing and new) for multiple use.
- Creation and strengthening of capacities on climate change, management of natural heritage and water resources.

- Implementation of communication, dissemination and capacity-building programs that allow the awareness of actors in the agriculture and water sector about the effects of climate change.

- Inclusion of climate change in the Territorial Planning at the local governments. In Galapagos, the Santa Cruz Municipality already has included climate change as one of the main pilars of local development, while Isabela and San Cristobal are in the process.

The priority sectors for intervention are energy, agriculture, water, and ecosystems, and regarding Galapagos territories, it is considered strategic. However, few are the actions implemented at the municipality level and NGOs, mostly carried out in the social and energy fields.

Regarding the productive sectors of the islands, the actions are more at the research level. Public and private organizations dedicated to research have generated important information on the effects of CC on marine and terrestrial ecosystems, which constitutes a great advantage that, when executing actions based on scientific knowledge, they will be mostly effective and efficient.

The Ministry of Agriculture and Livestock of Ecuador (MAG) and the Galapagos Government Council, as of 2018, has built 112 functional micro-reservoirs and 33.51 hectares under technician irrigation systems. At the provincial level, technical support was provided to 380 producers in terms of design, implementation of irrigation systems and construction of rainwater harvesting works through micro-reservoirs (MAG, 2018). Currently, some of these micro-reservoirs are no functional, others are used just as drinking water for livestock, and many of them do not have a continuous management and technical maintenance project by lack of budget. Currently, the capacity of this reservoirs do not satisfy the necessity of farmers, especially in the dry season. The program in this proposal hopes to integrate all these micro-reservoirs into Galapagos water system proposed.

In 2018, the MAG's National Climate-Resilient Livestock Program was expanded to the islands, as a strategy to transform extensive livestock farming into intensive livestock systems resilient to climate change, seeking to increase their profitability without increasing the range of grasslands. Unfortunately, the program has been halted by lack of budget and technical considerations. This component of the project hopes to apply the practices applied by this project as successful adaptation measures.

In 2016, the Institute for Agriculture Research (INIAP) implemented the first Center for Bioknowledge and Agrarian Development in Galapagos, to research, develop and transfer sustainable technologies adapted to the Galapagos ecosystem with a multidisciplinary approach that allows conserving agrobiodiversity and biological diversity. The program in 2019, due structural changes in INIAP, was downgraded to a research farm. Through the implementation of this program, this approach will be continued with the strengthening of the INIAP on their technical staff as well as their equipment.

It is also important to mention the participation of the Agency for the Regulation and Control of Biosecurity and Quarantine for Galapagos (ABG), in charge of control and eradication of quarantine pests, which have climatic controls, including fruit flies (Ceratitis capitata), the

African snail (Achatina fulica), among others. They are currently working together with INIAP in the development of early warning systems, for the control of agricultural pests as one of the adverse effects of climate change. Among its policies is to promote the adaptation of the agricultural sector to climate change, through the granting of certification at the farm level. Another push for exotic species control is led by the National Fund for the Environment (FIAS, Fondo Ambiental Nacional), which has funded a portfolio of projects related to invasive species through several programs, but without an specific focus on climate change.

Links to Mitigation to Climate Change

The adaptation activities to climate change are intrinsically related to climate change mitigation in Galapagos. Appendix 3 of this proposal is an estimation of the Carbon Balance for the activities proposed in this component, which have important mitigation environmental co-benefits. For this purpose, the Ex-Ante Carbon-balance Tool (EX-ACT), developed by FAO, was used. The tool estimates the impact of the agricultural practices on the carbonbalance. The carbon-balance is defined as the net balance from all GHGs expressed in carbon dioxide (CO2) equivalents that will be emitted or sequestered due to climate-resilient practices implementation as compared to a business-as-usual scenario (FAO, 2017).

EX-ACT is a land-based accounting system, measuring C stocks, stock changes per unit of land, and CH4 and N2O emissions expressed in t CO2-e per hectare and year. The main output of the tool is an estimation of the C-balance that is associated with adoption of alternative land management options, as compared to a 'business as usual' scenario (see Appendix 3).

Given the typology of the practices proposed under this program, the analysis considers a 20year period, which is in line with IPCC recommendations for considering the timeframe between transition states of natural systems and the period necessary to reach a new equilibrium for carbon stocks. Therefore, the program consists in five (5) years for the implementation phase and, the sequestration will continue capitalize for 15 more years to reach the 20-years period. In addition, the analysis assumes a linear dynamic of chance (from "without project (BAU)" to "with project) over the duration of the program.

This program consider that each practice will be adopted in at last 41% of the productive farms in Galapagos, considering the agro-production activity and farm size. Considering the potential implementation farms and using the area covered by different land uses in each multidimensional category, an intervention area for each practice were calculated (see Appendix 3). These values will be the key to model the net carbon balance in the upgrade process of each farm category.

Table 11 shows the carbon balance from the implementation of this program with an estimated co-benefit of one (1) million of tCO2-eq of avoided emissions and increased carbon sequestration over 20 years in 8,643 ha (intervention area). This translates into -131 tCO2eq per hectare over 20 years or -6.5 tCO2-eq per hectare per year. The principal contributions for this balance are the CO_2 sequestration from Biomass (-632,514 tCO_2-eq) and Soil (344,815 tCO_2-eq) through the resilient-practices implementation proposed in this program. Improvements in feeding practices and the implementation of biodigesters help generate an absorption from etheric methane (-11,895 tCO2-eq).

Table 11. Summary of net carbon-balance for program implementation. Details See Appendix 3.

RESILIEN FARMS	tCO2-eq per year			tCO2-eq in 5 years (project implementation)	tCO2-eq in 20 years (ecosystem equilibrium reached)
Total	-50,372			-251,860	-1,007,440
Greenhouse gases contribution (tCO2-eq)					
	CO2			**N2O**	**CH4**
	Biomass	**Soil**	**Inputs**		
Total	-632,514	-344,815	-8,254	-2,962	-11,895
Per ha per year	-4.2	-2.2	-0.1	0	-0.1

These results indicate that the Galapagos food system component can have an important contribution in mitigation which complements the adaptation and resilience objectives sought by the program. It will be important to closely monitor the assumptions made during program implementation to truly assess the impact of the program on the ground.

Key Barriers

1. **Weak institutional and technical capacity to address climate change in the Galapagos food system.**

As a function of tourist growth, the number of residents will increase, from 30,000 in 2019, to a number between 48,000 and 105,000 people by 2035 (Sampedro et al 2019), which coupled with the effects of climate change will create synergistic impacts negative to vulnerable people and ecosystems. Key institutions in charge of natural resources management have been incapable to adapt to the developing exogenous pressures (González et al. 2008; Hoyman and McCall 2013), including climate change (Quiroga et al. 2011; Mena et al. 2020; Hennessy 2018).

Despite being one of the most studied territories in the country, Galapagos has limited access and availability of information. A clear example is the lack of enough meteorological observations to cover the wide geographic and altitudinal variation of the islands, the lack of sources for give maintenance and automate the weather stations, and the entire absence of instruments to capture the geographical diversity and terrestrial hydrological variables such as runoff or aquifer dynamics.

This restricts the capacity for forecasting and reacting to climate change impacts and implementing adaptation measures. Moreover, despite the recognition of the importance of the agricultural and livestock sector for food security and the conservation of the island's ecosystem, little progress has been made in the transformation of the sector, which is characterized by low productivity, low profitability, and high vulnerability to changing climate conditions. Information gaps and poor inter-institutional coordination reduce the capacity of institutions to design climate risk management measures, including climate information for decision-making and for designing enabling mechanisms, to provide timely support to this sector in case of being adversely affected, and the search for long term solutions.

There is a need to improve institutional capacity to adapt to climate change and create resilience in the Galapagos Islands (Salinas-de-León et al. 2020). Unfortunately, despite calls for action at the local level two decades ago (Larrea and Di Carlo 2011) and beyond national large-scale strategies, local institutions in the Galapagos, including institutions that regulate and manage the food system, e.g., the Ministry of Agriculture and Livesttock, have not taken into consideration climate change as a pressing problem until recently. They are unprepared and underfunded for taking with adaptation and mitigation actions, especially in aspects related to generation and management of climatic information and the implementation of climate of sustainable resilient practices.

2. **Lack of water management options to guarantee enough water supply for human consumption and agricultural uses.**

As shown before in the climate rational analysis and impacts on the agricultural sector, there is a limited provision of freshwater in the Galapagos Islands for agricultural and urban use. Predictive models, including projections of the water balance, generate potential scenarios with significant decrease in the availability of freshwater.

One of the main barriers to climate change adaptation in the agricultural areas (highlands of Galapagos), with strong implications to the urban areas (lowlands of the Galapagos), is the lack of water management options, which generate conservation strategies, climate change actions and promotion of the resilience. Lack of strategic management for water resources management, considering climate change, is illustrated by the elimination of the National Secretary of Water in Galapagos (SENAGUA), including its Galapagos office (El Universo, 2020). In Galapagos, the responsibilities of SENAGUA have been transferred to the Galapagos National Park (GNP) and the Galapagos Government Council (CGREG), but under lower degrees within the hierarchy of necessities and no supplementary budgets.

3. **Vulnerable farmers lack knowledge of climate resilient agriculture approaches and technological packages.**

Despite that there have been efforts to transform traditional agricultural production in Galapagos into more sustainable and ecologically sensitive practices (e.g., Plan for BioAgriculture from the Ministry of Agriculture, starting in 2013), there is a lack of understanding of the specific effects that climate change has over the production systems and how to create resilient food production and distribution processes. More specifically, technical staff from the relevant governmental agencies and farmers do not have access to information about climate resilient agricultural solutions, how to be implemented and sustained them across time.

Unskilled management practices, inadequate for local conditions, and climatic vulnerability have reduced productivity and efficiency in the use of farm resources. Farmers have adopted practices through productive systems dependent on external inputs, while knowledge generated by local institutions is not fully disseminated among farmers. Similarly, farmers have limited knowledge of climate change impacts and what the appropriate adaptation options and practices are, coupled with the current low capacity of rural extension services to integrate climate change criteria into the design of agricultural practices and the transfer of knowledge to farmers. Based on Barrera et al. (2019), on average, only 32.21% of the farmers in Galapagos use different technologies in the farming system

4. **Limited knowledge and access to technological solutions to collect and store water during the rainy season for use during the dry season.**

There is also limited knowledge and access to effective water management. Specifically, in the agricultural areas, for water collection and storage, as reported above only 30% of the farms in Galapagos have access to irrigation.

Right now, rural agricultural and livestock areas that experience a water deficit are partly supplied by delivering brackish water in tanker trucks. This form of distribution is ineffective, dependent on the availability of material and economic resources and generates salinity in the soil that can have serious consequences for the productive activity and health of the ecosystem. MAG has delivered reservoirs and drip irrigation systems, but its scope is limited in relation to the agricultural and livestock surface area. The ability of farmers to invest is low given the insecurity of having reliable water supplies, the lack of incentives for local production and the costs associated with fighting invasive species.

5. **Farming lands abandonment and invasive species**

Agricultural land abandonment is widespread across the Galapagos. It is produced by several factors, including uncertainty about climate change, farmers moving to more lucrative jobs in the tourism industry, unfair competition with agricultural products brought from the mainland, lack of labor and access to technology, among others. Abandoned agricultural lands become repositories of invasive species which then spread across different landscapes, including areas of the Galapagos National Park. Abandoned agricultural fields covered by invasive species later are difficult to restore due the cost of eradication. Farmers lose livelihoods and ecosystem shift to vastly different regimes, often exacerbating the impacts of climate change in biodiversity.

6. **Farmers lack of financial resources to implement climate resilient practices.**

For many years, the agricultural production system has been isolated from markets in the Galapagos, as the largest portion of the food in the Galapagos is imported from the mainland. This has generated a decrease in the resilience of the food systems to exogenous shocks, including the impacts of climate change. Evidence emerges as (a) large problems of nutrition in vulnerable sectors of the local population becomes clear and (b) increase agricultural land abandonment, as mentioned before.

It is necessary to provide the basic infrastructure, equipment, and knowledge to integrate local production into the agricultural value chains, with a twofold aim, contribute the food security of the growing population and support the climate change adaptation agricultural practices.

7. Vulnerable Farmers are excluded from current value chains.

The exclusion of local agriculture and local products of the markets and final consumers, in Galapagos and outside, have produced abandonment of agricultural land, food security problems for the local population, increase of invasive species, which decrease climate change resilient alternatives for rural population. The exclusion is result of a combination of several factors, including the importation of cheap agricultural products from the mainland. Imported food is produced with lower labor costs, increase use of inputs not allowed in Galapagos (e.g., improved seeds, pesticides), and subsidized transportation. Another important factor is the high degree of uncertainty related to future climatic conditions in farming practices, which will not allow farmers to plan for short and mid-term investments in agriculture. This has produced a level of production, which is not predictable or constant and often, cannot satisfy regular demand. It is necessary to include vulnerable farmers to, climate resilient, food value chains that will lead them to reactivate, maintain and sustain agricultural land use.

CHAPTER 2: INTERVENTION PLAN

Design of the intervention plan

The main objective of this component is to strengthen the islands' food system, resulting in increased availability of local food to supply for visitor and resident populations, while simultaneously addressing the provision of fundamental ecosystem services, such as water as well as healthy ecosystems and emblematic species to sustain nature-based activities. In order to achieve these proposed objectives and indicators while accounting for the uncertainties and limitations (described in the previous sections), the proposed strategies look to follow a resilient, robust, and uncertainty-based approach.

There is a variety of adaptation options that allow for increasing the productivity of the agricultural system, improving its resilience to climate stress, and reducing greenhouse gas emissions under a concept of sustainability (CGIAR, 2013; Khatri-Chhetri, et al., 2017). These options have been defined as climate-resilient practices (FAO, 2010), which integrate traditional and innovative practices that are relevant for a specific location to adapt to climate change (CIAT, 2014; FAO, 2013b).

These practices are mainly focused on the sectors of agricultural production: crop production, livestock production and forestry; and in a climate-resilient use of natural resources: water; soil and genetic resources; in addition to considering energy management and value chains of the food system (FAO, 2018). Examples of these practices include the use of diverse varieties and species of seeds tolerant to climate stress, in addition to hybrid seeds, efficient irrigation programs with low energy consumption, sustainable cattle raising (i.e., silvopastural practices); tree integration in the agricultural system; restoration of degraded lands; improvement of fertilizer use and soil quality, energy solutions for agro-processing; organic waste management, including the use of anaerobic biodigesters (World Bank, 2016; Lipper et al., 2014); among others.

Through the incorporation of climate resilient technologies and practices, this proposal seeks to contribute to redefining the role of agriculture and its contribution to the sustainable development of the islands, simultaneously guaranteeing the conservation of their agroecosystems and the food security of the island population, current and future, in healthy balance with the nature of the islands. The main steps were considered in designing climate change mitigation and adaptation measures are detailed below:

1. Assessment of the food systems and consultation process with key stakeholders
2. Selection of climate resilient agricultural and livestock practices based on decision scaling approach for the resiliency of agro-ecosystems.
3. Beneficiaries

Consultation Process

In support of this study, information about current state of food system was obtained thorough consultations with farmers and key institutions of Galapagos. A household survey was conducted, during February of 2020 on 344 households, randomly selected from the 744 Unites of Agricultural Production (Farms), distributed on the three major inhabited islands: San Cristobal, Santa Cruz, and Isabela.

A long-form questionnaire was previously designed, which include questions about demographic characteristics, socio-economic conditions, social organization, gender, agricultural practices and outcomes, crop and livestock management, irrigation, and climate change. 119 farm households were surveyed in San Cristobal, 168 in Santa Cruz and 57 in Isabela (Figure 19). At the moment of this report, descriptive and cross-tabulations analysis were performed, and statistical modelling is in preparation. Additionally, a semi-structured, open ended, questionnaire was applied to key stakeholders from public and private institutions, community leaders and farmers, to understand their role and opinion about the Galapagos Food System.

Interviews with farmers, technical staff and authorities were performed between March and December 2020, by telephone and via email, due restrictions created by the COVID19 pandemics.

Selection of resilient agricultural and livestock practices based on decision scaling approach for the resiliency of agro-ecosystems.

Based on the assessment of the food system and the classification of agroecosystems, we selected resilient agricultural and livestock practices that contribute to the transition from conventional agriculture to an agriculture that is resilient to climate change. This selection has an agroecological focus, emphasizing the harmonic relationships of stabilizing processes and their functionality, as well as the system's capacity to tolerate different disturbances of different magnitudes, natural or anthropogenic.

The biggest challenge for climate change adaptation of the agricultural sector is the lack of data necessary to establish robust planning activities. We therefore sought alternative methods for a process to design and implement adaptation activities. Among the various approaches that exist, for this proposal we followed a decision scaling approach (also known as the Climate Informed Decision Analyses, CIDA or the Decision Tree Framework by the World Bank) (Brown et al., 2012). Here, the level of complexity as well as the resources needed to inform decisions is scaled (adjusted) according to the unique characteristics of the food and water systems, as well as the issues and decisions that may arise in the process that are generated by stakeholders. This approach consists of two main stages, which are herein, briefly described:

Phase 1. Diagnostic and Formulation. This phase corresponds to the understanding of the general characteristics of the resources system and the formulation of objectives and intervention strategies. In this stage it is represented and described the physical, infrastructure, uses, stakeholders and others which characterize the system. This physical characterization includes the examination of the relationship between climatic parameters and land parameters (e.g. soil, runoff, river flow, recharge, etc). At this point, it is also possible to estimate elasticities of key variables to shifts in climatic, and other, conditions. The characterization of the system then includes the definition of the metrics upon which a system, or investments, may be deemed as *successful*. Once these relationships and characteristics are understood, this stage finalizes with the listing of intervention strategies, which would be used to improve the metrics already, described.

Phase 2. Stress Test. The next stage corresponds to a deeper examination of the climatic and no climatic vulnerabilities of the analyzed food and water systems. Acknowledging the uncertainties that such systems may face, in this phase, risk is exhaustively evaluated and detected by testing a large set of possible scenarios which may occur. This stage principally makes use of tools such as stochastic generators of time series which in the case of climate change, correspond to weather generators, synthetic time series, and others. So, a wide number of plausible scenarios of climate, demand, land use, and others are used to evaluate how the indicators and metrics of such food and water systems respond under those scenarios and their combinations.

A decision matrix was built to identify the best alternatives for the resilience of the agroecosystems in Galapagos. The alternatives were weighted according to their grade of suitability considering climate, environmental, social and economic dimensions (Figure 23).

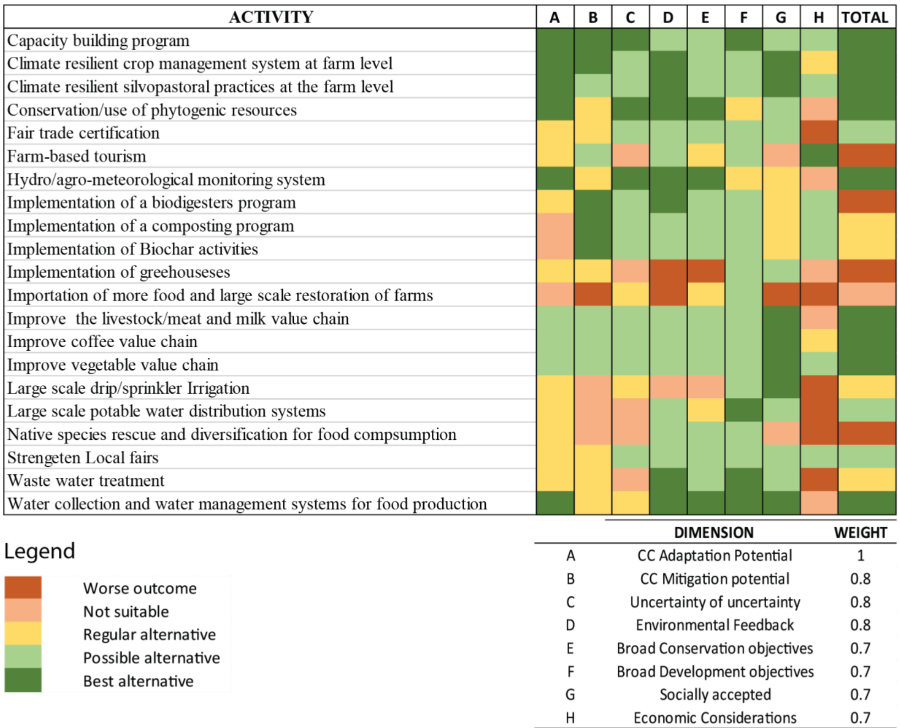

Figure 23. Decision matrix for resilient agricultural practices selection

In this context, this program promotes the adoption of practices and technologies resilient to climate change that are tailored to the needs of each production system present on the Islands. The practices will be oriented to maintain and conserve agrobiodiversity through rural development, training and awareness, mainly with the participation of women and focus on agro-ecological approaches.

Beneficiaries

Beneficiaries of this component are families managing 755 farms located in the Galapagos Islands. These farms cover an area of 19,000 hectares, containing 228 large-scale farms (> 20 hectares), 202 medium-scale farms (5-20 hectares), and 325 small-scale farms (< 5 hectares). Figure 24 shows the spatial location of the farms across different agricultural zones. The map also indicates whether the farm is mainly managed by male or female farmer. In addition, the map also shows the main activity within the farm, including if it is mainly devoted to coffee, crops, livestock, mix (crops+livestock) or other, which include native or invasive vegetation. This map also indicates the location of non-active (abandoned) farms.

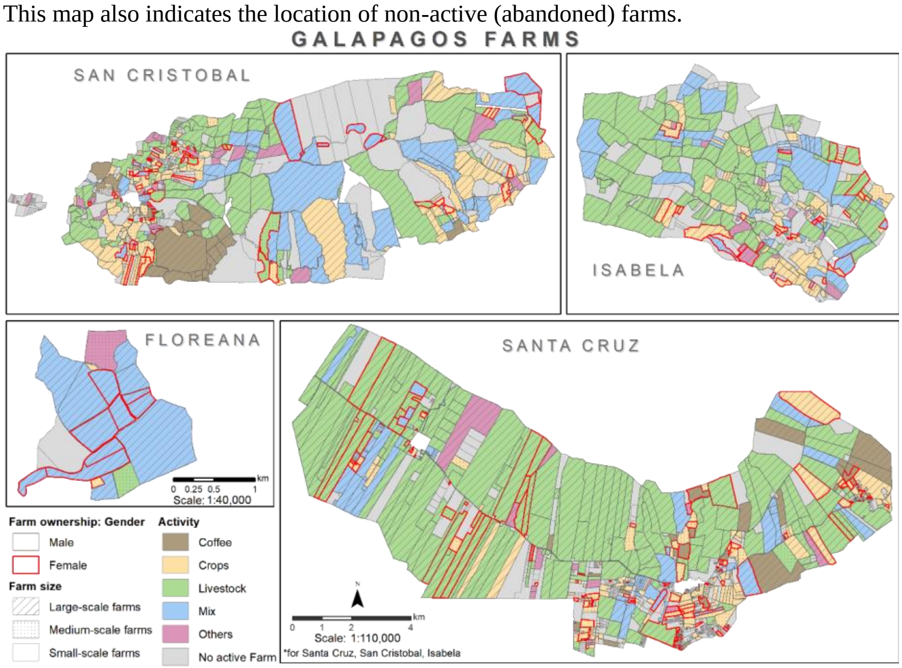

Figure 24. Map of the beneficiary farms in the agricultural areas of the Galapagos Islands

For the Galapagos in general, according to the 2014 Census, the percentage of people with “basic needs no satisfied” is 25,01%. Newer household surveys indicate different dimensions of poverty. As indicated before, in terms of nutrition, most women (55%) reported food insecurity and 60% reported limited availability of fresh produce. About

39.4% of household sampled in the Galapagos think that they live in a "poor" household and that conditions have worsening through the years. Lack of a formal employment is more than double for women (7.2%) than for men (3.0%), despite that women are slightly better educated than men (average years of reduction, 9.4 for men and 9.61 for women).

