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Agriculture and Temperate Fruit Crop Dynamics in South-Central Chile: Challenges for Fruit Crop Production in La Araucanía Region, Chile

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Abstract: The expansion of agricultural, forest plantation, and urban areas is among the main drivers of worldwide land use/cover change. However, little is known about the changes in the extent of highly profitable crops in the temperate zones of South America and their association with other land use/cover changes, especially in south-central Chile, which has experienced massive changes in recent decades. In this context, we aimed to assess land use/cover and fruit crop area changes at the regional and county levels in the Araucanía region, Chile. Hence, the quantity and location of past and future changes were identified using cross-tabulation, Markov chains and cellular automata. The results showed that agricultural land and meadows have decreased by 18% and 26%, respectively, between 1997 and 2013, mainly due to the expansion of forest plantations and urban areas. However, the fruit crop area increased by 645% between the years 2000 and 2019 and will continue increasing to 2033. These changes modified the relative weights of economic activities within the region, changing from cattle raising and marginal agriculture to more profitable activities such as fruit crops and forest plantations. Finally, this work shows a need to move toward the spatial monitoring of agriculture and fruit crops within the country.

Keywords: agriculture; fruit crops expansion; Chile; land use/cover change; Markov change; cellular automata

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1. Introduction

The expansion of agriculture, forest plantations, and urban areas is among the leading worldwide drivers of land use/cover change [1–3], which often decreases the ecological integrity of ecosystems and the provision of ecosystem services such as habitat availability and climate regulation [4]. Among those changes, understanding the dynamics of agriculture is critical due to its crucial role in providing food for the still-growing worldwide population [5], contributions to economic growth, and the provision of livelihoods for the local population [6]. Since the green revolution, agriculture has significantly expanded through agro-chemicals and fertilizers [7], transforming the Earth's surface [8,9]. Agricultural expansion has produced deforestation and the degradation of ecosystems due to the excessive application of fertilizers and pesticides [10]. However, the opposite, agricultural abandonment, despite being understood as positive by several authors due to the recovery of forests and the increases in habitat connectivity, also produces negative impacts due to the loss of cultural landscapes [11], traditional knowledge [12], and, in some settings, a decrease in water provision and loss of biodiversity [13,14]. Understanding these complex tradeoffs requires further research on agricultural dynamics on global, regional, and local scales to support decision-making, foster spatial planning, and provide guidelines for determining preferred locations that maximize benefits and minimize the impacts of changes in agriculture.

Recent studies of global land use/cover changes at the global scale using satellite images suggest that, from 1982 to 2016, the agricultural area has globally increased; however, this increase is not homogeneous in all regions of the world [15]. South America is the region with the largest growth in agriculture, mainly due to the high profitability of crops such as soybean, coffee, and cotton [16], which has fostered economic growth in developing countries. However, this has also produced deforestation in countries such as Peru, Colombia, Brazil, and Argentina [17]. Conversely, agricultural abandonment has increased throughout European countries [18], producing a loss of cultural landscape, especially in mountainous areas such as the Spanish Pyrenees, the eastern Alps, and French pre-Alps [11], despite the efforts made through subsidies provided by the Common Agricultural Policy (CAP) [19,20].

In Chile, agriculture has historically modified territorial dynamics and has shown stages of contraction and expansion over the last century. A new phase of agricultural expansion began with the agrarian reform and counter-reform, implemented in the 1960s and 1970s [21], which, together with the liberalization of the economy, boosted agricultural activity in the following decades [22]. In this way, an export-oriented growth model was established, which was strengthened by the signing of free trade agreements [22]. The result was a subsequent increase in exports [23], from USD 2070 to 6631 million free on board (FOB) between 2003 and 2019 [24]. In particular, high-profitability crops have become fundamental for the success of Chile's export-oriented growth model due to the high prices obtained by placing high-quality and out-of-season products on the Asian, North American, and European markets, increasing exports by 200% between 1990 and 2021 [25,26].

Temperate fruit crops are crucial for supporting general dietary requirement, comprising nearly 50% of the total fruit production worldwide [26]. Chile has a significant quantity of land suitable for producing fruit crops due to its diversity of agro-climatic and edaphic factors. However, most of the locations of fruit crops have historically been concentrated in the central regions [27]. Nevertheless, in recent years, the extension of fruit crops has increased in south-central Chile (Biobío, La Araucanía, and Los Ríos regions) [27]. In particular, fruit crops increased by 326% from 2003 to 2018 in the La Araucanía region [27], which has driven the development of emerging fruit crop production clusters [28]. However, little is known about the spatial characteristics of this expansion, undermining sound decision-making concerning the allocation of resources and the creation of social and environmental safeguards. Especially in the La Araucania region (Chile), high expectations are placed on fruit crop expansion as one of the main activities to improve socioeconomic indicators [27], making fruit crops a part of the public and private investment plan for the Araucanía by 2026 and beyond [28].

