UNIVERSIDAD SAN FRANCISCO DE QUITO USFQ

Colegio de Posgrados

System Dynamics in Food Security: Agriculture, Livestock, and Imports in the Galapagos Islands

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Trabajo de titulación de posgrado presentado como requisito

para la obtención del título de Máster en Ecología

Quito, 11 de mayo de 2017

UNIVERSIDAD SAN FRANCISCO DE QUITO USFQ

COLEGIO DE POSGRADOS

HOJA DE APROBACIÓN DE TRABAJO DE TITULACIÓN

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DEDICATORIA

Agradezco a la persona que siempre me impulso a ser un mejor ser humano y profesional, que siempre me apoyó con cariño y buenos consejos, quien ahora desde el cielo sigue guiando mis decisiones. Agradezco a mi papá Galo Sampedro quien se merece este esfuerzo y muchos más.

A mi esposo Esteban quien ha sabido apoyarme a lo largo de esta larga jornada, inspirándome siempre a dar lo mejor de mí, y a esforzarme para conseguir las metas que me proponga. También agradezco por su compañía y apoyo a mi familia Susana, Ana Cris y Nina, quienes son mis pilares.

Un especial agradecimiento a Carlos Mena, extraordinario como persona y como profesional, quien me ha enseñado y me ha permitido trabajar y crecer en el campo de la Geografía y la Ecología que tanto nos gusta.

RESUMEN

El Archipiélago de Galápagos, como ecosistema de isla presenta características intrínsecas tales como un tamaño reducido, lejanía, insularidad, propensión a desastres y fragilidad ambiental, las cuales se presentan como desventajas y se traducen en un acceso limitado a recursos naturales y sociales, generando dependencia a una estrecha gama de productos alimenticios y a una creciente dependencia de importaciones; lo que a su vez compromete la seguridad alimentaria de los habitantes de Galápagos. Una característica adicional de las Islas Galápagos es el alto nivel de endemismo de sus ecosistemas, los cuales se encuentran bajo muchas formas de presiones relacionadas con el ser humano tales como las especies invasoras y el crecimiento de la población, comprometiendo su conservación. En este contexto, esta investigación aplicó un enfoque de modelamiento usando la metodología de Sistemas Dinámicos para identificar las relaciones que influyen en el sistema de disponibilidad de alimentos en las Islas Galápagos, a través del análisis de las variables más relevantes y sus interacciones, con el objetivo de entender cómo el crecimiento poblacional y el consumo de alimentos en las Islas Galápagos están relacionados con la dinámica de la disponibilidad de alimentos, tales como la producción agrícola local y las importaciones. Se utilizaron tres escenarios de crecimiento del turismo desarrollados en investigaciones previas donde se aplicó los Sistemas Dinámicos para modelar distintos componentes de las Islas Galápagos (Pizzitutti et al., 2016): crecimiento acelerado, crecimiento moderado y escenario de crecimiento, a partir de los cuales se analizaron diferentes respuestas en relación al comportamiento del sistema. Se observó que la producción local mantiene una tendencia decreciente en los tres escenarios, así como se mantiene la tendencia del aumento de la dependencia de las importaciones. Además, las áreas agrícolas en las Islas Galápagos están reguladas principalmente por actividades ganaderas, las cuales presentan una tendencia creciente debido a las restricciones a la importación de carne. Y, mientras la producción agrícola y ganadera local continúa expandiéndose en el área agrícola, un control más eficaz de especies invasoras es posible. En este sentido, la seguridad alimentaria de Galápagos depende de la disminución de la agricultura local y de una creciente dependencia de las importaciones de alimentos, lo que a su vez aumenta la vulnerabilidad de la seguridad alimentaria de las islas. Estos tres escenarios de crecimiento, así como las tendencias de producción y consumo, demuestran aún más las dificultades y limitaciones de la seguridad alimentaria de las Islas Galápagos. Por lo tanto, superar las desventajas de la isla hacia una autosuficiencia en la producción local es una meta a perseguir.

ABSTRACT

The Galapagos Archipelago, as islands environment, have to deal with intrinsic disadvantages such as small size, remoteness, insularity, disaster proneness, and environmental fragility, which translate in limited access to natural and social resources (ONU, 1994) generating dependence on a narrow range of products and incrementing import reliance, which in turn compromise the Galapagos inhabitants´ food security. An additional characteristic of the Galapagos Islands is the high endemism ecosystems, which is under many forms of human–related pressures such as invasive species and population growth, compromising its conservation. In this context, this research applied an SD model approach in order to identify the driving forces and relationships that influence the food availability system through the analysis of its variables and interactions, to understand how population growth and food consumption in the Galapagos Islands are related to supply dynamics such as local agriculture production and food imports. Three tourism growth scenarios created in previous SD research in the Galapagos Islands (Pizzitutti et al., 2016) were used: accelerated growth, moderate growth and no growth scenario, from which different behavior of the systems were analyzed. It was observed that local production keeps a decreasing trend in the three scenarios, as well as an imports reliance increase. Also, agricultural areas in the Galápagos Islands are regulated mostly by cattle ranching activities, which present an increasing trend due to meat importation restrictions. And, that while production keeps expanding into the agricultural area, a more effective control of invasive species is possible. In this regard, Galapagos food security depends on a decreasing local farming and an increasing dependence on food imports, what in turn increases the vulnerability of the islands food security. These three growth scenarios as well as production and consumption tendencies, further proves the difficulties and limitations of the Galapagos Island´s food security. Therefore, overcome the island disadvantages towards a self-reliance in local production is a goal to pursue.

TABLA DE CONTENIDO

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FIGURES

1 Introduction

Most island populations, both developed and underdeveloped, have not been able to achieve food self-sufficiency because of their intrinsic disadvantages: small size, remoteness, insularity, disaster proneness, and environmental fragility (Briguglio, 1995). These disadvantages are expressed also in limited access to natural and social resources, such as water, energy, and labor (ONU, 1994) which generate dependence on a narrow range of products and increase import reliance (FAO, 2016a). Additionally, transport and communications become a critical issue to deal with, because a failure in either one may cause uncertainty with the timely supply of products. Besides, within island ecosystems which are in nature susceptible to adverse climatic conditions, human health and agricultural losses must be considered (Sharma, 2006). The Galapagos Islands, being a volcanic complex, meet the island's food self-sufficiency restraints, but with an additional consideration due its unique ecosystem that evolved through a natural process that rendered high endemism (Jackson, 2007), which makes this territory a living biodiversity laboratory and a highly valued place for conservation purposes. These characteristics not only entail the vulnerability that Galapagos Islands have because of its "island condition", they also underline the many forms of human–related pressures such as invasive species (González, Montes, Rodríguez, & Tapia, 2008), immigration and abrupt increases or decreases in the local consumption of food that may compromise its conservation.

Another particular characteristic of the Galapagos Islands that has to be considered, is that the tourism industry has become the most important driver of the economy, and its rapid growth is now the main factor of change in the social, economic and environmental systems (Taylor, 2006; Grenier, 2000). For instance, the tourism industry stimulated a demographic explosion in the last years, which in turn increased the requirement for goods and services to cover basic needs and livelihood standards (Salvador Ayala, 2015). In consequence, the local food production of the islands has not been able to keep up with such growth and fulfill the increasing demands, thus Galapagos population became even more dependent to importations. Though this supply – demand pattern is concordant with small islands developing States behavior (FAO, 2014), the Galapagos is only one of the twenty four Ecuadorian provinces and therefore it has not the autonomy of a State and it is governed not only by local policies. In this context, this research is looking forward to understand how population growth and food consumption in the Galapagos Islands are related to supply dynamics such as local agriculture production and imports, the within food security context.

Food security is defined as the physical and economic access of people, at all times, to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO, 1996). Though several are the proximate causes and driving forces that characterize the state of food security at a local level, the most relevant are already considered into the concept itself: food availability, food access, food utilization, and food stability (FAO, 2006, 2016b). This deconstruction of the term allows for the holistic investigation of food security (Christos, Naoum, & Dimitrios, 2014) through the analysis of the different variables that make up the food security system structure. In this regard, this research will focus on "food availability", which considers the adequate supply of food and includes variables such as food production, stock levels, and net trade.