Only 55% of the population have access to the National Institute of Social Security (IESS – Instituto Nacional de Seguridad Social) and only 11% have access to prepaid private medicine. These numbers are set to be amplified in rural households, where no official numbers exist.

In terms of the farming system, Figure 24 shows there is a large diversity of type of farms across islands. Table 12 through Table 16 show detail information for Galapagos and each of the islands, in terms of size and main agricultural activity.

Table 12. Farm type (scale) and main agricultural activity for all agricultural areas of the Galapagos

Main agricultural activity		**Farm size**			
		Large-scale farms	Medium-scale farms	Small-scale farms	Total
Crops	Farms	28	111	205	344
	ha	1,255.9	1,051.4	427.3	2,734.6
Coffee	Farms	8	13	10	31
	ha	931.0	149.5	30.8	1,111.3
Livestock	Farms	137	46	2	185
	ha	10,509.2	522.3	9.0	11,040.6
Mix	Farms	47	14	3	64
	ha	3,267.2	188.3	9.4	3,464.8
Other	Farms	8	18	105	131
	ha	387.0	164.6	106.7	658.2
Total	Farms	228	202	325	755
	ha	16,350.3	2,076.1	583.2	19,009.6

Table 13. Farm type (scale) and main agricultural activity in San Cristobal Island

		Farm size			
		Large-scale farms	Medium-scale farms	Small-scale farms	Total
Crops	Farms	14	44	101	159
	ha	728.3	429.4	201.5	1,359.2
Coffee	Farms	2	3	3	8
	ha	476.7	38.5	9.1	524.3
Livestock	Farms	25	19		44
	ha	1797.3	201.3		1,998.5
Mixed	Farms	15	1	1	17
	ha	1492.1	15.5	5.0	1,512.6
Other	Farms ha	4	7	21	32
		128.9	51.0	38.5	218.3
Total	Farms ha	60	74	126	260
		4623.2	735.6	254.1	5,612.9

Table 14. Farm type (scale) and main agricultural activity in Santa Cruz Island

		Farm size			
		Large-scale farms	Medium-scale farms	Small-scale farms	Total
Crops	Farms	8	46	79	133
	ha	286.8	414.6	164.2	865.6
Coffee	Farms	6	10	7	23
	ha	454.3	111.0	21.7	587.0
Livestock	Farms	74	18	2	94
Mixed	Farms	15	8		
	ha	806.7	113.7		920.4
Other	Farms	3	5	76	84
	ha	227.5	54.3	43.6	325.4
Total	Farms	106	87	164	**357**
	ha	8,444.1	909.0	238.6	**9,591.7**
					6,893.2
	ha	6,668.8	215.4	9.0	23

Table 15. Farm type (scale) and main agricultural activity in Isabela Island

		Farm size			
		Large-scale farms	Medium-scale farms	Small-scale farms	Total
Crops	Farms ha	6	20	21	47
		240.8	194.7	56.0	491.6
Livestock	Farms	38	8		46
Mixed	Farms	13	5	2	
	ha	763.1	59.1	4.4	826.6
Other	Farms	1	5	8	14
	ha	30.6	58.3	24.6	113.5
Total	Farms	58	38	31	**127**
	ha	3,077.7	412.8	85.0	**3,575.5**

				ha
			2,143.9	
2043.2	100.7		20	

Table 16. Farm type (scale) and main agricultural activity in Floreana Island

		Farm size			
		Large-scale farms	Medium-scale farms	Small-scale farms	**Total**
Crops	Farms		1	4	5
	ha		12.7	5.5	18.2
Livestock	Farms		1		1
	ha		5.0		5
Mixed	Farms	4			4
Other	Farms		1		
	ha		1.0		1.0
Total	Farms	7		4	**11**
	ha	224.0		5.5	**229.5**
					205.3
	ha	205.3			1

In terms of demographic variables, household size in the farms of Galapagos is, on average 3.0, which is significantly lower than the national average. Table 17 shows the distribution of people by age groups (< 5 years old, 6 – 18 years old, 19– 60 years old and > 60 years old). This table also shows the low number of young people (6-18 y.o) that live in the farms.

Table 17. Percentage of people, across different age groups in farms by Islands and farm size

	% of people within the farm			
	< 5 y.o.	6 – 18 y.o.	19 – 60 y.o.	> 60 y.o.
Island				
Isabela	6	15	61	17
San Cristobal	3	18	49	30
Santa Cruz	1	15	59	25
Farm size				
Small-scale farms	5	15	59	22
Medium-scale farms	4	21	50	25
Large-scale farms	1	13	52	34
Total	**3**	**16**	**54**	**26**

Among the key socioeconomic characteristics of these farms, and the households who manage them, are labor, access to credit, and production costs. As expected, these farms have differences, in terms of labor according to its size. Small farms are worked mostly as family units, 58% of the small farms have family as main labor force. In contrast, large farms have mostly hired labor as workforce. Men are primarily workers at the farms of Galapagos, but 29% of the small farms are managed by women. Figure 25 shows details for all the Galapagos farms. In terms of off-farm employment, 49% of the owners also have additional economic activities outside of the farms.

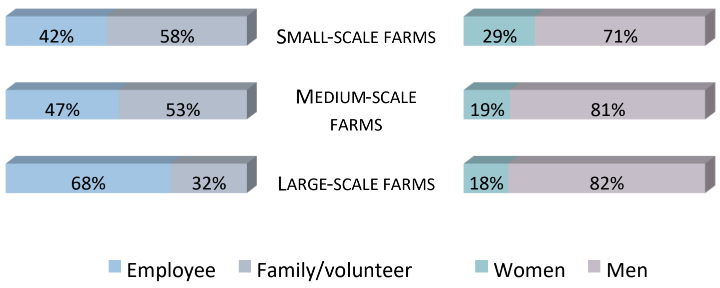

Figure 25. Description of the workforce in Galapagos farms

In terms of access to loans, in general, less than 45% of the farms had access to credits to improve their production (Table 18). San Cristobal is the island with less access to loans.

Table 18. Access to loans by farms in the Galapagos Islands

	Farms that had access to loans in the last 5 years (%)	
Island	No	Yes
Isabela	47.37	52.63
San Cristobal	59.76	40.24
Santa Cruz	53.95	46.05
Galapagos	55.10	44.90

In terms of the cost of production, defined here as the dollar value of all on-farm inputs for growing a specific or several crops in each period. This exploratory indicator estimates costs for seeds, irrigation water, fertilizer and pesticides, machinery time, purchase/maintenance of small farm tools, and labor, all reported by farmers. The annual hired labor was determined from total daily workers, daily wage, and an assumption of 180 labor days.

Results show that the average cost of production on-farm was approximately $7,000 in 2019. San Cristobal has the lower production cost in the islands, mainly due to the fact that San Cristobal is the only island with natural fresh water sources, reducing the irrigation water cost.

On the other hand, as expected, large-scale farms double annual production costs (~$12,000) compared to the small and medium-scale farms ($5,000), see Figure 26.

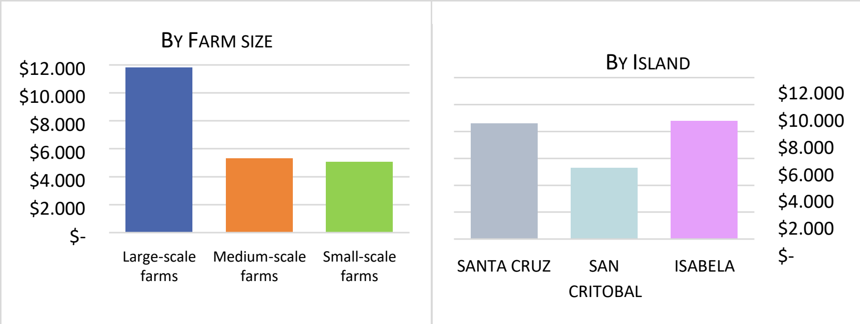

Figure 26. Agricultural production costs by farm size and Islands

Given the number of agroecosystems and their main household characteristics, the potential beneficiaries, which will be managed under climate-resilient practices proposed in this component, was selected based on farm type (scale) and agricultural activity. Thus, with these factors in mind, we determined that each practice will be adopted in at last 41% of the productive farms in Galapagos (Table 19), covering approximately 8,500 ha of productive lands across the four populated islands (see Appendix 3).

It is estimated that a total of around 624 farmers will benefit directly from the project (about 187 female and 437 male farmers). The average family size is 3 per household, thus, the number of total beneficiaries is estimated to be around 1,872 persons. The intervention plan is summarized in Table 20.

Table 19. Beneficiaries summary by Activity

Activity	Beneficiaries
Implement a capacity building program for government technical staff for dissemination of practical information, knowledge and training about climate change and climate resilient agricultural practices	• 15 technicians • 6 Institutions
Provide a hydro/agro-meteorological monitoring system to inform and tailor the information to the needs of vulnerable smallholder farmers	• 2 Institution (INAMHI, GSC) • 15 technicians • 755 farms
Develop a physical and knowledge network for conservation and use of phytogenic resources through in-situ and ex-situ conservation activities	• 25 seeders • 1 Institution (INIAP) • 624 farms
Implement an integrated climate resilient crop management system at farm level	• 404 farms (1,212 beneficiaries, 30% women)
Implement silvopastoral practices at the farm level	• 244 farms (732 beneficiaries, 30% women)

Develop and implement water collection and water management systems for climate-resilient food production	• 500 ha (1,704 beneficiaries, 30% women)
Implement strategies for improve the livestock/meat and milk value chain	• 244 farms (732 beneficiaries, 30% women)
Implement strategies for improve coffee value chain	• 67 farms (201 beneficiaries, 30% women)
Implement strategies for improve vegetable value chain	• 497 farms (1,491 beneficiaries, 30% women)

Intervention Plan:

Table 20. Outcomes, Activities, Sub-activities

OUTPUT	ACTIVITY	SUB-ACTIVITIES (Practices)
Output 2.1.1. Enhanced institutional capacity for climate-resilient planning and development	2.1.1.1. Implement a capacity building program for government technical staff for dissemination of practical information, knowledge and training about climate change and climate resilient agricultural practices	Develop a training program of 4 modules for governmental staff.
		Develop a framework to include climate change in the extension and rural advisory services for farmers
	2.1.1.2. Provide a hydro/agrometeorological monitoring system to inform and tailor the information to the needs of vulnerable smallholder farmers	Acquisition, placement, and implementation of sensors capable of measuring climate, water, and agriculture variables.
		Develop an information system capable of collecting information, processing and perform data quality/data control activities.
		Train technical staff for implementation of sensors and management of the information system.
Output 2.1.2. Improved farmers livelihoods and rehabilitated ecosystem services through climateresilient water and agricultural food productions systems	2.1.2.1. Develop a physical and knowledge network for conservation and use of phytogenic resources through in-situ and ex-situ conservation activities	Implement in-farms conservation activities: collect, conserve, use and distribute the agrobiodiversity existing in Galapagos (community-based seed bank), with special focus on the variety of crops resistant to biotic changes caused by climate change.
		Improvement of existing infrastructure at INIAP, which will work as agrobiodiversity repository, knowledge center and distribution facility, for long-term conservation.
	2.1.2.2. Implement an integrated climate resilient crop management system at farm level	Implement soil management practices in farms
		Establish crop and pest management practices, including a growing climate resilient seed
	2.1.2.3. Implement silvopastoral practices at the farm level	Farmers training to implement silvopastoral systems (guava-grass-breeding association)
		Implement of fodder banks in farms.
		Implement internal division of paddocks to apply rotational grazing through regularly moving livestock between paddocks
		Implements a manure management through biodigestor

	2.1.2.4. Develop and implement water collection and water management systems for climate-resilient food production	Install water sources and storage
		Install water distribution system
		Install climate smart irrigation systems
Output 2.1.5. Upgraded and more efficient green value chains and increased links to new markets developed	2.2.2.1 Implement strategies to improve the livestock/meat and milk value chain	Strengthening livestock production systems with environmentally friendly practices that are adapted to the context of Galapagos and help breach the productive gap in farms in terms of quantity and quality
		Strengthening adequate livestock slaughter and meat processing systems
		Strengthening of dairy processing plants
		Positioning of the local market
		Implementing a program to strengthen local capacity
	2.2.2.2 Implement strategies to improve coffee value chain	Strengthen knowledge on post-harvest strategies
		Mobilizing production to the local coffee agro-processing center
		Construction of a wet processing center
		Construction of a dry processing center
		Monitoring system
	2.2.2.3 Implement strategies to improve vegetable value chain	Agroprocessing of Banana, Plantain and Cassava flours and chips
		Agro-processing of preserves and pulps of citrus fruits, pineapple and tomato
		Agro-processing of aromatic and medicinal herbs
		Monitoring System

Output 2.1.1. Enhanced institutional capacity for climate-resilient planning and development.

This Output addresses barriers 1 and 3. The activities proposed in this output will improve the knowledge of Galápagos' government staff and vulnerable farmers on climate change issues and climate-resilient agricultural best practices. In addition, the generation and access to hydrometeorological information for decision-making in a changing climate will be strengthened, and consequently decision-makers and farmers will act against climate change. These activities will enhance the adaptive capacity of farmers and allow climate change adaptation planning to be sustained beyond the activities proposed in this component and program.

Beyond national large-scale strategies, local institutions in the Galapagos, including institutions that regulate and manage the food system, including the Ministry of Agriculture and Livestock, have not taken into consideration climate change as a pressing problem. Moreover, as a function of tourist growth, the number of local residents will increase to a number between 48,000 and 105,000 people by 2035 (Sampedro et al 2019). This range of growth in the local population indicates the need for a corresponding growth in the institutional capacity to adapt to external shocks, including climate change.

Unfortunately, in the last years, there have been a systematic weakening of local governmental institutions, because, among other things, decrease in the national income due fall of international of commodities and the COVID19 pandemics resulting on the complete collapse of the tourism industry. This institutional weakening has been more explicit in sectors of Galapagos government which deal with environmental and social issues, key for the improvement of resilience. For example, reduction of the budget for education (El Comercio, 2020), elimination of key local institutions, including the National Secretary of Water in Galapagos -SENAGUA Galapagos (El Universo, 2020), and the reduction of monitoring programs dependent on the fee that tourists pay to enter Galapagos. This leads to unprepared and underfunded institutions for implement adaptation and mitigation actions.

Uncertainty about short- and long-term climatic conditions does not allow investment on agricultural lands, promoting agricultural land abandonment. Local government agencies are not prepared to offer any type of solutions that prevent land abandonment due erratic climatic conditions or information, which support resilient land management practices. Additionally, the network of meteorological stations in Galapagos, managed by the Ecuadorian National Meteorological and Hydrological Institute (INAMHI, by its acronym in Spanish), is not enough to cover the whole extend of the islands and capture the entire geographical diversity of the Archipelago. At the same time, there is an entire absence of devices which would allow to examine terrestrial hydrological variables such as runoff or aquifer dynamic. The lack of sufficient observational records (meteorological and hydrological) available for the islands has not allowed the implementation of hydro-meteorological early warning system that alert population about dangerous conditions for improved water resources management and agricultural planning.

Barrera et al (2019) report uncertainty of weather conditions as a main challenge that farmers in the Galapagos face. This study accounts that 71,1% of farmers report emergent and unexpected droughts as one of the main challenges for the food system. Additionally, it is reported that invasive plant species and plagues benefit from erratic El Niño like conditions and make it difficult for farmers to control and cultivate land.

In this context, this package of activities is built into the assumptions that local, on-time, information is key for any adaptation activity or program in the agricultural sector. It also assumes that one of the pillars of sustainability of this program is the knowledge accumulated and shared by agricultural extension program[1] and applied by farmers. The extension program will take in account local knowledge and Galapagos agroecosystems conditions based on ongoing monitoring.

In this context, the activities of this output will be focused on:

a) implementation and strengthening of local capacities in key governmental institutions (Ministry of Agriculture and Livestock (MAG), Ecuadorian Institute of Agricultural Research (INIAP), municipalities, and the Galapagos Government Council (CGREG)) into the importance of climate chance, impacts into the food system, and more importantly, about climate resilient agricultural practices to be disseminated at the farm level, as an extension program; and

b) strengthening of the hydro-meteorological stations network and implementation of a hydro/agro meteorological monitoring system to support farmers and producer organizations with key and time-sensitive hydro-climatic information relevant for land management decision making. Weather/climate/hydrological information will be appropriately packaged and combined with other sources of information related to household vulnerability/food security by multi-institutional task team (INAMHI, Galapagos Science Center[2]), and disseminated through Climate users interface platform.

Activity 2.1.1.1. Implement a capacity building program for government technical staff for dissemination of practical information, knowledge and training about climate change and climate resilient agricultural practices.

The objective of this activity is to implement a capacity building program to strengthen the knowledge of key local governmental agencies and vulnerable farmers. It is expected that people trained will be able to develop an extension program for farmers and their families about climate change and agricultural adaptation and mitigation practices based on local knowledge. This activity will guarantee sustainability of the activities of this program.

This activity will be the base for the implementation and the sustainability for climate-resilient agricultural practices (Output 2.2.1) at the farm level in Santa Cruz, San Cristobal, and Isabela Islands. Fifteen specialists from the MAG, INIAP, CGREG, and three Municipalities will receive formal training, for 4 months, in topics related to climate change, the effects of climate change in Galapagos and the technical aspects of climate resilient agricultural practices. The

[1] Agricultural extension is how new knowledge and ideas are introduced in rural areas in order to generate changes and improve the quality of life of farmers and their farmers. This agricultural extension program is coordinate and implemented by the Ministry of Agriculture and Livestock.

[2] Investigation Center of the San Francisco de Quito University and North Carolina at Chapel Hill University

trained participants will be the base of a long-term extension program about the agricultural practices based on local conditions to improve resilience in the agricultural areas of Galapagos.

It is important to mention that each organization will carry out the implementation of activities and training for farmers according to their competencies and using the agricultural extension program. MAG will oversee resilient agricultural practices, CGREG will deal with resilient water management, INIAP with adaptative use of phytogenetic resources, and the Municipalities with the integration of agricultural products into the value chain.

Human capital development is key for the agricultural sector to adapt to climate change (Mustapha et al 2012) and it is imperative for achieve a climate resilient food system in Galapagos. Knowledge acquisition and co-creation and sharing among government agencies and farmers will be key for long-term adaptation action beyond this program and key for long term climate resilience of the food system of the Galapagos Islands.

This activity will address the following vulnerabilities:

- Lack of knowledge within government officials, functionaries, and extension staff about the specific impacts of climate change in the agricultural lands of Galapagos.
- Lank of knowledge about agricultural practices resistant to drought, floods, and climatecontrolled pests.
- Lack of knowledge of best management practices to deal with water availability and water scarcity in the agricultural areas and downstream.
- Lack of knowledge and capacity, from the cattle ranching sector, to respond to extreme climate events.

This activity includes the following sub-activities that allow to improve the adaptive capacity of the technical staff and farmers in Galapagos:

a. Develop a training program of 4 modules for governmental staff in Galápagos.

A set of 4 educational modules will be taught to 15 local government staff members (MAG, INIAP, municipalities, and CGREG), with a duration of 80 hours synchronous and 160 hours of complementary work. The proposed contents for the modules are:

1. The scientific basis of climate change (8h)
2. Climate change and the agricultural systems in the Galapagos (8h)
3. Exposure, vulnerability, risk, and adaptive capacity of the agricultural areas in the Galapagos (8h)
4. Climate resilient agricultural practices (56h):
    - Silvopastoral systems
    - Vegetative Species Diversification - Integrated crop management - Use of genetic resources.
    - Other on farm actions: biodigester, composting, biochar
    - Climate smart value chains
    - Best practices in water management

- Information interpretation and diffusion
- Implementation of extension and rural advisory services
- Gender
- Others

The training will be endorsed by the organizations that will implement this component and the program; and the endorsement of an educational center will also be sought if possible. The participants will be selected based on their institutional functions which may be related with the training program. The training will be implemented three times during the five years of the implementation program.

b. Develop a framework to include climate change in the extension and rural advisory services for farmers.

This component will be developed by the staff already trained. Five technical staff will work in each island and will be divided as follows:

- 2 MAE staff members for agricultural services
- 1 INIAP staff member for phytogenetic resources (seed management, agrobiodiversity conservation)
- 1 CGREG staff member for water management
- 1 Municipality for climate resilient productivity (agricultural value chain)

These trainings will be done directly on the farms or in places accessible to farmers, considering appropriate hours and considering gender aspects. This framework will be carried out during one month every six months and should seek to include the largest number of farmers (755 farms), especially women to achieve gender equal participation in all activities as well as promoting gender equality and women's opportunity through women's empowerment activities. Additionally, results framework will seek to monitor progress program, it will allow to re-assess baselines as needed and discuss farmers experiences and challenges.

Environmental Benefits and adaptation scenario

These interventions provide indirect impacts on the protection of agricultural diversity, soils, and water resources. It generates an additional mechanism for the long-term sustainability of the program. Other environmental indirect benefits are described below:

✦ Local knowledge co-generation and sharing for greater sustainability and protection of the crops, protection of water sources, control of the expansion of invasive species, increase of natural pollinators, and resilience of ecosystem and agroecosystem services to climate change at the agricultural landscape scale.

Social Benefits

The strengthening of the capacities of key actors in this case to achieve a resilient production system is considered a measure to improve the adaptive capacity. Vulnerable farmers will have this knowledge, and learnings to apply on their farms. On the other hand, the decision-makers of the different institutions in Galapagos may consider the climate change variable in their actions and policies. By building capacity in key agricultural agencies, the program supports the sustainability of the climate-resilient agricultural practices. Sustainability will be ensured by building on existing institutional structures that include MAG and agricultural extension workers.

Beneficiaries
✦ **DIRECT:** 15 technical staff members of the Ministry of Agriculture (MAG), Ecuadorian Institute of Agricultural Research (INIAP), the Galapagos Government Council (CGREG), and three Municipalities
✦ **INDIRECT:** Landowners of active farms where climate resilient practices will be implemented: 260 farms in San Cristobal (5,612.9 Hectares), 357 farms in Santa Cruz island (9,591.7 Hectares), 127 farms in Isabela (3,575.5 Hectares) and 11 farms in Floreana (229.5 Hectares).

Activity 2.1.1.2. Install a hydro/agro-meteorological monitoring system to inform and tailor the information to the needs of vulnerable smallholder farmers and for implementation of water collection infrastructure.

Access, generation, and delivery information is critical in the process of enhancing the adaptive capacities of the rural areas to climate change (Mustapha et al 2012). There are no information services at any scale for Galapagos as a region, any component of the food system, and specifically, for farmers and their families. This action will collect data, produce information, analyze, and interpret, and disseminate information for decision making at different levels, from the farms to the province. These actions will reduce the uncertainty of drastic hydrometeorological changes and climatological variability. By generating information about hydro-meteorological conditions will also help to understand agricultural productivity through restoration and rehabilitation strategies, look increment carbon sequestration and create or maintain microclimatic conditions that favor the sustainability of a cropping system.

This activity will address the weakness of hydrometeorological data in the Islands and will strengthen the capacities of local government agencies like The National Meteorology and Hydrology Institute (INAMHI) and CGREG. Initially, the Galapagos Science Center (GSC), located in San Cristobal Island will lead the management, analysis, and distribution of meteorological and climatic data. The GSC is a research center co-managed and co-funded by Universidad San Francisco de Quito and the University of North Carolina at Chapel Hill (USA). GSC in 2019 signed a Memorandum of Understanding with INAMHI to provide technical and logistic support in the Galapagos Islands. For this adaptation activity, GSC will provide in kind support for this action, in the form of equipment, i.e., servers and technical staff for data management. The provision "in-time" information and services will allow the construction of a climatic information system for land management decisions.

The objectives of this activity are:

a. Collect relevant hydrometeorological and climatic data suitable for land management decisions and climate change adaptation practices.
b. Process and distribute, on-time, climate change information to relevant users of different levels, to promote adaptation practices.