This public–private partnership is essential for overcoming the territorial obstacles that may prevent the development of this activity from achieving its maximum potential for fruit crop production [29]. Such collaboration should be a fundamental feature of developing the first land-use plan in the Araucanía region for the upcoming years. This first spatial plan would be implemented only due to a recently approved law (Law 21.074), which transfers competency from the central to the regional government. Therefore, understanding the territorial dynamics through spatial data analysis has become a crucial endeavor to support the assessment of future spatial plans. However, such spatial analyses are still unavailable. For instance, it is unknown how the expansion of fruit crops affects other land use/cover at the regional level.

Thus, we aimed to spatially analyze the changes in land use/cover and the dynamics of fruit crop area extension, including the projection of fruit crop trends at the regional levels. A change analysis was performed using land use/cover data between 1997 and

2013 and data from the fruit crop cadaster from 2012, 2016, and 2019. Additionally, future fruit crop changes at regional and county levels were assessed by a spatial simulation of trends until 2033 using Markov chains and cellular automata.

2. Materials and Methods

2.1. Study Area

The Araucanía region is located in south-central Chile, between 37°35′ and 39°37′ S and from 70°50′ W to the Pacific Ocean. It has a total area of 31,842.30 km^2, equivalent to 4.2% of the national territory. The climate is temperate humid, with an average rainfall of 1400 mm, average temperatures of 17 °C in summer and 5 °C in winter, and an average annual relative humidity of 80%. Rain is distributed mainly in winter, with 1 or 2 months of drought in summer [30]. Administratively, the region of Araucanía is divided into 32 counties and two provinces: the province of Malleco and Cautín (Figure 1) [31]. The population reaches 957,224 inhabitants, with a density of 30.06 inhabitants/km^2. 32% of the population lives in rural areas, and 31.2% identify themselves as belonging to an indigenous group, mostly Mapuches.

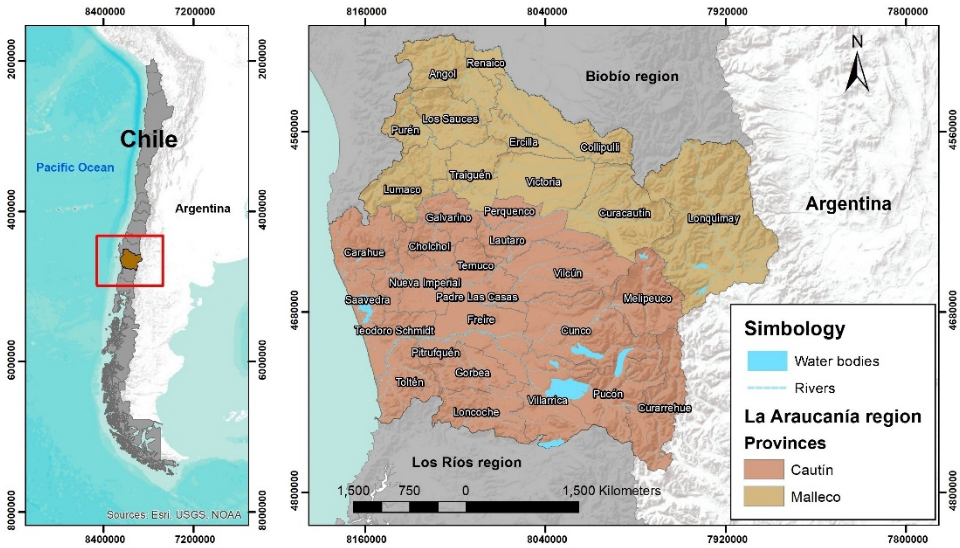

Figure 1. Study area: Araucanía region, Chile.

2.2. Change in Land Use/Land Cover at the Regional Level

The land use/cover change analysis for the Araucanía region was performed using data from the cadaster of native vegetation of Chile for 1997 and 2013 (http://sit.conaf.cl/, accessed on 3 March 2021). The original subuse categories in each cadaster were homogenized into eleven final classes, including: (1) agricultural land, (2) meadows, (3) shrubland, (4) native forest, (5) secondary forest, (6) forest plantations, (7) wetlands, (8) waterbodies, (9) bare land, (10) urban and industrial areas, and (11) snow and glaciers. The change in area was calculated for each category through cross-tabulation to obtain the net change, gain, loss, and persistence [32,33]. All processes were performed using the Crosstab and Land Change Modeler functions in TerrSet. Maps were generated in ArcGIS Pro using Universal Transversal Mercator (UTM), with zone 18S and Datum WGS 84.