According to the existing literature, food security issues have been mostly addressed through theoretical and partial approaches which reveal a gap in integrated and systemic approaches, becoming a downside for dealing with planning and policy making (Christos et al., 2014; Guma, Rwashana, & Oyo, 2016; Hammond & Dubé, 2012). That is why modeling techniques from complexity science began to be used in this field of knowledge, as a tool that connect interrelated systems across different disciplinary lines (Hammond & Dubé, 2012) and explicitly examine its interaction, through the use of flow rates, accumulations, and feedback loops involving delays and non-linear relationships (Jay Wright Forrester, 1961). Therefore, giving powerful insights of the dynamic tendencies and behavioral patterns of the system (Meadows, 1980). In this context, the food supply structure is considered as a richly integrated and highly dynamic social-ecological system, in which ecological factors shape the possibilities for food production and social factors govern the goals and operations of actors in the system (Stave & Kopainsky, 2015). Hence, the use of a System Dynamic model technique is an appropriate approach, since it allows to identify the main driving forces operating on the food system, and to analyze future implications on the different system structure conditions. In this way achieve the main purpose of learning about their modes of behavior, for the design of policies that improve its performance (Forrester, 1961, 1969; Lane, 1997).

In essence, modeling techniques provided a mean by which food security issues could be addressed. For instance, among the literature review some approaches are based in the theorical conceptualization of the existent interelations within the food security framework, which were used as an important reference for the system conception (Hammond & Dubé, 2012; Stave & Kopainsky, 2015). Other system dynamic approaches presents an integrated perspective where different processes are examined and scenarios are tested (Atherton & Slobodan Simonovic, 2013; Ayenew & Kopainsky, 2013; Candy, Biggs, Larsen, & Turner, 2015; Giraldo, Betancur, & Arango, 2008; Khodeir & Abdel-salam, 2015; Monasterolo, Mollona, & Pasqualino, 2015; Stave & Kopainsky, 2014, 2015). In which can be identified that the level of detailed at which the food system is interpreted and the variables that are used within the model depends on the objectives of the model, the singularities of the study area and the scale at which the problem is of the model is managed. As for the Galapagos Islands, no integrated approach has been used specifically for food system analysis. Though the food supply system tend to be relatively simple, it still faces high levels of vulnerability as in other islands occur (Sharma, 2006), and local interactions such as agriculture production, livestock production, imports trade and agricultural land use need to be address.

Previous research, have used an system dynamic approach to model different components of the Galapagos Islands (Espín, 2016; Pizzitutti et al., 2016). The goal was to create a decision-support system to examine tourism management in the Galapagos Islands, through the analysis of the impacts of tourism and residential population growth. Some of the sub-models in these papers include the introduction of alien species, protected area tourism management, land occupation, land tourism infrastructure, goods imports, electrical production, carrying capacity of the Galapagos National Park, and population and employment. In this regard, this research is part of this extensive effort to understand the impacts resulting from the coupled human-natural system interactions in a closed and unique scenery such as the Galapagos Islands. It contributes with a scenario-planning tool that can be used by policy-makers to achieve and enhanced the understanding of the Galapagos Islands systems. Furthermore, this research applied an SD model approach in order to identify the driving forces and relationships that influence the food availability system through the analysis of its variables and interactions, to understand how population growth and food consumption in the Galapagos Islands are related to supply dynamics such as local agriculture production and imports.

2 Materials & Methods

2.1 Study Area

The Galapagos Islands stretch over a 320 km axis from east to west and the equator line passes through the archipelago (Constant, 2000). As oceanic islands are, the archipelago has never been part of the continent, allowing the natural ecosystems to evolve through natural processes which have generated a very high level of endemism (González et al., 2008). The total extension of the islands is over 799313.1 hectares, from which only 25059 hectares are designated for agriculture and livestock activities with a proportion of 9% and 44% respectively, while the remaining 47% corresponds to abandoned lands, invasive species and native vegetation (Consejo de Gobierno del Régimen Especial de Galápagos, 2014). The agricultural area is located in the highlands of the islands and is characterized by higher levels of rainfall than in the coastal zones and fertile volcanic soils (Jackson, 2007).

The Galapagos Islands is one of Ecuador's 24 provinces and according to INEC, the total population of the islands in 2015 was of 25.244 inhabitants (INEC, 2015c) accounting for 0.18% of Ecuador´s total population (INEC, 2012). From this, approximately 95% corresponds to residents and 5% represent the people who stay in Galapagos for a short period of time, such as the case of tourists or relative´s short visits (Salvador Ayala, 2015). Several factors have influenced a rapid increase in the population rate, which is reflected in the growth percentage of 95% over the last 65 years (INEC, 2015c); being the tourism industry one of most important. According to Ker (Kerr et al., 2004), tourism employs 40% of Galapagos residents, and is responsible for the 65% of Galapagos economy; becoming the driver of the high rates of immigration, which is directly related to the half to two thirds of population growth in Galapagos (Kerr et al., 2004). In this regard, population growth is occurring rapidly in the Galapagos Islands as a response to the rapid growth of the tourism sector (Epler, 2007; J. E. Taylor, Hardner, & Stewart, 2009).

This large demographic explosion increased the need for goods and services to cover basic needs and livelihood standards (Salvador Ayala, 2015) making it difficult for the ecosystem services and local labor of the islands to fulfill the increasing demand. Moreover, abandonment of agriculture and cattle ranching occurred, while the proportion of rural population in Galápagos decreased from 42% in 1974 to just 17% in 2010 (INEC, 2010) decreasing the local production and the self-reliant food security of the islands. As a consequence, the abandoned areas are likely to become centers of establishment and propagation of invasive species such as Guava and blackberry (González et al., 2008) which will easily invade neighboring properties including the National Park restricted area.

Nowadays it is estimated that the Galapagos residents and the floating population consume approximately 58.588 metric tons of food (INEC, 2014) of which 91% corresponds to local consumption and 8% to tourism consumption. This matter has become a very important issue to deal with because the agriculture and livestock production area has decreased by 3% (Consejo de Gobierno del Régimen Especial de Galápagos, 2014) instead of increasing according to the increment of food demand. Meanwhile local agricultural production satisfied 37% of the islands food requirement, while the reports of StoreOcean show that agricultural food imports from the mainland have raised 25% from 2011 to 2015 (Storeocean S.A., 2011, 2012, 2013, 2014, 2015). Thus, local production is decreasing while food demand in the islands is increasing according to population growth, hence this gap is being filled by importations.

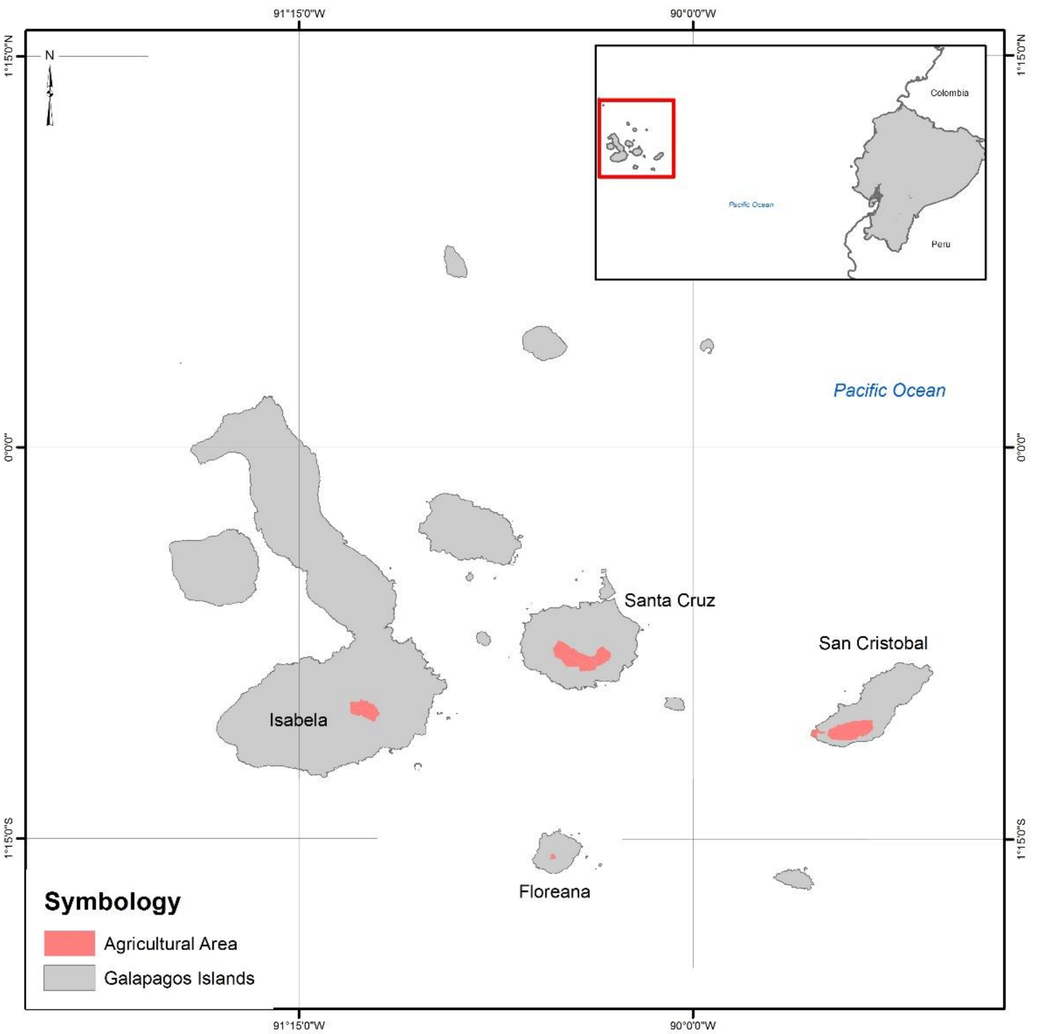


Figure 1. Galapagos Islands. The four inhabited islands: Santa Cruz, San Cristobal, Isabela and Floreana, with their respective agricultural area

