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History of Land Cover Change on Santa Cruz Island, Galapagos

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Abstract: Islands are particularly vulnerable to the effects of land cover change due to their limited size and remoteness. This study analyzes vegetation cover change in the agricultural area of Santa Cruz (Galapagos Archipelago) between 1961 and 2018. To reconstruct multitemporal land cover change from existing land cover products, a multisource data integration procedure was followed to reduce imprecision and inconsistencies that may result from the comparison of heterogeneous datasets. The conversion of native forests and grasslands into agricultural land was the principal land cover change in the non-protected area. In 1961, about 94% of the non-protected area was still covered by native vegetation, whereas this had decreased to only 7% in 2018. Most of the agricultural expansion took place in the 1960s and 1970s, and it created an anthropogenic landscape where 67% of the area is covered by agricultural land and 26% by invasive species. Early clearance of native vegetation took place in the more accessible—less rugged—areas with deeper-than-average and well-drained soils. The first wave of settlement consisted of large and isolated farmsteads, with 19% of the farms being larger than 100 ha and specializing in diary and meat production. Over the period of 1961–1987, the number of farms doubled from less than 100 to more than 200, while the average farm size decreased from 90 to 60 ha/farmstead. Due to labor constraints in the agricultural sector, these farms opted for less labor-intensive activities such as livestock farming. New farms (popping up in the 1990s and 2000s) are generally small in size, with <5 ha per farmstead, and settled in areas with less favorable biophysical conditions and lower accessibility to markets. From the 1990s onwards, the surge of alternative income opportunities in the tourism and travel-related sector reduced pressure on the natural resources in the non-protected area.

Keywords: land cover dynamics; agricultural expansion; off-farm employment; deforestation; Galapagos Islands

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1. Introduction

From the advent of agriculture 12,000 years ago [1] until 1960, agricultural land occupied 44 million km^2 worldwide [2]. Later on, the conversion rate from natural vegetation into agricultural land soared, and approximately 4 million km^2 were converted worldwide between 1960 and 2018 [2]. In 2014, there were more than 570 million farms globally [3], and there were about 889 million people working in agriculture in 2018 [2]. These modifications in land cover led to the loss of biodiversity [4], soil erosion and degradation [5,6], alterations to the water cycle [7,8], a decrease in air quality [9], an increase in carbon dioxide emissions, and the perturbations of biogeochemical cycles [10].

Understanding land cover change requires insights into how and why farmers determine where to change native vegetation into agricultural land [11]. Land cover products have been derived from historical aerial photographs, remote sensing, and, more recently, unpiloted aerial vehicles [12–14]. Standardized procedures were established to collect and validate land cover information [15], and open geo-portals contain the latest landcover products from different parts of the world [16], including Europe [17], or the USA [18]. Despite vast progress in land cover data acquisition and availability, there are still important gaps in our understanding of the environmental and societal predictors of land cover change. Farmers respond to opportunities and constraints from their physical environment and social context and they often aim to increase their well-being [19]. The biophysical and socioeconomic variables involved in their decision-making processes are known as land cover change drivers.

At a regional scale, hydrometeorological, topographic, and geological factors control soil characteristics and long-term land cover dynamics. Physical constraints such as steep slopes or constant drought deter decisions to convert native vegetation into agricultural land or influence farmers' decisions to abandon a cultivated area so that it can revert to native or secondary vegetation [11]. Also, farmers' choices about which parcels are left fallow are related to land quality requirements and the biophysical characteristics of the area [20,21]. The magnitude and direction of short-term land cover changes are determined by market variables, employment options, accessibility, and demographic aspects that change dynamically across space and time [22]. The rate of agricultural expansion is changing in response to the demand/offer for agricultural and forest products, the accessibility to markets and suppliers [23], and new employment options [24]. For example, the creation of off-farm jobs in the tourism sector, construction, or manufacturing is reported to be a potential way to alleviate pressure on natural vegetation [25]. In addition, land tenure and the legal ownership of the land have a cumulative effect on land cover dynamics. Land fragmentation caused by inheritance divisions often leads to diminishing farm sizes, especially in the case of old farmsteads [26,27].

Across millennia, news about small habitable landforms in the sea propelled people to migrate towards new territories [28], often bringing crop seeds and livestock with them [29]. In the past, islands were seen as the world's borders, the frontier of exploration, and became centers of demographic expansion and agricultural colonization [30]. Now, they are seen as a microcosmos of what happens in the mainland [31,32], but they are special places in their own right, with unique vulnerabilities and strengths [33]. The local environmental context shapes island-specific human–environment interactions that might have evolved over previous centuries or millennia [34]. Communities living on small islands rely on local resources to meet their basic needs, such as the provision of food and water, the regulation of erosion and pollination, recreation, and eco-tourism [35]. The clearance of native vegetation for agricultural expansion is reported to enhance habitat degradation, biodiversity loss, and the unsustainable exploitation of natural resources [36–38].

Besides these latent environmental threats, islands also present specific opportunities and strengths in response to global changes [26,27]. Though being geographically isolated, island' communities traditionally have a culture tied to the sea and its associated resources that provide food and fiber [39]. They are accustomed to maritime trade, which boosts their capacity to import goods and technologies [40]. Many archipelago societies are known to have strong social networks that might contribute to improving their resilience [41]. The development of island tourism brings with it new threats and opportunities, with implications for the management of natural resources and small island economies [42]. In 2019, tourism generated 10.3% of global GDP, supporting 330 million jobs [43]. Although tourism is often cited to contribute to biodiversity conservation via the creation of national parks and reserves and is justified for its potential benefits in terms of off-farm employment and education [33], there are still significant data gaps when studying the potential influence of tourism development on land cover dynamics in the context of small islands [44].

The small volcanic islands in the Caribbean and Pacific Ocean are known for their long history of occupation [45,46]. Geoarchaeological research revealed that small island communities have strived to optimize the use of natural resources by residing in the habitats with the highest levels of biophysical suitability [47]. Declines in natural resources appear to have been offset by efforts to replace these resources with expanding food production or a new phase of agricultural colonization [29]. This study focuses on the land cover dynamics of Santa Cruz Island, one of the Pacific islands in the Galapagos Archipelago, Ecuador. We used standardized methods to reconstruct the land cover dynamics over the last six decades (1961–2018) to critically evaluate the spatiotemporal pattern of change and the biophysical and socioeconomic variables associated with the observed land cover dynamics. First, we analyzed the physical constraints that influenced farmers' decisions to convert native vegetation into agricultural land or to abandon a cultivated area. Second, we looked into six decades of land use change in the agricultural area and how alternative income sources alleviated pressure on forests and natural vegetation in the non-protected area. Third, we analyzed how land cover dynamics are related to changes in farming systems and different strategies to manage agricultural farmsteads.

2. Methods

2.1. Study Area

About 97% of the Galapagos Archipelago is a protected as national park. Only the islands of Santa Cruz, San Cristobal, Isabela, and Floreana have permanent human settlements [48]. Santa Cruz Island is a 992 km^2 elliptical shield volcano [49] rising 950 m above sea level [50] that emerged about 2 million years ago [51] (Figure 1). The island has an inverted-plate shape, with gentle slopes (5–10°) in the upper areas, steep to very steep slopes (15–25°) in the middle areas, and gentle slopes (2°) in the basal areas [52,53]. Other remarkable topographic features are the steep volcanic cinder cones, large pit craters (more than 100 m diameter and 100 m depth) and deeply incised ephemeral or permanent river channels [53]. Soils developed from the in-situ weathering of volcanic rocks and pyroclastic material [54,55]. Laruelle [56,57] and Stoops [58] studied the soil climosequence of Santa Cruz Island. They identified Andosols with shallow (<20 cm) to medium (20–50 cm) depth in the upper areas; Inceptisols and Alfisols with medium to high (>100 cm) depth in the middle areas, with the local appearance of Entisols with abundant coarse fragments on colluvial deposits; and shallow Mollisols, Alfisols, Inceptisol, and Entisols in the basal areas [55,59].

The climate is characterized by two distinct seasons, with hot temperatures between January and May and warm temperatures during the "garua" season between June and December [60]. At Charles Darwin station (6 m a.s.l.), temperatures of 23–32 °C are recorded in the hot season, and 20–25 °C in the "garua" season. There is a sharp altitudinal gradient in air temperature of –0.8 °C per 100 m increase in altitude. The mean annual temperature is 24 °C at 6 m a.s.l. and 23 °C at 190 m a.s.l. (Table 1). Heavy rainstorms occur during the hot season, with peaks in February–March. During the "garua" season, the rainfall has lower intensity and falls during prolonged rain events. The mean annual rainfall increases with altitude from 332 mm at the coast to 950 mm at 194 m a.s.l. (Table 1) [60,61]. Marine currents and oceanic winds are responsible for the strong differences in precipitation between the humid windward side of the island and the arid leeward side: a precipitation of 332 mm is registered at the south coast (Charles Darwin Station) while only 122 mm is recorded for Seymour Airport in the north. Interannual variations in rainfall amounts can be important: la Niña (cold ENSO phase) events resulted in abnormally cold conditions and drought, while el Niño (warm ENSO phase) produced high air temperatures, a sustained high sea surface temperature, increased rainfall, and a longer than usual warm season [62,63].

Santa Cruz was the one of the last islands of the Galapagos Archipelago to be occupied in modern times [64]. The agricultural colonization of the island started around 1904 [65–67]. When the national park was created in 1959, there were only 500 inhabitants [68]. About 707 km^2 of the continental surface area of Santa Cruz is now protected, and a buffer zone of 152 km^2 separates it from the non-protected area. The latter corresponds to the windward side of the central part of the island and the bay area of Puerto Ayora. Under the agrarian land reforms of 1963 and 1974, the government offered land titles to stimulate the agricultural colonization of the islands [69]. Following the creation of the province of Galapagos, government officials and small traders arrived [70]. In 1974, there were 1577 inhabitants, of which 197 were farmers and 198 people worked in other sectors [71].

The migration from the continent to Santa Cruz accelerated from the 1980s onwards. In 1982, 3154 inhabitants were registered, with 253 persons working in the primary sector (agriculture) and 1098 in the public sector and services [72]. In 2015, the population rose to 15071 inhabitants. Employment in the public sector and services incremented 6.2-fold, while there was only a 1.8-fold increase in the primary sector [73]. From the 1970s onwards, the Ecuadorian government and private companies promoted (eco)tourism as an alternative economic activity [74], causing a rapid rise in the number of tourists from 4500 in 1970, to 17,000 in 1982 and 275,817 in 2018 [74,75].

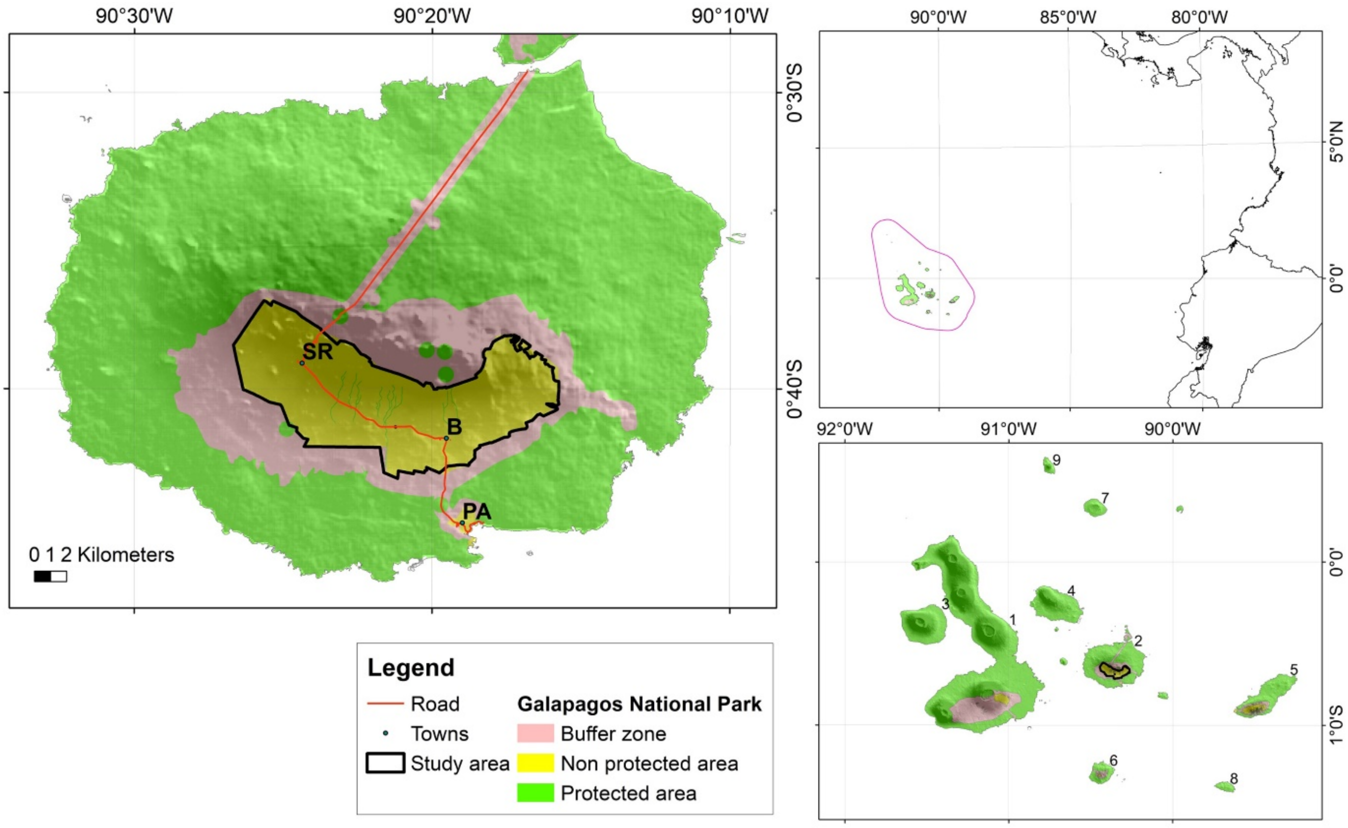

Figure 1. Location of Santa Cruz Island in the Galapagos Archipelago in the Pacific Ocean. The main towns on Santa Cruz Island are marked by black dots (SR = Santa Rosa, B = Bellavista, and PA = Puerto Ayora), and the main road is delineated with a red line. On the maps, the protected area of the Galapagos National Park is colored in green, the non-protected area in yellow, and the buffer zone in pink.