2.3. Fruit Crop Expansion

The spatial and nonspatial data from the fruit cadasters were used to identify the variation in fruit crop area between 2000, 2012, 2016, and 2019 at the county level. Vector data downloaded in shape format were transformed into raster format, providing an equal number of rows and columns. The raster images were imported into TerrSet to calculate the change in fruit crop area for the periods 2012–2016 and 2016–2019 [34,35]. Additionally, the type of land use/cover replaced by fruit crop expansion between 2012 and 2019 was determined by overlapping fruit crop expansion areas with the land use/cover data of 2013 (Figure 2). All these calculations were performed by cross-tabulation using TerrSet's Crosstab function.

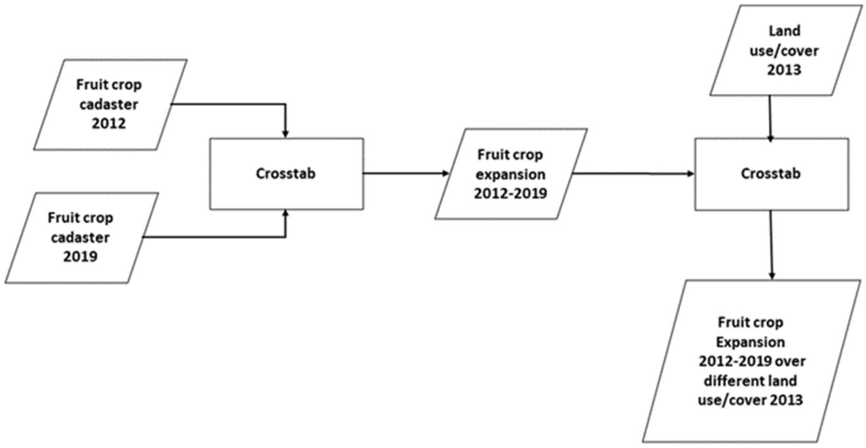

Figure 2. Workflow to obtain fruit crop expansion and which land use/cover was replaced by this expansion.

2.4. Spatial Simulation of Fruit Expansion to 2033

Future fruit crop area changes were simulated at the regional level by a model based on Markov chains and cellular automata [36,37]. The spatial data of fruit cadastral between 2012 and 2019 was used as entry data for the Markov function in TerrSet [32]. Then, the spatial representation of fruit crop location for 2033 was obtained through the CA-Markov function. Finally, we obtained the areas of expansion of the fruit crops between 2019 and 2033, which was overlapped with land use/cover of 2013 (using the Crosstab function) to obtain over which land use/cover fruit crop areas expanded between 2019 and 2033 [36].

2.5. Dynamics of Fruit Crops by County

The variations in area of the main four fruit crops of the Araucanía region: (1) red apple, (2) European hazelnut, (3) cherry, and (4) blueberry, were determined using nonspatial information indicating the area of crops at the county level published by the Office of Agrarian Studies and Policies (ODEPA) [38,39].

3. Results

3.1. Change in Land Use/Land Cover at the Regional Level

Figure 3 shows the changes in land use/cover for the region of La Araucanía between the years 1997 and 2013. In this period, the area of agricultural cover decreased from 953,651 to 781,700 ha (−18% of the agricultural cover in 1997). Similarly, meadows and wetlands decreased by 125,177 ha (26% of the area in 1997) and by 3156 ha (13.7% of the area in 1997), respectively. In contrast, the forest plantations increased by 79% from 378,400 to 678,918 ha.