2.2 Data Sources

The elaboration of the model used secondary data collected from local and national institutions, official documents, statistical databases and scientific papers based on the Galapagos Islands.

Data	Source	Year
Residents Consumption	Living Conditions Survey	2014
Tourists Consumption	Food Consumption in Cruise Survey	2017
Agricultural Land Use and Land Cover	Census of Agriculture	2000-2014

Agricultural Production	Census of Agriculture	2000-2014
Livestock numbers: cattle, pig, poultry, laying hens	Census of Agriculture	2000-2014
Meat Production: cattle, pig, poultry	Census of Agriculture	2000-2014
Milk Production	Census of Agriculture	2000-2014
Egg Production	Census of Agriculture	2000-2014
Annual cabotage statistics	StoreOcean S.A.Anual Reports	2011-2012-2013-2014-2015
Amount of organic load in metric ton imported into Galapagos	Biosafety and quarantine regulation and control agency for Galápagos - ABG	2007-2008-2009-2010-2011-2012-2013-2014-2015-2016
Population Data	Census of Population and Housing	2000-2006-2010-2015
Population Data	(Pizzitutti et al., 2016)	2012-2036 Projection
Economic Activity	Census of Population and Housing	2006-2016
Invasive Species Area	Landsat object-based classifications	2009/2016

Table 1. Data sources

2.2.1 Consumption

The data for consumption per capita for local residents was determined by the Living Conditions Survey raised by INEC in 2014, which define consumption as all the products that each member of the household consumed during the month prior to the collection of the information (INEC, 2015b). The food component considers consumption on purchased foods (consumption) and consumption of non-purchased foods (self-consumption) made by the household. For the interest of this research, both consumption and self-consumption are considered as one.

The consumption per capita data for the Galapagos province was obtained from the primary databases of the Living Conditions Survey 2014. The units for consumption that were used in the model are tons per year per person. In the model, it was assumed that the consumption per capita would prevail stable for the years considered in the model.

On the other hand, tourist consumption was obtained from a data of a tourism cruise. It was assumed that it is a standard menu for all the cruises that provide their service in Galapagos and that the tourists on land consume the same proportions of food per day, and that the pattern will remain the same for the years to follow. The units are the same as for resident's consumption.

In this context, the consumption data was divided into four food groups based on the production source: G1) Agricultural products, which considers fresh fruits and vegetables, G2) Livestock products, including meat, milk and eggs, G3) Fishery products, where all sea products are considered, and G4) Processed-imported products, which include all foodstuffs that are not produced in the Galapagos, referring especially to processed food. For the scope of this research G1 and G2 groups were considered.

The consumption data is as follows:

	Residents Consumption		**Tourists Consumption**	
Group	**kg/day**	**Tons/year**	**kg/day**	**Tons/year**
1	0.8546	0.1319	0.50078	0.1828
2	0.3614	0.0238	0.04569	0.0167
3	0.0652	0.6792	0.07022	0.0256
4	1.8607	1.1468	0.50575	0.1846
Total	**3.1419**	**0.3119**	**1.12243**	**0.40969**

Table 2. Residents and tourists consumption per capita

2.2.2 Agriculture and Livestock information

The agriculture and livestock information was obtained from the census of agricultural production units of Galapagos in 1974, 2000 and 2014 which are considered as the official information available in Galapagos. The indicators that were used for this research included: abandoned agricultural area, total agricultural area, agricultural produced area, area of pasture production, total agricultural production per year, non-consumed agricultural production, number of cattle heads for meat production, number of cattle heads for dairy production, cattle meat production per year, milk production per year, number of poultry for meat production, number of poultry for egg production, production of chicken meat per year, production of egg per year, number of pig heads for meat production and production of pork meat per year.

2.2.3 Food Import

The food import data was collected from the cabotage statistics from the StoreOcean terminal which concentrate most of the maritime transportation of food from Guayaquil to Galapagos. Also, the "Agencia de regulación y control de la bioseguridad y cuarentena para Galapagos – ABG" data for organic food imports through air and sea transportion was considered, even though it was clear that not all the organic cargo that arrive in Galapagos is registered, due to the registration method. A complete and detailed database of food imports in Galapagos is not available at the moment.

2.2.4 Demographic data

The local residents and tourists population data was obtained from previous dynamic models for tourism analysis made by the Galapagos Science Center as a consultancy for the Galapagos National Park and the Ministry of Environment of Ecuador (Pizzitutti et al., 2016). In that research work, the trends of population growth are already established considering three different types of scenarios of tourism and resident population growth: 1) Moderate Growth, 2) Accelerated growth and 3) No tourism growth. Meanwhile, for tourism is considered the number of tourists at the same time in Galapagos which represent the number of tourists that stay at the same time on board or inland. The demand for goods and services from tourist was based on this number.

Also, information about economic activities was obtained from the census of population and housing data from 2006 and 2015 (INEC, 2006, 2015a).

2.2.5 Invasive Species, abandonment areas

The land use and land cover maps were a result of an object-oriented classification approach using Landsat imagery acquired over the agricultural area of the four inhabited islands. Three Landsat scenes namely Path/Row 17/61, 18/60 and 18/61 were necessary to cover the study area. Two reference dates were selected in order to detect the land use and land cover change in the agricultural area, being 2009 - 2016. The acquisition dates for the images under cloud-free conditions were 27th February, 2009 (San Cristobal), 22th March, 2009 (Santa Cruz, Isabela and Floreana), 27th February, 2009 (San Cristobal), 8th March, 2015 (Santa Cruz, Isabela and Floreana). The Objects-oriented classification was performed using e-Cognition software, which consist on spatial and spectral analysis, which integrates relevant properties such as shape, texture and spectral information to analyze entities in the terrain. This process is divided in two principal steps: the Segmentation where individual pixels are grouped with neighbors to form a significant object that is defined by scale parameters and homogeneity criteria, and the Classification where is built a hierarchical classification scheme and defined the classes using classification rules based on membership functions. The broad categories that were classified are abandoned land, agriculture and pastures, invasive vegetation and nature vegetation. The total areas for each class was the input used in the model.

2.3 Methods

The methodology applied in this research is based on System Dynamics and is presented according to the scientific method for System Dynamic presented by Sterman (Sterman, 2000). It is divided into three stages: problem articulation, formulation of the dynamic hypothesis, formulation of a simulation model, and testing the model. A diagram of the methods elements is shown in figure 1.