Table 1. Weather data for Santa Cruz Island based on a review of existing datasets [60].

Name of the Station	Lat	Long	Z (m)	Years Functioning	Mean Annual Rainfall (mm)	Mean Annual Temperature (°C)
Seymour-Airport	0°25′ S	90°16′ W	16	1963–1982	122	25
Charles Darwin—INAMHI	0°44′ S	90°50′ W	6	1964–now	332	24
Bellavista—Isla Sta. Cruz	0°41′ S	90°19′ W	194	1964–now	950	23
Sta. Rosa—Galápagos	0°39′ S	90°18′ W	184	1978–1983	697	n.d.

2.2. Reconstruction of Land Cover Change (1961–2018)

The land cover dynamics were reconstructed from published land cover maps from public institutions and peer-reviewed articles. Existing land cover products were carefully revised (Table 2) so as to obtain a consistent set of land cover maps that are regularly spaced over time (1961, 1985, 2007, 2012, and 2018). The land cover data from 1961 [76] and 1985 [77] were based on the manual interpretation of aerial photographs. High-resolution satellite data were the main input source for the consecutive land cover products of 2007 [78], 2012 [79], and 2018 [80]. In addition to the fact that the remote sensing data of 2012 and 2018 had a higher spatial resolution than previous sources, the 2018 study used fusion techniques to fuse 3-m resolution PlanetScope images with multispectral 10-m resolution Sentinel-2 images [80]. For this study, all spatial information was reprojected in WGS 1984 UTM Zone 15S and processed in ArcGIS (version 10.6).

Table 2. Sources of land cover information.

Description	Date	Source	Resolution (cm)
Land cover maps	1961	Trueman et al. (2013) [76]	1/100,000
	1985	PRONAREG-ORSTOM [77]	1/100,000
	2007	CLIRSEN [78]	1/50,000
	2012	SENPLADES [79]	1/5000
	2018	Lasso et al. (2020) [80]	1/18,000
Aerial photographs	1959	Instituto Geografico Militar [81]	1/50,000
	1960	Instituto Geografico Militar [82]	1/50,000
	1963	Instituto Geografico Militar [83]	1/50,000
	1985	Instituto Geografico Militar [84]	1/60,000
	2007	Instituto Geografico Militar [85]	1/30,000
	2012	SIGTIERRAS [86]	1/5000

A multisource data integration procedure was followed. To optimize the thematic generalization, a common land cover classification scheme was established, with five major land cover categories (Table 3): agricultural land, natural forest, natural shrubland, natural grassland, and invasive species. The existing land cover data were reclassified following the scheme described in the Supplementary Materials S1. Furthermore, to enhance the comparability between the land cover maps that were derived at different spatial scales (Table 2), the maps were spatially aggregated to a common spatial aggregation level. Based on similar work on land cover change in the region [12], a minimum mapping unit of 100 by 100 m was used to discriminate land cover polygons.

Table 3. Categories of land cover.

Name	Description
Agricultural land	Rural agricultural land including vegetable fields, orchards, coffee plantations (*Coffea arabica*), pasture (*Penisetum purpureum* or *Penicum maximun*), farms, and rural centers.
Natural forest	Forests with a dominance of native tree species such as *Scalesia pedunculata*, *Bursera graveolens*, *Unchair tomentosa*, and *Psidium galapageium*.
Natural shrubland	Shrubland with native plants (up to 3 m height) such as *Cyathea Weatherbyana*, *Miconia robinsoniana*, and *Caesalpinia bonduct*
Natural grassland	Grassland with native grasses such as *Paspalum longepedunculatum*, *Paspalum pinicillatum*, and *Calamagrostis pumila*.
Invasive species	Areas covered by non-native species such as blackberries (*Rubus niveus*), guayaba (*Psidium guajava*), quinine (*Cinchona Pubescens*), and cedar (*Cedrela odorata*).

The homogenized land cover products were validated with existing sets of aerial photographs from the Military Geographic Institute: black and white 1/50,000 photographs from 1961, 1/60,000 photographs of 1985, color 1/30,000 photographs from 2007, and

1/5000 photographs from 2012 (Table 2). After the georeferentiation of the aerial photographs in ArcGIS 10.6, the land cover classifications were evaluated for 600 randomly selected points in the area. More technical details are provided in Supplementary Materials S2. The accuracy of the homogenized land cover products was assessed with the Kappa coefficient (Supplementary Materials S3).

Land cover change was analyzed by traditional (pixel-based) post-classification change detection. The trajectories of land cover change were regrouped into six classes: (1) agricultural expansion (change from natural forest, shrubland, or grassland to agricultural land), (2) forest degradation (change from forest to natural shrubland or natural shrubland to natural grassland), (3) restoration (change from agriculture to natural vegetation, i.e., either forest, shrubland, or grassland), (4) the expansion of invasive species (change from any class to invasive species), (5) the control of invasive species (change from invasive species to any other class), and (6) no change.

A major challenge in mapping land cover in the Galapagos Islands is the detection of invasive species (Supplementary Materials S4). This mainly concerns guayaba (*Psidium guajava*), cedar (*Cedrela odorata*), quinine (*Cinchona pubescens*), and shrubs such as blackberries (*Rubus niveus*, Table 3). Mapping is done based on spectral signatures in remote sensing products and field work. While some invasive species such as cedar and quinine trees have a distinctive shape, others such as blackberries are difficult to map. Therefore, the land cover maps were validated with/without the category of invasive species.

2.3. Ancillary Biophysical and Socioeconomic Data

To understand the land cover dynamics in the non-protected area of Santa Cruz, biophysical, socioeconomic, and demographic data were collected. As data availability is limited in this part of the world, cartographic and remote sensing products were preferentially used to derive proxies for biophysical terrain characteristics. Information on parent material [87], soil depth, and fertility [88] was provided by SIGTIERRAS [89]. The 1/100,000 maps are derivatives of the cartographic products developed by PRONAREG ORSTOM and the Galapagos National Institute in 1989 [90]. Topographic information was derived from the void filled elevation data from the Shuttle Radar Topography Mission (SRTM) at 1 arc-second (~30-m) distributed by USGS [91]. The mean annual precipitation is derived by spatial interpolation of the 1/100,000 isohyet maps of Trueman and D'Ouzeville (2010) [60]. To further account for the socioeconomic context, the cost distance to markets and touristic sites was calculated. We used the method described in Vanacker et al. (2003) [92], with the digital elevation model and the shapefiles of roads and towns as input data [93].

Household data were derived from early accounts of the living conditions in Galapagos described by Black (1973) [68], Larrea (2001) [94], and the demographic surveys of 1960, 1974, 1982, 1990, 2001, and 2015 that were performed by the National Board of Planning and Economic Coordination in the 1970s and the Ecuadorian Institute of Statistics and Census (INEC) later on [68,71,73,95–97]. The national surveys contain information on population, employment, and housing conditions, and are available at the household level. Additional information on the number of tourists was derived from Epler (2006) [74], Jones (2020) [75], and publicly available records [98]. Data on agricultural activities were taken from two agricultural censuses realized in 2000 and 2014 at farmstead level (Supplementary Materials S4). Farm information from 1974 [99] and 1982 was also obtained from INEC [100].

The 2000 agricultural census was a joint effort of the Ecuadorian Institute of Statistics and Census (INEC), the Ministry of Agriculture, and the National Agricultural Statistics Service [101]. The 2014 census on the agricultural production units of Galapagos was a joint effort of the two formerly mentioned institutions and the Governing Council of the Galapagos Special Regime [102]. As the scope of both surveys slightly differed, we had to limit our analyses to the variables that were common in both surveys. Four variables were retained for analyses: the total surface area (ha), the surface area covered by permanent crops (ha), the surface area covered by pasture (ha), and the total number of cattle (number).

These variables explained about 50% of the observed variance in the datasets as determined from principal component analysis.

To analyze temporal changes in demographic and agricultural data, we derived the rate of change of the number of existing farms, the number of farmers, the number of people working in other sectors (services, governmental agencies, tourism, etc.), the total population, and the number of tourists visiting Galapagos.

2.4. Statistical Analysis

First, we tested whether the agricultural land taken into cultivation in 1961 was different in terms of geographic location, topography, and biophysical properties compared to remaining patches of natural forest, shrubland, and grassland. For these analyses, we created a random point file to extract the spatial information from ArcGIS at pixel level and compiled a comprehensive database for statistical analyses in R 4.1.2 Software [103]. All variables were scaled to the unit variance to allow for the intercomparison of results using scaling function. The comparison of the four land cover types and the nine biophysical variables was performed using one-way analysis of variance (ANOVA), and *p*-values were estimated using the Bonferroni correction in the kruskal.test function of the "PMCMRplus 1.9.4" package [104]. As the *p*-value showed heterogeneity of means, the post-hoc Dunn's non-parametric all-pairs comparison test was then applied to verify if the four main land cover types of 1961 had significantly different associations with location, topography, and biophysical characteristics. We rejected the null hypotheses (i.e., that there are no differences between the means of the land cover types) at the 0.05 significance level. Then, we tested whether the biophysical constraints associated with land cover dynamics changed over time. We compared the geographic location, topography, and biophysical properties of sites taken into cultivation before 1961 and between 1961–1985, 1985–2007, 2007–2012, and 2012–2018. We only included sites that were converted to agricultural land, and did not consider forest degradation, restoration, or changes in invasive species.

Second, possible associations between agricultural expansion and changes in demography and socio-economic conditions were studied with Pearson's correlation analyses using the function corr. To facilitate the comparison, the information was aggregated at the level of the island and scaled to the unit using the function scaling. The correlation coefficients are a measure of the association between the rate of forest conversion to agriculture for a given time period, and the change in population, employment, and economic activities.

Third, we verified if farming systems changed over the last two decades based on the information from the agricultural censuses of 2000 and 2014. Hierarchical clustering of the farm units was performed with the four variables that were common in the 2000 and 2014 censuses: the total surface area (ha), the surface area covered by pasture (ha), the surface area covered by permanent crops (ha), and the total number of cattle (number). The agglomerative hierarchical clustering method was selected, as the variables were quantitative and continuous and the optimal number of clusters was unknown. The Ward's Euclidean distance method was used to group data which aims to minimize the intra-class variance and maximize the inter-class variance since this minimizes the total within-cluster variance using the dist and hclust function [105].

3. Results

3.1. Reconstruction of Historical Land Cover Maps

Figure 2 shows the homogenized land cover maps for the years 1961, 1987, 2007, 2012, and 2018. The overall accuracy of the individual maps equals 92%, 91%, 92%, and 97% for the years 1961, 1987, 2007, and 2012; with kappa values of 0.87, 0.81, 0.77, and 0.92, respectively (Supplementary Materials S4). The largest uncertainty is related to the identification of invasive species. When dissolving the category of invasive species, the kappa values raised from 0.77 to 0.81 for 2007 and 0.92 to 0.99 for 2012 (Supplementary Materials S3). The kappa values indicate that the land cover is overall well classified, although higher accuracy is noted for the 2012 and 2018 products [79,80] that were derived from higher resolution remote sensing data (Table 2). The 2018 map has a more granular aspect, which is probably due to the 3-m pixel resolution of the data sources and the use of fusion techniques.

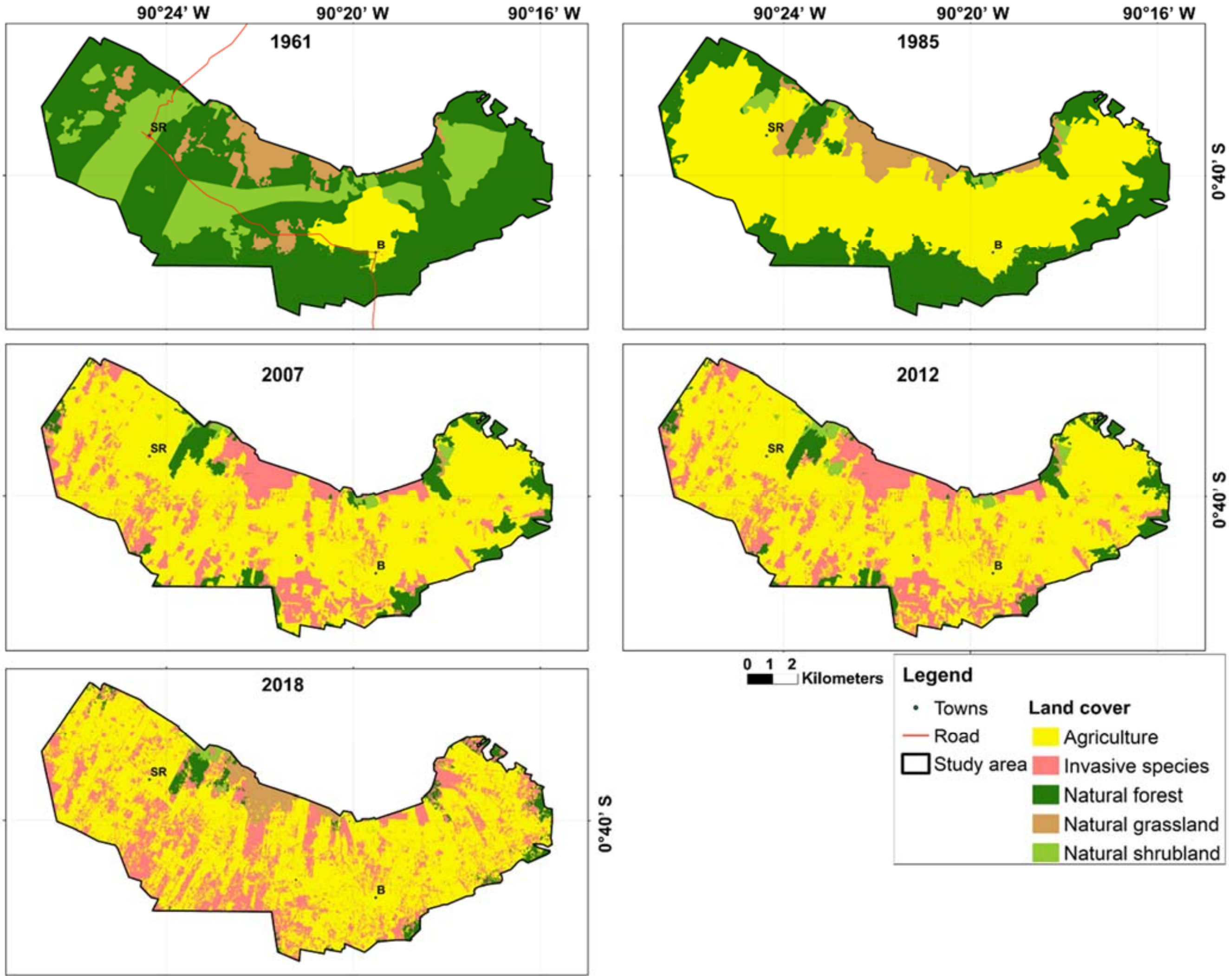

Figure 2. Land cover maps from 1961, 1985, 2007, 2012, and 2018. The main towns (SR = Santa Rosa and B = Bellavista) are given with black dots and the main road a with red line on the land cover map of 1961.