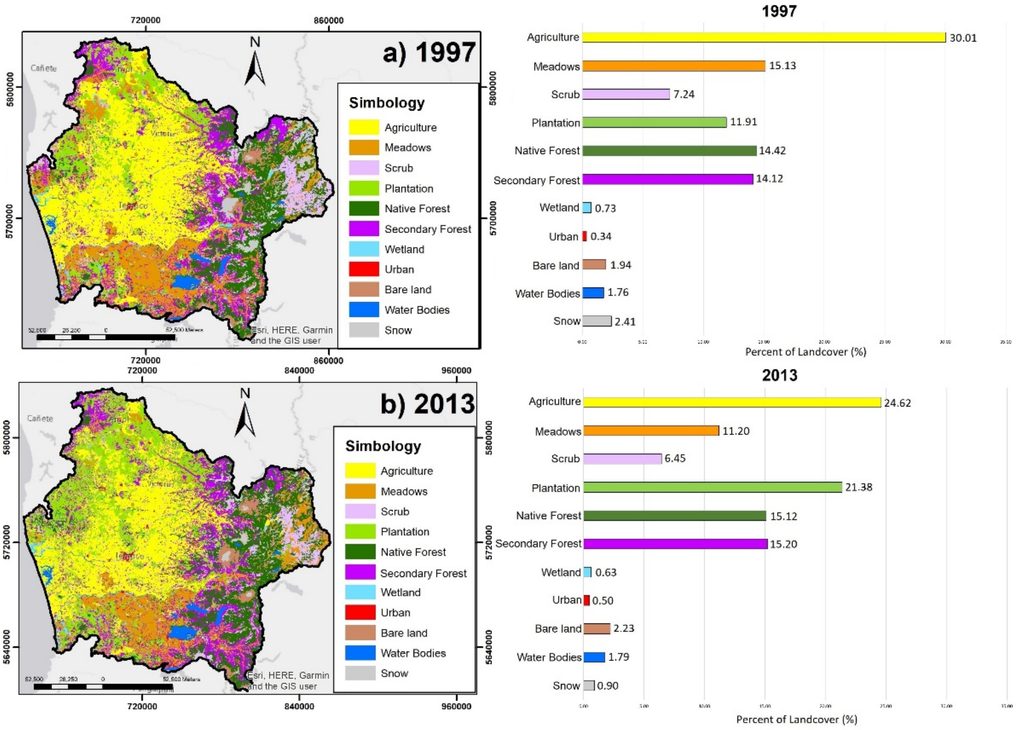

Figure 3. Changes in use/coverage at the regional level in 1997 and 2013.

The agricultural category showed a persistence (pixels that did not change to another category) of 714,150 ha (75% of the area in 1997), with a loss of 239,502 ha (25% of the area in 1997) and a gain of 67,550 ha (7% of the area in 1997) (Figure 4). The transitions that most contributed to the loss of agricultural area were substitution by forest plantations (170,806 ha), secondary forest (34,260 ha), shrubland (12,990 ha), meadows (8990 ha), and native forest (4910 ha). Conversely, the agricultural gains occurred due to the expansion over meadows (30,485 ha), secondary forest (13,792 ha), forest plantations (10,022 ha), and wetlands (3025 ha) (Table S1)

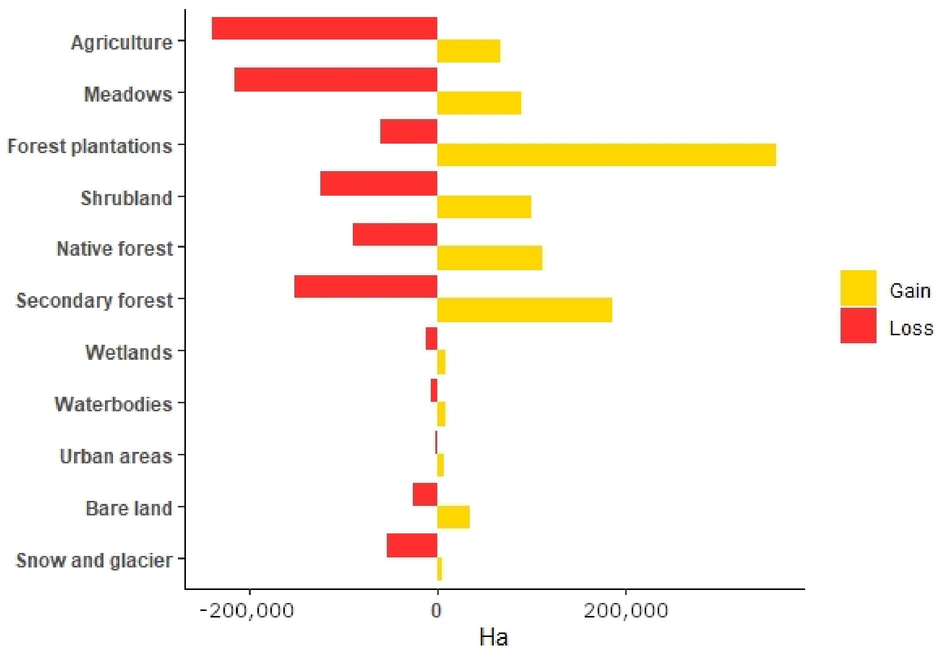

Figure 4. Gains and losses by category of land use/cover change 1997–2013.