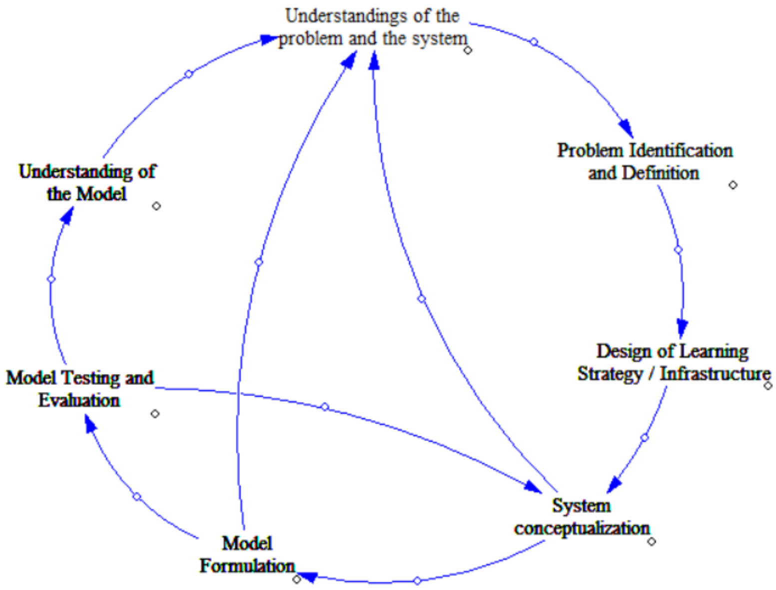


Figure 1. Overview of the System Dynamic Modeling approach ((Zock, 2004), adapted from Richardson and Pugh, 1981)

The problem articulation and system conceptualization refer to the definition of the characteristics and limits of the study system where the problems to be faced within the model are described. For this initial step, literature review was the key component, due papers with a theorical conceptualization of food systems dynamics (Christos et al., 2014; Hammond & Dubé, 2012) were the starting point for the Galapagos supply system conceptualization. In this regard, concepts definitions and an initial model structure with its key variables were developed, allowing to stablished the boundaries of the model. Based on time, data availability and resources not all the components of the Galapagos food security system were address, in this sense food consumption and food supply in the islands became the central part of the analysis. The result of this step was the dynamic hypothesis, which is synthetized through a conceptual diagram. Based on the model conceptualization and the definition of the variables, the data collection and systematization was perform.

The formulation of a Simulation Model consists on building a flowchart or Forrester diagram, which is a detailed representation of the system dynamics model. The Forrester diagram specifies the characteristics of the interactions of all elements of the model to reach its transcription in terms of mathematical equations. This step has a strong component of data collection and analysis. This stock-and-flow model structure for the Galapagos food availability model was made using VenSim software, and based on secondary data. The model begins simulation in the year 2012 until 2037 accounting for 5 years of historical data and 20 years of the planning horizon.

Testing the Model begins as soon as the first equation is written. Part of the testing takes over the comparison of the simulated behavior of the model to the actual behavior of the system. However, in addition, the testing is in charge of checking the structure and the mathematical and dimensional consistency of the model.

2.3.1 System Hypothesis

In Figure 2, is outlined the framework for the theorical structure of the dynamic system for Galapagos food supply, were the main variables and relations are shown.

Accounting for a theorical exercise the model assumes a state of equilibrium between supply and demand, which means that supply equals the demand. This is the equilibrium point, where the allocation of goods is at its most efficient point because the amount of goods being supplied is the same as the amount of goods being demanded (Heakal, 2017). The food demand corresponds to the consumption of food demanded by Galapagos residents and tourists. This assumption allows to estimate the quantity of food that will be needed to be produced and imported to satisfy food requirement in the Islands. Local production influence the importation amount, as imports must fulfill the gap of populations food consumption that is not produced locally.

The food stock of the islands calculates as the sum of the local production and the importations, and it corresponds to the total food availability for population consumption, which as mention before, is equal to food demand. In addition, the food stock also influence the amount of local food production and importation, as it may accumulate food excess that will be available for consumption and it will not be necessary to fulfill.

On the other hand, local production and productivity rates determine the number of hectares that will be needed for agriculture and livestock production. And at the same time, at a certain point farming land will determine local production, as the agricultural area in the Galapagos islands corresponds to a pre-established area with a limited extension, surrounded by the national park limits. Likewise, the agricultural area that is not used by production will determine the invasive species area extension, as abandoned and not occupied areas are likely to become centers of establishment and propagation of invasive species such as Guava and blackberry (González et al., 2008).

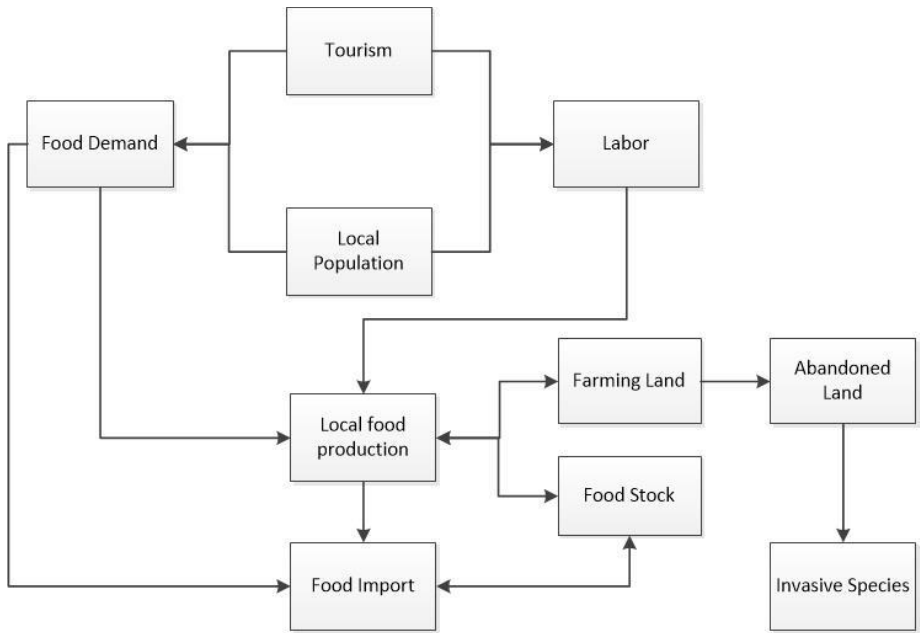


Figure 2. Model Hypothesis Diagram

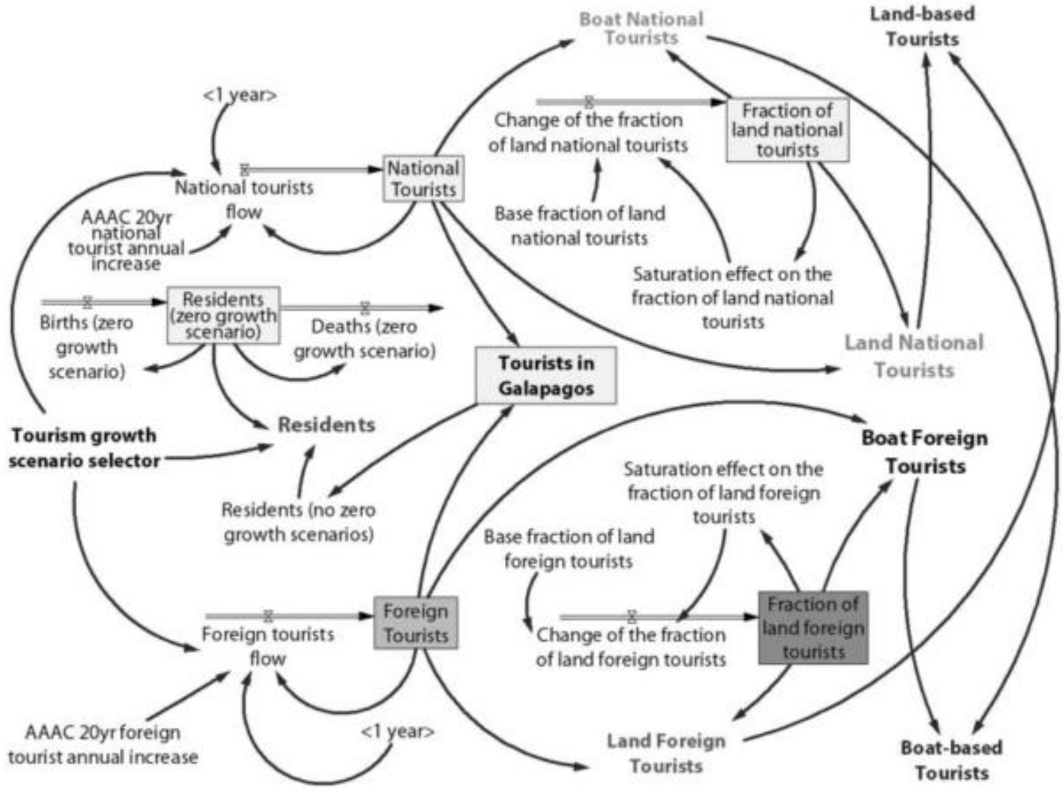
2.3.2 Model Implementation

2.3.2.1 Population and Tourism sub-models

As mentioned before, the sub-model of Population and Tourism was based on an existing dynamic model performed for Galapagos (Pizzitutti et al., 2016) where three possible scenarios of tourism growth for the next 20 years (2013-2033) were built. The first scenario corresponds to the “moderate growth” scenario that is used as a reference scenario and reproduces the assumption of what would probably happen in Galapagos if the tourist arrivals regime does not vary substantially over the next 20 years. The second scenario is the “high growth” or exponential growth of tourist arrivals, which makes calculations under the assumption that the number of tourists will grow following the same average annual growth rate during each year in the future, as it did during the base period. The third scenario corresponds to “zero growth” where tourist arrivals remain frozen in time to the level reached in 2012. The first two scenarios were calibrated with respect to the intensity in which tourist arrivals were recorded in the last 20 years (1992-2012). Two different analytical functions were used to calculate the projections, a linear function and an exponential function, respectively. The third scenario was based on a conjecture of freezing tourism growth, which means that the projection of tourist arrivals is based on the hypothesis that the flow of tourist arrivals is established through an imposition from a decision in politics in the management of the Galapagos Islands. Accordingly, these three scenarios were the base to build the resident population projections assuming a direct relationship between the number of tourist arrivals and the growth in the local population.