In 1961, about 94% of the area was covered by natural vegetation, with 64% being forest, 23% shrubland, and 7% grassland. The forests and shrublands were widespread in the non-protected area, whereas native grasslands occurred mostly in the upper areas (above 550 m a.s.l.). In 1961, only 6 % of the non-protected area was occupied for agricultural activities, corresponding to the areas close to the rural center of Bellavista (Figure 2). Between 1961 and 1985, more than 55% of the native vegetation in the area was converted to agriculture (Table 4). This corresponds to an agricultural expansion rate of 267 ha/year. As a result, in 1985, agricultural land was the dominant land cover type, covering 63% of the area, with natural vegetation covering 37% of the area, forest 31%, shrubland 2%, and grassland 4%. Natural vegetation was preserved close to the Galapagos National Park borders (Figure 2).

Table 4. Land cover change over the periods 1961–1985, 1985–2007, 2007–2012, and 2012–2018.

	Land Cover Change Attributed to Different Trajectories (%)				Amount of Land Cover Change (ha/Year)			
	1961 to 1985	1985 to 2007	2007 to 2012	2012 to 2018	1961 to 1985	1985 to 2007	2007 to 2012	2012 to 2018
Agricultural expansion	56.9	16.1	1.0	1.6	266.7	75.4	4.9	7.8
Forest degradation	1.7	<0.1	0.6	0.0	7.8	0.1	3.0	0.0
Invasive species expansion	0.0	18.8	1.9	12.9	0.0	88.3	8.7	60.6
Invasive species control	0.0	0.0	0.3	3.8	0.0	0.0	1.4	17.7
Restoration	0.0	0.0	0.0	3.2	0.0	0.0	0.0	15.1
No change	41.5	65.1	96.2	78.4				
Total	100							

The rate of agricultural expansion decreased to 75.4 ha/year between 1985 and 2007. In 2007, the dominant land cover type was agriculture (71%), followed by invasive species (19%) and native vegetation (10%). Invasive species were systematically reported in the land cover maps from 2007 onwards. Sometimes, people intentionally introduced non-native species to the islands, but they were also introduced unintentionally through increased accessibility. They appeared in abandoned agricultural land and were located close to the Galapagos National Park borders, spreading into the protective area. Native vegetation could be found in isolated and remote patches, and included shrublands (1%), forests (9%), and grasslands (0.2%).

The rate of agricultural expansion steadily diminished: from 75.4 ha/year between 1985 and 2007, to 4.9 ha/year between 2007 and 2012, and 7.8 ha/year between 2012 and 2018 (Figure 3). From 2007 onwards, the land cover pattern is rather steady, with ~70% of the non-protected area used for agriculture, ~7 to 9% covered by native vegetation, and the remaining part covered by invasive species. Over the past two decades, most changes were related to the expansion and control of invasive species (Table 4). The expansion of invasive species in the non-protected area remains a point of concern, with an expansion of +88.3 ha/year or 27 km^2 in the period 1985–2007 and +60.6 ha/year in the period 2012–2018. Restoration is also reported to have occurred in the latter period, on 3.2% of the non-protected area (Table 4).

3.2. Drivers of Agricultural Expansion

The geographic location of agricultural land, and its expansion over time, is controlled by a combination of geographic location, topography, and biophysical variables (Figure 3). Figure 4 compares the geography of the four major land cover types in 1961 using the outcomes of the ANOVA analyses. The one-way analysis of variance revealed significant differences between the land cover types in terms of topographic setting (altitude and hillslope gradient), precipitation, soil depth, and location (cost distance to markets and touristic sites; Figure 4). Using posthoc tests, the pairwise comparison revealed that the first sites converted to agricultural land were located on significantly lower altitudes and had deeper soils than the sites under natural vegetation. Also, the accessibility of the sites played an important role, as the farmers occupied land that was located at a significantly shorter distance from markets and touristic sites than natural forests and grasslands. No differences were found in terms of slope gradient between agricultural sites, natural shrubland, and grassland; however, natural forests were more preserved on sites with lower slope gradients. Sites with intermediate precipitation rates were preferred for agriculture, as they also correspond to deeper, more fertile soils on moderately weathered lava. About 90% of the sites that were colonized first corresponded to soils developed on moderately weathered lava (Figure 5). The first sites that were cleared for agriculture had the most favorable biophysical conditions for farming and were well connected to market locations.

Over time, as the agricultural expansion continued, the parcels that were taken into cultivation had lower accessibility with longer cost distances to markets and touristic sites (Figure 5). There is a gradual change that was noticeable when the available land with higher accessibility had been cleared first. Over the period 1961–1985, sites with optimal soil properties for farming were preferred: deeper, more fertile soils on moderately weathered lava were preferentially cleared for agriculture, with 80% of the sites located on moderately weathered lava. Other variables such as slope gradient or altitude did not show a clear spatial pattern, suggesting that these biophysical properties were not limiting for agricultural production. As time progressed, people settled farther away from the road network. Later settlers cleared forested land on slightly or highly weathered lava featuring shallower and less fertile soils (Figure 5). Over time, more soils with low fertility were taken into cultivation: their proportion increased from 0% in 1961 to 20% in 2007–2018. These sites often corresponded to lower altitudes, with lower and more erratic precipitation rates (Figure 6).

In 2018, natural vegetation was preserved on remote sites with poor accessibility (Figure 3). Compared to the agricultural sites taken into cultivation in the period of 1960–2010, such sites have systematically shallower and less fertile soils developed on slightly or highly weathered lava. They can occur over a wide range of precipitation, elevation, and slope gradients, as these biophysical variables do not seem to have been critical in the relevant land use decisions.

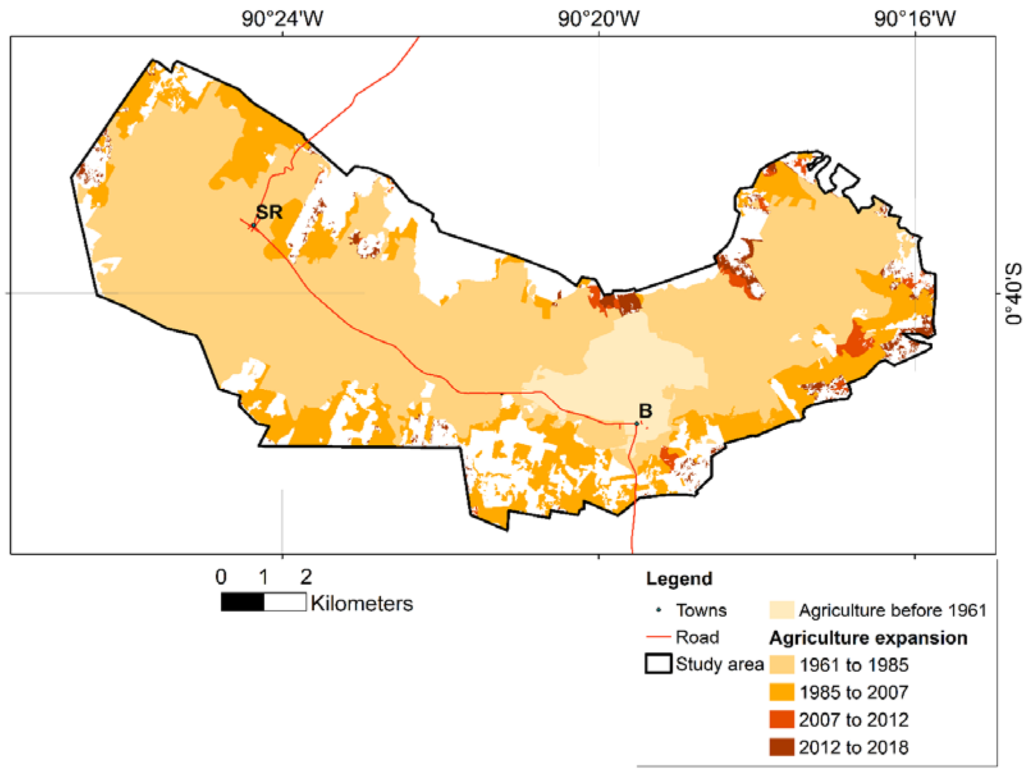

Figure 3. Agricultural expansion between 1961 and 2018 in the non-protected area of Santa Cruz Island. The different periods are shades of orange to red. The main towns (SR = Santa Rosa and B = Bellavista) are given with black dots and the main road with a red line.

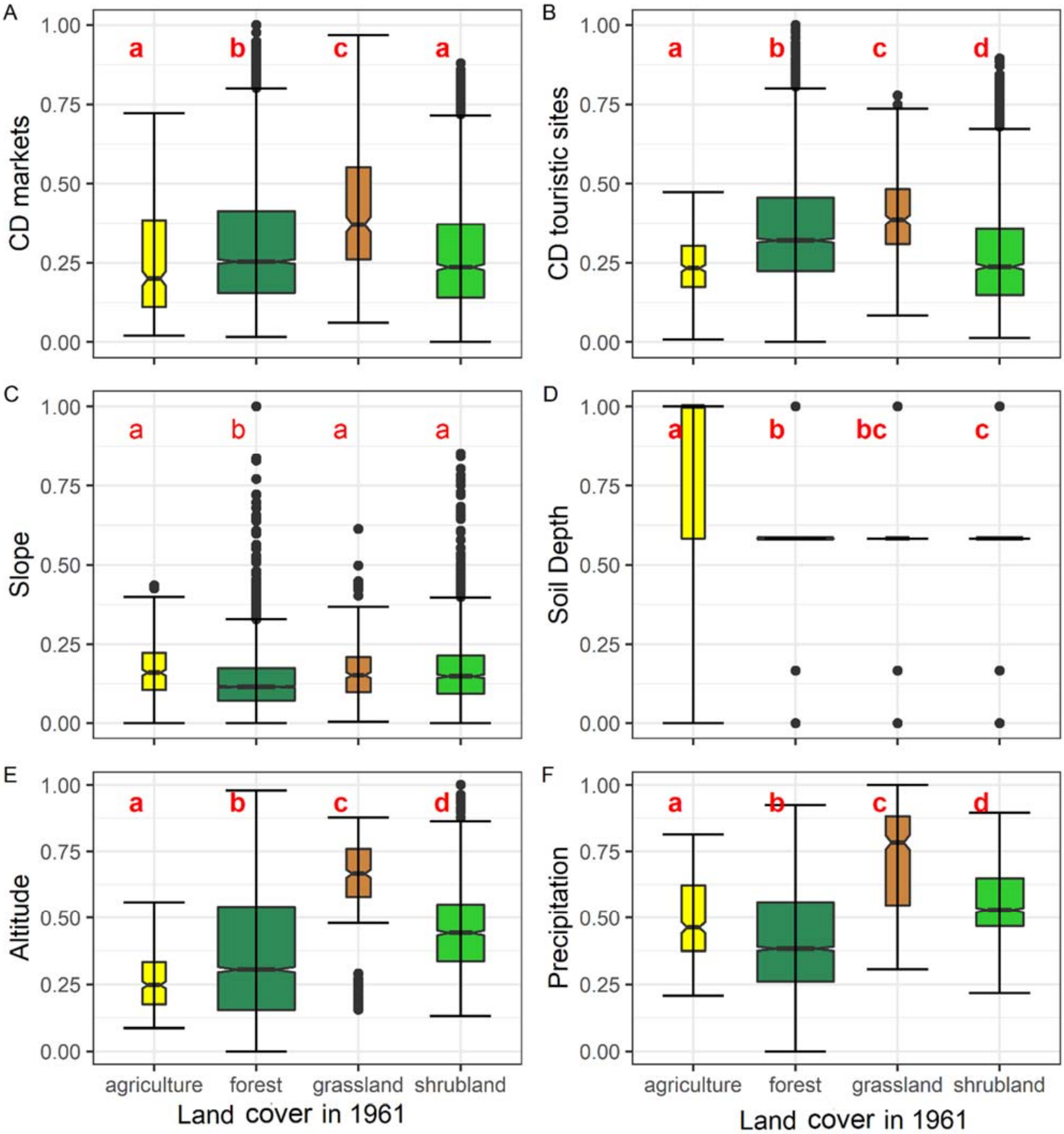

Figure 4. Comparison of location, topography, and biophysical setting between the major land cover types of 1961. The cost distance to markets (**A**), distance to touristic sites (**B**), average hillslope gradient (**C**), soil depth (**D**), average altitude (**E**), and mean annual precipitation (**F**) were scaled to the unit variance to allow for the intercomparison of results. The difference between land cover types was tested with the ANOVA test and *p*-values were estimated using the Bonferroni correction. Boxplots with a common red lower-case letter are not significantly different by the Dunn's non-parametric all-pairs comparison test at 5% level of significance.