The monitoring system will include:

a. Climatological monitoring: This is the base of the input information in water and irrigation planning and operations. Temperature, precipitation, humidity, wind velocity, radiation and cloud fraction are the variables that give the base towards a sophisticated understanding of the water fluxes and dynamics in the Islands. At the same time, as indicated, fog plays a major role in the Galapagos, especially in areas above 400m above sea level. Thus, it is important to also monitor this process and the real contribution that it may have on water offer.

b. Surface hydrology monitoring: Next, monitoring surface water variables are useful to estimate water flow levels at the catchment or farm level. Key variables here include surface runoff, interflow, and baseflow. and interflow. Since the Islands do not count with direct observations, at present, these variables are obtained from assumptions or modelling efforts as the one used here. Yet, naturally, a comprehensive water resources management initiative should establish a minimum of direct observations and measurements of these variables which in turn support local-level decisions as well as modelling efforts.

c. Groundwater monitoring: Similarly, the Galapagos do not count with a system which monitors groundwater levels and dynamics. It is important to note that aquifers and springs are the principal water source specially in Santa Cruz and Isabella. As such, herein is proposed a series of instruments to permanently monitor the conditions of the aquifers and thus inform decisions about recharge levels and its quality.

d. Train farmers in decision making based on the information generated and disseminated.

It is important to note that these three aspects will be integrated within a Climate Information System for Galapagos, which would aggregate and distribute this information. This tool would be a dashboard which would, apart from generate technical data, could facilitate decision making in the sector. In coordination with GSC/INAMHI. Under this activity, the database and information system will be strengthened and linked to agricultural, irrigation and environmental information systems through signing of cooperation agreements for the development of joint protocols for data collection, exchange, processing, analysis, and risk assessment. Based on the protocols, institutions owning meteorological stations will be endowed with the right equipment for data gathering, processing, and archiving. This local information will be integrated into the downscaling of global circulation models for improved forecasting and prediction. Data will be available for different users, at different scales and different platforms, including a dedicated web portal for external users and an app, to be built with a participative approach, to disseminate in-time information across farmers.

A key component is a training for technical staff in the use of equipment, process of data, troubleshooting, and data distribution. This component is also articulated with Activity 2.2.1.2, which, includes the implementation of training for better water management practices for farmers, where the use of information is key.

This activity will address the following vulnerabilities:

- Lack of information about current hydrometeorological and climatic conditions to take decisions and actions to combat climate change.
- Lack of information of potential upcoming drought and floods

- Uncertainty related to water availability and water scarcity in the agricultural areas and downstream.
- Lack of adequate time frame, from the agricultural and cattle ranching sector, to respond to extreme climate events.
- Lack of integration of existing information for adaptation purposes
- Lack of adequate dissemination of climate information across the set of actors in the Galapagos Islands

This activity proposes to use traditional devices and tools which help to understand the hydroclimatological conditions of the Islands. Yet, it also looks to use sophisticated instruments such as towers to measure atmospheric fluxes, remotely sensed imagery, and other tools to estimate these conditions.

The practices (sub-activities) to improve the adaptive capacity are:

a) ***Acquisition, placement, and implementation of sensors capable of measuring climate, water, and agriculture variables.***
   This practice looks to address the strong lack of hydrometeorological data in the Islands through a rigorous study about the current situation of ground and surface water to survey the geophysical, geological, and hydrogeological characteristics of the Islands. The hydrological baseline will be conducted in the first year of the implementation period. Additionally, traditional devices and tools will be acquired to the monitoring program which will record the main hydro-climatic variables mentioned below.
   - Temperature
   - Precipitation
   - Humidity
   - Wind velocity
   - Radiation
   - Cloud fraction
   - Surface runoff
   - Interflow and baseflow
   - Groundwater levels and dynamics
b) ***Develop an information system capable of collecting information, processing and perform data quality/data control activities.*** This information system will be capable to distribute data in real time, interpret data for farmers and distribute data to local governments, scientific institutions, and external users. Data interpretation, modelling and forecasting capacity building will be tailored to different stakeholders: decision makers, farmers, and communities.
c) ***Train technical staff for implementation of sensors and management of the information system***. Under this sub activity, capacity building will take place to ensure that protocols are followed by all the key actors. Training sessions will be given by technical staff of INAMHI and GSC.

Environmental Benefits

These activities and sub activities provide indirect impacts on the protection of natural and water resources. Access, analysis, use and sharing information is a mechanism to act and protect vulnerable areas and maintain local biodiversity. Consequently, it also provides resilience of ecosystem and agroecosystem services at the agricultural landscape level. Lastly, these interventions support the access and analysis of reduction and capture of CO_2 information.

Social Benefits

By decreasing the uncertainty related to climatic conditions and its hydrometeorological drivers, authorities, and technical staff will be informed on time of potential conditions that could harm their crops, animals, investments and put pressure over the food chain, causing stress to the food security of the islands. Farmers will also benefit from access to more accurate, dependable, and tailored information on weather, climate, and hydrological resources, which will allow them to plan agricultural tasks and manage crops, soil, and water.

Beneficiaries
✦ **DIRECT:** ○ 35,000 local users of the information ○ Government agencies: MAE, INIAP, CGREG, INAMHI ○ Universities and ONGs ✦ **INDIRECT:** ○ 755 farm households and 19,009. 6 Hectares ○ 3 Municipalities

Output 2.1.2. Improved farmers livelihoods and rehabilitated ecosystem services through climate-resilient water and agricultural food productions systems

This output will address the barriers #2,3,4,5 and 6. This output focuses on strengthening farmers capacities to adopt and implement climate-resilient agricultural practices to enhance agricultural productivity in the face of increasing climate hazards. GCF resources, combined with CAF co-financing, will be invested in providing Galapagos farmers with the skills, knowledge, and technologies they need to manage soils, water and biomass to enhance soil moisture/fertility sufficiently for production of a diversity of climate-resilient crops through agroforestry systems or other climate-resilient practices. These practices are based on agroecology principles and are also considered "non-regreat" practices, considering climate variability and the impacts of climate change in Galapagos.

Agriculture has a high degree of sensitivity to both short-term weather changes and long-term seasonal changes. Agricultural productivity is impacted by changes in temperature and precipitation as well as infestation by pests, diseases, and weeds (climate rationale). Economically, it has an impact in terms of profitability, prices, supply, demand, and trade. The expected changes in the climate will have a negative impact on the Galapagos agricultural sector, including a greater dispersion of invasive species favored by a warmer and wetter climate, effects on the aquifer recharge process that provide water for agriculture and the population, loss of soil´s capacity to retain nutrient and water, greater evapotranspiration and, an interspersion of rainy years with years of low rainfall that would cause severe droughts in the rural area. In the long term, such impacts can further reduce the productive capacity of the agricultural and livestock sector disturbing development processes and food security.

The history of colonization of Galapagos is recent, less than 100 years, and the evolution of agriculture has been limited by a series of regulatory frameworks. Unfortunately, agriculture in the Galapagos, for decades has been seen as an activity with negative consequences for the fragile ecology of the archipelago and, consequently, its development has been limited by a series of restrictions imposed by the conservation sector. Consequently, great extension of the agricultural area has been covered by invasive species, which require high use of labor to combat them and in turn reduce the levels of agricultural production, increasing the dependence on the provision of food such as fruits and vegetables, imported from the mainland.

On the other hand, industrial practices from the green revolution have also contributed to the degradation of the island’s natural resources, making agriculture potentially problematic activity in the context of Galapagos. Industrial agriculture methods that are typical of globalized agriculture (e.g. an increasing dependence on external inputs or using resourcedemanding seeds) do not value local wealth and diversity of agroecosystems. This oversight is responsible for causing environmental imbalances and is wasteful for not making full use of the functions that ecosystems serve for productive lands.

From the adaptive capacity point of view of agriculture, the fact that there are limited options for improvement of farming productivity, poses a serious vulnerability for food security. The only way to maintain food security while maintaining regulations that forbid the importation of species resistant to drought and floods, is to generate the ability to maintain the existing genetic material and diversity of crops and pastures, discover and improve its use, and distribute it widely, among farmers of the Galapagos.

In response to the myopic practices of industrial food systems, agroecological perspective is focused on sustainable agroecosystems. Agroecology strengthens ecological interactions with surrounding areas, develops biological processes to their optimum level, and intertwines agricultural activities with the conservation of biodiversity. Non-domesticated farm elements provide several ecological services within organic systems: pollination, pest control, and maintenance of soil fertility. Biodiversity strengthens essential functions for agricultural systems and, therefore, for agricultural performance. Increasing functional biodiversity constitutes a key strategy to achieve a more economically and ecologically sustainable production.

In this context, the activities of this output seek to transform degraded agricultural areas into healthy agroecosystems capable of address climate change, optimizing quality in all aspects of agriculture and the environment, by respecting the natural capacity of plants, animals, and the landscape, which are key to the Galapagos Islands. These activities will also lead to improved water recharge and productivity and contribute to the population's and ecosystem's increased resilience to climate change. As one of the impacts of climate change is the scarce availability of water for agriculture, especially in dry seasons, one of the activities will help better access, storage and distribution of water considering the climate variables.

In this context, the activities of this output will be focused on:

a) Develop a physical and knowledge network for conservation and use of phytogenic resources through in-situ and ex-situ conservation activities.
b) Implement an integrated climate resilient crop management system at farm level.
c) Implement silvopastoral practices at the farm level.

d) Develop and implement water collection and water management systems for climateresilient food production.

Activity 2.1.2.1. Develop a physical and knowledge network for conservation and use of phytogenic resources through in-situ and ex-situ conservation activities.

The objective of this activity is to improve timely access to quality and climate resilient seeds in sufficient quantity, as a decisive means of production to increase productivity at the farm level, and therefore the availability of nutritious food. This will enable the farmers to improve their bargaining power in the local agro-food chain through improved access to adapted seeds to environmental changed caused by climate change.

A non-conventional system to produce quality seed will be implemented through a set of articulated actions, which include the (a) improvement of existing infrastructure at INIAP, which works as a seed bank, (b) Generation of a network of users who will collect, store, and use in the farms different types of seeds with the assistance provided by INIAP. In addition, this practice aims to strengthen and value the role of women in agricultural development, agrobiodiversity conservation and traditional knowledge, supporting the seed distribution activity. This activity seeks to support farmers to improve food and nutritional security and, in turn, the agricultural diversification through the restitution of high-quality and climate-adapted seeds; also strengthen the use and marketing of the local seeds to improve farmer´s income, mainly in women farmers, strengthening their capacities to access and control their agricultural resources.

Community seed banks are repositories of local genetic diversity that is adapted to prevailing climate conditions, including biotic stresses and are useful to contribute a community-based strategy for adaptation to climate change (Vernooy et al 2017). By proposing community-based actions to explore, restore and distribute seeds, this activity will recover and promote the use of existing crops resistant to different biotic changes generated by climate change. Consequently, this activity will decrease the risk of food insecurity due strong climatic events including pests, droughts, and floods.

With the support of extension services from INIAP, farmers will explore, find, select the best seeds of different crops in the field. Part of those seeds will go back to the farm/community seed banks. The focus will be on the conservation and use of all the native and endemic diversity of usable plants, including major and minor crops, neglected varieties, medicinal plants, wild relatives, and trees. Seed production with and without the implementation of this component in the program are showed below (Table 21):

Table 21.. Seed production with and without program implementation

Crops	Has without project	Has with Project (1 year)	Has with Project (5 years)
Lemon	9.47	13.97	22.97
Coffee	133	136	142.00
Musacea-plaintain	106.19	110.49	119.09

Crops	Has without project	Has with Project (1 year)	Has with Project (5 years)
Musacea-banana	40.93	43.51	48.67
Musasea-orito	0	1.72	5.16
Cassave	71.78	79.78	95.78
Sugar cane	8.67	15.07	27.87
Beans (Fréjol)	12.55	15.28	20.75
Vegetables	17.34	27.34	47.34
Maize	41.94	64.67	110.12
Maize	0	22.73	68.18
Tangerine	11.75	29.75	65.75
Orange	55.34	73.34	109.34
Papaya	8.54	10.54	14.54
Potato	1.49	8.14	21.45
Pepper	7.25	10.25	16.25
Pineapple	26.68	27.47	29.06
Tomato	17.37	23.37	35.37
Peanut	0	0.11	0.34
Passion fruit	0	1.25	3.75
Aromatics	0	0.05	0.14
Medicinals	0	0.08	0.23
Grassland	11000	11000	11000
Forage	0	12.00	36
TOTAL ha	11570.29	11726.90	12040.14
TOTAL ha (without grassland)	570.29	726.90	1040.14

Increase in hectares in five years 469.85 Increase in tonnes per year 625.18

This activity will address the following vulnerabilities:

- Deficit in the quantity and quality of locally adapted seeds with tolerance to biotic and abiotic factors, and changes in the weather and climate.
- Low productivity measured in volume per crop and in crop diversity, which generates low harvest yields.
- Genetic erosion of food varieties adapted to Galapagos conditions, and loss of traditional knowledge associated with these varieties.
- Food insecurity of both tourists and local population due to crop production losses derived from effects of climate change.
- High risk of entry of pathogenic species associated with traditional seeds brought from the continental territory.

Implement an unconventional system to produce quality seeds (community bank and "seed" farmers), which will be performed into agriculture fields and seed bank based on current regulations. For this purpose, is important the strengthening of capacities of "seed" farmers, focal points, and technicians; with emphasis on the participation of women, as responsible for guaranteeing food security and family nutrition. In addition, the implementation of protocols to ensure quality and quantity of seeds at the farm level will be considered in each practice.

This activity includes the following sub-activities that allow to improve the adaptive capacity of the agroecosystems in Galápagos.

a) ***Implement in-farms conservation activities: collect, conserve, use and distribute the agrobiodiversity existing in Galapagos (community-based seed bank), with special focus on the variety of crops resistant to biotic changes caused by climate change.***
This component will be implemented in 25 “seed” farms distributed in the four inhabited islands. “Seed” farmers capacities will be strengthened through annual training workshops (5 workshops at provincial level) to bred, establish, operationalize, coordinate, and distribute the agrobiodiversity conservation (resilient varieties). The main action that will be developed are:

- Seed collecting campaigns will be carried out to obtain resilient varieties of seeds of the main usable species that farmers use in their diet (grains, vegetables, fruits, tubers). These procedures will be carried out under protocols within farms.
- Small structures within farms will be built, where seed management will be carried out to carry out multiplication, conservation-storage, and restitution.
- Seed classification, selection, documentation, and sharing procedures will be carried out at the same time, on specialized farmers' fairs, leaded by women organizations.
- Annual technical report where the harvested, stored and returned seed is recorded (kg-unitsplants), through a month monitoring. This monitoring will be carried out after the first 6 months of implementation in both “seed” farms and farms that will receive seed capital.

b) Improvement of existing infrastructure at INIAP, which will work as agrobiodiversity repository, knowledge center and distribution facility, for long-term conservation. This component will be implemented through the following actions:

- The operation, production, and maintenance of germplasm in INIAP seed bank, located in San Cristobal island, will be carried out according to established protocols and under integrated crop management practices, with low use of external inputs. This project will improve existing infrastructure, with the provision of a storage room, fridges, and a curator.
- In close exchange with community network, essential food security germplasm (corn, beans, bananas, cassava, potatoes, fruits, medicinal plants, forages) will be collected. As the process advance, it will be possible to work with all usable species, present on the islands, related to food and agriculture.
- Development of protocols for quality control and quality assessment processes, to ensure compliance with the minimum quality standards, in the seed production.
- Distribute seeds stored in the community seed bank to farmers who need them, covering at least 80% of the total Galapagos farmers.

Environmental Benefits:

- Improvement and diversification of agricultural production at farm level (biodiverse farms).

- Efficient contribution to increase adaptive capacity in the farms and farmers to climate change.
- Promoting the conservation and sustainable management of the agrobiodiversity through self-consumption of local varieties.
- Contribute to the conservation and adaptation of species, with the promotion of fair exchanges.

Social Benefits:

- Strengthening the participation of women in agricultural production, both in their capacities to access and control their agricultural resources.
- Diversification of the economic income of farmers.
- Promoting a healthy food environment – including food systems that promote a diversified, balanced, and healthy diet (fruits, vegetables, roots, grains, among others) for both tourist and local population, mainly for children.

Beneficiaries
✦ **DIRECT:** ○ INIAP seed bank and 25 “seed” farmers distributed in the four islands: 8 in Santa Cruz, 7 in San Cristobal, 8 in Isabela and 2 in Floreana, where plots for efficient production and reproduction of quality seeds will be implemented. ○ Seed distribution will be implemented in 624 farms that include those with crop, livestock, and mixed production. ✦ **INDIRECT:** 755 farm households

Activity 2.1.2.2. Implement an Integrated climate resilient crop management system at farm level.

Climate change will alter the environmental conditions for crop growth and require adjustments in management practices at the field scale. This activity will generate greater climate change adaptive capacity to the production system, by: (a) improved soil moisture growing conditions, reduced impact of rainfall variability and droughts on yields, and reduced pest and disease problems; (b) improved rainfall infiltration, minimum runoff, and soil erosion; (c) increased soil carbon sequestration through higher levels of humid and non-humid Soil Organic Matter and soil biota, and improved aquifer recharge and stream flow. The changes in cropping and land use pattern, soil management, over-exploitation of water storage and changes in irrigation pattern have a mitigating effect by reducing greenhouse gas emissions and increasing soil carbon sequestration, through less soil disturbance, crop rotation, residue management, among others which improve soil organic matter and soil function.

The objective of this activity es to strengthen crops, minimizing pest pressure and maintain soil fertility, creating crops with greater tolerance to droughts, floods and the attacks of pests driven by climate change.

Integrated Crop Management (ICM) is a basic strategy that will allow the development of a healthy agricultural system resilient to climate change. ICM is a holistic approach that promotes an efficient use of natural resources, soil, water, and germplasm and combines them with phytosanitary products, beneficial organisms, and effective cultural practices to obtain favorable crop productivity levels.

New agricultural practices will be adopted according to the assimilation capacity and the availability of labor. This incorporation will go through three different levels of change:

- Knowledge change: which will be achieved by presenting to the farmer alternative technologies friendly to island ecosystems (see Appendix 4).
- Attitude change: which will be achieved by testing the technology on farms; and through the farmer's reflection regarding the advantages and disadvantages that the technological offer represents for his productive interests.
- Acceptance of the technology, which has already been tested by farmers, and then the acceptance and adoption of these improvements in their agricultural practices takes place permanently.

This ICM program includes: (i) Soil management, (ii) establishing crop and pest management (knowing the behavior of crops), iii) implement strategies to minimize effects in their environment through crop species diversification.

This activity will address the following vulnerabilities:

- Vulnerable crops and pastures to droughts, floods, and pests
- Invasion of exotic plant species in abandoned agricultural areas
- Current release of 100% of CO_2-eq and chemical components into the atmosphere by slow fermentation or burning of crop residues and cutting invasive plant species.
- Contamination of water sources with microorganisms and inorganic residues.
- Loss of beneficial ecosystem services in agricultural landscapes, including water storage and biodiversity.
- Soil erosion and production loss in the presence of extreme weather events (frost, floods, droughts, winds, rain and/or runoff).
- Economic losses due to attacks by pests, diseases, and invasive species.
- Instability in the diversified supply of local production.
- Greater evapotranspiration of crops and endemic species and risks of crop death, mainly in drought periods.
- Use of synthetic fertilizers in agricultural production, which increase production costs, acidify the soil, and release Nitrous Oxide (N_2O) into the atmosphere. Lack of alternatives to substitute synthetic fertilizers.

ICM will be incorporated into daily management of the production systems, through technical assistance, monitoring and adaptation cycle. This activity seeks to implement at least four ICM practices (See Appendix 4, where are listed the most efficient and effective ICM practices for Galapagos conditions) per farm with an increase of two (2) practices per year.

This activity includes the following sub-activities that allow to improve the adaptive capacity of the agroecosystems in Galápagos.

a) Implements Soil management practices in farms.

Soil comprises a set of components that interact to give the system characteristics of structure and function. The functions that soil perform are the foundation of agricultural, livestock and forestry production systems that provide a wide variety of ecosystem services. Improving the chemical, physical, and biological processes that take place in the soil through sustainable land management practices are essential to improve soil health, increase agricultural productivity, and improve the performance of agroecosystems. Soil management involve minimum soil disturbance, maintain soil cover through crop residues or other cover crops, place fertilizer more precisely into the soil to make it more accessible to crops roots, and improve nitrogen use efficiency.

This practice aims to retain GHG and other elements in the biomass of crop residues and invasive plant species, as well as take advantage of stable nutrients and composting structure to improve soil health and fertility. This practice will be focused on farms with crops and mix production and will receive permanent technical support that will increase compost production and CO2 retention. We must promote the way of making compost and biodigesters through a) collection of organic waste, and b) making piles with waste (some farmers add sawdust and yeast). Some of the actions that will be carry out in this practice are detailed below:

- Annual training workshops (2 workshops at province level) and on-site assistance by lead farmers to facilitate farmer-to-farmer learning to scale up implementation, under FAO team supervision.
- Strengthen knowledge about composting strategies for managing crop residues and other cut invasive species, which are important in the retention of CO2 and other chemical elements. Also, reflect on the negative effects of the burning or decomposition of these residues for the environment.
- Minimal disturbance of the soil, for example instead of tilling or ploughing the land (conventional agricultural system), farmers plant crops directly into the soil to improve soil porosity, builds up soil organic matter and beneficial soil biota leading to improved soil health and productivity.
- Prepare and execute fertilization plans with compost and other organic components to maintain a permanent organic soil cover (at least 30%), while at the same time adding biologically fixed nitrogen to keep the soil fertile. It would improve the resilience of the agricultural soil (structure and fertilized) in extreme climatic conditions.
- Implement a Monitoring system for i) biodegradation and CO_2 capture; and ii) use of compost and other organic components for soil resilience. The monitoring process will be carried out after the first 6 months of activity implementation and will be conduct six (6) regular monitoring visits monthly to ascertain the progress of activities.

b) Establish crop and pest management practices, including a growing climate resilient seed.

Crop and Pest management refers to the implementation of timely and adequate pre-cultural and cultural practices according to Galapagos agroecosystems conditions. This practice will be focused on farms with crops and mix production and will receive permanent technical support to train farmers to expand food production with a wide variety of drought and food tolerant products to reduce the vulnerability to climate change and improve market balances, through polycultures, association and crop rotation, pest management and the design and implementation of agroforestry systems to improve and restore agroecosystems healthy. The main action that will be implemented are mentioned below:

- Annual training workshops (2 workshops at province level) and on-site assistance by lead farmers to facilitate farmer-to-farmer learning to scale up implementation, under FAO team supervision.
- Strengthen knowledge in: i) proper use of pesticides and in native biological control management, ii) strategies for the protection of species beneficial to agriculture and conservation, and iii) the importance of maintaining the diversity of plant species within their agroecosystems to mitigate the effects of climate change and offer permanent food to the local community.
- Redesign, together with farmers, the farms; considering a sowing system with a diversification of no less than 12 transitory crops, 8 perennial species and 4 forest species (identify species and varieties of crops resistant to pests and diseases and tolerant to climate change), through the integration of an annual planting plan (requirement of seeds from the community-seed bank) and harvesting of transitory and perennial crops plan (maize, beans, plantains, cassava, potatoes, vegetables) with projections of volumes to be offered to the community.
- Promote the use of organic fertilizers, ideally produced on the farm itself, facilitating the process of trophobiosis in crops.
- Integrate live fences for protecting crops, through the integration into agro-ecosystems of natural protective species (endemic/native arboreal plants with medium/high CO2 capture capacity such as Acacia and Ziziphus) and native legumes of the island (Leucaena leucocephala, Phaseolus mollis, Dalea tenuicaulis, among others,) with the capacity to fix nitrogen in the soil.
- Breaking the cycle of pests by: i) rotating crops, through the identification of the most critical crop´s phases in relation to attack by pests and diseases; ii) management of exogenous weeds to avoid reproduction of pests; and iii) covering the ground to prevent the emergence of insect-pest larvae.
- Implementation of four (4) island nurseries for the production of endemic / native tree species with medium / high CO2 capture capacity and leguminous species to improve soil fertility.
- Implement a Monitoring system for monitoring climate resilience of farms and biological corridors in agricultural areas. The monitoring process will be carried out after the first 6 months of activity implementation and will be conduct six (6) regular monitoring visits monthly to ascertain the progress of activities.