3.2. Changes in Fruit Production for the Region of La Araucanía in the Periods 2000–2019 and 2019–2033

Fruit crops expanded from 2,056 to 15,321 ha, between the years 2000 and 2019, in 24 of the 32 counties of the region. Moreover, the trend until 2033 shows a deepening of this pattern, where the fruit area is projected to reach 25,614 ha distributed in 25 counties of the region (Figure 5).

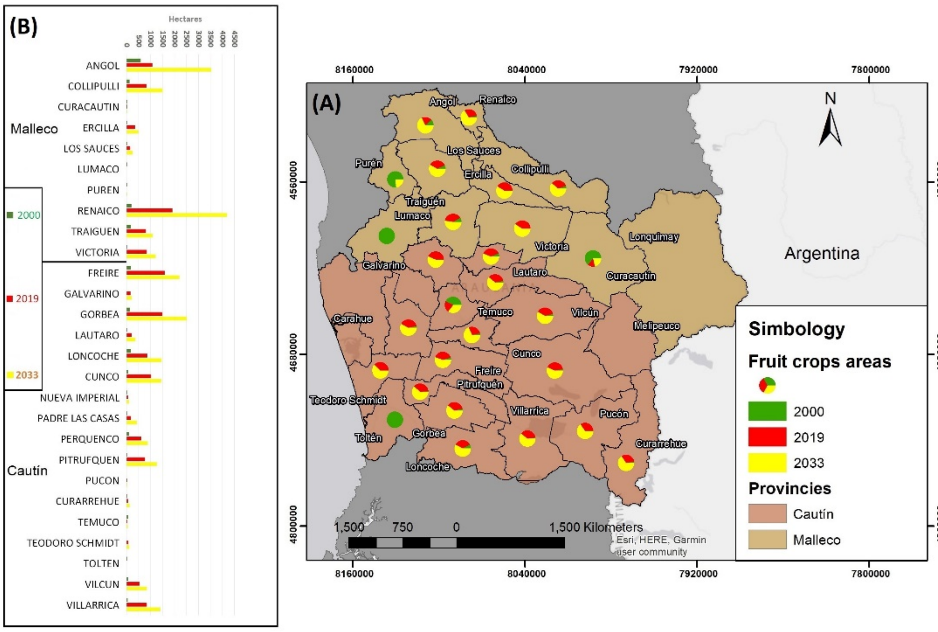

Figure 5. Fruit crop area by county in the Araucanía region in 2000, 2019, and 2033. (**A**) fruit crop area in hectares for each year, by county, in the Araucanía region. (**B**). Percentage of fruit crop area by county for the years 2000-2019-2033.

The counties with the greatest fruit crop increase between the years 2000 and 2019 were Renaico and Freire (Figure 5, Table S2). In Renaico, the area of fruit crop increased from 197 ha in 2000 to 1903 ha by 2019. In the county of Freire, the fruit crop area increased from 184 ha to 1595 ha during the same period. The simulated trend of fruit crop dynamics until 2033 indicated the consolidation of three productive clusters in the region: one in the province of Malleco and two in the province of Cautín. The cluster located in the province of Malleco consists of the counties of Angol, Renaico, Collipulli, Ercilla, Victoria, Traiguén, and is where the largest expansion of fruit cultivation will take place from 2019 to 2033, reaching 12,010 ha. This expansion is 47% of the total area of fruit crops expected for the Araucanía region by 2033. The second cluster located in southern Cautín (Cautín 2) includes the counties of Freire, Gorbea, Cunco, Loncoche, Pitrufquén and Villarrica. The cluster will have an expansion of 10,256 ha in fruit crops, representing 40% of the total projected expansion for the whole region. Finally, the third cluster, located in northern Cautín (Cautín 1), includes the counties of Vilcún, Lautaro, and Perqueco, with an expansion of fruit crop area reaching 2072 ha, representing 8.1% of the expected expansion in the region (Figure 6).