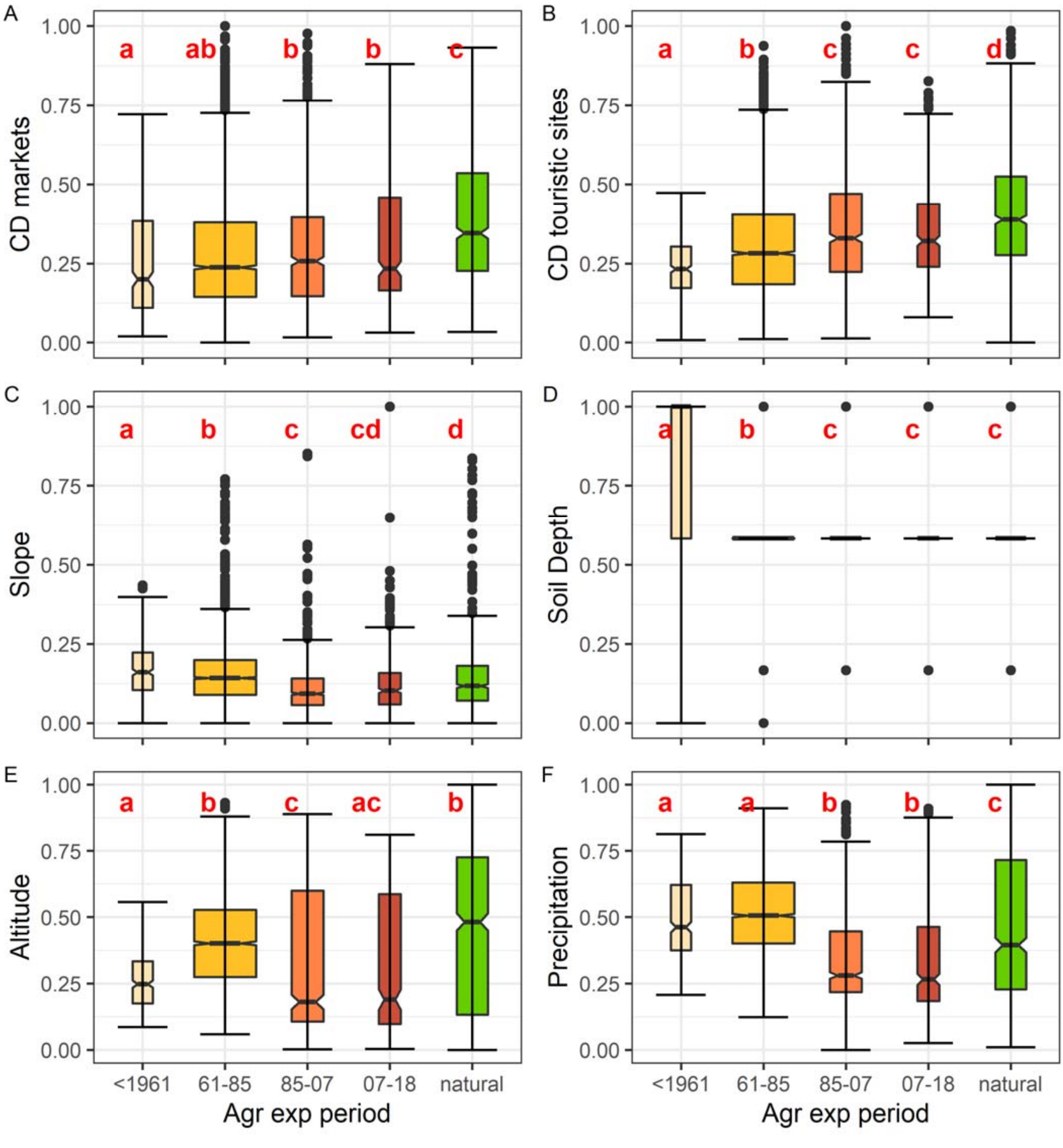

Figure 5. Agricultural expansion (1961–2018) and its association with geographic location, topography, and biophysical variables. The cost distance to markets (**A**), distance to touristic sites (**B**), average hillslope gradient (**C**), soil depth (**D**), average altitude (**E**), and mean annual precipitation (**F**) were scaled to the unit variance to allow intercomparison of results. Difference between land cover types was tested with the ANOVA test, and *p*-values were estimated using the Bonferroni correction. Boxplots with a common red lower-case letter are not significantly different by the Dunn's non-parametric all-pairs comparison test at 5% level of significance. Note that the values of the ancillary variables (*Y*-axis) were scaled to unit for the intercomparison of the data.

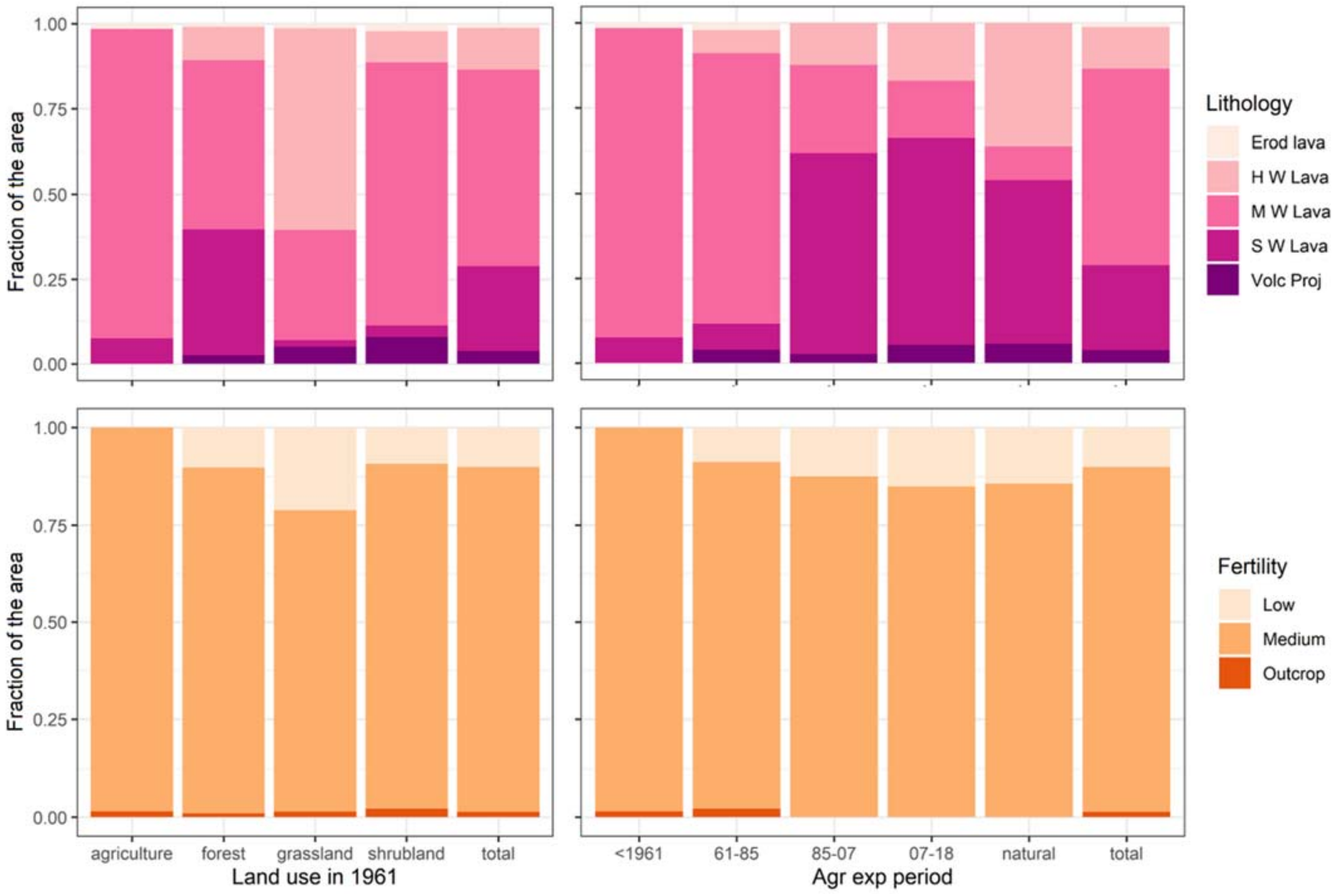

Figure 6. Distribution of land cover types in 1961 and land cover changes between 1961–2018 with respect to the rock weathering degree and soil fertility. There are five weathering degrees: eroded lava (Erod lava), highly weathered (H W lava), moderately weathered (M W lava), and slightly weathered lava (S W lava), and volcanic projections (Volc Proj).

3.3. Association between Agricultural Expansion, Demography, and Socio-Economic Conditions

Agricultural expansion rates were highest during the first phase of agricultural colonization (1961–1987), but relented over time (Figure 7). During this initial colonization phase, when the population density was low, a limited number of large-scale farms was present and the majority of the active population was employed in the agricultural sector (Figure 7). Over the period 1961–1987, the number of farms doubled from less than 100 to more than 200, while the average farm size decreased from 90 to 60 ha/farmstead (Figure 7). There was some time lag between the increase in the number of farms and the number of farmers, with this statistic increasing most in the period 1980–2000. After 2000, the growth in the agricultural sector relented. From the 1990s onwards, the rapid growth in the population was mainly due to the rapid migration of people from the Ecuadorian mainland working in other jobs (such as tourism and services). The period 2000–2015 was characterized by a 4-fold increase in the number of tourists (Figure 7).

The rate of agricultural expansion (1961–2018) is positively correlated to farm size (0.89) and was highest when the farms were largest. It is negatively correlated to the change in the number of tourists (−0.77), the active population working outside the agricultural sector (−0.80), and population growth (−0.65).

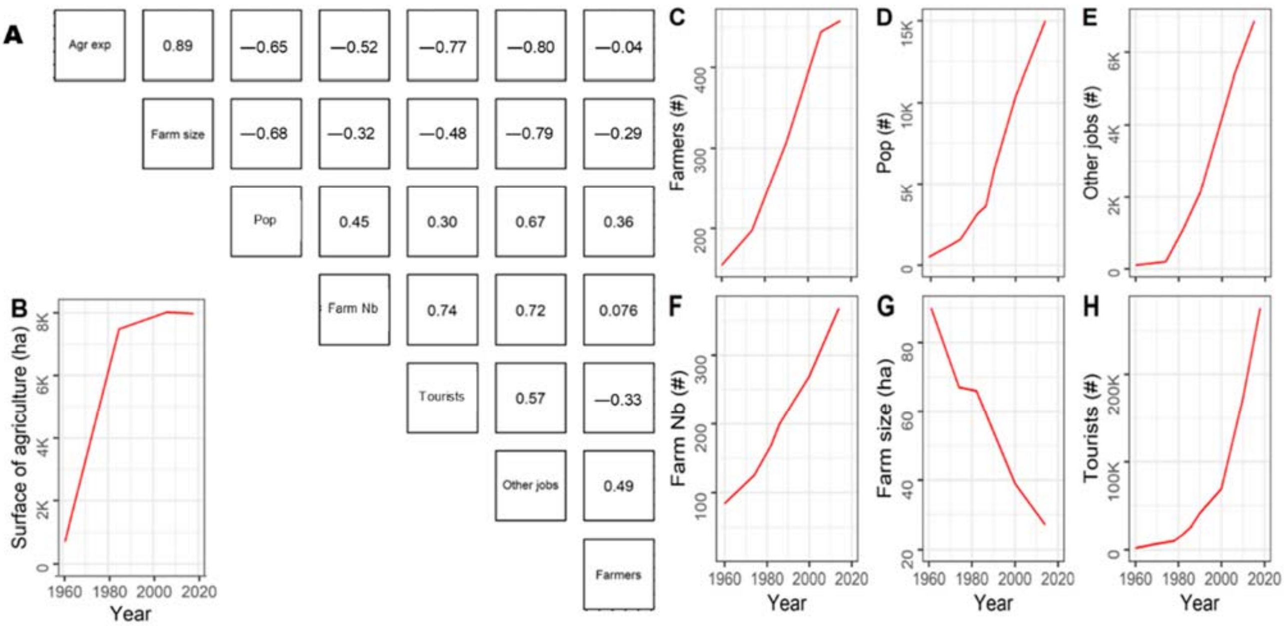

Figure 7. Correlation between the rate of agricultural expansion and changes in demographic and socio-economic conditions. The correlation matrix (**A**) shows correlation between the agricultural expansion rates (Agr exp; 6185, 8507, 0712, and 1218) and changes in farm size, number of inhabitants (POP) and farms (Farm Nb), number of tourists, and the active population working in the agricultural sector (Farmers) and other sectors (Other jobs). The remaining panels (**B**–**H**) show the temporal evolution of (**B**) the total surface area occupied by agriculture (ha), (**C**) the numbers of farmers, (**D**) population numbers, (**E**) the active population not working in the agricultural sector, (**F**) the number of farms, (**G**) farm size, and (**H**) number of tourists.

3.4. Farm Typology and its Relationship with the Land Cover Change

Through agglomerative hierarchical clustering, three types of farms were identified in 2000 and four types in 2014 (Figure 8). The most common farm type (type 1) regroups 65% of the total number of farms in 2000 and 2014, representing 173 farms in 2000 and 233 farms in 2014. Type 1 corresponds to small farmsteads of approximately 7 ha in 2000 and 4 ha in 2014. The primary strategy of the farmers of these farmsteads was to use the land for grazing, with there being on average 2 ha of grazing land and five cows per farm. They dedicated a small area for cultivating permanent crops (such as coffee, banana, and orange), and this area increased from 1 ha in 2000 to 2 ha in 2014.

The second type regroups 8% of the farms, representing 22 farmsteads in 2000 and 27 in 2014. They correspond to large farms featuring—on average—200 ha of agricultural land in 2000 and 160 ha in 2014. Over time, the size of the farms became smaller (Figure 8). They were mainly dedicated to cattle ranging (meat and dairy farms), with them featuring more than 100 cows per farm in 2000 and 2014 and about 150 ha of pasture in 2000 and 140 ha in 2014. In addition to cattle ranging, the farmers dedicated 5 to 15 ha to permanent crops in 2000 and around 5 ha in 2014.

The third type is the medium-sized farmstead, regrouping 27% of the total number of farms in each period, with 73 farms in 2000 and 97 in 2014. The size of these farms was—on average—90 ha in 2000: 80 ha dedicated to pasture and about 1–10 ha to permanent crops. In 2000, they used to have about 50 cows each. Over time, these farms specialized either in cattle raising (type 3) or permanent crops (type 4). Their average size decreased to about 70 ha; while some still focused on cattle ranging, others increased the area of permanent crops by 5 to 10 ha.