Environmental Benefits:

The Integrated Crop Management promotes the restoration of the natural ecological balance, the biological processes development until the optimum level, and enhance the relationship between agricultural activities and biodiversity conservation inside farms. It greatly increases the resilience capacity of these agroecosystems in response to adverse effects of climate change.

By implementing an ICM System, this project will reduce the need for herbicide and chemical pesticide application by introducing crop rotation and bio-fertilization strategies, which maintain agricultural production, preserve profitability, and reduce water pollution and GHG emissions including those of carbon and nitrogen origin. This practice will replace the use of synthetic fertilizers in at least 25% of the productive area in the implemented farms.

Also, by increasing biomass production (diversification), this project will facilitate the conservation of soil and water in the agricultural landscapes making them more tolerant to climate variability. Furthermore, the soil compaction will be reduced through elimination of heavy farm machinery that is highly disruptive to soil life and structure.

Social Benefits:

Combining local knowledge with new research and technologies, this activity takes a wholefarm approach that encompasses all of the relevant socio-economic and environmental factors. Strengthening farmer support system would increase number of service providers in the input and output supply chains. It would promote food and water security, and a diversified, balanced and healthy diet (fruits, vegetables, roots, grains, among others) for both local population (mainly children) and tourist.

In addition to the environmental contributions, farmers will generate economic income by obtaining sub-products by managing the decomposition process of harvest waste such as biofertilizer.

Beneficiaries
✦ **DIRECT:** In general, this activity will be implemented in at least 55% of the total Galapagos farms (404 farms), excluding livestock production, distributed in the following way: ○ At least four ICM practices will be implemented in medium and small-scale farms, covering 334 farms (1,002 beneficiaries, 30% women). ○ At least four ICM practices will be implemented in large-scale farms, covering 70 farms (210 beneficiaries, 30% women)

Activity 2.1.2.3. Implement silvopastoral practices at the farm level.

The development of livestock on the Galapagos islands is complex and carries a large cultural load, being the preferred rural economic activity. However, extensive cattle ranching is not a practice resilient to climate change. There are reports of heavy economic losses within cattle ranchers in 2016-2017 droughts, which were in part solved by the importation of pastures and water from mainland (El Comercio 2019). For this reason, it is necessary to generate local adaptations measures, which include the replacement of extensive cultivation of low drought tolerant pastures to intensive use of drought tolerant varieties (community-seed bank), under different types of tree coverage. Thus, it is important to promote the scaling-up of silvopastoral systems in Galapagos in order to support sustainable livestock production.

Silvopastoral systems (SPS) are agroforestry arrangements that purposely combine fodder plants, such as grasses and leguminous herbs, with shrubs and trees for animal nutrition and complementary uses. They allow the intensification of cattle production based on natural processes and are recognized as an integrated approach to sustainable land use (Nair et al., 2009).

The silvopastoral model proposed for the islands, integrates an efficient management of invasive plants, mainly *Psidium guajava*, in the livestock production system (guava-grassbreeding association), since it is considered highly invasive in Galapagos and its eradication is not feasible. For this reason, this activity seeks to control the actual expansion of this particular alien species at lower density in at least 49% (Table 22) providing water and shadow facilities in guaranteeing the continuous production of the herd. Additionally, other native trees species will be integrated in the landscape as generators of shade and ecological services.

Table 22. Control of invasive species (*Psidium-guajava*) under Silvopastoral system implementation

Current guava presence in farms		**Guava presence under SPS**		
Distance between trees	Number of trees	Distance	Number of trees between trees	**Change (%)**
8.5 x 8.5	134	12 x 12	69	49%

Thus, this activity aims to implement a silvopastoral system in Galapagos for cattle ranching to improve production efficiency and to integrate the management of the invasive species *Psidium gua*java (guava) and endemic/native species as associated arboreal species.

Besides tree incorporation in the landscapes, this SPS model comprises: i) Farmers training to implement silvopastoral systems (guava-grass-breeding association), ii) fodder banks with shrubs, iii) internal division of paddocks to apply rotational grazing with occupation periods, and iv) manure management through biodigestor. These practices seek reduce the vulnerability of livestock production to climate change as they stabilize forage availability throughout the year by favoring water infiltration and soil conservation.

This set of actions is based on spatial explicit modeling, see Appendix 2.1, where this proposal shows different scenarios of an invasive plant, i.e, guayaba, invasion on agricultural lands, under different scenarios of climate change and with the impact of the project.

To establish the income and/or savings that the practice will generate, it is important to identify the following resources described in the next table 23:

Table 23. Livestock sources (*Source: Flores Estrada, 2014)

INCOME	**Without project**	**With project**
Nº of dairy, meat and dual-purpose bovine units (25 per farm, 244 farms)	6,100	6,100
*Average daily milk production (Daily lts)	4.66	6.99
*Adult bovine units (UBA) per ha	8	8
*Adult Bovine Units (UBA) average weight (Kg per UBA)	154	462
Hectares involved in the practice	6,000	6,000
Increase in daily lits = 2.33	**Increase in Kg per UBA =**	**308**

This activity will address the following vulnerabilities:

- Climatic stress over pasture and dehydration of cattle, in extensive grazing systems
- The guava-pasture-breeding synergy needs to be consolidated in all the agroecosystems of Galapagos, enhanced by including endemic and/or native tree, shrub, and forage species.
- Lack innovative approaches to control invasive species.
- High demand for water, labor, and other inputs
- Emission of greenhouse gases
- Soil erosion and loss of soil fertility
- Contamination of water sources with microorganisms and inorganic residues.
- GHG emissions (N2O and CH4) to the atmosphere emitted by the fermentation of manure.

This activity includes the following sub-activities that allow to improve the adaptive capacity of the livestock production in Galápagos.

a) Farmers training to implement silvopastoral systems (guava-grass-breeding association).

Training workshops (2 workshops at province level) will be carried out during one week every year and should seek to include knowledge about trees incorporation into livestock systems that has the purpose to enhance resilience of the soil to degradation, improve water holding and infiltration capacity of the soil which contributes to the regulation of the hydrological cycle by reducing runoff intensity. The main activities considered in the workshops are:

- Preparation of participatory inventory per farm (rancher, agricultural technicians, interested community students) for the participatory design of a Guava management plan according to the needs of each farm. It is important to determine: i) symbiotic relationships between species, ii) Live Fences, iii) Rotation of Sustainable Paddocks, iv) fodder banks, among others.
- Dissemination of knowledge about silvopasture techniques, the economic benefits and the long-term ecological implications to the livestock sector of the four populated islands.
- Strengthen the knowledge about the contributions of the Silvopasture System in: i) the ecosystem, ii) animal feed and, iii) livestock productivity (milk and meat).
- Transform the guava-pasture-breeding bovine association towards Agroecological Silvopastoral system adapted to the Galapagos conditions. For this action, it is important to improve the guava tress distribution on the pasturelands. In addition, implement a Monitoring System on emerging synergistic management and its effects on the GuavaPasture-Breeding Bovine association, with the support of competent institutions (e.g. MAG). The monitoring process will be carried out after the first 6 months of activity implementation and will be conduct a monthly regular monitoring visit to ascertain the progress of activities
- Introduction of native tree in the design of the Silvopastural System with the support of a community-seed bank. This design could be structured as scattered trees in pasturelands and windbreaks/live fences to divide paddocks.

b) Implementation of fodder banks

Fodder banks are enclosed areas of forage plants, such as grasses and leguminous herbs, with shrubs and trees for animal nutrition and as season supplementary grazing of cattle. This practice consists in implementing protein banks in farms with over 20 head of cattle. The proposed fodder banks are enclosed areas of 2,500 m2 that include shrubs and native legumes of the island, such as *Leucaena leucocephala, Phaseolus mollis, Dalea tenuicaulis*, among others, with high protein-containing leaf biomass. Introducing leguminous species is particularly beneficial for fixing atmospheric nitrogen and improving soil fertility.

c) Implement internal division of paddocks to apply rotational grazing through regularly moving livestock between paddocks

One of the main strategies for increasing the efficiency of grazing management is through rotational grazing, in which the frequency and timing of grazing is adjusted to match the livestock's needs with the availability of pasture resources. Through targeted temporal grazing exclusions, rotational grazing allows for the maintenance of forages at a relatively earlier growth stage. This enhances the quality and digestibility of the forage, improves the productivity of the system and reduces methane emissions per unit of live weight gain. This action would be managed under pasture/paddock division based on temporal solar powered electric fences in farms with over 20 head of cattle. The paddocks that were built, have been grazed from 12 to 24 hours and 45-day rest periods. The farmers will acquire the machinery through direct credit lines promote by the program.

d) Manure management through biodigestor

The fermentation process of manure from farm animals (cattle, pigs, minor domestic animals) generates between 10% and 15% of the total GHG released when carrying out livestock activities. Biodigestion is a technology that adjusts to an efficient manure management, helping in the capture of GHG (especially N2O and CH4), elaboration of bio-fertilizers, avoids the proliferation of insects (especially flies), viruses, bacteria, parasites, filters wastewater, and generates gas, which can be used as alternative energy. This practice will be implemented on 66 livestock farms (dairy and pig cattle) suitable for the adaptation and construction of biodigesters and will be developed through:

- Two training workshops every year (at province level) to strengthen knowledge about the environmental impacts of livestock (manure decomposition process) and the importance of adopting alternative management technologies and practices to reduce GHG emissions from this sector.
- Implement participatory manure management protocols for GHG reduction, with the support of competent institutions (MAG, ABG).
- Build 66 Biodigesters, each with storage and waste handling capacity for at least 20 dairy cattle units and 25 pig units. Include a waste classification system and a reservoir or tank to store the bio-fertilizer (liquid). The farmers will acquire the machinery through direct credit lines promote by the program.
- Exploitation of biogas for domestic use and/or for agro-artisan processing. In addition, to strengthen the use of biogas from biodigestion through incentives from public policy.
- Use of biofertilizers from biodigestion to reduce the use of imported synthetic fertilizers.
- Implement a monitoring system to quantify the reduction of GHG, production of domestic biogas and use and quality of biofertilizers. The monitoring process will be carried out after the first 6 months of activity implementation and will be conduct a monthly regular monitoring visit to ascertain the progress of activities.

Environmental Benefits:

Silvopastoral design provides multiple services to help farmers adapt to more variable and extreme weather due to climate change. During severe droughts, cattle experience elevated mortality rates due to unbearable temperature and dehydration levels. High temperatures and low precipitation rates may also cause pastures to die, leaving cattle with no food. Thus, the introduction and strengthening of silvopastoral systems in Galapagos, would likely improve environmental quality, both via increased C sequestration and nutrient removal as compared to grass monocultures. In addition, Silvopastoral systems (trees introduction) can provide watershed and biodiversity benefits as well. Trees and bushes improve the microclimate below them, reduce evapotranspiration, and protect grasses from strong winds. Compared to grasses that grow in full sun exposure, many species of grasses grow better under the shade of the tree canopy, produce a greater quantity of forage, and have a higher nutritional quality (lower fiber content and higher crude protein content). Furthermore, trees provide organic matter to the system, which improves the physical and chemical characteristics of the soils and their capacity for infiltration and water retention for the entire landscape. The natural fall of leaves and pruning helps increase the availability of water, light, and nutrients for all the system components, improving the productivity of surrounding pastures. This feeds production unit (forage bank) will provide sources of protein, energy, and fiber for cattle, even during dry spells.

On the other hand, planting nitrogen-fixing trees within pastures will increase soil nitrogen and reduce the need for synthetic fertilizer in several ways: through their ability to fix atmospheric nitrogen, through their symbiotic relationship with bacteria in their roots, and by contributing organic matter to the soil through periodic shedding of their leaves, branches, and fruit. Furthermore, their roots can absorb nutrients from deep soil layers and bring them to the surface, making them available for surrounding pastures or associated crops. In some cases, nitrogen-fixing trees can increase the availability of phosphorus (symbiosis with mycorrhizae), calcium, potassium, and magnesium.

Social Benefits:

Synergies between cattle and trees mean that a combined system can provide more income than either system on its own. It increases animal welfare and productivity (more and higher quality beef and milk). Silvopastoral design reduces the need for synthetically produced farm inputs, which are carbon-intensive industrial processes, while simultaneously reducing the need to expand the agricultural frontier. The division of paddocks or grazing areas with fences allows sustainable management of the pastures and an adjustment of the animal loads, periods of occupation, and optimal rest, avoiding the degradation of the fields by overgrazing and trampling. With these methods, producers have enough feed for livestock, preventing the expansion of grazing areas. Consequently, it allows the surrounding forest cover to be conserved and recovered.

In addition, according to research carried out, a 1.5 was established as the index of increase in milk production in livestock farming under the Silvopastoral System (Estrada, 2014). If we apply the index in the Silvopastoral System implemented in Galapagos, an average daily production of 6.99 liters per Adult Bovine Unit (UBA) is estimated. On the other hand, when implementing the Silvopastoral System in Galapagos, it has been estimated as an increase rate of 3 in meat production. In this sense, each UBA could have a weight of 462 Kg.

Beneficiaries
✦ **DIRECT:** Implement an Agroecological Silvopastoral System in 244 farms in medium and large-scale farms mostly devoted for cattle ranching activities (Livestock and mixed farms). Specific activities, such as fodder banks and paddock division, will be implemented on farms with over 20 cows (68 farms). Additionally, in 66 livestock production farms will be implemented Biodigesters: 42 in cattle production farms and 24 in swine production farms

Activity 2.1.2.4. Develop and implement water collection and water management systems for climate-resilient food production.

Water scarcity is the major problem in the Galapagos agroecosystems, which is mainly caused by changing rainfall patterns and higher temperatures. The lack of rains and scarce water available in the Islands have even prompted authorities to decree a state of emergency in 2016.

Despite the main inhabited Islands have diverse characteristics, in various cases they share similar problems. For example, across Santa Cruz, San Cristobal, Isabela, and Floreana, the lack of universal coverage (or even the total absence) of drinking water systems force people to store locally water on roof tanks (Grube et al. 2020). Due to the ageing network, lack of and adequate maintenance, leaks and overflows, a significant amount of water is being wasted and lost (Reyes et al. 2015). More information is detailed in the water supplementary documentation that supports the Water balance analysis (See Appendix 2).

The objective of this proposed strategy is to improve the water collection and distribution system for the agricultural sector in the Galapagos Islands by including 500 new hectares with climate resilient farms and new water collection, storage, and distribution systems. The new farms will cover certain crops to generate a new harvest in the dry period. These irrigated areas will enhance farmers' profits by adding one more harvest than usual and keeping fodder fresh for livestock consumption. Additionally, the proposed interventions in the water irrigation system aim to increase its diversity and redundancy, both in sources and in operating infrastructure.

This activity relates to the implementation of a water system that supports the agricultural needs of the Islands, mainly in the dry season. This system will lead to important innovations in the way by which water is traditionally collected in the Islands. The system can be improved by in situ analysis of collecting rates with different net dispositions and locations, and it can be scaled based on the results. This practice could be addressed together with water reuse methods, one of the most popular IFDM (Integrated Farm Drainage Management) used by the National Water Research Center of Cairo, Egypt (SJVDIP, 1999d). Moreover, we also propose to technify the irrigation mechanisms of the system through the use of drip and sprinkle techniques of irrigation which uses water more efficiently and also leads to more agricultural yields.

Broadly, this refers to the implementation of a water system (Figure 27) which consists of three staged sub-activities:

1. Water Sources & Intakes, and water Storage (which is split into natural and grey infrastructure), 2. Water Distribution, and
3. Irrigation.

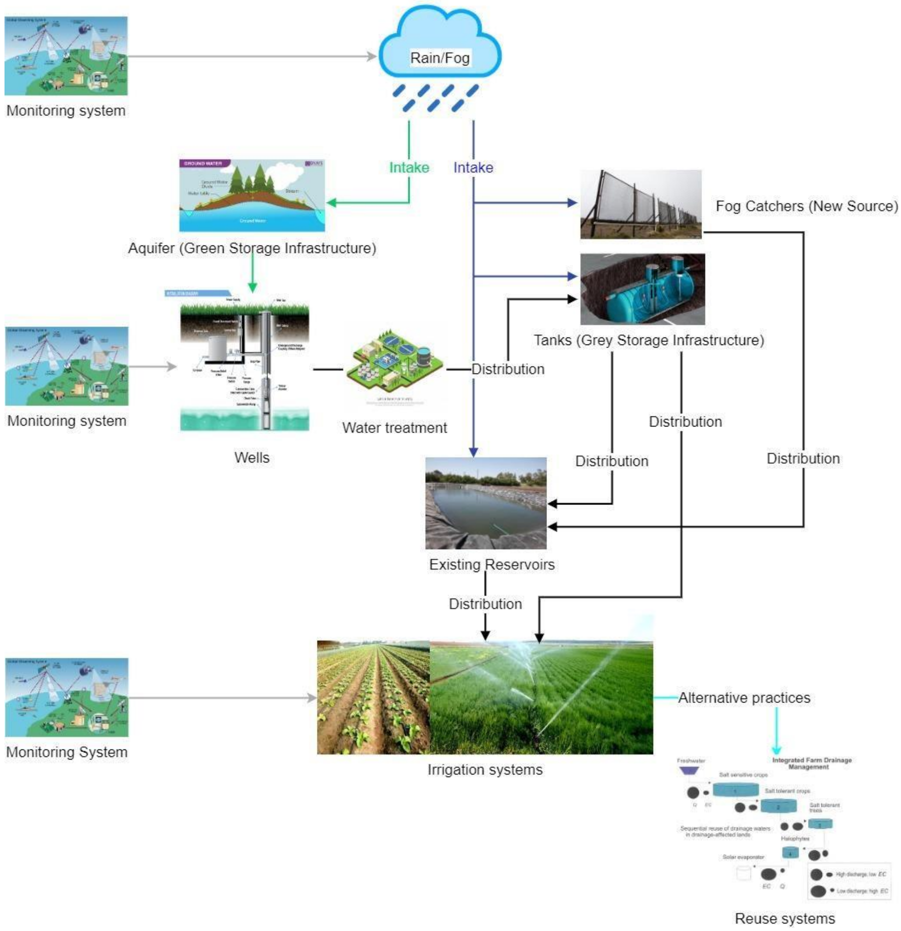

Figure 27. Flowchart of the practices implemented in the Galapagos water system

The baseline and project implementation areas are detailed below (Table 24).

Table 24. Baseline and project implementation areas based on irrigation coverage.

Irrigation and types of crop systems	**Hectares baseline**	**Hectares new practices**
Has under irrigation	37 has*	500 has
Has under climate resilient farms	0	500 has
Has under silvopastoral systems	3496 has*	6000 has

*Census 2014

As a result of the seasonality of the hydroclimatological process (see Appendix 1), having enough water to sustain human, agricultural, and economic practices have been identified as a great challenge for the Islands. The main threat is the increase in droughts caused by climate change, which leads to less availability of water for agricultural purposes. The vulnerability to be addressed is the lack of new sources and infrastructure for collecting rain, which affects agricultural production, especially in the dry season. However, this latent threat results from a series of constraints relate to the lack of water information, technology and knowledge which are described below:

- Lack of a robust water information system in Galapagos
- Limited knowledge and access to technological solutions to collect and store water during raining season for use during dry season.
- Limited understanding of the role of water on both environmental and biological processes
- Lack of water management options to guaranty enough water supply for human consumption and agricultural uses.

By proposing new wells as well as fog catchers increases the diversity of places which could effectively supply farms. Similarly, by proposing two types of storage (green infrastructure and new tanks and reservoirs) our strategies also enhance, not just the number of places where water is stored, but also the type of them. As such, if the operation of reservoirs and tanks need to be suspended the Islands could use the natural reservoirs (i.e., groundwater) as an alternative of supply in such circumstances. These conditions could occur when reservoirs and tanks are under maintenance, when intense dry conditions leave high evaporation rates, or other unexpected events.

It is important to note that the prioritization of investments and the roadmap scheme are the two stages necessaries for the strategy aims, an integrated management of water resources to guarantee an agricultural production through securing water flow regulation in both natural and agricultural landscapes in the Galapagos Islands. First, the prioritization of investments shows the specific benefits of each investment, not just in terms of the performance indicators, but also in terms of general resilience and robustness which include uncertainty. Second, the roadmap scheme (Figure 28) needs to be created as a dynamic adaptation technique as shown below and attempt to improve each one of the specific benefits of the investments implementing new levels of uncertainty.

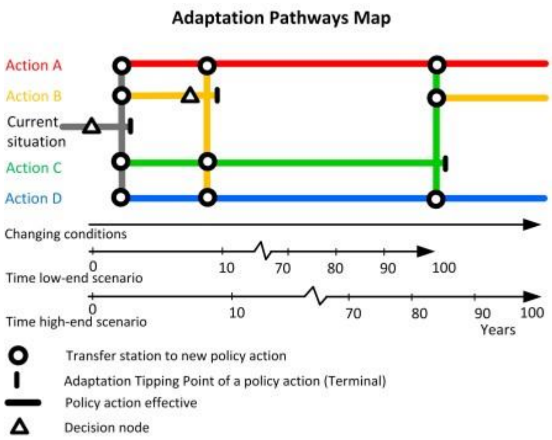

Figure 28. Roadmap scheme

This activity includes the following sub-activities that allow to improve the adaptive capacity of the agroecosystems in Galapagos.

a) Water sources, intakes, and storage

- *Rainfall collection:* One of the sources to directly fill reservoirs and tanks, and indirectly aquifers is rainfall. For the grey infrastructure (reservoir and tanks) the amount of rain that can be stored depends, apart from the rainfall rates, on the surface of reservoirs and the drainage area around buried tanks. The contribution estimates are calculated assuming the average monthly precipitation rate, free surface of the existing reservoirs and drainage area around tanks. The contribution rates are between 3 – 4 thousand m3/month in the wet period and 2 – 3 hundred m3/month in the dry period. This contribution rate aims to fill all tanks and reservoirs to cover the first months of water irrigation demands, before activating the groundwater system. Their storage capacity is linked with the amount of water that is daily required to satisfy crop needs for each island: 7,220m3 for Santa Cruz, 5,358m3 for San Cristobal, and 3,931m3 for Santa Cruz. The water requirements that are needed, in m3, to satisfy the crop needs are shown below (Table 25). These estimates are also calculated utilizing the sensitivity experiment, in this case, it was used the results for the dry months of the driest scenario.