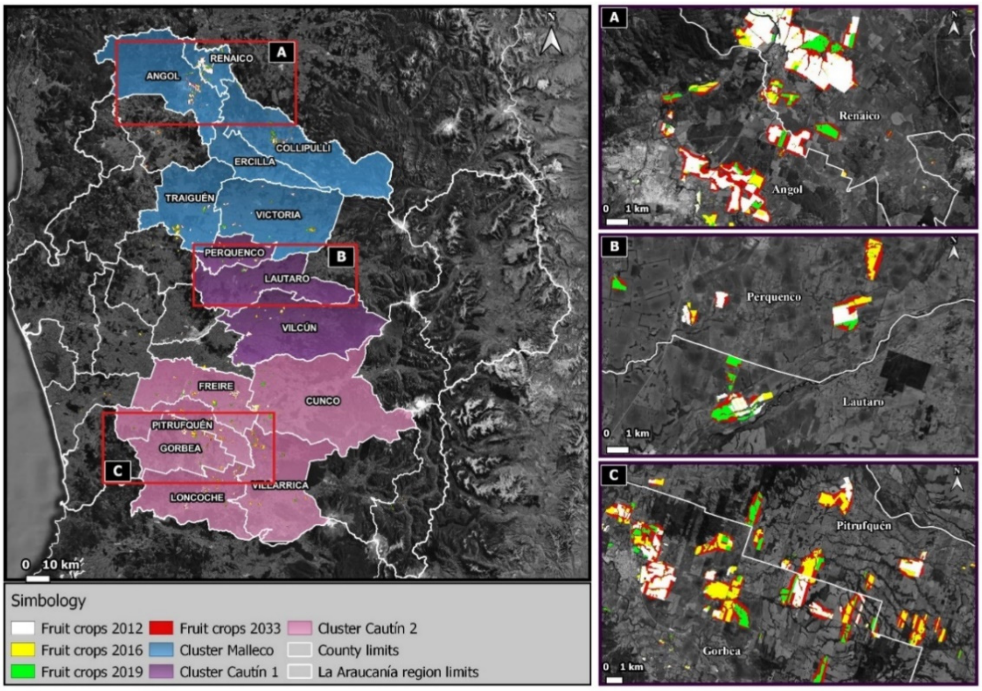

Figure 6. Fruit crop area for 2012, 2016, 2019, and 2033, and the production clusters in the provinces of Malleco (**A**), Cautín 1 (**B**), and Cautín 2 (**C**) of the Araucanía region.

3.3. Expansion of Fruit Crops into Land Use/Cover Areas in the Region of La Araucanía

Until 2019 most of the fruit crops in the region were mainly located on agricultural land (67.7% of fruit crops by 2019); however, the fruit crops also expanded into meadows (25%), forest plantations (4.8%), and, to a lesser extent, on secondary forest (1.2%) and native forest (0.3%). The trend indicates that by 2033, of the 100% expansion of fruit crops, 58% will be on agricultural land, 26% on meadows, 8% on forest plantations, 4.8% on secondary forest, 0.9% on native forest, and 1.2% on shrubland (Table 1).

Table 1. Fruit crops area on different land use/cover types.

Land Cover/Year	2012	2016	2019	2033	Δ 12–16 (ha)	Δ 16–19 (ha)	Δ12–19 (ha)	Δ 19–33 (ha)
Agriculture	6,181.3	7,889.2	10,368.5	14,899.0	1,707.9	2,479.3	4,187.2	4,953.0
Meadow	1,274.1	2,545.2	3,831.4	6,841.4	1271.1	1,286.2	2,557.3	3,010.0
Scrubland	8.3	47.7	154.5	313.2	39.4	106.8	146.3	158.7
Plantation	297.5	445.1	737.0	2,066.4	147.6	291.9	439.5	1,329.4
Native forest	14.8	21.6	38.4	232.1	6.8	16.8	23.6	193.7
Secondary forest	83.5	82.2	178.6	1232.8	−1.3	96.4	95.1	1054.2
Wetland	1.5	1.3	5.5	22.9	−0.2	4.2	4.0	17.4
Urban area	0.6	1.2	5.5	5.5	0.6	4.3	4.9	0
Bare land	0.1	0	0	0	−0.1	0	-0.1	0
Water bodies	1.1	1.2	1.2	1.2	0.1	0	0.1	0
Snow and Glacier	0	0	0	0	0	0	0	0
Total	7862.8	11,034.7	15,320.6	25,614.1	3171.9	4285.9	7457.8	10,716.4

3.4. Fruit Crop Dynamics by County

The surface area of the main four fruit crops (blueberry, European hazel, cherry, and red apple) increased in the entire region by 347%, from 2954 ha to 13,218 ha between 2006 and 2019. The European hazelnut crop had a notable increase of 6500 ha (63%) of the total increase in the four crops between 2006 and 2019). Thus, the European hazelnut became the dominant crop, accounting for 49% of the total area. Conversely, red apple lost its higher relative abundance in the area, with 51% in 2006 and only reaching 22% in 2019 (Table 2).

Table 2. Area (ha) type of fruit crops between the years 2006 and 2019.