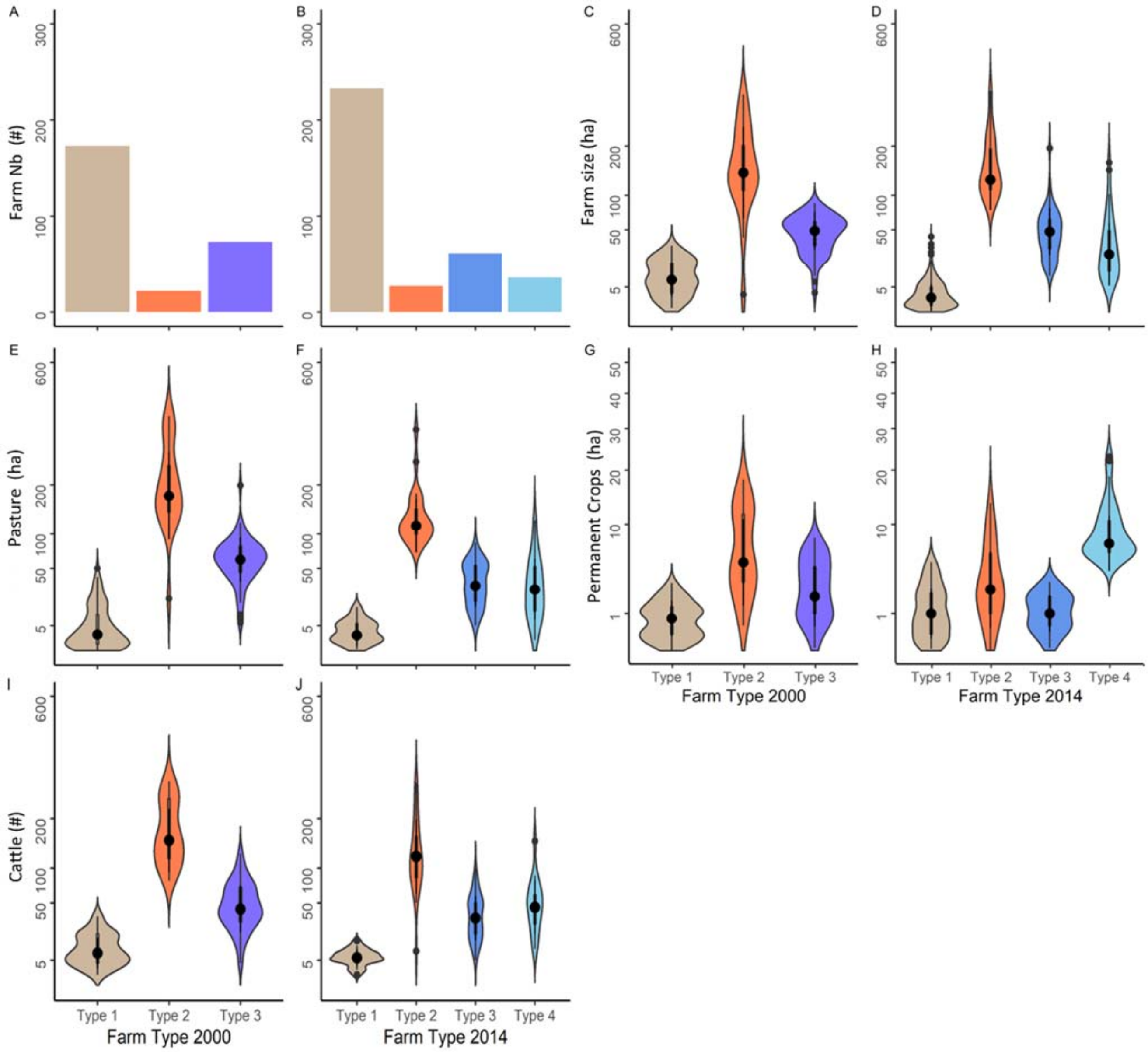

Figure 8. Classification of farms based on agglomerative hierarchical clustering. The figures show the main descriptive values for the farm types in the years 2000 and 2014, including the number of farms per type (**A**,**B**), the farm size expressed in ha (**C**,**D**), the area of pasture expressed in ha (**E**,**F**), the area designated for permanent crops expressed in ha (**G**,**H**), and the number of cattle (**I**,**J**). Each type of farm is color coded.

4. Discussion

4.1. Land Cover Change Dynamics

On Santa Cruz Island, agricultural expansion is heavily related to the distance to markets (Figure 5A). Past studies of Jamaica [106] and other Atlantic [34] and Pacific Ocean [107] Islands have already shown that people first cleared native vegetation and implemented agriculture in more accessible—less rugged—areas. As a result, the areas that are left untouched are undoubtedly more remote than the agricultural land. Farmers choose places with deep soils first (Figure 5D), corresponding to soils on moderately weathered lava on Santa Cruz Island (Figure 6). Soil characteristics played a more critical role during the earlier settlement process, as farmers expected that a crops' productivity was reflecting in the quantity and quality of plant-available nutrients in the soil [108].

Previous work showed how the geographic distribution of traditional Hawaiian cropping systems correlated with multiple climate and nutrient thresholds [109–111].

Over the period of 1960–2018, agricultural expansion on Santa Cruz Island continued with the conversion of natural vegetation in areas with less favorable biophysical conditions (lower precipitation rates and shallower and less fertile soils) and lower accessibility to markets (Figures 4 and 5). Topography was not a limiting factor in land use change, as the early farmsteads were located in areas with steeper-than-average slope gradients. This could be explained by the island's shape, as the steep middle section of Santa Cruz island has the deepest soils and best access to markets and water sources [57]. In 2018, natural vegetation was preserved at sites where soils are less suitable for agricultural activities [44].

The land cover dynamics of Santa Cruz Island conform with behavioral ecology models on the human colonization of islands. Such models were developed to explain settlement patterns in the Pacific and Caribbean regions, and case-studies included work on East and South Polynesia [112], California's Northern Channel Islands [113,114], the southern Lesser Antilles of the Eastern Caribbean [115,116], Rapa, and the Austral Islands [117]. These models postulate that the first permanent settlements occur in areas that are considered to be most suitable because of water availability, climate, soil quality, and food resources [34,39]. Then, as the population increases, people settle in lower-ranked habitats [45–47]. In the case of Galapagos, such a model explains the ancient settlement pattern in terms of agricultural areas and provides insights into present land use behavior when the essential predictors of a market-driven agricultural and economic system are included.

4.2. Decreasing Rate of Agricultural Expansion

The rescinding agriculture expansion rates on Santa Cruz Island are related to the consolidation of employment in the tourism industry and service sector, which has become the primary sources of income for the families living in the Galapagos Islands (Figure 7A). It generates directly and indirectly about 80% of the total employment in Galapagos [118] and accounts for 25% of Province's GDP ($242.7 million US) [119]. The alternative income sources outside of the agricultural sector started to increase rapidly from the 1990s onwards and reduced pressure on the natural resources in the non-protected area. This is a relatively recent phenomenon. At the beginning of the 20th century, it was thought that an active population in Galapagos was necessary to avoid the attempts of external parties to gain territory and resources [120]. In the 1930s, Santa Cruz island was deemed suitable for agriculture [121,122]. The Agrarian Reform laws of 1964 and 1973 offered tax incentives for people to move to Galapagos [123]. The Agrarian Reform had resulted in the agricultural colonization of 81.87 km^2 by 125 families by 1974 (65 ha was allocated per family on average) [124]. Due to hard environmental conditions and a lack of support for agriculture [60,111], some farmers sought alternative income sources to make their livelihood while others sold their lands [124], resulting in a reduction in the average farm size (Figure 7B).

Since the creation of the National Park in 1959, the Galapagos Islands have been promoted as a place of scientific investigation and tourism [125]. Luxury tourism demanded the training of locals as tourist guides [75,126]. Later on, local-based tourism was promoted in the Special Law for Galapagos of 1998 [74]. As a result, settlers switched their agrarian livelihoods for other opportunities with greater economic returns, less labor-intensive work on the land, and less risk of losing investments [127]. Local investments in hotels, restaurants, and shops quickly rose [128]. As time passed, tourism was perceived as beneficial by the local population because of its indirect effects on the local economy and the way the island had become less isolated from the continent [129]. Marine and air transportation facilitated the import of food and goods [70,130] but also increased the threat of invasive species [131].

The growth of the tourism sector had a strong impact on the agricultural sector. With the rapidly growing number of tourists, there was a rising demand for high-quality food, goods, services, and specialized labor. Nowadays, there is a steady supply of food from the continent, further discouraging the local agricultural sector [132]. It is expected that by 2027, 95% of the agricultural food supply will be transported from the mainland if no policies for sustainable agriculture are implemented [133].

As the rate of agricultural expansion decreased, the area covered by invasive species increased rapidly. Some species—such as *Psidium guajava*—arrived at the time of the first human settlements on the archipelago and then spread from island to island [134,135], while others—such as *Cinchona pubescens or Cedrela odorata*—were introduced in the 1940s and 1950s as sources of quinine or timber and then spread widely across farmland [136,137]. In areas that were abandoned for agriculture, there was a rapid spread of invasive species. Manual control and pathogen attack reduced their population [137,138]. Over the past decade, various initiatives have attempted to joint efforts to manage invasive species [139]. Their control methods include manual destruction, the application of pesticides, biological controls, educational campaigns, and alternative forms of farm management [140–142]. In addition, several ecological restoration initiatives, such as Galapagos 2050, were launched [143,144]. The changes in the surface area with invasive species is related to the relative success of control strategies and restoration projects and improvements in the technology used to monitor vegetation changes [145,146].

4.3. Change in Farm Typology over Time

By applying hierarchical clustering techniques to agrarian census data, three types of farms were identified in 2000: (i) small farmsteads with approximately 7 ha of land used for cattle grazing, permanent crops, vegetables, and fruit; (ii) large farmsteads with approximately 200 ha of land used for meat and dairy production, and (iii) medium-sized farmstead of 90 ha on average used for cattle ranging and permanent crops. The latter farm type had further specialized by 2014, either in raising cattle or permanent crops. The heterogeneity in terms of farm size and strategy can be linked to various migration waves that occurred under different political conditions as well as land and resources availability.

The first wave of settlers arrived prior to or during the Agrarian Reforms. Land that was taken into cultivation during that period belonged to large and isolated farmsteads: around 19% of the farms were larger than 100 ha, 76% had between 10 and 100 ha, and only 5% were smaller than 10 ha [99]. The majority of the properties were covered by permanent pastures, which were used for diary and meat production. The land was used extensively, with about 1 head/ha [99], and dairy products (such as cheese and yogurt) were locally processed. On average, the farmsteads had 1 to 3 ha reserved for permanent crops, and 78% of the farmers cultivated bananas, 38% corn, 32% yucca, and 31% coffee. When these landowners saw opportunities in the tourism sector, they sold the less productive (and more remote) areas of their land to the second wave of settlers who arrived between 1975 and 1990. The effect this had on the average size of the farms is clear, with 17% of the farms larger than 100 ha, 70% between 10 and 100 ha, and 13% of them already being smaller than 10 ha [100]. The settlers of the 2nd wave (1975–1990) also cultivated vegetables and fruit for the growing tourism sector and kept livestock mainly for meat, with loads of 0.3 to 0.8 head/ha [124]. As labor is a severe constraint for agriculture in the Galapagos, these farmers opted for less labor-intensive activities so as to secure sufficient income and started to form cooperatives [147].

The third wave of newcomers, who arrived in the 90s and 2000s, had little land left to on [124], and their farms are often less than 5 ha in size. Because of a rush on the land, a law regulating migration to the Galapagos Islands was approved in 1998. Under the said law, only permanent residents are allowed to buy land, limiting the market. Currently, only 8% of the farms are larger than 100 ha, 27% are medium-sized farms, and 65% of the farms are small-holdings. Although farm sizes have decreased, the main farm typology and farming strategies remain similar.

The farm distribution patterns follow the logics of the behavioral ecology models mentioned beforehand. These models indicate that resource depression occurs in the highest-ranked habitats prior to the occupation of lower-ranked habitats due to the increase in population density and use of resources. However, if the control of resources is centralized, residents of high-ranked habitats will force newcomers to occupy land in lower-ranked locations to prevent resource depression. On Santa Cruz Island, this process seems to have been halted due to the institutional laws that were imposed to regulate the land market in the early 2000s.

5. Conclusions

The non-protected area of Santa Cruz Island was characterized by a rapid expansion of agricultural land over the period of 1961–2018. While natural vegetation occupied 94% of the unprotected area in 1961, this was reduced to 7% of the non-protected land by 2018. The remaining land area was covered by agricultural land (67%) and invasive species (26%). Biophysical variables strongly controlled the land cover change patterns, with soil depth and fertility and precipitation conditioning early farming activities. Accessibility to local markets and harbors was a key determinant in the selection of sites for farming. The first sites cleared for agriculture were on accessible—less rugged—areas with deeper-than-average and well drained soils on moderately weathered lava and favorable meteorological conditions for crop growth and cattle ranging. Over time, the land taken into cultivation had lower accessibility and longer cost distances to markets. Currently, the few remnants of natural vegetation are found in less accessible areas, on shallower-than-average soils developed on slightly or highly weathered lava.

The rate of agricultural expansion was highest (267 ha/year) during the period from 1961–1985, when the land was occupied by early settlers acquiring large farms. This explains why agricultural expansion is positively related to farm size (0.89). The rescinding agriculture expansion rates (7.8 ha/year between 2012–2018) are related to the consolidation of employment in the tourism and service sector (−0.80), which is also expressed by the increasing number of tourists (−0.77). Counterintuitively, the population growth is negatively related to agricultural expansion (−0.65), indicating that alternative employment options alleviated pressure on the agricultural land.