Table 25. Daily water demand by crop and scenario. (SX: Santa Cruz, SC: San Cristóbal, Isb: Isabela)

Crop	Proposed area to be increased by year (ha)			Area to be increased in 3 years			Daily water demand (m3/ha)		Total demand for the proposed area (m3/day)					
							Scenario		Santa Cruz		San Cristobal		Isabela	
	SX	SC	Isb	SX	SC	Isb			Scenario		Scenario		Scenario	
							Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Limón	2.7	1.5	1.5	8.1	4.5	4.5	14.5	11.5	39.0	30.9	21.7	17.2	21.7	17.2
Café	1.5	1.5	1.125	4.5	4.5	3.375	33	30	49.4	44.9	49.4	44.9	37.1	33.7

Musáceas	4.5	3	3.75	13.5	9	11.25	42.2	39.2	189.9	176.4	126.6	117.6	158.3	147.0
Yuca	4.5	3	2.25	13.5	9	6.75	38.5	35.5	173.3	159.8	115.5	106.5	86.6	79.9
Caña	3	2.25	2.25	9	6.75	6.75	44.1	41.1	132.2	123.2	99.1	92.4	99.1	92.4
Fréjol	1.35	1.395	0.9	4.05	4.185	2.7	40.4	37.4	54.5	50.4	56.3	52.1	36.3	33.6
Hortalizas	6	4.5	3	18	13.5	9	36.7	33.7	219.9	202.0	164.9	151.5	110.0	101.0
Maíz	15	10.5	6	45	31.5	18	27.4	24.4	411.0	366.2	287.7	256.3	164.4	146.5
Maíz	15	11.25	5.625	45	33.75	16.875	27.4	24.4	411.0	366.2	308.3	274.6	154.1	137.3
Papaya	1.2	0.9	0.6	3.6	2.7	1.8	38.5	35.5	46.2	42.6	34.7	32.0	23.1	21.3
Papa	3	3	2.25	9	9	6.75	40.4	38.8	121.1	116.3	121.1	116.3	90.8	87.3
Pimiento	3	1.5	1.5	9	4.5	4.5	34.8	31.8	104.4	95.4	52.2	47.7	52.2	47.7
Piña	0.45	0.3	0.225	1.35	0.9	0.675	8.9	5.9	4.0	2.7	2.7	1.8	2.0	1.3
Tomate	7.5	4.5	2.25	22.5	13.5	6.75	31.1	28.1	233.3	210.8	140.0	126.5	70.0	63.2
Maní	0.045	0.06	0.03	0.135	0.18	0.09	40.4	37.4	1.8	1.7	2.4	2.2	1.2	1.1
Maracuyá	0.75	0.375	0.375	2.25	1.125	1.125	31.1	28.1	23.3	21.1	11.7	10.5	11.7	10.5
Aromáticas	0.024	0.024	0.018	0.072	0.072	0.054	40.4	37.4	1.0	0.9	1.0	0.9	0.7	0.7
Medicinales	0.0375	0.03	0.03	0.1125	0.09	0.09	40.4	37.4	1.5	1.4	1.2	1.1	1.2	1.1
Forrajes	4.5	4.5	4.5	13.5	13.5	13.5	42.2	39.2	189.9	176.4	189.9	176.4	189.9	176.4
Total per day and per year									2406.5	2189.3	1786.2	1628.7	1310.3	1199.3
Total per year and per 3 years									7219.6	6568.0	5358.5	4886.1	3930.9	3598.0

- *New Groundwater Wells and Boreholes:* The number of wells is determined by the specific water needs of crops in the driest scenario. In general, we estimate that the daily water needs of the 500 has proposed for Santa Cruz, San Cristobal, and Isabela are about 7,220m3, 5,358m3, and 3,931m3, accordingly (supplementary material). Since these requirements are daily, tanks need to be filled in about 12h of continuous extractions and treat for salinity and other parameters found in the groundwater. Ideally, this is to be done during night-time so that water is used during daytime. This process is going to be monitoring as shown in the flow chart. The decision of the amount of groundwater extraction will be taken considering the previous aquifer data collected and the aquifer levels in that moment. The monitoring system plays an important role in the decision making of groundwater extraction due to the over coverage of water demands in some months (Table 26).

Table 26. Daily demand of proposed irrigation areas covered by wells.

Island		Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Santa Cruz	Wells extraction m3	7776	7776	7776	7776	7776	7776	7776	7776	7776	7776
	Cover %	400%	197%	122%	121%	111%	114%	112%	107%	104%	112%
San Cristobal	Wells extraction m3	5184	5184	5184	5184	5184	5184	5184	5184	5184	5184
	Cover %	374%	183%	113%	112%	103%	107%	104%	99.7%	98%	104%
Isabela	Wells extraction m3	3888	3888	3888	3888	3888	3888	3888	3888	3888	3888
	Cover %	374%	183%	113%	112%	103%	107%	104%	99.7%	98%	104%

The specific location of these wells is a result from the previous practice which will survey the geophysical, geological, and hydrogeological characteristics of the Islands. The total number of wells proposed are 6 in Santa Cruz, 4 in San Cristobal and 3 in Isabela to cover the total amount of agricultural water demands in the dry season. This practice considers three important points for insurance the aquifer sustainability:

- Data of previous studies and aquifers monitoring.
- Water treatment before and after irrigation (shared responsibility)
- Alternative practices of water reuse if reach limit points (Integrated Farm Drainage Management, increase of Fog Catchment coverage)

- *Fog Catchers:* This option will cover about 1000m2 of croplands; yet it is important to note that the expected amount of water from fog catcher may not fully satisfy crops requirements. Fog Catchers are distributed 20 in Santa Cruz (collecting 7m3 of water), 17 in San Cristobal (collecting 5.5m3 of water) and 10 in Isabela (collecting 3.2m3 of water). In particular, they are to be located in areas over 400 m.a.s.l since in these areas fog reaches its maximum potential to contribute to water yields (Pyret, 2010). The fog catchers proposed here have an area of 40m2 and they, in average, contribute to about 300 l/day.

  Due to the low contribution in terms of water, the total of fog catchers will be used in the reactivation of the old reservoirs without depending on the water tankers to fill them. This system will be a sustained form of water harvesting showing net benefits after the fourth year of implementation. Today, the water used in the reservoirs has a cost of 3.93 $/m3 in a 7m3 tank truck, the fog collectors will cover the need for 471m3/month or 67 full water tankers per month.

b) Water distribution

The next stage then addresses the distribution of water from the sources and storage elements to the farms. Thus, this corresponds to a series of canals and pipelines which facilitate water transport to local farms. Depending on the natural gradient, these pipelines could be pressurized or free flowing canals. Due to evaporation losses, pipe flow is encouraged. The length would address the distance between the water intake or well to the storage tanks and finally to the farmlands. An estimated length of 25km for Santa

Cruz, 20km for San Cristobal, and 15km for Isabela is considered for the distribution network on each Island.

c) Irrigation

This strategy corresponds to the amount of water effectively used by crops. In this proposal, we aim to cover 100% of the needs from croplands. Yet if the system has an excess of water due the benefits of rainfall, the operation decisions in wells and reservoirs can be modified. This could be done to relief extraction rates from the aquifer or to store more water in reservoirs. The number of hectares to be covered by irrigation is the same as those shown in Table 2 above. The mechanisms to irrigate that are proposed are:

- *Drip irrigations:* Drip irrigation is known for its reduction in losses within irrigation systems. Due to the water scarcity in the islands, this method is the best option to implement an irrigation plan. This type of irrigation has shown a significant improvement in agricultural production in similar areas with water scarce conditions. In spite of these benefits, drip-based systems lose their efficiency when irrigation water is saturated with salt, which is the reality in some places in the Galapagos. This proposal addresses this problem by ensuring that the distributed water is pretreated. Drip irrigation systems were calculated to cover 152.8 Has per year, a total of 458.4 Has in the three years of project development. The water needs to be covered by these systems are summarized in the Table 1. Furthermore, the characteristics of this system are mentioned below; however, these characteristics will change in function of the crop type.

  - Pump with 2hp and discharge accessories
  - 2 inches filter
  - Fertilization couple
  - 2 inches principal pipe - 100mts
  - 1-inch secondary pipe - 200mts
  - 12 valves
  - 6800 mts dropper tape every 20cm.

- *Sprinkler irrigation:* Sprinkler irrigation is an irrigation method that attempts to balance costs and losses of water in the system. This project proposes to cover the fodder areas with sprinkler irrigation that are going to focus on livestock feeding for driest periods by adding 13.5 has per year up to a total of 40.5 has by the end of the project. One of the benefits of this method is the lack of salt-water treatment, as the pipes and sprinklers do not have clogging problems with it. The characteristics of this system are mentioned below.

  - Pump with 9hp
  - High pressure pipes
  - Fertilization couple
  - 63 millimeters principal pipe - 125mts
  - 50 millimeters secondary pipes - 200mts
  - 25 millimeters sprinkler pipe - 820mts
  - 4 valves
  - 70 sprinklers

Environmental Benefits:

The inclusion of 500 has of new resilient climate systems and 6000 has of silvopastoral systems (baseline) aims to improve the integrated management of water resources in Galapagos. The monitoring system and previous studies proposed in the first output will allow the understanding of the recharge processes of aquifers, hydraulic regimes, and critical seasons, which is why it seeks to comprehensively improve both agricultural production and the conservation of natural processes by reducing ecosystem alterations to the maximum. For example, by estimating in detail the characteristics of the regional water cycle, this project will facilitate the monitoring of fauna and flora dynamics and their links with climate change. Because of this uncertainty range we proposed a package of alternative practices such as Fog Catchers and water reuse, this will cover certain deficits if having them.

Also, by enhancing the understanding of the groundwater physical component, this would open the door to link this aspect with general biodiversity conditions of the Islands.

Social Benefits:

By implementing the water system described here, this firstly supports general food security of the Islands. At the same time, the system in place could be used to enhance water security conditions beyond the agricultural sector. This naturally includes water for human consumption, water risks management (flood and droughts), and others.

Beneficiaries
These practices will be implemented in farms of San Cristobal, Santa Cruz, and Isabela islands. The indicator of this strategy is “By the end of the fifth year, at least 500 new ha. of agricultural land with improved water management practices.” So, this broadly refers to the establishment of rainwater collection, water harvesting, treatment, storage, and efficient irrigation systems at a farm scale. 1. Water sources and Intakes:

- ✦ The total number of wells proposed are 6 in Santa Cruz, 4 in San Cristobal and 3 in Isabela
- ✦ The total number of fog catchers are 20 in Santa Cruz, 17 in San Cristobal and 10 in Isabela 2. Water storage:
- ✦ Green Infrastructure. - At present, it is not possible to totally estimate recharge and extraction rates in existing aquifers. These outputs will be explicitly obtained when the monitoring (specially the geophysical, geological, and hydro-geochemical evaluations) phase kicks off.
- ✦ Grey infrastructure. - the storage capacity calculated for each island to satisfy crops needs is 7,220 m^3 in Santa Cruz, 5,358 m^3 in San Cristobal and 3,931 m^3 in Isabela

3. Water distribution: The length would address the distance between the water intake or well to the storage tanks and finally to the farmlands. An estimated length of 25km for Santa Cruz, 20km for San Cristobal, and 15km for Isabela is considered for the distribution network on each Island.
4. Irrigation:
   - ✦ Drip irrigation systems were calculated to cover 153 Has per year, a total of 459 Has in the three years of project development (209 Has in Santa Cruz, 149 Has in San Cristobal and 101 Has in Isabela).
   - ✦ This project proposes to cover the fodder areas with sprinkler irrigation by adding 13.5 Has per year up to a total of 41 Has by the end of the project.

Output 2.1.5. Improved climate-resilient local value chains or Upgraded and more efficient green value chains and increased links to new markets developed.

This Output addresses barriers 6 and 7. The activities proposed in this output will strengthen the value chain for the main agricultural products of the region. A stronger and more dynamic value chain will allow actors address the difficulties of producing processing, and marketing organic food products more effectively. Strategic interventions and incentives to help the main agricultural products of Galapagos can generate a significant positive impact for all the actors involved in the food production chain.

The lack of integration of vulnerable farmers to the existing value chains decrease their resilience to onset and drastic events caused by climate change. The exclusion from local value chains is the result of a combination of several factors, including the importation of cheap agricultural products from the mainland. Imported food is produced with lower labor costs, increase use of inputs not allowed in Galapagos (e.g., improved seeds, pesticides), and subsidized transportation. Another important factor is the high degree of uncertainty related to future climatic conditions in farming practices, which will not allow farmers to plan for short and mid-term investments in agriculture.

On the other hand, as a step towards food security of the island's growing population, there is an increased demand for access to quality agricultural products, with higher nutritional value, and of affordable and timely access. In addition, there is a growing demand from consumers for more information about the content, origin, and processing of their food products, including any social and environmental impacts they have. Adequate traceability systems Galapagos agroecosystems would guarantee a safe and organic production of at least their staple crops.

Some of the products in greatest demand for Galapagos include dairy and meat products, coffee, and vegetables (such as tubers, grains, fruits, and medicinal plants).

Within this context, “agro-processing” should be developed within a framework of regulations adjusted to the reality of Galapagos, which should promote a healthy balance between optimization and efficient use of resources, sustainable economic and environmental development, without generating an increase in GHG emissions, in the territory.

It is important to recognize the impacts of the dynamics of “agro-processing” as a whole, reflecting the interconnected processes of change at different levels, from production to distribution. In this way, Barret et al. (2001), cited by FAO (2013a), indicate the need to examine the environmental impacts of agro-processes through three different perspectives: i) direct effects on agriculture and on previous supply industries; ii) direct downstream effects on processing, distribution, and related business activities in food supply chains; iii) indirect effects, such as increased income and other structural changes.

In this context, the activities of this output will be focused on improving the “agro-processing” of the most produced agricultural products in Galapagos: i) meat and milk, ii) coffee, and iii) banana, plantain, cassava, citrus fruits, tomato, aromatic, and medicinal plants.

Activity 2.1.5.1 Implement strategies for improve the livestock/meat and milk value chain.

A national-level value chain analysis of raising livestock for meat and dairy products suggests that over 50% of cattle ranchers are redundant and represent an uneven distribution of resources in the food system. During the study, 80% of cattle ranchers identified slaughterhouses as a bottleneck of the meat value chain (Acebo Plaza & Castillo, 2016). The loss of quality and contamination of meat products tended to occur at this stage. In the case of dairy products, milk processing plants were identified as having inadequate processes that lower quality and raise the price of the final products.

The absence regulatory laws that are specific the context of Galapagos is another critical area to address before cattle ranching can become an activity that truly contributes towards the resiliency of the region, both in terms of food security and the conservation of the islands.

In general, it is important to carry out actions at the production, processing, and market stages.

- ✦ Production stage: strengthening farm production processes that have a clear focus on sustainability and climate resilience.
- ✦ Processing stage: strengthening processes of manufacturing and adding value to products, as well as the use of more efficient technologies that pollute less while increasing their competitiveness in the market.
- ✦ Market stage: improving reliability in food product availability and quality, as well as establishing local systems for the fair trade between producers and consumers.

Cattle ranching is a critical intersection for the adaptation of Galapagos food systems to the challenges presented by climate change. Involving cattle ranchers is necessary to improve the productivity of food systems within farms, to optimize the use of natural resources, and to promote environmentally friendly strategies and technologies.

Incorporating sustainable practices for the meat and dairy industries of Galapagos is necessary for the mitigation of greenhouse gas (GHG) emissions that contribute to climate change and other pollutants which impact the island environments. These practices include: 1) the conservation and efficient use of natural resources like water, soil, and genetic diversity of crops and livestock; 2) a shift away from extensive livestock production strategies with high GHG emissions, in favor of intensive and semi-intensive production systems with lower demands of external farm inputs; 3) an improvement of the manufacturing and processing methods for meat and dairy products with resource-efficient technologies mitigates the impact of pollution sources and the degradation of island ecosystems.

Thus, the objective of this activity is to strengthen the traceability of dairy and meat products in Galapagos food systems to improve their positioning in the local market and increase their profitability at all stages of the value chain, but most critically for the farmer-rancher at the production stage. It will be achieved through: i) Implementing farming practices that conserve natural resources for livestock and milk production; ii) Establishing manuals for good manufacturing practices (GMP) for dairy processing plants, iii) Establishing a monitoring and traceability system for the transport and maintenance of a cold transport chain for meat and dairy products; and iv) Strengthening the recognition and certification third party vendors.

This activity will address the following vulnerabilities:

- “Extensive” livestock production systems are highly demanding of natural and economic resources.
- Livestock production systems with high pollution levels impact surrounding ecosystems.
- Limited access of Galapagos residents to high-quality locally produced meat and dairy products negatively impacts the nutrition and economy of local inhabitants.
- Large extensions of agricultural lands abandoned due to low profitability of livestock production leads to the proliferation of invasive plant species.
- Cattle ranching is one of the most important productive sectors in Galapagos, and its weakening represents a deterioration of local economies for the entire region.

This activity includes the following sub-activities that allow to improve the adaptive capacity of the local value chain in Galápagos.

a) **Strengthening livestock production systems with environmentally friendly practices that are adapted to the context of Galapagos and help breach the productive gap in farms in terms of quantity and quality**.
   Annual training workshops (one per island) will be implemented to strengthen the knowledge about the improvement of pastures, animal nutrition/health, and management of genetic resources of livestock and crops. Additionally, these workshops will seek to improve the knowledge, management, and use of highly competitive strategies to empower the local market. In the case of meat products, with the sale of calves that have become safety and genetically adapted to island ecosystems.

Furthermore, the program will promote the recognition of farms that integrate sustainable farming practice for raising livestock and delivery of incentives or certificates that promote sustainable practices.

b) Strengthening adequate livestock slaughter and meat processing systems.

Based on rigorous analysis, the program will provide means and alternatives for establishing adequate meat processing infrastructure (slaughterhouses) in San Cristobal, Isabela and Floreana islands considering the supply and demand within the internal market and the environmental and climatic conditions of each island. Additionally, will be integrated a management plan and infrastructure that minimize effluents generated in slaughterhouses. The assurance of a reliable cold transport chain for food products, Isabela and San Cristobal slaughters will be equipped with refrigerated trucks.

In the four inhabited islands will be standardized minimum quality and traceability standards though an integrated system for third-party meat vendors.

c) Strengthening of dairy processing plants

The existing processing plants in the four islands will be strengthened adequately and in a timely manner based on a baseline of the economic and social status and installed capacity. Additionally, through the program (CAF loans), direct credit lines will be stablished for the improvement of the local productive infrastructure, inputs and raw material in San Cristobal, Isabela and Floreana islands.

In the four inhabited islands will be standardized product quality and traceability standards, promoting local brands. Finally, the program will support projects relating to technological innovation that contribute to overcome local environmental restrictions and regulations; in an efficient climatic, social and economically sustainable way, in the medium and long term

d) Positioning of the local market

Identify the best inter-institutional and multisectoral strategies for setting prices of food products under the principles of fair trade through an adequate traceability system for dairy and meat production that ensure the food safety of local products by enhancing their preference over the consumer.

Additionally, the program will promote economies of scale for the distribution and commercialization of semi-processed and processed meat and dairy products, minimizing the cost of intermediation and promoting and strengthening local brand through advertising campaigns, mainly in San Cristobal, Isabela and Floreana islands

e) Implementing a program to strengthen local capacities

Annual workshops will be conducted in Santa Cruz and San Cristobal to strengthen the: i) meat processing practices in slaughterhouses; ii) knowledge about production of pasteurized milk, cheese, yogurt, and caramel; iii) local capacities and the culture of consumption, to implement the sale of meat by cuts, promoting greater use of meat to the carcass; iv) Strengthening and raising awareness of the normative, regulatory and health frameworks, to the local reality, so that they facilitate and support the processes of production, processing and commercialization of meat and dairy products and their derivatives.

Environmental Benefits:

- Reducing GHG emissions
- Making cattle ranchers a strategic ally for the control of invasive species on large extents of land
- Adapting production and manufacturing systems to the impacts of climate change while mitigating negative environmental impacts
- Increasing regional resiliency to the impacts of climate change.
- Disminución del potencial de contaminación ambiental durante el procesamiento o agregados de valor de carnes y lácteos
- Incremento del cuidado y conservación del recurso agua; fomentando sistemas de riego tecnificado en la producción y disminuyendo el potencial de contaminación durante el agro procesamiento **Social Benefits:**

- Strengthening a prominent agro-productive sector
- Dynamizing small-scale local economies
- Improving the economic situation of families whose main productive activity is livestock
- Mejora de la seguridad alimentaria de la población, con el incremento de una oferta diversificada de alimentos de calidad y en cantidad
- Fortalecimiento de la resiliencia del territorio, mediante la integración de acciones productivas, institucionales y agro industriales, que les permita una mejor adaptación a los efectos del cc

Beneficiaries
DIRECT: The beneficiaries will be the same as those where silvopastoral practices become applied, 244 farms in medium and large-scale farms mostly devoted for cattle ranching activities (Livestock and mixed farms) across all islands.

Activity 2.1.5.2 Implement strategies for improve coffee value chain

The 2014 Census of Agricultural Production Units suggests that coffee growing is the agricultural activity with highest income generation for farmers. Coffee production generates a cumulative gross annual income of $923,841, which is equivalent to $1,277 per hectare. If Galapagos coffee could be processed for the local market and sold at the price of high-quality ground coffee ($0.025 per gram), then the average production of 6.5 metric quintals of roasted coffee beans per hectare could fetch about $7,370 per hectare each year.

Permanent labor is required in Galapagos agroecosystems to maintain the coffee plantations. In addition, to avoid the intermediation of parchment coffee and leakage of its conservation value, it is necessary to implement a local coffee agro-processing system with high quality standards and within the framework of the social and solidarity economy (SSE).

Why implement an SSE framework? The value of coffee must be redistributed among farmers. Therefore, a solidarity company must ensure not only the quality of locally produced coffee, but also the well-being of the island's farmers. The coffee species to be used in the project include: Bourbón, Typica, Caturra, Catimoro, and Villalobo varieties.

In coffee production there are a total of 144 families who are both sources of labor and the owners of their means of coffee production. Engaging this economic sector can open the doors to involving and having a greater impact on subsequent stages of the coffee value chain (labor in processing, restaurants, cafeterias, etc).

Thus, the objective of this activity is to promote the local coffee market by covering the surface of Galapagos agroforestal systems with quality coffee plants, promoting resilient post-harvest practices for different stages for separating the coffee cherry fruit's flesh and skin from the beans, including dry processing and wet processing stages. For this, it is necessary to:

- Obtain quality coffee in a cup (with a rating of over 90 points);
- Comply with the Specifications of the Denomination of Origin of the Galapagos Coffee (wet and dry processing);
- Establish the Social Solidarity Economy as an approach that generates social, cultural, and environmental, and economic equity.

Maintaining and increasing the use of coffee has multiple effects to help adapt agroforestal systems to climate change and environmental deterioration. Coffee plants improve soil structure through roots growth and by adding to the leaf litter. Coffee also establishes a synergy with endemic and native hanging plant species, generating microclimates, and capturing water from atmospheric humidity with their branches. Furthermore, active coffee plantations prevent the expansion of invasive plant species such as blackberry and guava.

The classification of mature grains, removal of mucilage, pulping, washing, and fermentation stages of coffee production generate polluting wastewaters. These effluents decompose and impact surrounding environments releasing CO^2-eq gases, polluting watersheds, and modifying the pH of the soil. Its contribution to climate change can be mitigated by establishing a wastewater management system that re-captures CO^2 through anareobic processes. This would decontaminate water sources while also taking advantage of the by-products obtained from the treatment to improve the health of the soil and crops.

This activity will address the following vulnerabilities:

- Wastewater is generated when fermented coffee is washed.
- Different brands of roasted coffee are being positioned in the local market. However, agroprocessing processes do not maintain quality standards.

This activity includes the following sub-activities that allow to improve the adaptive capacity of the local coffee value chain in Galapagos.

a) Harvesting coffee at its optimal ripeness.
An annual workshop will be conducted in the first two years of the program implementation where specialist will strengthen farmers knowledge on coffee post-harvest strategies which include:
   - Field inspection for the valuation of the general state of the crop

- ✦ Topographical planning (consideration of altitudinal levels) of coffee plantations to define the sequence for harvesting.
- ✦ Harvest planning and available manpower
- ✦ Establishment of biosecurity procedures

b) Mobilizing production to the local coffee agro-processing center.

An annual workshop will be conducted in the first two years of the program implementation where specialist will strengthen knowledge on mobilization of production with biosecurity measures to prevent contamination and loss of quality of the product. Additionally, each coffee plant (Santa Cruz and San Cristobal), through direct credit lines promote by the program, will acquire a vehicle for the product transportation which will equipped with mobile infrastructure to conserve the organoleptic conditions of the coffee.

c) Implementation of a wet processing center.