For the identification of impacts and demands of goods and services due to the presence of tourists, a new variable was constructed based on a concept named "tourists at the same time" (Pizzitutti et al., 2016), which addresses the average number of tourists that are in any day of the year in Galapagos. This number is calculated based on the average number of days a tourist stays in Galapagos and therefore different types of tourism are considered: boatbased and land-based, and national and international tourists for both previous classes. Each of the four groups presents different characteristics and stays. In this context, the average number of people in Galapagos corresponds to the number of residents plus the number of tourists at the same time. Figure 2 presents the relationship between residents and tourists, and tourists at the same time.

a)



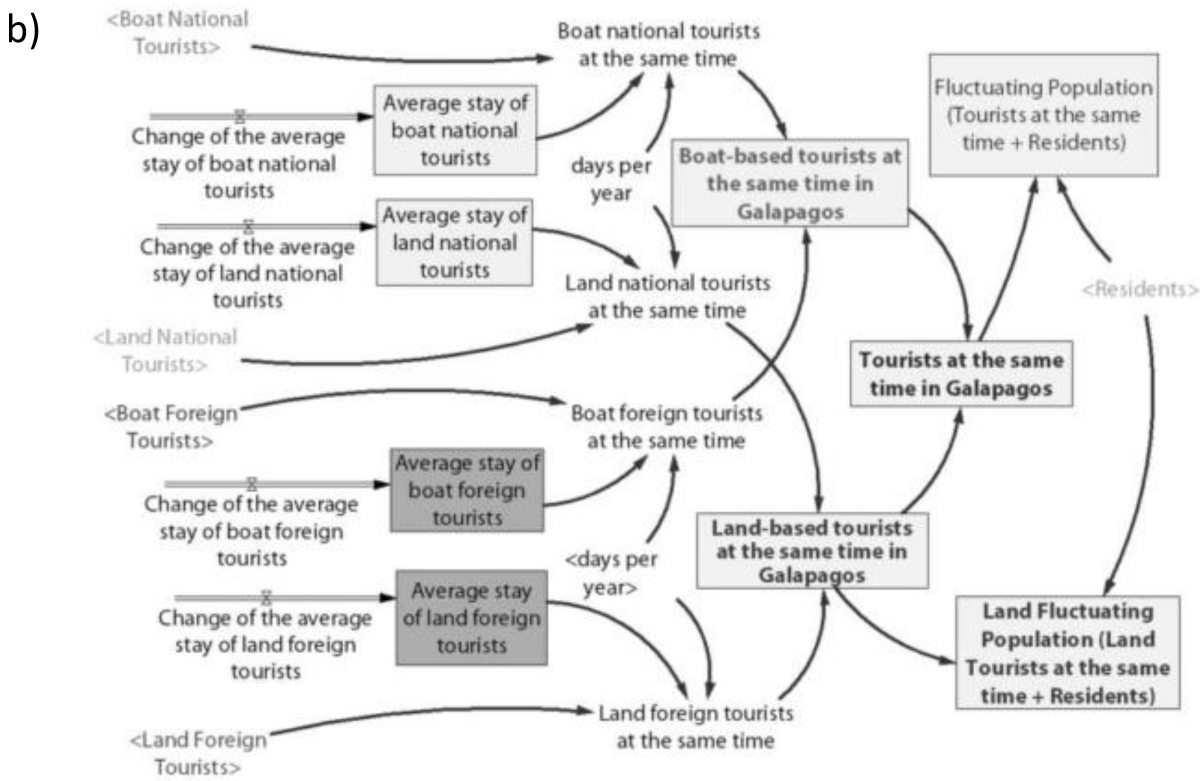


Figure 2. Stock flow diagrams a)Calculations of the number of yearly tourists arrivals and residents in Galapagos b)Calculations of the number of tourists at the same time in Galapagos.(Pizzitutti et al., 2016)

2.3.2.2 Consumption sub-model

As metioned before, the model assumes a state of equilibrium between the supply and the demand, which will allow to estimate the quantity of food that will be needed to be produced and imported to satisfy the food consumption in the Islands. This assumption is considered reasonable because according to the economic approach of the poverty lines, there is no extreme poverty in Galapagos given that all inhabitants have an amount of monetary resources that allows them to guarantee at least the required minimum food intake (Granda, Sandra, & Calvopiña, 2012). Additionally, the distribution of goods among the inhabitants of the Galapagos Islands is more equitable than in the rest of the country (Granda et al., 2012) which means that in general, the Galapagos population has the economic conditions to access their regular food requirements. Also, the consumption per capita of food for the residents and tourists was based on a diet proportion for agriculture and livestock products that are assumed to prevail stable for the number of years included in the model.

Regardless, the consumption sub-model calculates the total amount of food for G1 and G2 to establish which production and imports will be needed to fulfill (figure 5). This number corresponds to the resident´s consumption (figure 3) plus tourist consumption (figure 4) which is estimated through the relation between the number of residents and tourists at the same time and the consumption per capita values for each group.

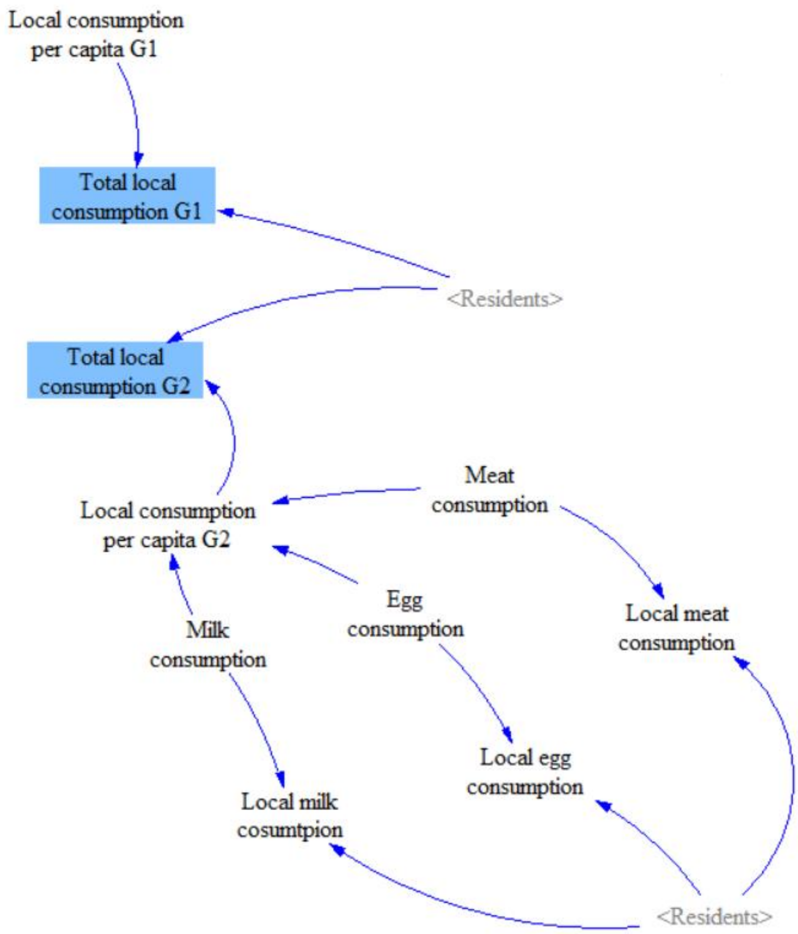


Figure 3. Dynamic diagram from the calculation of the total local consumption for agriculture products (G1) and livestock products (G2) in the Galapagos Islands