The first wave of settlement, before and during the Agrarian Reforms, consisted of large and isolated farmsteads specializing in dairy and meat production, with 19% of the farms being larger than 100 ha and 76% of them being between 10 and 100 ha. Farms have become smaller due to land tenure and migration policies in the Galapagos Islands. Currently, the majority (65%) of farms have less than 5 ha of land and combine cattle ranging, cash crops, and permanent crops of coffee, orange, and papaya. Although the proportion of large farmsteads with more than 70 ha of land strongly decreased over the period of 1961–2018, they continue to play an important role in the land use dynamics of the non-protected area as they occupy almost half of the total land area. Therefore, land use policies need to account for the existence of diverse and distinct farming systems on Santa Cruz Island.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land11071017/s1, S1: Reclassification of land cover information from historical maps; S2: Inventory of aerial photographs used for validation; S3: Accuracy assessment of the land cover maps; S4: Overview of variables used in statistical analyses; S5: Cross tabulation of the land cover changes; S6: Outcomes of the analyses of variance.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data are available upon reasonable request to the corresponding authors.

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References

1. Tauger, M.B. *Agriculture in World History*, 2nd ed.; Routledge: London, UK, 2020; Volume 1, ISBN 9780367420918.
2. Food and Agriculture Organization FAOSTAT. Available online: http://www.fao.org/faostat/en/#data/RL/visualize (accessed on 25 June 2021).
3. Lowder, S.K.; Skoet, J.; Raney, T. The Number, Size, and Distribution of Farms, Smallholder Farms, and Family Farms Worldwide. *World Dev.* **2016**, *87*, 16–29. [CrossRef]
4. Wilson, T.; Sleeter, B.; Sleeter, R.; Soulard, C. Land-Use Threats and Protected Areas: A Scenario-Based, Landscape Level Approach. *Land* **2014**, *3*, 362–389. [CrossRef]
5. Bouchoms, S.; Wang, Z.; Vanacker, V.; Van Oost, K. Evaluating the Effects of Soil Erosion and Productivity Decline on Soil Carbon Dynamics Using a Model-Based Approach. *Soil* **2019**, *5*, 367–382. [CrossRef]
6. Tarolli, P.; Vanacker, V.; Middelkoop, H.; Brown, A.G. Landscapes in the Anthropocene: State of the Art and Future Directions. *Anthropocene* **2014**, *6*, 1–2. [CrossRef]
7. Sterling, S.M.; Ducharne, A.; Polcher, J. The Impact of Global Land-Cover Change on the Terrestrial Water Cycle. *Nat. Clim. Chang.* **2013**, *3*, 385–390. [CrossRef]
8. Bosmans, J.; Van Beek, L.; Sutanudjaja, E.; Bierkens, M. Hydrological Impacts of Global Land Cover Change and Human Water Use. *Hydrol. Earth Syst. Sci* **2017**, *21*, 5603–5626. [CrossRef]
9. Heald, C.L.; Spracklen, D.V. Land Use Change Impacts on Air Quality and Climate. *Chem. Rev.* **2015**, *115*, 4476–4496. [CrossRef]
10. Vitousek, P.M. Ecosystem Science and Human-Environment Interactions in the Hawaiian Archipelago. *J. Ecol.* **2006**, *94*, 510–521. [CrossRef]
11. Lambin, E.; Geist, H. Regional Differences in Tropical Deforestation. *Environ. Sci. Policy Sustain. Dev.* **2003**, *45*, 22–36. [CrossRef]
12. Balthazar, V.; Vanacker, V.; Molina, A.; Lambin, E.F. Impacts of Forest Cover Change on Ecosystem Services in High Andean Mountains. *Ecol. Indic.* **2015**, *48*, 63–75. [CrossRef]
13. Jadin, I.; Vanacker, V.; Hoang, H.T.T. Drivers of forest cover dynamics in smallholder farming systems: The case of northwestern Vietnam. *Ambio* **2013**, *42*, 344–356. [CrossRef] [PubMed]
14. Gobbi, B.; Van Rompaey, A.; Loto, D.; Gasparri, I.; Vanacker, V. Comparing Forest Structural Attributes Derived from UAV-Based Point Clouds with Conventional Forest Inventories in the Dry Chaco. *Remote Sens.* **2020**, *12*, 4005. [CrossRef]
15. Tsendbazar, N.; Herold, M.; Li, L.; Tarko, A.; De Bruin, S.; Masiliunas, D.; Lesiv, M.; Fritz, S.; Buchhorn, M.; Smets, B.; et al. Towards Operational Validation of Annual Global Land Cover Maps. *Remote Sens. Environ.* **2021**, *266*, 112686. [CrossRef]
16. Buchhorn, M.; Smets, B.; Bertels, L.; Lesiv, M.; Tsendbazar, N.-E.; Masiliunas, D.; Linlin, L.; Herold, M.; Fritz, S. Copernicus Global Land Service: Land Cover 100m: Collection 3: Epoch 2015: Globe (Version V3.0.1). *Zenodo* **2020**, 1–14. [CrossRef]
17. Land Monitoring Core Service (LMCS) Home | Copernicus Global Land Service. Available online: https://land.copernicus.eu/global/ (accessed on 20 April 2022).
18. Earth Resources Observation and Science (EROS) Center National Land Cover Database | United States Geological Survey. Available online: https://www.usgs.gov/centers/eros/science/national-land-cover-database (accessed on 20 April 2022).
19. Verburg, P.H.; Veldkamp, A. Projecting Land Use Transitions at Forest Fringes in the Philippines at Two Spatial Scales. *Landsc. Ecol.* **2004**, *19*, 77–98. [CrossRef]

20. Smiraglia, D.; Ceccarelli, T.; Bajocco, S.; Perini, L.; Salvati, L. Unraveling Landscape Complexity: Land Use/Land Cover Changes and Landscape Pattern Dynamics (1954–2008) in Contrasting Peri-Urban and Agro-Forest Regions of Northern Italy. *Environ. Manag.* **2015**, *56*, 916–932. [CrossRef] [PubMed]
21. Bajocco, S.; Ceccarelli, T.; Smiraglia, D.; Salvati, L.; Ricotta, C. Modeling the Ecological Niche of Long-Term Land Use Changes: The Role of Biophysical Factors. *Ecol. Indic.* **2016**, *60*, 231–236. [CrossRef]
22. Jayne, T.S.; Muyanga, M.; Wineman, A.; Ghebru, H.; Stevens, C.; Stickler, M.; Chapoto, A.; Anseeuw, W.; Van der Westhuizen, D.; Nyange, D. Are Medium-Scale Farms Driving Agricultural Transformation in Sub-Saharan Africa? *Agric. Econ.* **2019**, *50*, 75–95. [CrossRef]
23. Geist, H.; McConnell, W.; Lambin, E.; Moran, E.; Alves, D.; Rudel, T. Causes and Trajectories of Land-Use/Cover Change. In *Land-Use and Land-Cover Change*, 1st ed.; Lambin, E., Geist, H., Eds.; Springer: Berlin/Heidelberg, Germany, 2006; pp. 41–70, ISBN 978-3-540-32202-3.
24. Byerlee, D.; Stevenson, J.; Villoria, N. Does Intensification Slow Crop Land Expansion or Encourage Deforestation? *Glob. Food Sec.* **2014**, *3*, 92–98. [CrossRef]
25. Hoang, H.T.T.; Vanacker, V.; Van Rompaey, A.; Vu, K.C.; Nguyen, A.T. Changing Human-Landscape Interactions after Development of Tourism in the Northern Vietnamese Highlands. *Anthropocene* **2014**, *5*, 42–51. [CrossRef]
26. Perz, S.G.; Walker, R.T.; Caldas, M.M. Beyond Population and Environment: Household Demographic Life Cycles and Land Use Allocation among Small Farms in the Amazon. *Hum. Ecol.* **2006**, *34*, 829–849. [CrossRef]
27. Serra, P.; Pons, X.; Saurí, D. Land-Cover and Land-Use Change in a Mediterranean Landscape: A Spatial Analysis of Driving Forces Integrating Biophysical and Human Factors. *Appl. Geogr.* **2008**, *28*, 189–209. [CrossRef]
28. Royle, S.A. *Geography of Islands*, 1st ed.; Routledge: London, UK, 2002; ISBN 9780203160367.
29. Napolitano, M.; Stone, J.; DiNapoli, R.; Thompson, V. Introduction: The Archaeology of Island Colonization. In *The Archaeology of Island Colonization: Global Approaches to Initial Human Settlement*, 1st ed.; Napolitano, M., Stone, J., DiNapoli, R., Thompson, V., Eds.; University Press of Florida: Gainesville, FL, USA, 2021; pp. 1–34. ISBN 978-0-8130-5778-1.
30. Braje, T.J.; Leppard, T.P.; Fitzpatrick, S.M.; Erlandson, J.M. Archaeology, Historical Ecology and Anthropogenic Island Ecosystems. *Environ. Conserv.* **2017**, *44*, 286–297. [CrossRef]
31. Graham, N.R.; Gruner, D.S.; Lim, J.Y.; Gillespie, R.G. Island Ecology and Evolution: Challenges in the Anthropocene. *Environ. Conserv.* **2017**, *44*, 323–335. [CrossRef]
32. Percy, M.S.; Schmitt, S.R.; Riveros-Iregui, D.A.; Mirus, B.B. The Galápagos archipelago: A natural laboratory to examine sharp hydroclimatic, geologic and anthropogenic gradients. *Wiley Interdiscip. Rev. Water* **2016**, *3*, 587–600. [CrossRef]
33. Newman, R.; Capitani, C.; Courtney-Mustaphi, C.; Thorn, J.P.R.; Kariuki, R.; Enns, C.; Marchant, R. Integrating Insights from Social-Ecological Interactions into Sustainable Land Use Change Scenarios for Small Islands in the Western Indian Ocean. *Sustainability* **2020**, *12*, 1340. [CrossRef]
34. Norder, S.J.; De Lima, R.F.; De Nascimento, L.; Lim, J.Y.; Fernández-Palacios, J.M.; Romeiras, M.M.; Elias, R.B.; Cabezas, F.J.; Catarino, L.; Ceríaco, L.M.P.; et al. Global Change in Microcosms: Environmental and Societal Predictors of Land Cover Change on the Atlantic Ocean Islands. *Anthropocene* **2020**, *30*, 100242. [CrossRef]
35. Balzan, M.V.; Potschin-Young, M.; Haines-Young, R. Island Ecosystem Services: Insights from a Literature Review on Case-Study Island Ecosystem Services and Future Prospects. *Int. J. Biodivers. Sci. Ecosyst. Serv. Manag.* **2018**, *14*, 71–90. [CrossRef]
36. Massetti, A.; Gil, A. Mapping and Assessing Land Cover/Land Use and Aboveground Carbon Stocks Rapid Changes in Small Oceanic Islands' Terrestrial Ecosystems: A Case Study of Madeira Island, Portugal (2009–2011). *Remote Sens. Environ.* **2020**, *239*, 111625. [CrossRef]
37. Vitousek, P.M.; Chadwick, O. Pacific Islands in the Anthropocene. *Elem. Sci. Anthr.* **2013**, *1*, 11. [CrossRef]
38. Vanacker, V.; Bellin, N.; Molina, A.; Kubik, P.W. Erosion regulation as a function of human disturbances to vegetation cover: A conceptual model. *Landscape Ecology* **2014**, *29*, 293–309. [CrossRef]
39. Fitzpatrick, S.M.; Giovas, C.M. Tropical Islands of the Anthropocene: Deep Histories of Anthropogenic Terrestrial–Marine Entanglement in the Pacific and Caribbean. *Proc. Natl. Acad. Sci. USA* **2021**, *118*, e2022209118. [CrossRef] [PubMed]
40. Ratter, B.M. Introduction to the Geography of Small Islands. In *Geography of Small Islands: Outposts of Globalisation*, 1st ed.; Springer International Publishing AG: Cham, Switzerland, 2018; pp. 1–24. [CrossRef]
41. Campbell, J.R. Development, Global Change and Traditional Food Security in Pacific Island Countries. *Reg. Environ. Chang.* **2015**, *15*, 1313–1324. [CrossRef]
42. Brewington, L. The Double Bind of Tourism in Galapagos Society. In *Science and Conservation in the Galapagos Islands*; Walsh, S.J., Mena, C.F., Eds.; Springer: New York, NY, USA, 2013; pp. 105–125. [CrossRef]
43. Mestanza-Ramón, C.; Pranzini, E.; Anfuso, G.; Botero, C.; Chica-Ruiz, A.; Mooser, A. An Attempt to Characterize the "3S" (Sea, Sun, and Sand) Parameters: Application to the Galapagos Islands and Continental Ecuadorian Beaches. *Sustainability* **2020**, *12*, 3468. [CrossRef]
44. Brewington, L. Transitions and Drivers of Land Use/Land Cover Change in Hawai'i: A Case Study of Maui. In *Land Cover and Land Use Change on Islands Social & Ecological Threats to Sustainability*, 1st ed.; Walsh, S., Riveros-Iregui, D., Arce-Nazario, J., Page, P., Eds.; Springer Nature Switzerland AG: Cham, Switzerland, 2020; pp. 89–117. ISBN 978-3-030-43973-6.
45. Leppard, T.P. Similarity and Diversity in the Prehistoric Colonization of Islands and Coasts by Food-Producing Communities. *J. Isl. Coast. Archaeol.* **2014**, *9*, 1–15. [CrossRef]