Based on rigorous analysis, the program will provide strategies and characteristics for the implementation of two coffee processing plants (Santa Cruz and San Cristobal) that meets the needs of each island. The coffee producers (SSE) will acquire the functional infrastructure and equipment to implement a wet processing center through direct credit lines promote by the program. During the wet processing stage farmers will perform:

- Separation of impurities in crops with:
  - Sieves to classify coffee cherry fruits with imperfections. ○ Tanks to wash coffee cherry fruits and eliminate grains that have been attacked by coffee borer beetles.
- Mechanical pulping of coffee (according to technical studies)
- Composting: Composting areas for coffee husks.
- Demucilagination (according to technical studies)
- Fermentation, which requires:
  - Tanks for fermentation, according to the best processes (equipment is required).
  - Technical advising to improve the fermentation process.
- Washing: requires use of equipment for specialized washing of coffee beans ○ Natural water processing to remove excess minerals from water used for washing. ○ Wastewater treatment: Pools for water oxidation (accumulates water from ripe grains, pulped, mucilage, fermented and washed honey).
  - Mobilization of washed coffee in containers (drawers) to the drying area.

d) Construction of a dry processing center.

In the same way, coffee producers (SSE) will acquire the functional infrastructure and equipment to implement a dry processing center through direct credit lines promote by the program. During the dry processing stage, farmers will perform:

- Drying of washed coffee beans (raised beds are required infrastructure). Storage of parchment coffee. Requires:
  - Storage areas
  - Special covers for storage and jute bags
- Threshing/cleaning: Requires a threshing machine, screens, and fans to obtain green coffee.
- Tasting of coffee. Requires:
  - Training of local tasters ○ Equipment for coffee tasting

- Roasting of coffee. Requires:
    - Training local roasting specialists
    - Coffee bean toasters and specialized equipment.
- Grinding: Requires specialty grinders for quality coffee

e) Implements a Monitoring system. The implementation institution will conduct monitoring visits in the coffee farms and in the processing plants to control and validate the safety processes on i) post-harvesting and mobilization strategies implemented, and ii) tasting and roasting of coffee. These visits will be carried out each six months.

Environmental Benefits

By using a local coffee agro-processing center for wet and dry processing, wastewater and emissions that would normally be released at these stages will be treated or captured on-site. Simultaneously, these treated waters will serve as biofertilizers for coffee plantations.

Social Benefits

- Agro-processing coffee with high quality standards will lead to increased income for coffee growers, which, in turn, will lead to a renewed interest in coffee production from the wider community.
- Agro-processing coffee with a Social and Solidarity Economy framework will distribute the economic gains among coffee growers, according to the efforts they have invested to obtain high quality gourmet products.
- The capacities of small and medium-scale coffee growers will be strengthened during harvest, post-harvest, and agro-processing stages.
- The different coffee agroprocessing stages (wet processing, tasting, roasting) generates direct employment opportunities for the local population.
- The commercialization of Galapagos coffee produced under high-quality agro-processing standards generates indirect employment opportunities for the local population by catering gourmet products and experiences.

Beneficiaries
The aim is to construct one coffee processing center (for wet and dry processing) on each island. Each processing center should be managed by organizations operating under a Social and Solidarity Economy (SSEn) framework. There are 31 farms that exclusively produce coffee (640 Hectares) and 67 farms (3,856 Hectares) of coffee plantations mixed with other corps, distributed across three inhabited islands: Isabela, San Cristobal, and Santa Cruz. The average size of these farms is 5 ha. This action will include the 31 farms that exclusively produce coffee and 36 farms with mixed crops. In total at least 67 coffee farms will be included in this activity with a total of 201 beneficiaries (30% women).

Activity 2.1.5.3 Implement strategies for improve vegetable value chain.

Given the reality described above, as part of this proposal, we suggest promoting the development and/or strengthening of the agro-processing of primary production in order to reduce losses and environmental pollution from waste. In addition to generating new sources of employment and contributing to food security of the population, there will be a greater and more varied offer of local, non-perishable products.

Thus, the objective of this activity is to strengthen the local agri-food system, with the development of micro-enterprises that add value to potential agricultural products (bananas, plantains, cassava, citrus, tomato, aromatics and medicinal) from integral production systems, which in the medium term contribute to strengthening agroecology as an official form of cultivation in the islands. Based on the premise that agroecology rightly represents the most effective and efficient way to achieve climate resilience of agriculture worldwide and especially in island ecosystems highly vulnerable to climate change, such as Galapagos.

In this context, it is necessary: i) The implementation of Good Practices of Artisan Agroprocessing; ii) Agro-processing plants under strict principles of climate sustainability and social responsibility, with renewable energy sources, waste and waste management, wastewater treatment, production systems that are friendly to the Galapagos ecosystem; and iii) Use of biodegradable containers for storage and packaging of agro-processed products.

This activity will address the following vulnerabilities:

- Tons of organic products wasted annually.
- Limited supply (in time and variety) of organic products that contribute to food security of the local population.
- Proliferation of agricultural pests due to inadequate post-harvest management of products and/or abandonment of harvest residues in the cultivation plots.
- In strict adherence to the strategic line of adaptation to CC of the National Strategy for Adaptation to CC (ENCC 2012-2025) "Reduce social, economic and environmental vulnerability to the impacts of climate change". The weakness of the productive sector to access to local markets reducing intermediation, in addition to contributing to the generation of new sources of employment with the creation of agro-processing companies.

This activity includes the following sub-activities that allow to improve the adaptive capacity of the local value chain in Galapagos.

a) Agroprocessing of Banana, Plantain and Cassava flours and chips.

An annual workshop will be conducted in the first two years of the program implementation where interested local actors with basic knowledge in agro-processing of flours and chips will be identified; and with the support of specialist will strengthen farmers knowledge about technical practices and norms to process flours and chips of banana, plantain, and cassava.

Based on rigorous analysis, the program will provide strategies and characteristics for the implementation of two agro-processing plant for flours and medium-capacity chips (Santa Cruz and San Cristobal) that meets the needs of each island. The producers (SSE) will acquire the functional infrastructure and equipment to implement the agro-processing plants through direct credit lines promote by the program. Each plant will be implemented with the following basic areas:

- Reception
- Selection
- Washing
- Choping
- Coooking and Drying
- Pre-grinding
- Grinding
- Packaging
- Storage

• Construction of Public Policy to position a local Brand of cassava, banana and plantain chips and flours.

b) Agro-processing of preserves and pulps of citrus fruits, pineapple, and tomato. An annual workshop will be conducted in the first two years of the program implementation where interested local actors with basic knowledge in canned and pulp agro-processing will be identified; and with the support of specialist will strengthen farmers knowledge about technical practices and norms to process tomato cans and citrus fruit pulps.

Based on rigorous analysis, the program will provide strategies and characteristics for the implementation of two agro-processing plant for preserves and pulps (Santa Cruz and San Cristobal) that meets the needs of each island. The producers (SSE) will acquire the functional infrastructure and equipment to implement the agro-processing plants through direct credit lines promote by the program. Each plant will be implemented with the following basic areas:

- Reception
- Selection
- Washing
- Chopping
- Cooking
- Packaging
- Storage

• Construction of Public Policy to position local brand production of preserves and pulps of, at a minimum, pineapple, citrus, and tomatoes.

c) Agro-processing of aromatic and medicinal herbs.

An annual workshop will be conducted in the first two years of the program implementation where interested local actors with basic knowledge in agro-processing of medicinal and aromatic herbs will be identified; and with the support of specialist will strengthen farmers knowledge about technical practices and norms to process aromatic and medicinal herbs.

Based on rigorous analysis, the program will provide strategies and characteristics for the implementation of two agro-processing plant for aromatics (Santa Cruz and San Cristobal) that meets the needs of each island. The producers (SSE) will acquire the functional infrastructure and equipment to implement the agro-processing plants through direct credit lines promote by the program. Each plant will be implemented with the following basic areas:

- Reception
- Selection
- Washing
- Drying
- Packaging
- Storage

d) **Implements a Monitoring system and Public Policy.** The implementation institution will conduct monitoring visits in the farms and in the processing plants to control and validate the safety processes and efficiency achieved in the agro-processing of i) flour and chips; ii) preserves and pulps; and iii) aromatics herbs. These visits will be carried out each six months. Additionally, based on rigorous analysis, a Public Policy will be built to position local brand production of the processed products in the Islands.

Environmental Benefits

Being an undeveloped sector in Galapagos, the agroprocessing of products, should rather be subject to a sustainable strategic planning according to the environmental requirements and regulations that contribute to the Clean Development Mechanism (CDM), contemplated within the ENCC (National Strategy for Climate Change).

Regarding operation, according to the proposal, its operation must be guaranteed under strict principles of climatic and social sustainability, with renewable energy sources, waste and waste management, wastewater treatment, environmentally friendly production systems with the Galapagos ecosystem.

By increasing the demand for organic products, as raw material for the supply of small agroprocessing companies, an adequate pre- and post-harvest management of crops will be stimulated, generating less contamination due to poor waste management, less contamination of water and soil, and lower risk of proliferation of agricultural pests in the field.

Social Benefits

The increase in the greater variety of products offered by local brands, strengthens the territory in terms of food security, generation of jobs, revitalization of the local economy, which contributes to generating greater resilience of the territory towards climate change.

Additionally, the implementation of companies within the framework of the Social and Solidarity Economy (SSE) generate a direct employment to farmers, personnel in agroprocessor, distributors, among other, as well as the dynamization of small-scale local economies.

There are multiple positive impacts that could be generated on the resilience of Galapagos with the strengthening or development of agro-processes. However, in trying to group these benefits into large productive sectors, it is considered:

1. Production systems, as those in charge of supplying the raw material, will be directed towards important processes of productive improvement and optimization of resources, generating climate resilience, since agro-processing "promotes" quality and safety in primary production.

2. Strengthening economies of scale, which help boost local economies by generating new sources of employment aimed at combating poverty in families that currently do not have direct access to means of production.
3. Interinstitutional and multisectoral strengthening of the territory in the face of the adverse effects of climate change, since the Government must create favorable conditions for private investment and innovation (access to credit, policies to support local production, regulations and regulations adapted to the territory).

Beneficiaries
By supplying the agro-processing plants, at least 497 farms (1,491 beneficiaries, 30% women) will be direct beneficiaries. They are distributed in the following way: o 272 farms in the agro-processing of flour and chips (816 beneficiaries, 30% women) o 150 farms in the agro-processing of preserves and pulps (450 beneficiaries, 30% women) o 75 farms in the agro-processing of aromatic herbs (225 beneficiaries, 30% women) It should be noted, the prices established by the processing plant will be within the framework of the Social and Solidarity Economy and Fair Trade.

Appendices (see below the references)

Appendix 1: Water Balance

Appendix 2: Carbon Estimation

Appendix 4: Integrated Crop Management Monitoring

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Appendix 2. Galapagos Water Balance

The Galapagos Islands are importantly influenced by ENSO conditions. During ENSO's warm phase, or El Niño, high sea temperature in the eastern Pacific displace the ITCZ which results in more intense rainfall and hot seasons in the Galapagos (Snell and Rea, 1999). On the other hand, During ENSO's cold phase, or La Niña, the Islands experience abnormal colder seasons as well as droughts. In the last decades the most extreme El Niño events include those of 1975–6, 1982–3, 1986–7, 1993–4 and 1997–8; additional recent high-rainfall events in 2002 and 2010 were also associated with these conditions. The way by which these general climatological patterns then translate to water availability and water fluxes can be understood by describing the general water balance of the Islands.

Water Balance is defined here as the description of flows and fluxes that enter and leave the water cycle in the Galapagos Islands, i.e., the way by which precipitation compares with runoff and evapotranspiration fluxes. In order to calculate the water balance of Santa Cruz, San Cristobal and Isabela Islands here we use the WEAP (Water Evaluation and Planning System) model created by SEI (Stockholm Environmental Institute) (Sieber & Purkey, 2015) as our main tool.

The hydrological model rainfall-runoff processes are simulated using a 2-bucket representation, the first one a root zone layer and the second a deep layer (Yates 1996; Yates et al., 2005a) (Figure 1). To represent the elevation gradient of climatic variables such as precipitation and temperature the WEAP model creates elevation bands as a unique WEAP catchment. This WEAP objects had their own spatial variables and temporary series. Land cover variability is represented by multiple areas with land cover types that are parameterized individually.

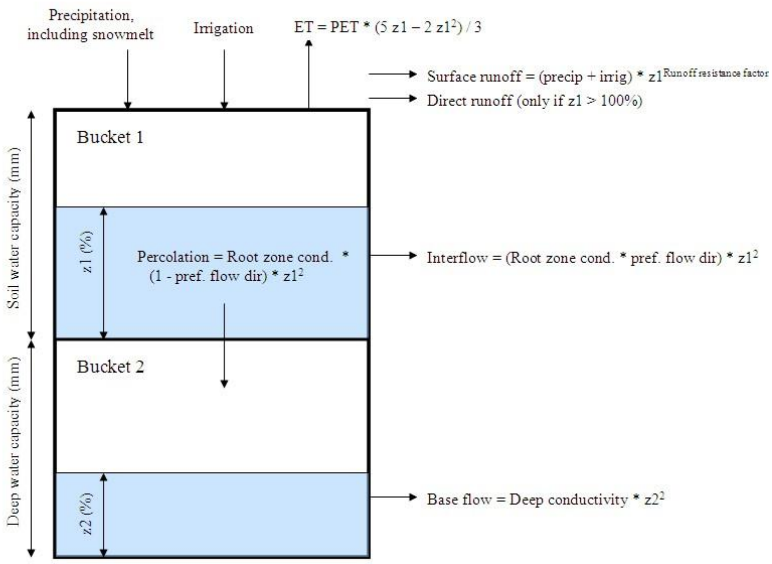

Figure 1. Bucket representation of the soil moisture method in WEAP model (SEI,2016).

Briefly, for the Galapagos Islands the model is set up by using a range of available data. This includes climatological data from the ERA5 reanalysis effort, soil parameters from available studies (González Iñiguez, 2013; Pryet et al, 2012) as well as a DEM (Lehner et al., 2008) at 3 arc-second spatial resolution. This model generates as output the following variables: evapotranspiration, surface runoff, subsurface flow, base flow, and changes in soil humidity. The model setup does not contemplate an aquifer simulation due to the lack of groundwater data such as volume, recharge percentage and water levels. Then, the base flow will represent both the percolated water and the aquifer recharge without separating them.

This balance cannot be validated by observed flows because of the lack of discharge information. Reason why one of the proposed actions mention in output 2.2.2 include a monitoring system of discharges in the island. We intend to build a robust balance by evaluating the different flows such as the aquifer recharge flow and identify specific zones for intervention because of their hydric importance. This balance can be a guide to know if the model represents in a good way the fluxes in the ground Figures 2-4. The different water balances were calculated as the average of each flow (m^3/s) within the agricultural area for each island. The figures show a clear seasonality in the three islands with high precipitation in the period Jan-May and low precipitation in Jun-Dec. While the evapotranspiration and the baseflow shows to be the most influential processes in the dry period because it consumes all the available water from precipitation and slowly the water stored in the soil. Also, the hydrological model was developed so that it can easily accept more data as it becomes available, such as climatic and hydrological values, in future projects.

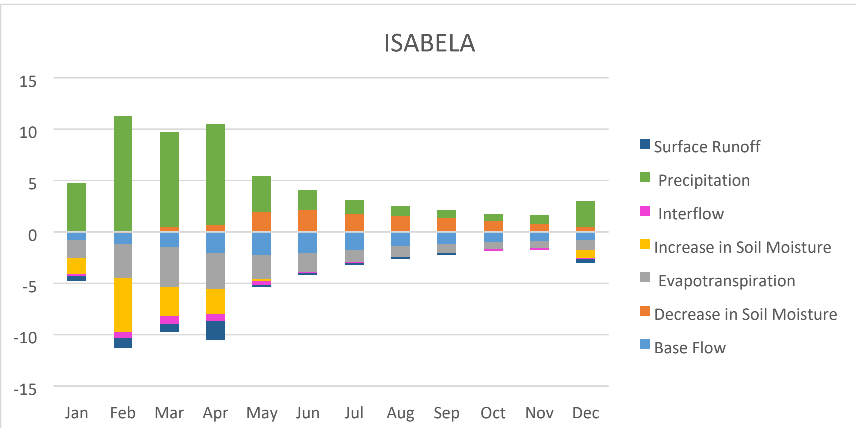

Figure 2. Hydrological balance in Isabela island

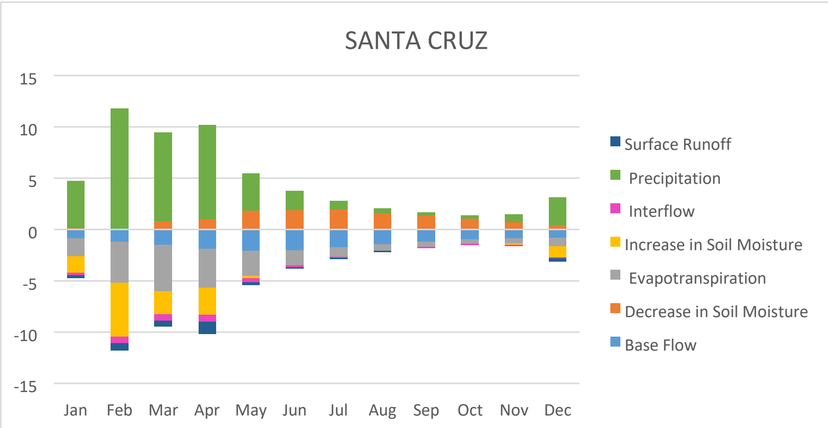

Figure 3. Hydrological balance in Santa Cruz island

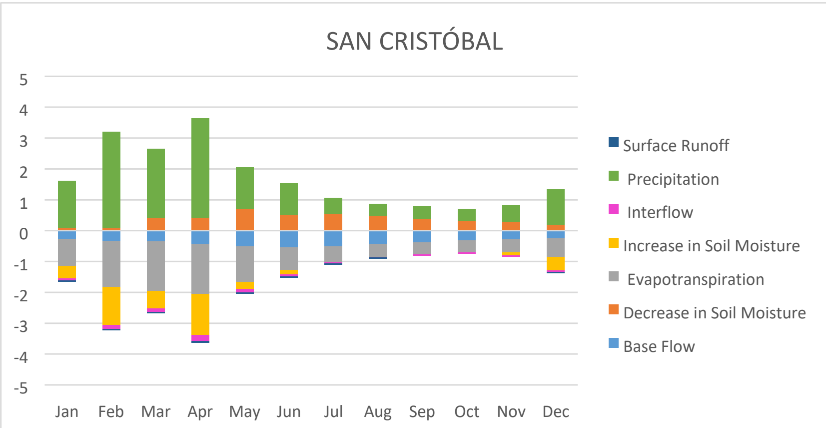

Figure 4. Hydrological balance in San Cristóbal island

The water balance shown here depicts the mean historical average surface flow for two time periods: 1981-2000 and 2001-2019 (Figure 5). The first period represents a time of high precipitation where El Niño events (1982-1983 and 1997-1998) were relevant and particularly impactful in the region. Conversely the most recent period represents a time of apparent dryness, characterized by the absence of strong El Niño events.

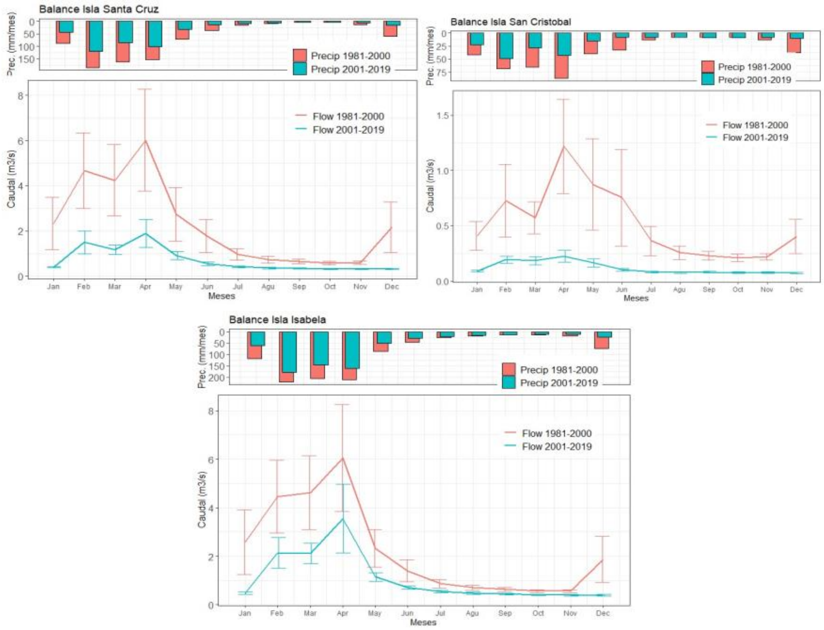

Figure 5. Water balance for the Galapagos Islands - Historical Conditions (precipitation and surface flow). Bars represent standard error

Climate Change Scenarios

Following the development of the model we performed a climatic sensitivity analysis. This experiment attempts to capture the elasticity of the system (and thus, the key output variables) to a range of climatic scenarios. We built 48 scenarios which represent combinations of different percentages of precipitation and temperatures from historical records. Historical precipitation is modified in 10% intervals of change from -50% up to 200% whereas temperature modifications represent increases in the historical series from +0.5°C up to +3°C. This approach permits us to understand the elasticity of the chosen variables of analyses when they are subject to levels of stress. An example of the results of this exercise are shown below (Figure 6):

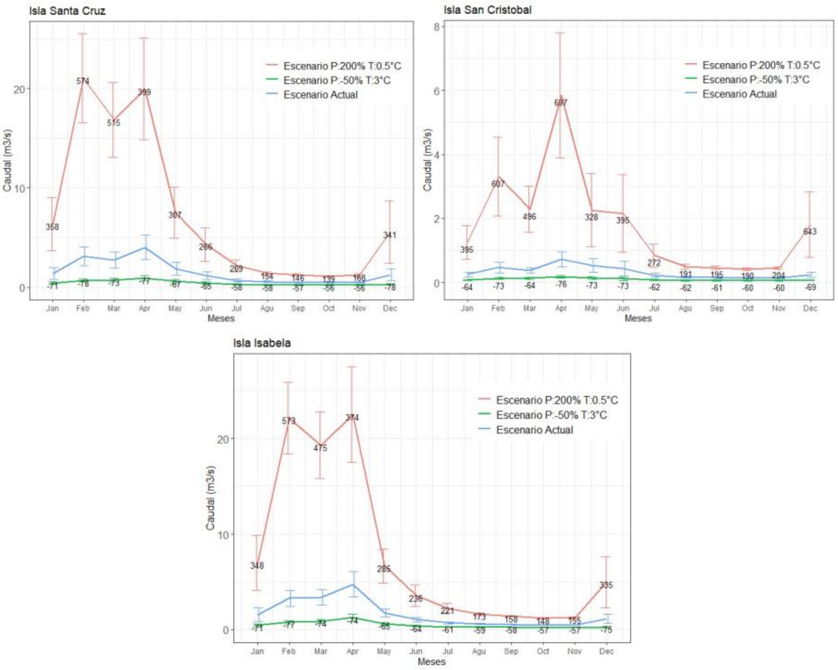

Figure 6. Example of water balance sensitivity analysis for the Galapagos Islands under extreme conditions. The numbers show the percentage of change and the bars the standard error.

Moreover, we also estimate how land-hydrological variables may be affected by climate change. This is done by utilizing mean annual hydrological results of our sensitivity analysis, which are then plotted in surface response maps (showing the increases in temperature and precipitation, and their resulting output variable) against the CMIP5 climate projections. For reference, we also delineate the hydroclimatic conditions of El Nino 1982-1983, 1997-1998 and the dry conditions of 2015-2016. The first two caused important damages and losses in the Islands as result of severe floods. The recent dry conditions led to local authorities to decree a regional state of emergency due to severe impacts that droughts caused on society. See figure 7 below.

As such, we first note that none of the projected climate scenarios estimate that the mean annual drought conditions in 2015-2016 would not be repeated (or intensified) in the upcoming decades. This is the case for the three variables used here: base flow, surface runoff, and streamflow. While this result may provide a sense of robustness and certainty of Galapagos water systems, it is important to once again highlight the general pluvial tendency of existing GCMs in the Islands; this in turn contradicts recent observed drying trends, as discussed above.