	2006				2019			
County/Crops	**Blueberry**	**European Hazel**	**Cherry**	**Red Apple**	**Blueberry**	**European Hazel**	**Cherry**	**Red Apple**
Renaico	0	0	1.85	662.1	117.6	0	342.6	1272.1
Angol	94.76	0	72.04	350.72	147.8	0	403.1	272.9
Collipulli	111.81	0	42.38	61.45	238.8	197	85.7	208.6
Los Sauces	0	0	0	0	10.3	0	34.9	24.2
Ercilla	16.99	0	13	0	6.5	234.8	8	0
Curacautín	0	0	0	0	6.6	0	0	0
Traiguén	24.05	0	0	141.17	84.3	131.7	78.7	473.4
Victoria	35.74	0	0	32.92	85.8	687.6	18.5	32.9
Lumaco	0	1.49	7.97	0	0	0	0	0
Cunco	28.78	313.15	0	0	79.4	946.9	0	0
Curarrehue	0	0	0	0	0	57.5	0	0
Freire	31.67	80	0	139.26	215.7	1031.3	14.1	266.6
Galvarino	0	0	0	0	38.1	98	0	0
Gorbea	198.24	104.25	10.16	0	236.9	1167	68.3	0
Lautaro	59.75	0	7.5	0.81	97.5	103.5	7	0
Loncoche	34.83	31.47	21	0.43	181.8	438	38.7	0.3
Nueva Imperial	0.03	0	0	0.07	5.3	55	0	0
Padre las Casas	0.25	0	0	13.22	2.8	6.9	20.9	132.9
Pitrufquén	4	6.5	0	29.05	23.9	683	0	17.4
Pucón	0	0	0	0	1.3	0	0	0
Temuco	8.12	0	0.54	31.3	0	0	0	29.7
Teodoro Schmidt	19	0	0	0	41.5	34.5	0	0
Vilcún	41.44	0	0	14.89	272.3	254.2	5.2	6.5
Villarrica	4.9	1	0	8.68	188.5	630.4	0	7.2
Perquenco	4	6.5	0	29.05	75.2	287	44.5	101

4. Discussion

This research shows that agricultural land and meadow areas decreased by 18% and 26%, respectively, between 1997 and 2013 in the Araucania region. This decrease was mainly caused by the expansion of forest plantations and urban areas. Despite the decrease in agricultural area at the regional level, fruit crops increased from 2000 to 2019, varying from 2056 to 15,321 ha. Fruit crop expansion mainly occurred in agricultural areas (10,369 ha) but also occurred on meadows (3831 ha) and, to a lesser extent, on areas previously occupied by forest plantations (737 ha), secondary forest (179 ha), scrubland (155 ha), and native forest (38 ha). The spatial simulation of fruit crops trend until 2033 showed that the area of fruit crops will reach 25,614 ha (a 67% increase for the period between 2019 and 2033), increasing the pressure on natural covers (secondary forest, native forest, scrubland, and wetlands).

Degraded soil with low productivity and better labor opportunities offered in urban areas seem to be among the main factors that explain the loss of agricultural land and meadows in the Araucania region [40]. Similarly, in the county of Ancud (Los Lagos region, Chile), the development of new economic activities such as aquaculture have contributed to agriculture becoming a less attractive activity [41]. Additionally, this has been enhanced by the higher profitability of forest plantations on land with low productivity, partially due to subsidies given for afforestation between 1974 and 2012 (DL 701, 1974) [40,42]. A comparable pattern can also be observed in Asia, where forest plantations have replaced agricultural areas in China and Vietnam [43,44]. Likewise, the expansion of oil palms and crops for biodiesel has decreased agricultural areas in tropical regions of South America. In Europe and the Global North, agricultural land abandonment is often associated with the low profitability of marginal lands, low-quality soils, and little working capital [17], producing a natural forest transition [11]. On the other hand, according to previous studies, urbanization and industrialization are among the main drivers of agricultural conversions worldwide [45]. However, urban areas replaced far less agricultural area than forest plantation in this study.