46. Hunt, T.L.; Lipo, C.P. The Last Great Migration: Human Colonization of the Remote Pacific Islands. In *Human Dispersal and Species Movement From Prehistory to the Present*; Boivin, N., Crassard, R., Petraglia, M., Eds.; Cambridge University Press: Cambridge, UK, 2017; pp. 194–216, ISBN 9781107164147.
47. Giovas, C.M.; Fitzpatrick, S.M. Prehistoric Migration in the Caribbean: Past Perspectives, New Models and the Ideal Free Distribution of West Indian Colonization. *World Archaeol.* **2014**, *46*, 569–589. [CrossRef]
48. Pazmiño, A.; Serrao-Neumann, S.; Choy, D.L. Towards Comprehensive Policy Integration for the Sustainability of Small Islands: A Landscape-Scale Planning Approach for the Galápagos Islands. *Sustainability* **2018**, *10*, 1228. [CrossRef]
49. Toulkeridis, T.; Angermeyer, H. *Volcanoes of the Galapagos*, 2nd ed.; Universidad de las Fuerzas Armadas: Quito, Ecuador, 2019; ISBN 9789942364883.
50. Bow, C. Geology and Petrogeneses of the Lavas of Floreana and Santa Cruz Islands: Galapagos Archipelago. Ph.D. Thesis, University of Oregon, Eugene, OR, USA, 1979.
51. White, W.M.; McBirney, A.R.; Duncan, R.A. Petrology and Geochemistry of the Galápagos Islands: Portrait of a Pathological Mantle Plume. *J. Geophys. Res. Solid Earth* **1993**, *98*, 19533–19563. [CrossRef]
52. McBirney, A.R.; Williams, H. Geology and Petrology of the Galápagos Islands. In *Geological Society of America Memoirs*; Geological Society of America: Boulder, CO, USA, 1969; Volume 118, pp. 1–197.
53. Schwartz, D. Volcanic, Structural, and Morphological History of Santa Cruz Island, Galápagos Archipelago. Masters's Thesis, University of Idaho, Moscow, ID, USA, 2014.
54. Taboada, T.; Rodríguez-Lado, L.; Ferro-Vázquez, C.; Stoops, G.; Martínez Cortizas, A. Chemical Weathering in the Volcanic Soils of Isla Santa Cruz (Galápagos Islands, Ecuador). *Geoderma* **2016**, *261*, 160–168. [CrossRef]
55. Lasso, L.; Espinosa, J. Soils from the Galapagos Islands. In *The Soils of Ecuador*, 1st ed.; Moreno, J., Espinosa, J., Bernal, G., Eds.; Springer International Publishing AG: Cham, Switzerland, 2018; pp. 139–150, ISBN 978-3-319-25319-0.
56. Laruelle, J. *Galapagos*, 1st ed.; Natuurwetenschappelijk tijdschrift: Ghent, Belgium, 1967; Volume 47, 237p.
57. Laruelle, J. Study of a Soil Sequence on Indefatigable Island. In *The Galápagos*; Bowman, R.I., Ed.; University of California Press: Berkeley, CA, USA, 1966; pp. 87–92.
58. Stoops, G. Soils and Palaeosoils of the Galápagos Islands: What We Know and What We Don't Know, a Meta-Analysis. *Pacific Sci.* **2013**, *68*, 1–36. [CrossRef]
59. Laruelle, J.; Stoops, G. Minor Elements in Galapagos Soils. *Pedologie* **1967**, *17*, 232–257.
60. Trueman, M.; D'Ozouville, N. Characterizing the Galapagos Terrestrial Climate in the Face of Global Climate Change. *Galapagos Res.* **2010**, *67*, 26–37.
61. Violette, S.; D'Ozouville, N.; Pryet, A.; Deffontaines, B.; Fortin, J.; Adelinet, M. Hydrogeology of the Galápagos Archipelago: An Integrated and Comparative Approach Between Islands. In *The Galapagos: A Natural Laboratory for the Earth Sciences*; Harpp, K., Mittelstaedt, E., D'Ozouville, N., Wilson, L.G., Eds.; Wiley Blackwell: Washington, DC, USA, 2014; pp. 167–183, ISBN 9781118852538.
62. Paltán, H.A.; Benitez, F.L.; Rosero, P.; Escobar-Camacho, D.; Cuesta, F.; Mena, C.F. Climate and Sea Surface Trends in the Galapagos Islands. *Sci. Rep.* **2021**, *11*, 14465. [CrossRef] [PubMed]
63. Mena, C.F.; Paltán, H.A.; Benitez, F.L.; Sampedro, C.; Valverde, M. Threats of Climate Change in Small Oceanic Islands: The Case of Climate and Agriculture in the Galapagos Islands, Ecuador. In *Land Cover and Land Use Change on Islands: Social and Ecological Interactions in the Galapagos Islands*; Walsh, S.J., Riveros-Iregui, D., Arce-Nazario, J., Page, P.H., Eds.; Springer Nature Switzerland AG: Cham, Switzerland, 2020; pp. 119–135, ISBN 978-3-030-43973-6.
64. Idrovo, H. *Galápagos, Huellas En El Paraíso*, 1st ed.; Ediciones Libri Mundi: Quito, Ecuador, 2005; ISBN 978-9978-57-043-2.
65. Hickman, J. The Enchanted Islands: The Galapagos Discovered. *Not. Galapagos* **1985**, *1*, 26–27.
66. Lundh, J.P. The Colonia de Santa Cruz of 1926. *Not. Galapagos* **1996**, *1*, 21.
67. Lundh, J.P. A Brief Account of Some Early Inhabitants of Santa Cruz Island. *Not. Galapagos* **1995**, *55*, 2–3.
68. Black, J. *Galápagos, Archipiélago Del Ecuador*, 1st ed.; Imprenta Europa: Quito, Ecuador, 1973.
69. Gondard, P.; Mazurek, H. (Eds.) 30 Anos de Reforma Agraria y Colonización En El Ecuador: 1964–1994. In *Dinámicas Territoriales: Ecuador, Bolivia, Perú, Venezuela, Estudios de Geografía*; Colegio de Geógrafos del Ecuador, CGE/Corporación Editora Nacional, CEN/Institut de Recherche pour Ie Developpernent; IRD/Pontificia Universidad Católica del Ecuador, PUCE/Quito: Quito, Ecuador, 2001; Volume 10, pp. 15–40.
70. Grenier, C. *Conservación Contra Natura: Las Islas Galápagos*; Instituto Francés de Estudios Andinos: Quito, Ecuador, 2007; ISBN 9978226540.
71. Junta Nacional de Planificación y Coordinación Económica. *III Censo de Población 1974: Resultados Definitivos; Galápagos*, 1st ed.; Junta Nacional de Planificación y Coordinación Económica: Quito, Ecuador, 1976; Volume 10.
72. Instituto Nacional de Estadística y Censos. *IV Censo de Población, 1982: Galápagos*, 1st ed.; Instituto Nacional de Estadística y Censos: Quito, Ecuador, 1984; Volume 18.
73. Instituto Nacional de Estadística y Censos Censo de Población y Vivienda-Galápagos. 2015. Available online: https://www.ecuadorencifras.gob.ec/censo-de-poblacion-y-vivienda-galapagos/ (accessed on 29 March 2022).
74. Epler, B. Tourism, the Economy, Population Growth, and Conservation in Galapagos. *Charles Darwin Found.* **2007**, *55*, 75.

75. Jones, G. Luxury Tourism and Environmentalism Business History of Emerging Markets View Project History of Beauty Industry View Project. In *The Oxford Handbook of Luxury Business*, 1st ed.; Donzé, P.-Y., Pouillard, V., Roberts, J., Eds.; Oxford University Press: Oxford, UK, 2020; pp. 571–590. [CrossRef]
76. Trueman, M.; Hobbs, R.J.; Van Niel, K. Interdisciplinary Historical Vegetation Mapping for Ecological Restoration in Galapagos. *Landsc. Ecol.* **2013**, *28*, 519–532. [CrossRef]
77. Huttell, C. Cartografia de La Vegetacion En Las Islas Galapagos. *Monog. Syst. Bot. Missouri Bot. Gard.* **1990**, *32*, 117–122.
78. Villa, A.; Segarra, P. *Changes in Land Use and Vegetative Cover in the Rural Areas of Santa Cruz and San Cristóbal*; Galapagos Conservancy: Santa Cruz, Ecuador, 2011.
79. Bustamante, B.; Cadillo, J.; Cevallos, J.; Liger, B.; Llive, F.; Medina, F.; Parra, R.; Ramos, J.; Villarraga, H.; Ma, S.; et al. *Diagnóstico y Análisis Biofísico para Evaluación y Formulación de Escenarios de Desarrollo en el Archipiélago de Galápagos*; Instituto de Altos Estudios Nacionales: Quito, Ecuador, 2014.
80. Laso, F.; Benítez, F.L.; Rivas-Torres, G.; Sampedro, C.; Arce-Nazario, J. Land Cover Classification of Complex Agroecosystems in the Non-Protected Highlands of the Galapagos Islands. *Remote Sens.* **2020**, *12*, 65. [CrossRef]
81. Instituto Geográfico Militar (IGM). *Aerial Photographs of Santa Cruz Galapagos. 1/50,000*; Instituto Geográfico Militar: Quito, Ecuador, 1959.
82. Instituto Geográfico Militar (IGM). *Aerial Photographs of Santa Cruz Galapagos. 1/50,000*; Instituto Geográfico Militar: Quito, Ecuador, 1960.
83. Instituto Geográfico Militar (IGM). *Aerial Photographs of Santa Cruz Galapagos. 1/50,000*; Instituto Geográfico Militar: Quito, Ecuador, 1963.
84. Instituto Geográfico Militar (IGM). *Aerial Photographs of Santa Cruz Galapagos. 1/60,000*; Instituto Geográfico Militar: Quito, Ecuador, 1985.
85. Instituto Geográfico Militar (IGM). *Aerial Photographs of Santa Cruz Galapagos. 1/30,000*; Instituto Geográfico Militar: Quito, Ecuador, 2007.
86. Sistema Nacional de Información y Gestión de Tierras Rurales e Infraestructura Tecnológica (SIGTIERRAS). *Fotografía Aérea y Ortofotos Sistema Nacional de Informacion de Tierras Rurales e Infraestructura Tecnológica*; Sistema Nacional de Información y Gestión de Tierras Rurales e Infraestructura Tecnológica (SIGTIERRAS): Quito, Ecuador, 2012.
87. Sistema Nacional de Información y Gestión de Tierras Rurales e Infraestructura Tecnológica (SIGTIERRAS); Instituto Nacional Galápagos (INGALA); Programa Nacional de Regionalización Agraria (PRONAREG ORSTOM). *Mapa Geomorfológico de La Isla Santa Cruz Galápagos. Escala 1/100 000*; Sistema Nacional de Información y Gestión de Tierras Rurales e Infraestructura Tecnológica (SIGTIERRAS); Instituto Nacional Galápagos (INGALA); Programa Nacional de Regionalización Agraria (PRONAREG ORSTOM): Quito, Ecuador, 2011.
88. Sistema Nacional de Información y Gestión de Tierras Rurales e Infraestructura Tecnológica (SIGTIERRAS); Instituto Nacional Galapagos (INGALA); Programa Nacional de Regionalizacion Agraria (PRONAREG ORSTOM). *Mapa de Suelos de La Isla Santa Cruz Galapagos. Escala 1/100 000*; Sistema Nacional de Información y Gestión de Tierras Rurales e Infraestructura Tecnológica (SIGTIERRAS); Instituto Nacional Galapagos (INGALA); Programa Nacional de Regionalizacion Agraria (PRONAREG ORSTOM): Quito, Ecuador, 2011.
89. Sistema Nacional de Información y Gestión de Tierras Rurales e Infraestructura Tecnológica (Sigtierras). *Memorias Técnicas Variables*; Sistema Nacional de Información y Gestión de Tierras Rurales e Infraestructura Tecnológica (Sigtierras): Quito, Ecuador, 2011.
90. Instituto Nacional Galápagos (INGALA); Programa Nacional de Regionalización Agraria (Pronareg); Oficina para la Investigación científica y Técnica de Ultramar (ORSTOM). *Inventario Cartográfico de Los Recursos Naturales, Geomorfología, Vegetación, Hídricos, Ecológicos y Biofísicos de Las Islas Galápagos, Ecuador. 1:100,000 Mapas*; INGALA: Quito, Ecuador, 1989; 161p.
91. USGS USGS EROS Archive—Digital Elevation—Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global | U.S. Geological Survey. Available online: https://www.usgs.gov/centers/eros/science/usgs-eros-archive-digital-elevation-shuttle-radar-topography-mission-srtm-1?qt-science_center_objects=0#qt-science_center_objects (accessed on 9 March 2022).
92. Vanacker, V.; Govers, G.; Barros, S.; Poesen, J.; Deckers, J. The Effect of Short-Term Socio-Economic and Demographic Change on Landuse Dynamics and Its Corresponding Geomorphic Response with Relation to Water Erosion in a Tropical Mountainous Catchment, Ecuador. *Landsc. Ecol.* **2003**, *18*, 1–15. [CrossRef]
93. Instituto Geográfico Militar. I. Cartografía Base Escala 1:50,000 Del Ecuador. Available online: http://www.geoportaligm.gob.ec (accessed on 21 December 2018).
94. Larrea, C. *Demografía y Estructura Social En Galápagos: 1990–2008*; Universidad Andina Simon Bolivar: Quito, Ecuador, 2008.
95. Junta Nacional de Planificación y Coordinación Económica. *Plan de Conservación y Desarrollo Selectivo Para La Provincia de Galápagos*; Junta Nacional de Planificación y Coordinación Económica: Quito, Ecuador, 1975; 250p.
96. Instituto Nacional de Estadísticas y Censos V Censo de Poblacion y IV de Vivienda. 1990. Available online: http://redatam.inec.gob.ec/cgibin/RpWebEngine.exe/PortalAction?BASE=CPV1990 (accessed on 17 June 2020).
97. Instituto Ecuatoriano de Estadísticas y Censos VI Censo de Población y V de Vivienda. 2001. Available online: http://redatam.inec.gob.ec/cgibin/RpWebEngine.exe/PortalAction?BASE=CPV2001 (accessed on 3 May 2018).
98. Galapagos Conservation Trust History of Tourism—Discovering Galapagos. Available online: https://www.discoveringgalapagos.org.uk/discover/sustainable-development/sustainable-tourism/history-of-tourism/ (accessed on 10 March 2022).