In line with this, we also note that in general, and across the Islands, the future climate projections estimate *normal* mean annual hydrological conditions for the upcoming decades. This can be observed as mean annual projected changes in the three hydrological variables do not reach the mean annual levels experienced in 1982-1983 and 1997-1998. An exception to this can be observed in San Cristobal where various scenarios project that mean annual surface runoff conditions would resemble those El Niño years, and even one scenario projects conditions *more* intense than those observed in the mentioned periods. Yet, it is important here to note the discussed deficiency of GCMs to project general climatological variability in the area. Similarly, this analysis is based on mean annual conditions and does not include changes in seasonality.

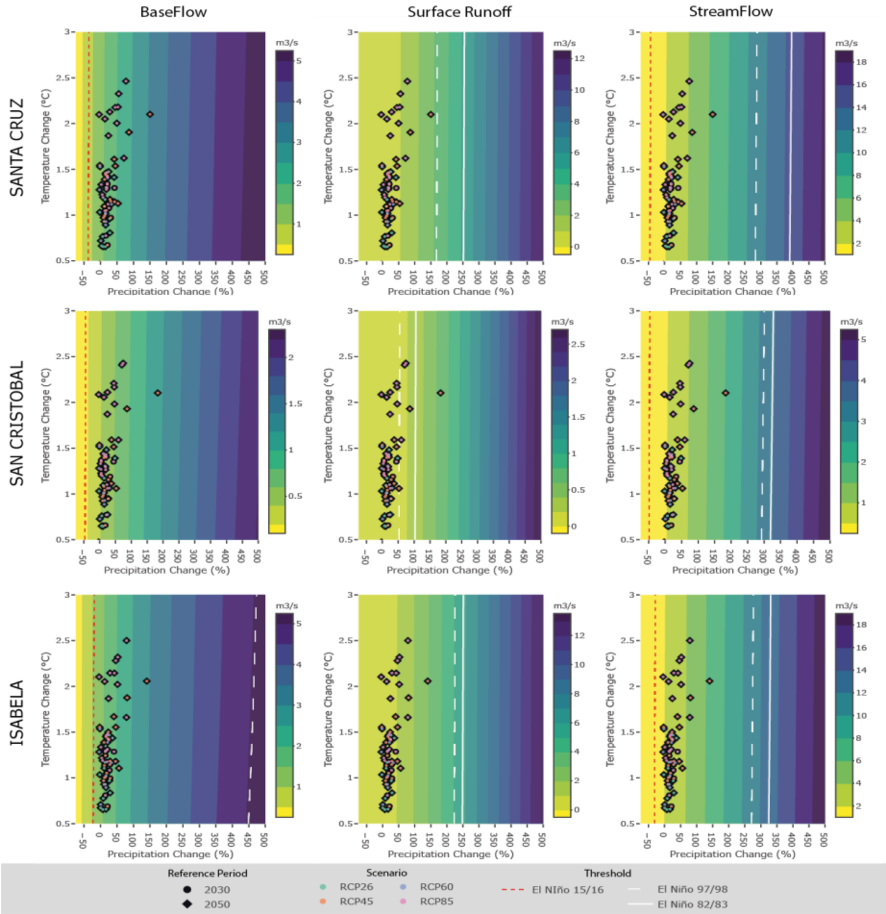

Figure 7. Surface response maps for the sensitivity analysis of mean annual conditions of key hydrological variables (baseflow, surface runoff, and streamflow) to changes in precipitation and temperature. Colors represent the mean annual hydrological output when combinations of temperature and precipitation are run. Those ranges of change (scenarios for the sensitivity experiment) are reflected on the x and y axis for precipitation and temperature respectively. Dots represent climate projections from the

CMIP5 experiment. White lines show mean annual conditions of El Niño events of 1982-83 and 1997-98; the red line shows drought mean annual conditions of the drought 2015-2016.

Finally, water demands for different types of crops are also included to refine these calculations. Here, water demands are calculated as the difference between evapotranspiration and precipitation. The actual evapotranspiration (ETA) value is an output of the WEAP model that is based in crop coefficients (Kc) methodology (Allen et al., 1998) and potential evapotranspiration (PET) calculated by the Penman-Montheith method (Monteith, 1985). As seen in the water balance figures (Figure 2, 3 and 4) the evapotranspiration, simulated by the model, is correlated with the available precipitation. This process shows that evapotranspiration fluxes in dryer months take all the available water in precipitation and soil moisture. Because of the lack of irrigation in the agroecosystems, the land is affected by a drought process with negative consequences in the farm productivity.

Furthermore, due to the type of climate in Galapagos, the crop coefficient values had to be corrected to improve the representation of ETA. These corrections are based on the relative humidity, precipitation depth and wind velocity. The process shows an increase in the crop coefficient values and therefore in the evapotranspiration values (Table 1). This increase affects directly to the water demands. Here we shown the dryer month (October) as an extreme point for the practices that we proposed.

Table 1. Water demand by crop in October

CROPS	**Eto (WEAP)**	**Modified crop coeficient Kc**			**Crop evapotranspiration daily demand (m3/ha)**			**Daily water supply-October (m3/ha)**			**Daily water demand-October (m3/ha)**		
	mm/day	Crop season			Crop season			Scenario			Scenario		
		Initial	Develp	Late	Initial	Develp	Late	Dry	Mod	Wet	Dry	Mod	Wet
Alfalfa	3.70	0.40	1.22	1.17	14.80	44.40	43.3	2.2	3.77	5.19	42.2	40.6	39.2
Porotón	3.70	0.40	1.03	0.63	14.80	37.00	23.1				34.8	33.2	31.8
Morera	3.70	0.40	1.03	0.63	14.80	37.00	23.1				34.8	33.2	31.8
Leucaena	3.70	0.40	1.03	0.63	14.80	37.00	23.1				34.8	33.2	31.8
Café	3.70	0.90	0.99	0.99	33.30	35.15	36.7				32.9	31.3	29.9
Pasto Gramínealeguminosa	3.70	0.40	1.08	0.88	14.80	38.85	32.4				36.6	35.0	33.6
Cedro	3.70	0.50	1.14	0.69	18.50	40.70	25.6				38.5	36.9	35.5
Maíz	3.70	0.40	0.84	0.74	14.80	29.60	27.2				27.4	25.8	24.4
Fréjol	3.70	0.40	1.20	0.40	14.80	42.55	14.6				40.3	38.7	37.3
Cítricos	3.70	0.50	0.54	0.49	18.50	16.65	18.2				14.4	12.8	11.4
Aguacate	3.70	0.60	0.92	0.82	22.20	31.45	30.3				29.2	27.6	26.2
Sandía	3.70	0.45	0.78	0.78	16.65	27.75	28.6				25.5	23.9	22.5
Yuca	3.70	0.30	1.13	0.53	11.10	40.70	19.7				38.5	36.9	35.5
Papa	3.70	0.00	1.17	0.67	0.00	42.55	24.9				40.3	38.7	37.3
Tomate	3.70	1.15	0.92	0.62	42.55	33.30	23.0				31.1	29.5	28.1

Pimiento	3.70	0.60	1.03	0.78	22.20	37.00	28.7				34.8	33.2	31.8
Banana	3.70	1.00	1.29	1.19	37.00	44.40	44.1				42.2	40.6	39.2
Maracuya	3.70	0.55	0.99	0.74	20.35	33.30	27.3				31.1	29.5	28.1
Pina	3.70	0.50	0.32	0.32	18.50	11.10	11.9				8.9	7.3	5.9
Cana de azucar	3.70	0.40	1.34	0.84	14.80	46.25	31.0				44.0	42.4	41.0
Papaya	3.70	0.50	1.19	1.09	18.50	40.70	40.2				38.5	36.9	35.5
Mani	3.70		1.22	0.67	0.00	42.55	24.6				40.3	38.7	37.3

Thanks to the robustness-based approach used in the present study, the evaluation of multiple GCMs is possible without biasing the future climate information. This allows the calculation of a water balance for each climate projection, concluding a greater probability of experiencing a decrease in base flows that directly affect the recharge of aquifers. This effect requires the generation of new water sources to meet agricultural needs in times of drought.

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APPENDIX 3: CARBON ESTIMATES

Introduction

Agriculture, Forestry and Other Land Uses (AFOLU) contribute around 23% of total net global anthropogenic emissions of GHGs, primarily through deforestation, livestock emissions and soil and nutrient management. These activities accounted for around 13% of CO_2, 44% of methane (CH_4), and 82% of nitrous oxide (N_2O) emissions during 20072016. When emissions associated with pre- and post-production in the global food system are included, the food system accounts for up to 37% of total net emissions (IPCC, 2019).

The purpose of this component is creating a climate-resilient food system in Galapagos through an appropriate agriculture management that improve inter-linkages between natural resources and the population providing opportunities to warranty food security, strengthen conservation, reduce emissions, and improve livelihood resilience to climate change. The resilient farm model includes restoration/improvement of ecosystem services through invasive species control and native/endemic planted forest interventions, adoption of improved cropland management, improvement of silvopasture systems, adoption of agroforestry and incorporate new technologies to waste management and reduction of emissions derivate of agriculture.

The climate-resilient practices proposed in this component have important mitigation environmental co-benefits, which are quantified through the Ex-Ante Carbon-balance Tool (EX-ACT) developed by FAO. The tool estimates the impact of the agricultural practices on the carbon-balance. The carbon-balance is defined as the net balance from all GHGs expressed in carbon dioxide (CO_2) equivalents that will be emitted or sequestered due to climate-resilient practices implementation as compared to a businessas-usual scenario (FAO, 2017).

Methodology

EX-ACT Tool

The EX-Ante Carbon-balance Tool (EX-ACT) is an appraisal system developed by the Food and Agriculture Organization of the United Nations (FAO) providing ex-ante estimated of the impact of agriculture, forestry and fishery development projects, programmes and policies on the carbon-balance.

EX-ACT is a land-based accounting system, measuring C stocks, stock changes per unit of land, and CH_4 and N_2O emissions expressed in t CO_2-e per hectare and year. The main output of the tool is an estimation of the C-balance that is associated with adoption of alternative land management options, as compared to a ‘business as usual’ scenario. The tool helps project designers to estimate and prioritize project activities with high benefits in economic and climate change mitigation terms. This is why it is widely used by World Bank investment projects and has already been used in the preparation of GHG analysis for various green climate fund projects.

EX-ACT has been developed using primarily the IPCC 2006 Guidelines for National Greenhouse Gas Inventories (IPCC, 2006), complemented by other existing methodologies and literature reviews of default coefficients associated with agricultural/forestry production system, farm operations and inputs acceptable to the scientific community.

EX-ACT is an easy tool to be used in the context of ex-ante project/programme formulation: it is cost-effective and includes resources (tables, maps) which can help in finding the information required to run the model. It therefore requires a minimum amount of data that project developers can easily provide and is usually collected in the phase of project appraisal. However, it is necessary prepare this data to determinate the adequate modeling of practices/interventions in the tool. This consider technical specifications, literature reviews and technical expertise to improve the accuracy of the assessment. All these aspects are discussed below to ensure a clear and transparent understanding of the assessment done for this component.

Geographic Characteristics

Galapagos is located approximately 1000 km to the west of the Ecuador´s Pacific coast in the American continent. In general, the Arquipelago has a tropical moist climate with a great diversity of micro-climates mainly influenced by a complex interplay of ocean currents, winds and altitude.

The agricultural regions are within the humid highland of the Galapagos, and receive nearly three times as much rain compared with the lowland. Although its volcanic origin, the severe seasonal temperature and precipitation fluctuations of highland areas have gradually weathered the islands' volcanic rocks, creating a patchwork of nutrient-rich soils of variable depths and textures where can grow both tropical-weather crops and temperate-weather crops (Tabodad et al., 2015; Chririboga et al., 2006). Based on studies conducted by PRONAREG-ORSTOM-INGALA (1987), in the older islands (Santa Cruz, San Cristobal and Floreana), where weathering and soil formation is more advanced, the highland area is dominated by soils of the order Alfisols, Inceptisols and Mollisols, being categorized by the IPCC as soils with High Activity Clay (HAC) minerals. On the other hand, the highland area on Isabela is dominated by soils of the order Andisols (Figure 1). This type of soils is categorized by the IPCC as Volcanic soils, showing a lower degree of weathering as compared with HAC soils.

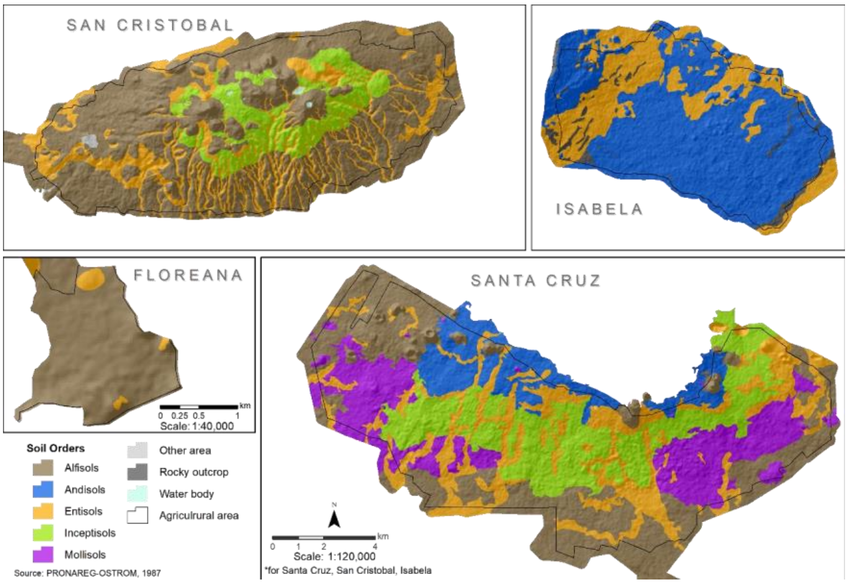


Figure 1. Soil distribution in the Agricultural area of Galapagos Islands

Business-as-Usual Scenario (Without project)

Extensive areas of agricultural land in Galapagos have been abandoned in the last decades, making this fragile and iconic agroecosystem vulnerable to the expansion of invasive plants (McCleary et al., 2013; Laso et al., 2019). Currently, the agricultural area of Galapagos records higher number of invasive plants, which cover 28.5% of its surface (Guézou et al., 2010; Laso et al., 2020). These plants not only threaten agricultural systems but also the remaining patches of native ecosystems that still exist in the nonprotected area. On the other hand, the uncontrolled spread of invasive plants in the agriculture zone is a latent threat to the local native/endemic biota located in the adjacent protected humid highlands.

The species considered highly invasive in Galapagos is the guava (Psidium-guava), which is often used in silvopastures (wooded pastures). In 1987, 1310 ha of guava forest were recorder in the agricultural area of San Cristobal (Villa and Segarra, 2010), while in 2019 the area covered by this invasive species was 1952 ha (Laso et al., 2020), corresponding to a natural increase of 49% of guava in the last 30 years.

If business-as-usual continues in the farmers activities, guava forest would be expected to increase by 32% (~1500 ha) in the next 20 years, considering that it currently occupies 4,958 ha of the agricultural land in Galapagos. In addition, 44% of the farm still keep a conventional production system that include monocultures, intense tillage, the use of synthetic fertilizers and chemical pesticides imported from Ecuador continental, among others. All these activities increase GHG emissions from the agricultural sector in Galapagos.

Proposed Agriculture Practices (With project)

The resilient farm model proposed in this component include four climate-resilient agricultural practices described in Output 2.2.1. These practices promote food security on the Islands, reducing dependency on imported agricultural inputs, food and fossil fuels from continental Ecuador. Improving field productivity, adapting productions patterns to be climate change resilient and adding value to local agriculture activity. Details of the proposed practices are summarized in Table 1.

Table 1. Climate-resilient agricultural practices to estimate carbon balance

Practice	Short description
1. Community-based Seed Bank	Improve timely access to quality seeds of selected climate change resistant crops in sufficient quantity, as a decisive means of production to increase productivity at the farm level, and therefore the availability of local nutritious food that contributes to increasing food security of the local and tourist population.
2. Integrated climate resilient Crop Management System	Strengthen crops through the combined use of these agricultural practices such as diversifying the Galapagos agroecosystems (farms), through polycultures, association and crop rotation, and the design and implementation of agroforestry systems (conserving native/endemic forest fragments inside farms), taking advantage of stable nutrients and composting structure to improve soil health and fertility, establishing an efficient pest control in the Galapagos Islands. These systems create greater tolerance to climate change effects, attack by pests or to suffer the effects of certain abiotic factors; making comprehensive management the pillar of sustainable agriculture
3. Silvopastoral System	Implement management under Agro-ecological Silvopastoral System in Galapagos cattle, improving the management and control of invasive species like *Psidium-guajava* (Guava), incorporating endemic/native forest species in contour fencing, implementing fodder banks, efficient manure management system, and grazing rotation to pasture recovery and soil conservation. These systems reduce GHG emissions (N2O and CH4), take advantage of bio-derivatives and build resilience to climate change.
4. Implement a water management system	Implement a water system that supports the agricultural needs of the Islands, mainly in the dry season and considering the reality of water availability in each island

Timeframe

The EX-ACT tool differentiates between two times periods; one for the implementation phase, where the climate-resilient practices are carried out, and another for the

capitalization phase, where the benefits of the program are still occurring due to the changes induced by the adoption of the practices.
Given the typology of the practices proposed under this program, the analysis considers a 20-year period, which is in line with IPCC recommendations for considering the timeframe between transition states of natural systems and the period necessary to reach a new equilibrium for carbon stocks. Therefore, the program consists of five (5) years for the implementation phase and, the sequestration will continue to capitalize for 15 more years to reach the 20-year period. In addition, the analysis assumes a linear dynamic of chance (from "without project (BAU)" to "with project) over the duration of the program.

Proposed area of intervention

This program considers that each practice will be adopted in at last 54% of the productive farms in Galapagos (Table 2), considering the agro-production activity and farm size. The water management system will be implemented to cover at least 500 new hectares of agricultural land with improved water management practices. This project proposes to cover at least 41 ha. of fodder areas (2500 m2 per farm) with sprinkler irrigation, supplying irrigation facilities to at least 164 farms. Additionally, 459 ha. of the agricultural farms that will include an adequate integrated crop management (404 farms), will be covered with drip irrigation according to their identified needs. Based on 2014 Census data analysis, in Galapagos there are 375 farms that are used by crop production, 185 farms that are concentrated in the livestock production and, 64 farms that have adopted both type of production (crop+livetock).

Restore native ecosystems in the agricultural landscapes will be focused in a passive restoration in farms that still conserve native forest fragments and with potential hydrological importance. These areas are usually located into inactive farms and farms categorized as "Other". Forthermore, agroforestry practices proposed in the program, will also allow the agroecosystems restoration incorporating native/endemic species in the agricultural landscape.

Table 2. Potential implementation farms for each proposed practice.

Practice	Crop	Coffee	Livestock	Mixed	Other	Total Impl.	Total Ref.	%
1. Communitybased Seed Bank	344	31	185	64		624	755	83%
2. Integrated Crop Management	275	25		51	53	404	755	54%
3. Silvopastural System			183	61		244	271	90%
4. Water management system	275	25	148	67	53	658	755	74%

Considering the potential implementation farms and using the area covered by different land uses in each multidimensional category, the next table (Table 3) summarize the intervention area for each practice. These values will be the key to model the net carbon balance in the upgrade process of each farm category.

Table 3. Intervention area by practice (ha)

Community-based seed bank

	Large-scale farms	Medium-scale farms	Small-scale farms	**Total**
Other Crops	163	137	56	355
Coffee	205	33	7	244
Livestock	3258	162	3	3423
Mixed	457	26	1	485
Total	*4083*	*358*	*66*	***4508***

Integrated Crop Management

	Large-scale farms	Medium-scale farms	Small-scale farms	**Total**
Other Crops	82	205	83	370
Coffee	233	112	23	368
Livestock	1126	165	3	1293
Mixed	817	141	7	965
	48			**150.0925**
Total	*2305*		*156*	***3146***
Others (Forest)		62	40	
		685		

Silvopastoral Systems

	Large-scale farms	Medium-scale farms	Small-scale farms	**Total**
Livestock	4414	219	-	4633
Mixed	817	47	-	864
Total	*5231*	*266*	*-*	***5497***

Water Management System

	Large-scale farms	Medium-scale farms	Small-scale farms	**Total**
Other Crops	45	89	164	298
Coffee	13	21	8	42
Livestock	27	9	1	37
Mixed	78	11	3	92
Others (Forest)	3	7	21	31
Total	*166*	*137*	*197*	***500***

Modelling

The resilient farm model proposed in this program seeks that farmers adopt a set of practices capable of increasing resilience and mitigate impacts, while also maintaining and improving farm productivity.

In this context, the net carbon balance will attempt to integrate all the climate-resilient practices above-mentioned and, quantify de CO2-eq emissions or sequestration due to program implementation as compared to a business-as-usual scenario. The first step before modelling is identify which Ex-Act module best fit to evaluate each of the activities proposed under each of the practices as well as the emission factors that will be used either tier 1 (default) or tier 2. The main emission factors per pool used for the assessment are described in table 4 and Table 5 characterize the modelling for each practice for their accounting in Ex-Act tool.