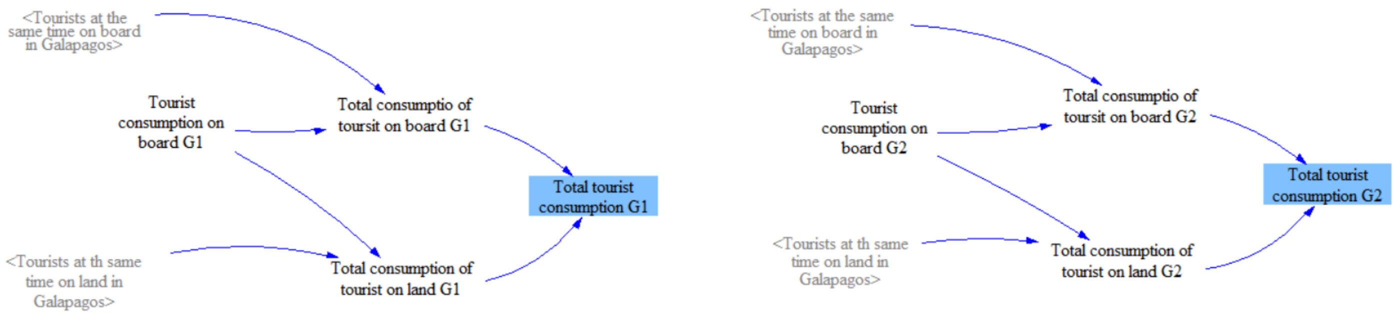


Figure 4. Dynamic diagram from the calculation of the total tourist consumption for agriculture products (G1) and livestock products (G2) in the Galapagos Islands

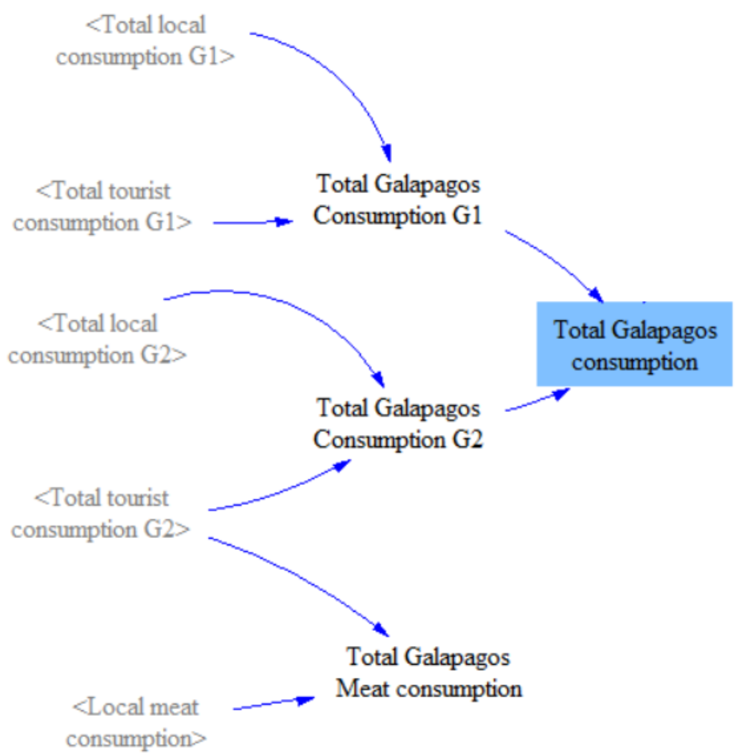


Figure 5. Dynamic diagram from the calculation of the total consumption of agriculture products (G1) and livestock products (G2) in the Galapagos Islands

2.3.2.3 Supply Sub-models

The model considers that there are no supply and demand constraints which means that the food demanded by the Galapagos population will be fulfilled by local production or otherwise by food importation. In this sense, the local production follows the trends of past years and the difference is offset by imports.

Under this premise, the supply sub-models section will present the agriculture production, agriculture imports, meat production, milk production and eggs production sub-models.

2.3.2.3.1 Agriculture Production Sub-model

Agriculture in Galapagos has shown a decreasing trend in the last ten years. Agricultural lands have decreased in 23% from 2000 to 2014 (Consejo de Gobierno del Régimen Especial de Galápagos, 2014). Nevertheless, an increment in productivity has been evidenced in the same years. Several factors affect in this decreasing tendency, being the rapid increment of the tourism industry one of the most important since there is a link between hand labor dropping from agriculture towards tourism business with an aim to enhance income (Carlos F. Mena; Stephen Walsh; Francesco Pizzitutti; Gunther Reck; Ronald Rindfuss; Daniel Orellana; Verónica Toral Granda;Carlos Valle; Diego Quiroga; Juan C. García; Ing. Lizeth Vasconez; Alexandra Guevara, 2013; Espín, 2016).

Accordingly, the agriculture production sub-model was built under the assessment that the increment or decrement of farming lands depends on hand labor availability, considering the past trends between tourism and agricultural activities labor. Also, in more detail, the movement between agriculture labor and livestock labor was specified. In addition, the increment tendency of productivity was cosidered which allows for calculation of the production for each year. All these dynamics are embodied in figure 6.

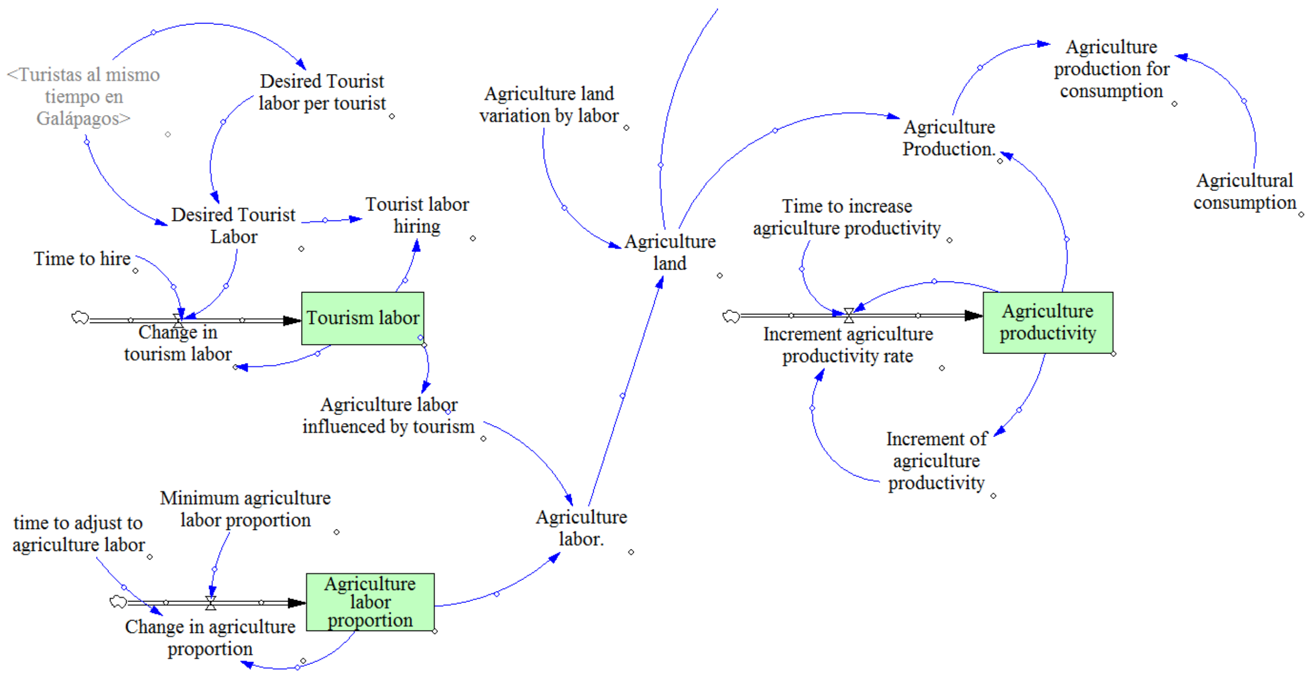


Figure 6. Dynamic diagram from the calculation of hand labor for agriculture activity, demanded farming land, productivity trend and total production

2.3.2.3.2 Agriculture Imports Sub-model

The Galapagos Island´s population relies almost entirely on food imported through maritime and air cargos. Given that local agriculture production is not capable of providing the Galapagos population demands for agricultural food, it is necessary to fulfill this demand with imports. In this sense, the model was based on the assumption that imports are the difference between the demand for agricultural products minus local production and in accordance with the population and local production, the trend will consistently increase. The amount of needed food was then divided between vessel importations and flight importations using a constant which corresponds to an average from ABG reports (ABG, 2017).