99. Instituto Nacional de Estadísticas y Censos. *Censo Agropecuario 1974—Cantón Santa Cruz*, 1st ed.; Oficina de Censos: Quito, Ecuador, 1978.
100. Rodríguez Rojas, J. *Indicadores Regionales de Galápagos Ecuador*, 1st ed.; Fundación Charles Darwin para las Islas Galápagos: Quito, Ecuador, 1992; ISBN 978-9978-53-002-3.
101. Instituto Nacional de Estadística y Censos Censo Nacional Agropecuario 2000 Galapagos. Available online: https://www.ecuadorencifras.gob.ec/censo-nacional-agropecuario/ (accessed on 21 July 2021).
102. Consejo de Gobierno del Régimen Especial de Galápagos (CGREG). *Censo de Unidades de Producción Agropecuaria de Galápagos 2014 (UPA)*; Martínez, R., Ed.; 2015; 143p, Available online: https://www.gobiernogalapagos.gob.ec/wp-content/uploads/downloads/2015/09/modelo-de-gestion-plan-galapagos-version-14_sep_2015.pdf (accessed on 10 April 2022).
103. R Core Team. R: The R Project for Statistical Computing. Available online: https://www.r-project.org/ (accessed on 29 March 2022).
104. Thorsten, P. Calculate Pairwise Multiple Comparisons of Mean Rank Sums. R package version PMCMRplus 1.9.4. 2021. Available online: https://cran.r-project.org/web/packages/PMCMRplus/index.html (accessed on 1 February 2022).
105. Cichosz, P. *Data Mining Algorithms: Explained Using R.*; John Wiley & Sons, Ltd.: West Sussex, UK, 2015; pp. 349–372, ISBN 9781118332580.
106. Newman, M.E.; McLaren, K.P.; Wilson, B.S. Long-Term Socio-Economic and Spatial Pattern Drivers of Land Cover Change in a Caribbean Tropical Moist Forest, the Cockpit Country, Jamaica. *Agric. Ecosyst. Environ.* **2014**, *186*, 185–200. [CrossRef]
107. Norder, S.J.; Seijmonsbergen, A.C.; Rughooputh, S.D.D.V.; Van Loon, E.E.; Tatayah, V.; Kamminga, A.T.; Rijsdijk, K.F. Assessing Temporal Couplings in Social–Ecological Island Systems: Historical Deforestation and Soil Loss on Mauritius (Indian Ocean). *Ecol. Soc.* **2017**, *22*, 29. [CrossRef]
108. Baer, A.; Chadwick, O.; Kirch, P.V. Soil Nutrients and Intensive Dryland Agricultural Production in Kaupō, Maui, Hawaiian Islands. *J. Archaeol. Sci. Reports* **2015**, *3*, 429–436. [CrossRef]
109. Kirch, P.V.; Holson, J.; Baer, A. Intensive Dryland Agriculture in Kaupō, Maui, Hawaiian Islands. *Asian Perspect.* **2009**, *48*, 265–290. [CrossRef]
110. Vitousek, P.M.; Ladefoged, T.N.; Kirch, P.V.; Hartshorn, A.S.; Graves, M.W.; Hotchkiss, S.C.; Tutjapurkar, S.; Chadwick, O.A. Soils, Agriculture, and Society in Precontact Hawai'i. *Science* **2004**, *304*, 1665–1669. [CrossRef]
111. Ladefoged, T.N.; Kirch, P.V.; Gon, S.M.; Chadwick, O.A.; Hartshorn, A.S.; Vitousek, P.M. Opportunities and Constraints for Intensive Agriculture in the Hawaiian Archipelago Prior to European Contact. *J. Archaeol. Sci.* **2009**, *36*, 2374–2383. [CrossRef]
112. Kennett, D.J.; Winterhalder, B. Demographic Expansion, Despotism and the Colonisation of East and South Polynesia. In *Islands of Inquiry: Colonisation, Seafaring and the Archaeology of Maritime Landscapes*, 1st ed.; Clark, G., Leach, F., O'Connor, S., Eds.; ANU Press: Canberra, Australia, 2008; pp. 87–96. ISBN 978-1-921313-90-5.
113. Winterhalder, B.; Kennett, D.J.; Grote, M.N.; Bartruff, J. Ideal Free Settlement of California's Northern Channel Islands. *J. Anthropol. Archaeol.* **2010**, *29*, 469–490. [CrossRef]
114. Jazwa, C.S.; Kennett, D.J.; Winterhalder, B. A Test of Ideal Free Distribution Predictions Using Targeted Survey and Excavation on California's Northern Channel Islands. *J. Archaeol. Method Theory* **2016**, *23*, 1242–1284. [CrossRef]
115. Hanna, J.A.; Giovas, C.M. An Islandscape IFD: Using the Ideal Free Distribution to Predict Pre-Columbian Settlements from Grenada to St. Vincent, Eastern Caribbean. *Environ. Archaeol.* **2019**, 1–18. [CrossRef]
116. Siegel, P.E.; Jones, J.G.; Pearsall, D.M.; Dunning, N.P.; Farrell, P.; Duncan, N.A.; Curtis, J.H.; Singh, S.K. Paleoenvironmental Evidence for First Human Colonization of the Eastern Caribbean. *Quat. Sci. Rev.* **2015**, *129*, 275–295. [CrossRef]
117. Lane, B.G. Geospatial Modelling for Predicting the Ideal Free Settlement of Rapa. *Archaeol. Ocean.* **2017**, *52*, 13–21. [CrossRef]
118. Instituto Nacional de Estadísticas y Censos. *Análisis de Resultados Definitivos Censo de Población y Vivienda Galápagos 2015*; Instituto Nacional de Estadísticas y Censos: Quito, Ecuador, 2015; 46p.
119. Eras-Almeida, A.A.; Egido-Aguilera, M.A.; Blechinger, P.; Berendes, S.; Caamaño, E.; García-Alcalde, E. Decarbonizing the Galapagos Islands: Techno-Economic Perspectives for the Hybrid Renewable Mini-Grid Baltra-Santa Cruz. *Sustainability* **2020**, *12*, 2282. [CrossRef]
120. Quiroga, D.; Sevilla, A. *Darwin, Darwinism and Conservation in the Galapagos Islands The Legacy of Darwin and its New Applications*, 1st ed.; Quiroga, D., Sevilla, A., Eds.; Springer International Publishing: Cham, Switzerland, 2016; pp. 54–90, ISBN 9783319340500.
121. Acosta Solís, M. *Galápagos Observado Fitológicamente*, 1st ed.; Imprenta de la Universidad Central: Quito, Ecuador, 1937; Volume 1.
122. Chalons, M.; Samandoroff, Y. *El Porvenir Agropecuario de Las Galápagos*; Ministerio de Agricultura: Guayaquil, Ecuador, 1937.
123. Perry, R. *The Galapagos Islands*; Dodd, Mead and Company: New York, NY, USA, 1972.
124. Maignan, S. En El Archipiélago de Colon: Sostener El Sector Agropecuario Para Garantizar La Conservación de Un Patrimonio Natural Único. In *Mosaico Agrario: Diversidades y Antagonismos Socio-Económicos en el Campo Ecuatoriano*, 1st ed.; Vaillant, M., Cepeda, D., Gondard, P., Zapatta, A., Meunier, A., Eds.; SIPAE-IRD-IFEA; 2007; pp. 268–292, ISBN 978-9978-45-810-5.
125. Fischer, J.; Zerger, A.; Gibbons, P.; Stott, J.; Law, B.S. Tree Decline and the Future of Australian Farmland Biodiversity. *Proc. Natl. Acad. Sci. USA.* **2010**, *107*, 19597–19602. [CrossRef]
126. Taylor, J.E.; Hardner, J.; Stewart, M. Ecotourism and Economic Growth in the Galapagos: An Island Economy-Wide Analysis. *Environ. Dev. Econ.* **2009**, *14*, 139–162. [CrossRef]

127. Miller, B.W.; Breckheimer, I.; McCleary, A.L.; Guzmán-Ramirez, L.; Caplow, S.C.; Jones-Smith, J.C.; Walsh, S.J. Using Stylized Agent-Based Models for Population-Environment Research: A Case Study from the Galápagos Islands. *Popul. Environ.* **2010**, *31*, 401–426. [CrossRef]
128. Burbano, D.V.; Meredith, T.C. Effects of Tourism Growth in a UNESCO World Heritage Site: Resource-Based Livelihood Diversification in the Galapagos Islands, Ecuador. *J. Sustain. Tour.* **2021**, *29*, 1270–1289. [CrossRef]
129. Celata, F.; Sanna, V.S. The Post-Political Ecology of Protected Areas: Nature, Social Justice and Political Conflicts in the Galápagos Islands. *Local Environ.* **2012**, *17*, 977–990. [CrossRef]
130. Walsh, S.J.; Mena, C.F. Perspectives for the Study of the Galapagos Islands: Complex Systems and Human–Environment Interactions. In *Science and Conservation in the Galapagos Islands. Social and Ecological Interactions in the Galapagos Islands*, 1st ed.; Walsh, S., Mena, C., Eds.; Springer Nature Switzerland AG: Cham, Switzerland, 2013; Volume 1, pp. 49–67, ISBN 9781461457930. [CrossRef]
131. Toral-Granda, M.V.; Causton, C.E.; Jager, H.; Trueman, M.; Izurieta, J.C.; Araujo, E.; Cruz, M.; Zander, K.K.; Izurieta, A.; Garnett, S.T. Alien Species Pathways to the Galapagos Islands, Ecuador. *PLoS ONE* **2017**, *12*, e0184379. [CrossRef]
132. Laso, F. Galapagos Is a Garden. In *Land Cover and Land Use Change on Islands Social & Ecological Threats to Sustainability*, 1st ed.; Walsh, S., Riveros-Iregui, D., Arce-Nazario, J., Page, P., Eds.; Springer Nature Switzerland AG: Cham, Switzerland, 2020; pp. 137–166, ISBN 978-3-030-43973-6.
133. Sampedro, C.; Pizzitutti, F.; Quiroga, D.; Walsh, S.J.; Mena, C.F. Food Supply System Dynamics in the Galapagos Islands: Agriculture, Livestock and Imports. *Renew. Agric. Food Syst.* **2020**, *35*, 234–248. [CrossRef]
134. Urquía, D.; Gutierrez, B.; Pozo, G.; Pozo, M.J.; Torres, M.D.L. Origin and Dispersion Pathways of Guava in the Galapagos Islands Inferred through Genetics and Historical Records. *Ecol. Evol.* **2021**, *11*, 15111–15131. [CrossRef] [PubMed]
135. Renteria, J.L.; Atkinson, R.; Crespo, C.; Gardener, M.R.; Grosholz, E.D. Challenges for the Management of the Invasive Blackberry (Rubus Niveus) in the Restoration of the Scalesia Forest in the Galapagos Islands. *Invasive Plant Sci. Manag.* **2021**, *14*, 20–28. [CrossRef]
136. Albuja, I. *Use of Molecular Markers to Describe the Invasion History of Cedrela Odorata, L. in Galapagos, Ecuador*; Universidad San Francisco De Quito: Quito, Ecuador, 2021.
137. Jäger, H.; Kowarik, I.; Tye, A. Destruction without Extinction: Long-Term Impacts of an Invasive Tree Species on Galápagos Highland Vegetation. *J. Ecol.* **2009**, *97*, 1252–1263. [CrossRef]
138. Jäger, H. Quinine Tree Invasion and Control in Galapagos: A Case Study. In *Understanding Invasive Species in the Galapagos Islands. Social and Ecological Interactions in the Galapagos Islands*, 1st ed.; Torres, M., Mena, C., Eds.; Springer Nature Switzerland AG: Cham, Switzerland, 2018; pp. 69–76. [CrossRef]
139. Gardener, M.R.; Atkinson, R.; Rentería, J.L. Eradications and People: Lessons from the Plant Eradication Program in Galapagos. *Restor. Ecol.* **2010**, *18*, 20–29. [CrossRef]
140. Rivas-Torres, G.; Adams, D.C. A Conceptual Framework for the Management of a Highly Valued Invasive Tree in the Galapagos Islands. In *Understanding Invasive Species in the Galapagos Islands. Social and Ecological Interactions in the Galapagos Islands*, 1st ed.; Torres, M., Mena, C., Eds.; Springer Nature Switzerland AG: Cham, Switzerland, 2018; pp. 193–217, ISBN 978-3-319-67177-2. [CrossRef]
141. Brewington, L. Stakeholder Perceptions of Invasive Species and Participatory Remote Sensing in the Galapagos Islands. In *Understanding Invasive Species in the Galapagos Islands. Social and Ecological Interactions in the Galapagos Islands*, 1st ed.; Torres, M., Mena, C., Eds.; Springer Nature Switzerland AG: Cham, Switzerland, 2018; pp. 175–192, ISBN 978-3-319-67177-2. [CrossRef]
142. Khatun, K. Land Use Management in the Galapagos: A Preliminary Study on Reducing the Impacts of Invasive Plant Species through Sustainable Agriculture and Payment for Ecosystem Services. *L. Degrad. Dev.* **2018**, *29*, 3069–3076. [CrossRef]
143. Walentowitz, A.; Manthey, M.; Preciado, M.B.B.; Chango, R.; Sevilla, C.; Jäger, H. Limited Natural Regeneration of Unique Scalesia Forest Following Invasive Plant Removal in Galapagos. *PLoS ONE* **2021**, *16*, e0258467. [CrossRef]
144. Jaramillo, P.; Lorenz, S.; Ortiz, G.; Cueva, P.; Jiménez, E.; Ortiz, J.; Rueda, D.; Freire, M.; Gibbs, J. *Galápagos Verde 2050: Una Oportunidad Para La Restauración de Ecosistemas Degradados y El Fomento de Una Agricultura Sostenible En El Archipiélago*; 2015; ISBN 9789942857101. Available online: https://www.galapagos.org/wp-content/uploads/2015/08/InformeGalapagos_2013-2014-19-Jaramillo-article.pdf (accessed on 10 April 2022).
145. Rivas-Torres, G.F.; Benítez, F.L.; Rueda, D.; Sevilla, C.; Mena, C.F. A Methodology for Mapping Native and Invasive Vegetation Coverage in Archipelagos: An Example from the Galápagos Islands. *Prog. Phys. Geogr. Earth Environ.* **2018**, *42*, 83–111. [CrossRef]
146. Sampedro, C.; Mena, C.F. Remote Sensing of Invasive Species in the Galapagos Islands: Comparison of Pixel-Based, Principal Component, and Object-Oriented Image Classification Approaches. In *Understanding Invasive Species in the Galapagos Islands. Social and Ecological Interactions in the Galapagos Islands*, 1st ed.; Torres, M., Mena, C., Eds.; Springer Nature Switzerland AG: Cham, Switzerland, 2018; pp. 155–174, eISBN 978-3-319-67177-2. [CrossRef]
147. Toledo, A. Rentabilidad de la producción agrícola en Santa Cruz, Galápagos. In *Ensayos Económicos Del Sector Agrícola de Galápagos*, 1st ed.; Viteri, C., Darwin, F.C., Eds.; Conservación Internacional Ecuador y Ministerio de Agricultura Ganadería Acuacultura y Pesca: Santa Cruz Galápagos, Ecuador, 2019; pp. 8–48.