In opposition, the increase in the area of fruit crops in the region of La Araucanía is a sign of the growing interest in this activity in one of the poorest regions of Chile. This expansion has simultaneously developed with the decrease in total agricultural area in the region. A plausible explanation for this phenomenon is the profitability of crops developed for export, including European hazelnut, blueberry, cherry, and red apple, the production of which accounts for 65.74% of exports, 29.7% of agribusiness, and 4.52% of the domestic market [39]. Similar growth in fruit crop area has been reported in California, where farmers have seized the opportunity to move from less-profitable to high-price crops such as nuts and grapes to mitigate the increases in production costs associated with drought and water scarcity [46]. The economic policies of countries usually play a crucial role in setting up the right environment for the development of agriculture. In Chile, the state's monetary incentives for infrastructure and the export-driven economy have fostered the growth in fruit crops since the beginning of the 1980s [47]. However, currently, The Federation of Fruit Producers of Chile (*Fedefruta*) calls for a new deal to promote and maintain the sustainable growth of this strategic economic activity, mainly to modernize production and maintain global competitiveness in the upcoming decades (https://blueberriesconsulting.com/, accessed on 15 February 2022).

Our simulation of land area trend, up to 2033 indicated that fruit crops in the Araucania region may cover 25,614 ha by 2033. However, Escalona et al. [28] indicates that the amount of area suitable for fruit crops in La Araucanía is at least 53,000 ha, which still leaves space for the further expansion of this activity [28]. From a territorial point of view, since 2012, the fruit production in the clusters of Malleco Norte (counties of Angol, Renaico, and Collipulli), and Cautín Sur (Villarrica, Los Laureles, and Freire), described in [28], has been further enhanced. At the same time, the area of fruit crops has expanded in other counties located in the central area of La Araucanía, such as Perquenco, Lautaro, and Vilcún, creating a new cluster in the Cautín province. The spatial simulation of the dynamics of fruit crops up until 2033 further enhanced the areas in which fruit crops have already expanded during the last decade. This may benefit the producers due to size economies [48], and may lead to a higher investment in infrastructure by the state. This dynamic is essential to the consideration of future land use planning if the goals of the regional government are to focus on achieving the full fruit crop growth potential in the region.

Accelerated fruit growth can generate territorial imbalances [49], which generally result in conflicts over the use of resources. This has already happened with forestry, creating a highly unequal productive matrix [50]. Agricultural activity, without proper management, can generate environmental impacts such as soil erosion [51], contamination of aquifers and surface water [52], human diseases by toxicity associated with the presence of agrochemical residues in food [53], and the loss of biodiversity [54]. These problems should be addressed by government policies and the new regional development strategy, as well as be considered by the future Regional Land Use Plan (PROT), which should be carried out in the region of La Araucania after the approval of Law 21.074 of 2018.

This work shows the need to move toward the spatial monitoring of agriculture and fruit crops within the country, given the current limitations of both the temporal and thematic resolutions of the spatial land use/land cover data in Chile. State agencies should generate disaggregated spatial data at the crop level, which would enable a better evaluation of the effectiveness of development policies and improve the process of territorial planning. Moreover, Markov chains and cellular automata were used to represent the spatial trend of fruit crop dynamics until 2033. However, future studies can explore the predictive capacity of regression models or machine learning algorithms that incorporate environmental variables (e.g., altitude, slope, and water availability) [33,55]. In addition, future studies can build nonpredictive spatial scenarios to support planning and adaptive management in facing dynamic changes in agriculture and fruit crop production in the future [56,57].

5. Conclusions

Understanding land use/cover change, especially the dynamics of agriculture and crops, is crucial for supporting spatial planning, decision-making, and resource allocation. Our land use/cover analysis showed how agricultural land and meadows decreased by 18% and 26%, respectively, in the Araucanía region between 1997 and 2013 due to the expansion of forest plantations and urban areas. Previous research suggests that the main drivers of forest expansion are high profitability from low-quality soil and the economic incentives given for afforestation. While agriculture decreased, fruit crop area expanded from 2,056 to 15,321 ha and are projected to increase by 2033 to 25,614 ha. The synergies in the export-driven economy of Chile and the high prices of fruit crops, together with the subsidies for water infrastructure, seem to have fostered this expansion. The spatial analysis revealed that most of the expansion of fruit crops took place over previous agricultural land and meadows, indicating a reconversion from less-profitable activities. However, fruit crop expansion replaced 265 ha of native vegetation from 2012 to 2019. This raises concerns about the possible environmental and social impacts related to the future expansion of fruit crops. New initiatives to implement spatial planning in the region, in coordination with new economic incentives, would help foster the expansion of fruit crops in the best locations to increase benefits and diminish the impact on the territory. Finally, better public spatial information is needed to provide higher temporal and thematic resolution of land use/cover data to enhance policy design and decision-making in the country.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land11060788/s1, Table S1. Transition matrix for La Araucanía for changes between the years 1997 and 2013. Data from the Cadastral of native vegetation, Conaf. Table S2. Tree crops for county for the years 2012, 2016, 2019, and 2033.

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