In a broader view, the local agriculture production plus the importations have to fulfill the agricultural food demanded by the Galapagos population for each year. This is shown in figure 7.

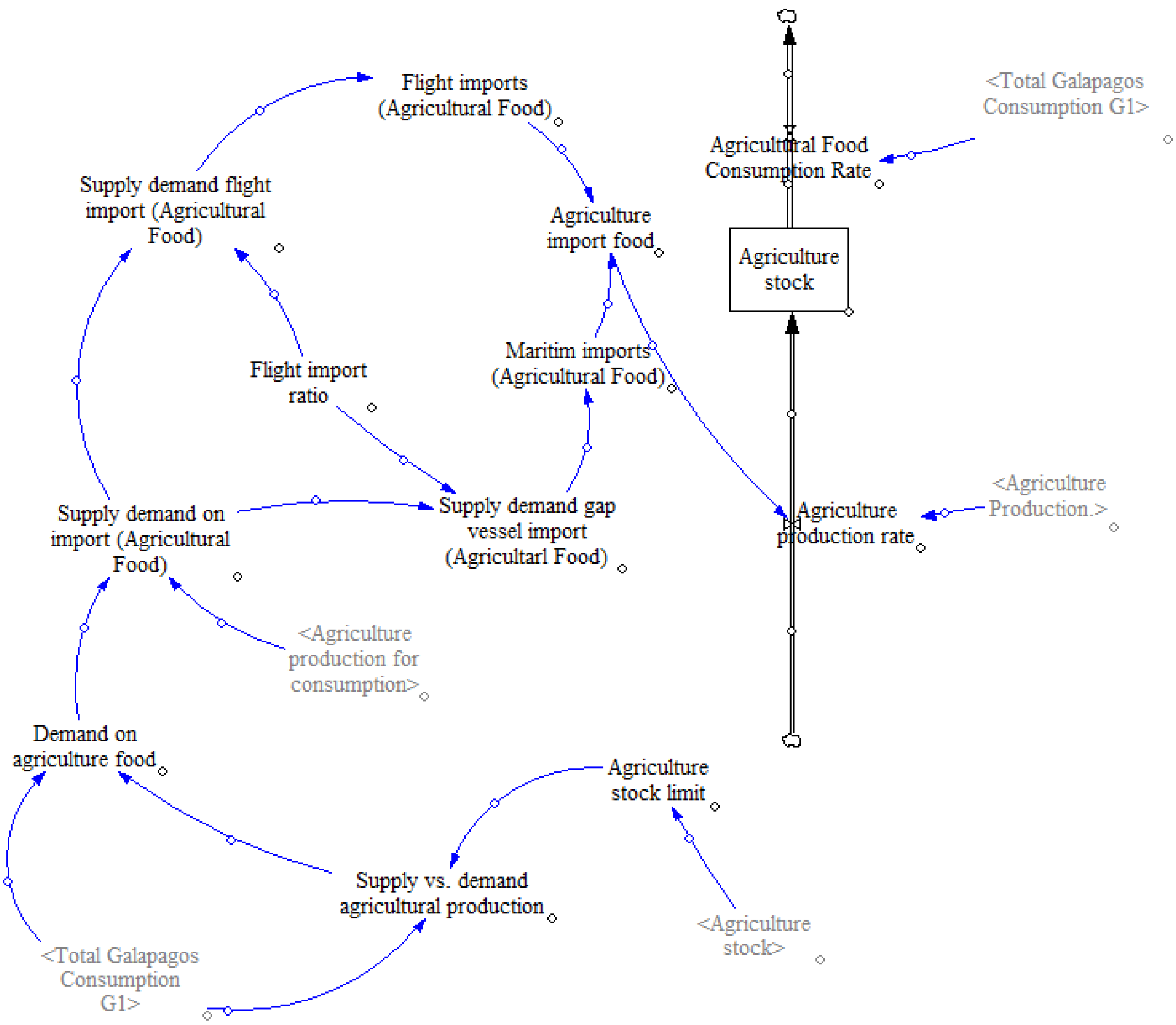


Figure 7. Dynamic diagram from the calculation of agriculture importations

2.3.2.3.3 Meat Production Sub-model

Since 2004, SESA which is the agricultural health committee, impose a prohibition of cattle, pork, sheep and goat meet imports from the continent and due to this, Galapagos has been declared free of aphtose fever (Tribunal Constitucional, 2004). Nevertheless, according to the ABG list of organic products, a group of pre-processed meat products are allowed to be introduced to Galapagos such as sausages and pre-cooked meat. However, imports registers are not complete nor detail so it was not possible to identify which proportion of pre-cooked meat is imported and this information was not considered in the model. On the other hand, since sausages are not produced in the Islands and there is a broad register of those into import reports, they have been considered into G4 for processed and imported products. Nevertheless, illegal introduction of fresh meat from the continent has been identified, especially from certain meat cuts that the local supply couldn´t fulfill in the required volumes. This proportion of imported meat was not included in the model analysis because there is no available data or estimations.

In this regard, the model assumed that only local meat production fulfills the Galapagos demand (figure 8) but sheep and goat meat is not considered because the consumption proportion of both is low and there is not enough information. In this sense, local production will fluctuate in relation to the demand of cattle and pork meat. Under this consideration, a constant number that represents the proportion of consumption for each has been established based on the consumption information which is considered to remain the same through time. For the model's purpose the main indicator of both diagrams was the number of pigs and cattle required to fulfill local consumption over the time horizon of the model.

Chicken production is regulated in a different way because chicken meat imports are allowed into the islands. The relationship between the production and the import is regulated by the market and there is no restriction on the amount of chicken import neither on the calculation of the price. In addition, a proper and complete import registration is non-existent so it is not possible to quantify the total import. In this sense, the production was established by a per capita production according to the 2014 agriculture census (Consejo de Gobierno del Régimen Especial de Galápagos, 2014) and the production of chicken is considered to increment based on population growth while the difference was assumed to be imported. The same as for the cattle and pig diagram, the main indicator corresponds to the number of chicken that must be produced locally for fulfilling local demand and the proportion of imported chicken as well.