Table 4. Main emission factors per pool used in the Carbon balance

Module	Value	Source
Native/Endemic Forest	ABG: 30.8 tnC/ha BGB: 12.3 ynC/ha (FC=0.4)	Kitayama and Itow, 1999
Psidium-guava	AGB: 18.2 tnC/ha BGB: 7.3 tnC/ha (FC=0.4)	Ivanova et al., 2018
Soil Organic Carbon in highlands	SOC: 90 tnC/ha	Rial et al, 2017
Afforestation and Reforestation	Growth rates for systems up to 20-yr old AGB: 1.88 BGB: 0.47 Growth rates for systems after 20-yr old AGB: 0.47 BGB: 0.19	Default tier 1 coefficients for AGB, BGB and Litter IPCC 2006
Annual crop systems	Soil: 2.79 Tons of CO2 per ha per year for improved: • Agronomic practices: 0.88 • Nutrient mgmt.: 0.55	Default tier 1 coefficients IPCC 2006
Perennial systems	Growth rate from Perennial remaining Perennial systems: AGB : 3.02 Soil sequestration rate: • Perennial after deforestation: 0.7 • Perennial after non-forest LU: 0.7	Default tier 1 coefficients IPCC 2006
Grassland system	Soil C stock for: • Non degraded : 65 • Moderately degraded: 62.4 • Improved without inputs: 75.4 • Improved with inputs: 83.7	Default tier 1 coefficients IPCC 2006

Livestock	Total head number • Dairy Cattle: 3532 (35%)	2014 Census
	• Other Cattle: 6568 (65%) • Swine (market): 3651 Enteric fermentation in Kg CH_4 per head/yr • Dairy Cattle: 63 • Other Cattle: 56 • Swine: 1 Methane from manure management • Dairy Cattle: 1.23 • Other Cattle: 1 • Swine: 1.19	Default tier 1 coefficients IPCC 2006 MAE, 2016
Inputs	Tonnes of N per year • Urea: 46.7% • Compost. 1.7% Urea Emissions • CO_2 emissions: 0.2 • N_2O emissions: 0.01 • Emmisions for production, transportation, storage and transfer: 4.77	Default tier 1 coefficients IPCC 2006 Tolagasi, 2013 Default tier 1 coefficients IPCC 2006

Table 5. Characterization of the analysis in the Ex-Act tool

Practice	Assumptions					Ex-Act Module to fill
	Without project	**With project**				
		Large-scale farms	**Medium-scale farms**	**Small-scale farms**	**Description**	
1. Communitybased Seed Bank	Not improve agricultural practices				Selection of improve varieties, tolerant to climate change. Diversification	• Crop production: Annual systems
2. Integrated Crop Management	No crop management				Crop rotation, improve N use efficiency, reduce tillage, effective irrigation, application of bio-fertilizers, use improve varieties • Crops diversification (annual+perennial+trees), Crop rotation • Increase production area Incorporate native/invasive leguminous and forest species, controlling invasive species expansion in abandoned farms	• Crop production: Annual systems • Inputs: Fertilizers
	Monocultures of: Annual crop Perennial crop	 81 619	 31 261	 8 62		• Crop production: Annual and perennial systems
	Grassland	450	66	1		• Land use Changes: Other land use changes (Grassland to Silvopastures)
	Psidium-guava	676	99	2		• Land use Change: Deforestation (Plantation zone 4 to Prennial/tree crop: Multistrata)

	Psidium-guava expansion over native ecosystem patches (32%) Use of synthetic fertilizers (196.8 kg/ha/año) Only 18% of the farmers use compost (3 t/ha/año)	479 2305	228 685	83 156	• Keep native ecosystem patches into farms • Adoption of improved cropland management. Improve in 80% the use of compost (bio-fertilize)	• Land use Change: Deforestation (Forest Zone 4 to degraded) • Crop production: Improve cropland management • Input (Fertilizers)
1. Silvopastoral System	Moderate Degraded grassland, no rotation. Psidium-guava Psidium-guava expansion over native ecosystem patches (32%) Manure emissions	3297 (165) (989) 1465 469	167 (8) (50) 75 24	- - -	• Improve animal production and grassland management. • Incorporate trees species 5% Live Fences 30% Silvospastoral system • Invasive species control (Psidium-guava): Reduce 30% of tree density • Keep native ecosystem patches into farms • Improve management of livestock/manure management	• Grassland/ Livestock: Grassland System • Land use Changes: Other land use changes • Land use Change: Deforestation (Plantation zone 4 to Perennial tree crops: Shaded perennialcrop system) • Land use Change: Deforestation (Forest Zone 4 to degraded) • Grassland/

						Livestock: Livestock
4. Water management system	No adequate irrigation system	166	137	197	Implement and improve irrigation system	• Land use change: Reforestation
TOTAL AREA		**8643 ha**				

*Values in blue color corresponds to potential degraded native forest by invasive species (32%)

*Values in red color are not considered in Carbon Calculation

Step by step Ex-Act entries:

1. *Land Use Change Module*

The specific activities that will be carry out in this module are firstly the conservation of native forest patches into the agricultural landscapes, followed by the removal of Psidium-guava (invasive plant) from areas with livestock and crop production. In farms with livestock production the guava tree density will be reduced and transformed in shaded perennial-crop system and, in farms with crop production the guava area will be removed and transformed in multistrata systems (combination of various trees and perennial and annual crops). The biomass removed will be used in Composting practices to store carbon and produce bio-fertilizers. Furthermore, the current degraded land in the agro-ecological landscape will be restore using native/endemic species. Finally, a hedgerow (Live fences) and silvopastures systems will be implemented over a specific percentage of the current grassland area into farms with livestock production (Figure 2).

2.1. Deforestation

? AEZ map | Zone 1 = Tropical rain forest | Zone 2 = Tropical moist deciduous forest | Zone 3 = Tropical dry forest

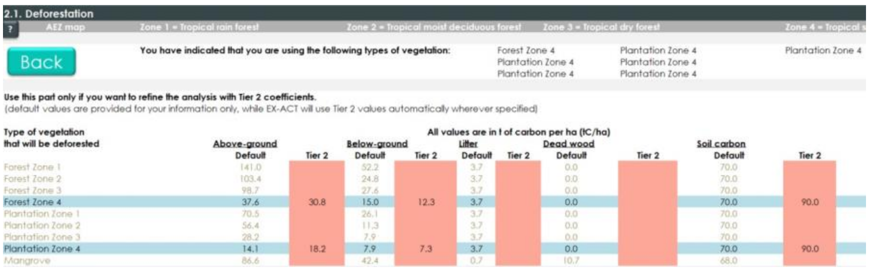
Type of vegetation that will be deforested	HWP# (tDM/ha)	Fire Use? (y/n)	Final use after deforestation	Forested area (ha) Start	Without	*	With	*	Deforested area (ha) Without	With
Forest Zone 4	0	NO	Degraded	1,283	872	D	1,283	D	411	0
Plantation Zone 4	0	NO	Perennial/Tree Crop	676	676	D	676	D	0	0
Plantation Zone 4	0	NO	Perennial/Tree Crop	99	99	D	99	D	0	0
Plantation Zone 4	0	NO	Perennial/Tree Crop	2	2	D	2	D	0	0
Plantation Zone 4	0	NO	Perennial/Tree Crop	1,465	1,026	D	430	D	439	1,035
Plantation Zone 4	0	NO	Perennial/Tree Crop	75	52	D	23	D	23	52
Select the vegetation	0	NO	Select Use after deforestation	0	0	D	0	D	0	0
Select the vegetation	0	NO	Select Use after deforestation	0	0	D	0	D	0	0

2.3. Other Land Use Changes

Fill with your description	Initial land use		Final land use	Message	Fire Use? (y/n)	Area transformed (ha) Without	*	With	*
Large-scale: Live Fences	Grassland	→	Perennial/Tree Crop		NO	0	D	165	D
Large-scale: Silvopastoral	Grassland	→	Perennial/Tree Crop		NO	0	D	989	D
Medium-scale: Live Fence	Grassland	→	Perennial/Tree Crop		NO	0	D	8	D
Medium-scale: Silvopastor	Grassland	→	Perennial/Tree Crop		NO	0	D	50	D
Large-scale: Multistrata	Grassland	→	Perennial/Tree Crop		NO	0	D	450	D
Medium-scale: Multistrata	Grassland	→	Perennial/Tree Crop		NO	0	D	66	D
Small-scale: Multistrata	Grassland	→	Perennial/Tree Crop		NO	0	D	1	D
	Select Initial Land Use	→	Select Final Land Use	Fill initial LU	NO	0	D	0	D
	Select Initial Land Use	→	Select Final Land Use	Fill initial LU	NO	0	D	0	D
	Select Initial Land Use	→	Select Final Land Use	Fill initial LU	NO	0	D	0	D

Figure 2. Land use change module entries

The coefficients-tier 2 used in this module based on local factors explained above are showed in Figure 3. For the other components will be used the coefficients by default (tier 1).



2.1. Deforestation

? AEZ map | Zone 1 = Tropical rain forest | Zone 2 = Tropical moist deciduous forest | Zone 3 = Tropical dry forest | Zone 4 = Tropical s

Back

You have indicated that you are using the following types of vegetation: Forest Zone 4, Plantation Zone 4, Plantation Zone 4, Plantation Zone 4, Plantation Zone 4, Plantation Zone 4, Plantation Zone 4

Use this part only if you want to refine the analysis with Tier 2 coefficients.
(default values are provided for your information only, while EX-ACT will use Tier 2 values automatically wherever specified)

All values are in t of carbon per ha (tC/ha)

Type of vegetation that will be deforested	Above-ground Default	Tier 2	Below-ground Default	Tier 2	Litter Default	Tier 2	Dead wood Default	Tier 2	Soil carbon Default	Tier 2
Forest Zone 1	141.0		52.2		3.7		0.0		70.0	
Forest Zone 2	103.4		24.8		3.7		0.0		70.0	
Forest Zone 3	98.7		27.6		3.7		0.0		70.0	
Forest Zone 4	37.6	30.8	15.0	12.3	3.7		0.0		70.0	90.0
Plantation Zone 1	70.5		26.1		3.7		0.0		70.0	
Plantation Zone 2	56.4		11.3		3.7		0.0		70.0	
Plantation Zone 3	28.2		7.9		3.7		0.0		70.0	
Plantation Zone 4	14.1	18.2	7.9	7.3	3.7		0.0		70.0	90.0
Mangrove	86.6		42.4		0.7		10.7		68.0	

Figure 3. Coefficients in the LUC-tier2. Native and Guava forest factors in Galapagos.

2. *Cropland Module*

The specific activities carry out in this module are firstly the improvement of annual crop management (Integrated crop management). The selection of the management option will be depend of the agro-ecological status of the farms. For the perennial system, the perennial crops will be diversified with the introduction of annual crops and native/endemic trees through multistrata and shaded perennial-crop systems (Figure 4). For this module will be used the coefficients by default (tier 1).

3.1.2. Annual systems remaining annual systems (total area must remain constant)

Fill with your description	Main season crop	Management options: Improved agronomic practices	Nutrient management	No till & residue retention	Water management	Manure application	Residue management	Yield? Yield (t/ha/yr)	Area (ha): Start	Without	*	With	*
Large-scale farm crops	Default	No	No	No	No	No	Please select		81	81	D	0	D
Large-scale farm crops improve	Default	Yes	No	Yes	Yes	Yes			0	0	D	81	D
Medium-scale farm crops	Default	No	No	No	No	No	Please select		31	31	D	0	D
Medium-scale farm crops impro	Default	Yes	Yes	Yes	Yes	Yes			0	0	D	31	D
Small-scale farm crops	Default	Yes	No	No	No	No	Please select		8	8	D	0	D
Small-scale farm crops improve	Default	Yes	Yes	Yes	Yes	Yes			0	0	D	8	D
description 7	Default	?	?	?	?	?	Please select		0	0	D	0	D
description 8	Default	?	?	?	?	?	Please select		0	0	D	0	D
description 9	Default	?	?	?	?	?	Please select		0	0	D	0	D
description 10	Default	?	?	?	?	?	Please select		0	0	D	0	D
								Total (ha)	120	120		120	

3.2.1. Perennial systems from other LU or converted to other LU (please fill step 2.LUC previously)

Description	Residue/ biomass burning	Yield (t/ha/yr)	Area (ha): Start	Without	With
Perennial after Deforestation	NO		0	462	1,087
Converted to A/R	NO		0	0	0
Perennial after non-forest LU	NO		0	0	1,729
Converted to OLUC	NO		0	0	0

3.2.2. Perennial systems remaining perrenial systems (total area must remain constant)

Fill with your description	Agroforestry systems	Residue/ biomass burning	Yield (t/ha/yr)	Area (ha): Start	Without	*	With	*
Large: Vegetation species diversification	Shaded perennial-crop systems	NO		619	0	D	175	D
Medium: Vegetation species diversification	Shaded perennial-crop systems	NO		261	0	D	614	D
Small: Vegetation species diversification	Multistrata systems	NO		62	0	D	155	D
Enter description of your system 4	Please select system	NO		0	0	D	0	D
Enter description of your system 5	Please select system	NO		0	0	D	0	D

Figure 4. Cropland module entries

3. *Grassland Module*

The specific activities carry out in this module are the improvement of the current moderately degraded grassland in the Islands. Furthermore, the cattle's feed practices will be improved with the grassland improvement, reducing the impact of enteric emissions. In addition, manure management will be implemented using cattle and swine livestock through biodigesters practice (Figure 5).

4.1. Grassland systems

4.1.1. Grassland systems from other LU or converted to other LU (please fill step 2.LUC previously)

Description	Initial State	Final state of the grassland: Without project	With project	Fire use to manage? Periodicity (Without) (y/n)	(year)	Periodicity (With) (y/n)	(year)	Yield (t/ha/yr): Start	Withou	With	Area (ha): Start	Without	With
Grassland after Deforestation	Select state	Select state	Select state	NO	5	NO	5				0	0	0
Converted to A/R	Select state	Select state	Select state	NO	5	NO	5				0	0	0
Grassland after non-forest LU	Select state	Select state	Select state	NO	5	NO	5				0	0	0
Converted to OLUC	Moderately Degraded	Moderately Degraded	Improved without inputs manage	NO	5	NO	5				1,729	1,729	0

4.1.2. Grassland systems remaining grassland systems (total area must remain contant)

Fill with your description	Initial State	Final state of the grassland: Without project	With project	Fire use to manage? Periodicity (Without) (y/n)	(year)	Periodicity (With) (y/n)	(year)	Yield (t/ha/yr): Start	Withou	With	Area (ha): Start	Without	*	With	*
Large-scale farms	Moderately Degraded	Moderately Degraded	Improved without inputs manage	NO	5	NO	5				2,143	2,143	D	2,143	D
Medium-scale farms	Moderately Degraded	Moderately Degraded	Improved with inputs improvemer	NO	5	NO	5				109	109	D	109	D
	Select state	Select state	Select state	NO	5	NO	5				0	0	D	0	D
	Select state	Select state	Select state	NO	5	NO	5				0	0	D	0	D
	Select state	Select state	Select state	NO	5	NO	5				0	0	D	0	D

4.2. Livestock (and manure management)

Livestock categories	Head number (mean per year): Start	Without project	*	With project	*	Technical mitigation option (%): Feeding practices*: Start	Without	With	Specific Agents*: Start	Without	With	Breeding*: Start	Withou	With
Dairy cattle	1,768	1,768	D	1,768	D	0%	0%	100%	0%	0%	0%	0%	0%	100%
Other cattle	3,282	3,282	D	3,282	D	0%	0%	100%	0%	0%	0%	0%	0%	100%
Buffalo	0	0	D	0	D	0%	0%	0%	0%	0%	0%	0%	0%	0%
Sheep	0	0	D	0	D	0%	0%	0%	0%	0%	0%	0%	0%	0%
Swine (Market)	600	600	D	600	D									
Swine (Breeding)	0	0	D	0	D									
Please select	0	0	D	0	D									
Please select	0	0	D	0	D									
Please select	0	0	D	0	D									

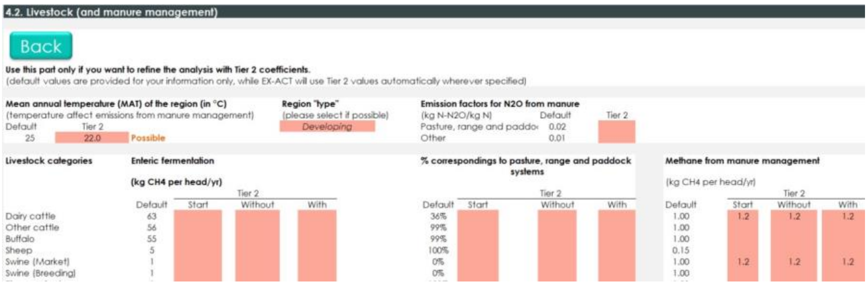
Feeding practices: e.g. more concentrates, adding certain oils or oilseeds to the diet, improving pasture quality,…

Specific agents: specific agents and dietary additives to reduces CH4 emissions (Ionophores, vaccines, bST…)

Breeding: increasing productivity through breeding and better management practices (reduction in the number of replacement heifers)

Figure 5. Grassland Module entries

The coefficients-tier 2 used in this module based on local factors explained above are showed in Figure 6. For the other components will be used the coefficients by default (tier 1).



4.2. Livestock (and manure management)

Back

Use this part only if you want to refine the analysis with Tier 2 coefficients.
(default values are provided for your information only, while EX-ACT will use Tier 2 values automatically wherever specified)

Mean annual temperature (MAT) of the region (in °C)
(temperature affect emissions from manure management)

Default	Tier 2	
25	22.0	Possible

Region "type"
(please select if possible)
Developing

Emission factors for N2O from manure

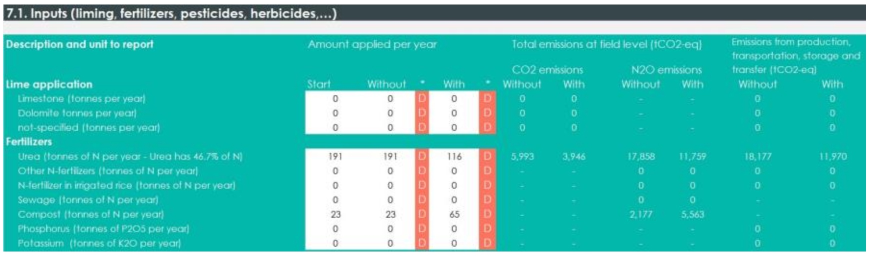
(kg N-N2O/kg N)	Default	Tier 2
Pasture, range and paddo	0.02	
Other	0.01	

Livestock categories	Enteric fermentation (kg CH4 per head/yr) Default	Tier 2 Start	Tier 2 Without	Tier 2 With	% correspondings to pasture, range and paddock systems Default	Tier 2 Start	Tier 2 Without	Tier 2 With	Methane from manure management (kg CH4 per head/yr) Default	Tier 2 Start	Tier 2 Without	Tier 2 With
Dairy cattle	63				36%				1.00	1.2	1.2	1.2
Other cattle	56				99%				1.00			
Buffalo	55				99%				1.00			
Sheep	5				100%				0.15			
Swine (Market)	1				0%				1.00	1.2	1.2	1.2
Swine (Breeding)	1				0%				1.00			

Figure 6. Coefficients in the LUC-tier2. Methane from manure management.

4. *Inputs Module*

Inputs include the use of bio-fertilizers in 2,532 ha (80% of the area where the ICM practices will be applied). Currently, about 82% of farmers use synthetic organic fertilizer (e.g. Urea) and 18% of the farmers use compost. The improved agronomic practices include the use of compost in the fertilization activities and the program aims to increase the use of compost in 80% of the farms, replacing at least 50% of the fertilizer consumption (Figure 7).



7.1. Inputs (liming, fertilizers, pesticides, herbicides,...)

Description and unit to report	Amount applied per year: Start	Without	*	With	*	Total emissions at field level (tCO2-eq): CO2 emissions Without	CO2 emissions With	N2O emissions Without	N2O emissions With	Emissions from production, transportation, storage and transfer (tCO2-eq): Without	With
Lime application											
Limestone (tonnes per year)	0	0	D	0	D	0	0	-	-	0	0
Dolomite tonnes per year)	0	0	D	0	D	0	0	-	-	0	0
not-specified (tonnes per year)	0	0	D	0	D	0	0	-	-	0	0
Fertilizers											
Urea (tonnes of N per year - Urea has 46.7% of N)	191	191	D	116	D	5,993	3,946	17,858	11,759	18,177	11,970
Other N-fertilizers (tonnes of N per year)	0	0	D	0	D	-	-	0	0	0	0
N-fertilizer in irrigated rice (tonnes of N per year)	0	0	D	0	D	-	-	0	0	0	0
Sewage (tonnes of N per year)	0	0	D	0	D	-	-	0	0	-	-
Compost (tonnes of N per year)	23	23	D	65	D	-	-	2,177	5,563	-	-
Phosphorus (tonnes of P2O5 per year)	0	0	D	0	D	-	-	-	-	0	0
Potassium (tonnes of K2O per year)	0	0	D	0	D	-	-	-	-	0	0

Figure 7. Inputs Module entries

5. *Results*

The carbon balance from program implementation is estimated to about -1 million of tCO2-eq of avoided emissions and increased carbon sequestration over 20 years analysis in 8,643 ha (Table 5). This translates into -131 tCO2-eq per hectare over 20 years or -6.5 tCO2-eq per hectare per year. The principal contributions for this balance are the CO2 sequestration from Biomass (-639,514 tCO2-eq) and Soil (-344,815 tCO2-eq) through the resilient-practices implementation proposed in this program. Improvements in feeding practices and the implementation of biodigesters help generate an absorption from enteric methane (-7,347 tCO2-eq).

<table>
<tr><th colspan="2">RESILIEN FARMS</th><th colspan="2">tCO2-eq per year</th><th>tCO2-eq in 5 years (project implementation)</th><th>tCO2-eq in 20 years (ecosystem equilibrium reached)</th></tr>
<tr><td colspan="2">Total</td><td colspan="2">-50,151</td><td>-250,755</td><td>-1,003,011</td></tr>
<tr><th colspan="6">Greenhouse gases contribution (tCO2-eq)</th></tr>
<tr><td></td><th colspan="3">CO2</th><th rowspan="2">N2O</th><th rowspan="2">CH4</th></tr>
<tr><td></td><td>Biomass</td><td>Soil</td><td>Inputs</td></tr>
<tr><td>Total</td><td>-639,514</td><td>-344,815</td><td>-8,254</td><td>-3,081</td><td>-7,347</td></tr>
<tr><td>Per ha per year</td><td>-4.2</td><td>-2.2</td><td>-0.1</td><td>0</td><td>-0.1</td></tr>
</table>

Table 7. Summary of net carbon-balance for program implementation

These results indicate that the Galapagos food system component can have an important contribution in mitigation which complements the adaptation and resilience objectives sought by the program. It will be important to closely monitor the assumptions made during program implementation to truly assess the impact of the program on the ground.

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MAIN INTEGRATED CROP MANAGEMENT PRACTICES (ICM)						
Subsystem	**Practice**	**Monitoring**				
		Yes	No	Product	Quantity	Unit
SOIL	Mantiene cobertura de suelos					
	Practica Cero Labranza					
	Aplicación de abonos orgánicos					
	Siembra de abonos verdes					
	Ha realizado algún tipo de enmienda					
	Realiza desinfección de suelos					
	Realiza análisis de suelos					
	Utiliza maquinaria para labrar el suelo					
WATER	Riego por goteo					
	Riego por aspersión					
	Uso de reservorio					
	Realiza análisis del agua de riego					
	Utiliza calendario de riegos					
	Realiza cosecha de agua					
ENVIRONMENT	Conserva árboles dentro de la parcela de cultivo					
	Conserva árboles en los bordes de las parcelas					
	Siembra de leguminosas en cercas vivas					
	Maneja compostera para residuos					
	Elimina envases de poductos químicos					
	Quema el residuo de cosechas					

CROPS						
				FREQUENCY		Product or Specie
PERIOD	PRACTICE	YES	NO	Times per crop	Times per year	
SOWING	Labranza mínima					
	Incorporación de abonos verdes antes de la siembra					
	Control mecánico de malezas					
	Planificación de siembras adelantadas					
	Realiza análisis de suelos					
	Utiliza semillas nativas o adaptadas					
	Uso de semilla seleccionada					
	Utiliza cercas vivas en contornos de parcelas					
	Siembra en policultivos					
	Siembra en monocultivo					
	Eliminación de malezas 30 días antes de la siembra					
	Utiliza abono orgánico a la siembra					
GROWING	Utiliza rotación de cultivos					
	Alterna entre gramíneas u otras y leguminosas					
	Realiza aporques y desyerbes manuales					
	Utiliza prácticas alternativas para controlar malezas					
	Incorporación de malezas al cultivo					
	Utiliza prácticas alternativas para controlar malezas					
	Utiliza trampas de colores para controlar insectos					
	Utiliza biofertilizantes					
	Utiliza algún controlador biológico					
	Utiliza biol para control de plagas					
	Utiliza plantas repelentes					
	Realiza podas y eliminación de hojas enfermas					
	Eliminación de plantas con virosis					
	Utiliza / Promueve la presencia de polinizadores					
	Utiliza productos químicos para control de plagas					
HARVESTING	Incorporación de residuos de cosechas					
	Realiza descomposición de productos no cosechados					
	Realiza selección positiva					
	Entierra frutos infestados por plagas					
	Desinfección orgánica de semillas					
	Desifección química de semillas					

AGROBIODIVERSITY IN THE AGROECOSYSTEMS

	= 5	5 a 10	10 a 15	+ 20	Purchased
Número de especies cultivadas					
Número de variedades por especie					
Número de Leguminosas					
Número de gramíneas					
Número de forrajeras					
Número de forestales					
Número de medicinales					
Número de aromáticas					

	Yes	No
Utiliza semillas nativas /adaptadas / campesinas		
Utiliza semillas mejoradas		
Utiliza su propia semilla en todos los cultivos		
Compra semillas del BCS y/o AS		

	Yes	No
Intercambia sus semillas		
Desinfecta la semilla con productos orgánicos		
Desinfecta la semilla con productos químicos		
Almacena sus semillas en recipientes herméticos		
Satisfacción con las semillas locales		

	Primero	Segundo	Tercero	Cuarto	Quinto

Cultivo más resistente a sequías					
Variedades resistentes a sequías					
Variedades exigentes en riego					
Variedades más tolerantes a plagas					
Variedades suceptibles a plagas					
Variedades más productivas					
Variedades más rentables					
Variedades más utilizadas en autoconsumo					