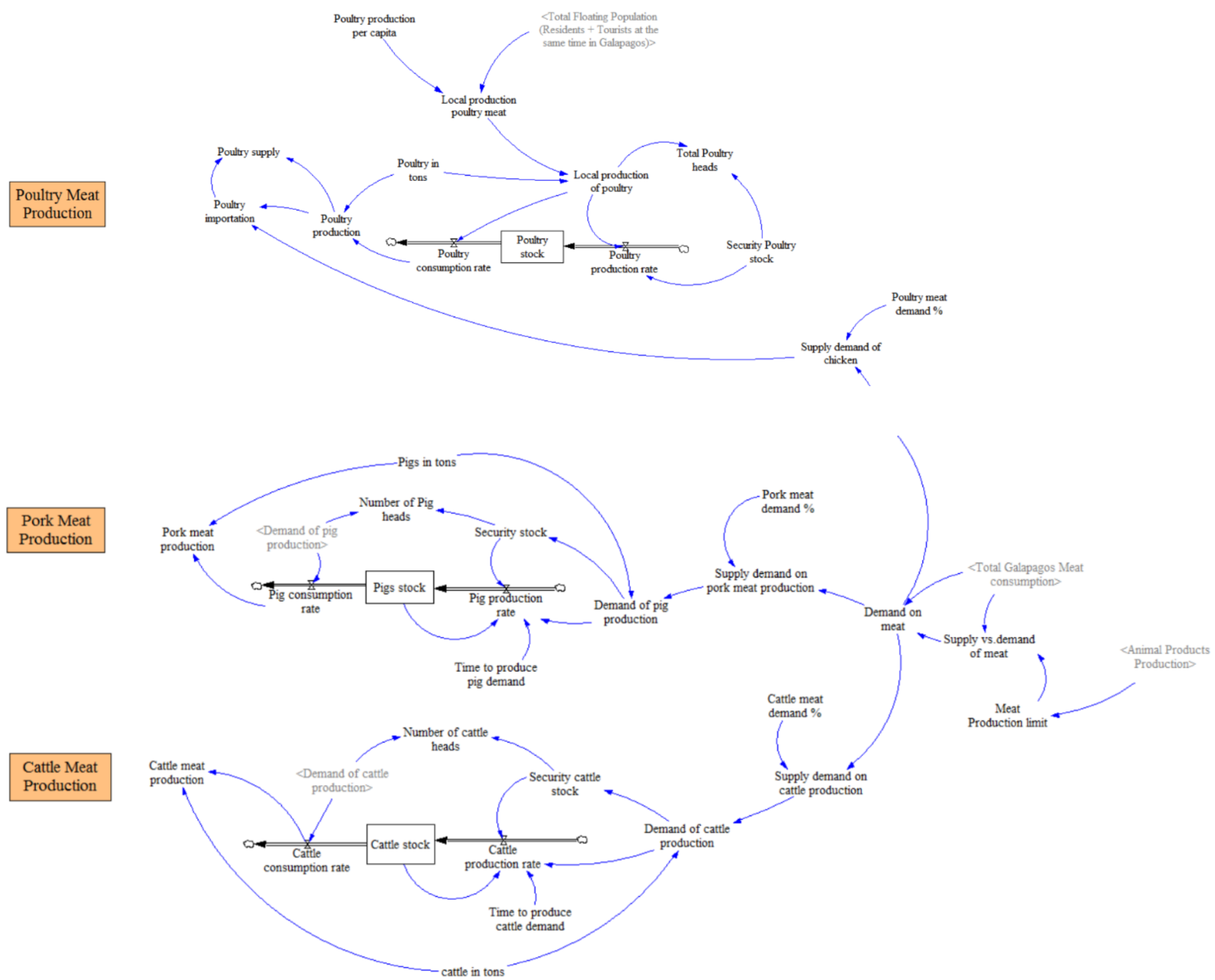


Figure 8. Dynamic diagram a) Calculation of the number of chicken produced and import b) Calculation of number of pig production c) Calculation of the number of cattle heads, both based on pork and cattle meat respectively

2.3.2.3.4 Milk Production Sub-model

The production of milk in the islands is regulated by the market as well and because there is an open market for milk import with lower prices, milk produced locally is even wasted occasionally. Therefore, milk growth depends on local preferences due to prices and quality. To capture these dynamics, a production per capita was calculated which determined that the increment of production is related to population growth and the difference was assumed to correspond to importation.

According to the 2014 census, 65% of the produced milk was used for consumption while the remaining 35% was used for local cheese, butter and yogurt production. Also, only 36% of the milk cattle was in production at the same time and the difference are in-rest and male cattle for reproduction was also considered. With this data, the total number of milk cattle that the islands needs for a sustainable production corresponds to the sum of both, milk cattle in production and milk cattle in rest. Figure 9 shows the dynamic diagram for milk production.

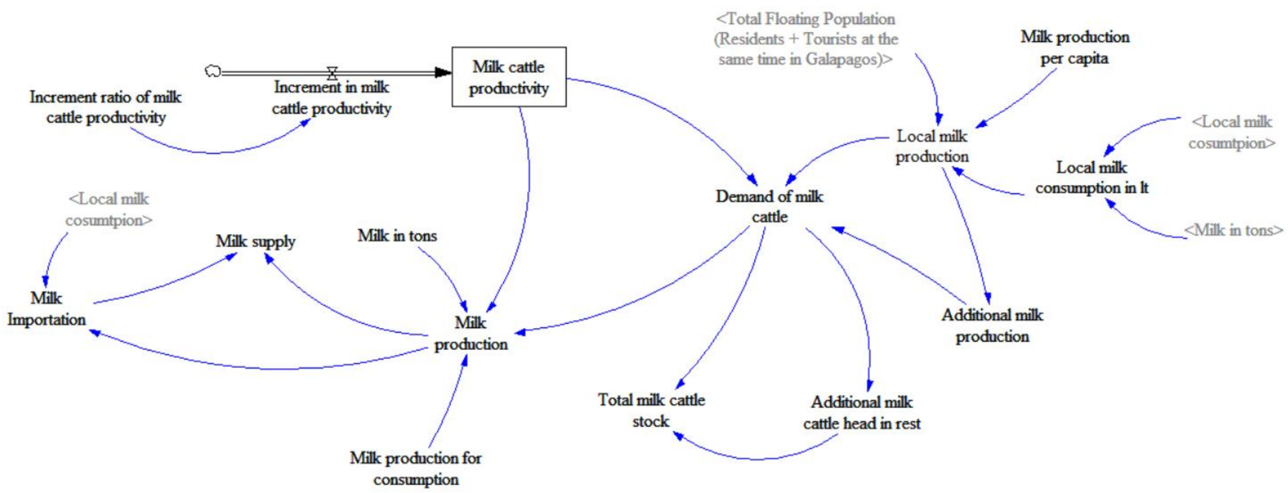


Figure 9. Dynamic diagram from the calculation of the number of milk cows needed for milk production accordingly to milk demand

2.3.2.3.5 Eggs Production Sub-model

Something similar happens in egg production, as market and prices of imported eggs regulate the production. Nevertheless, accordingly to local sources, the actual installed capacity would allow local production to supply for all the current demand for eggs and chicken meat in the islands. Hence, the producers are asking for a policy that allows them to produce the whole demand of these products. However, until this happens, the egg production will also remain dependent on imports.

The same considerations for milk and chicken meat production were made. A per capita per year production was calculated in accordance to the information presented in 2014 agriculture census (Consejo de Gobierno del Régimen Especial de Galápagos, 2014) which allows the model to reflect fluctuations in the production based on population numbers, and the remaining demand for eggs that are not supplied by the local production were assumed to be imported. The main indicator of this diagram corresponds to the number of laying hens that the local production will have to have to fulfill the demand by local production following the actual trend. This is shown in figure 10.

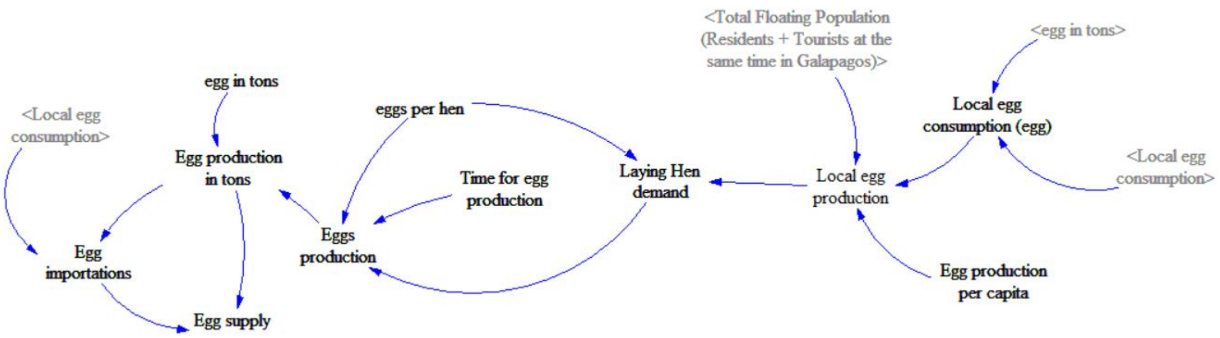


Figure 10. Dynamic diagram from the calculation of the number of laying hens needed for egg production accordingly to egg demand

2.3.2.4 Land Use Sub-model

The land use sub-model is related to the cattle and agricultural production because these are the local activities that use agricultural lands on the four inhabited islands. In the case of agriculture, the variation in the need of farming land is determined based on hand labor availability as mentioned before. For cattle production, which is an activity that since the 70´s seems to have remained stable with no significant increments or decrements. Before the

US currency was adopted in 1998, Galapagos was a cattle exporter but then the population boom and the prohibition of meat import happened and the number of cattle for export was redirected to local consumption. However, there is a trend in the increment of hand labor for livestock activities and an increment in productivity as well. In this regard, with a growing tendency of the Galapagos population, this activity has to increase production to fulfill the demand, and as the number of cattle rise, more land for pastures is needed as well. Hence, cattle ranching in the Galapagos responds to an extensive or semi-intensive production, which also seems as an appropriate approach for invasive species control into de agricultural area.

In this regard, the total productive area corresponds to the agricultural area plus the cattle ranching area. On the contrary, the agricultural land that is not used for agriculture or cattle production, which is calculated as the total available agriculture land minus the actually occupied productive land, seems to be under invasive species pressure due to abandonment or lack of labor. In this sense, the trends for invasive species and natural vegetation were established based on trends determined by remote sensing classifications of Landsat satellite images from 2009 and 2016. Thus, the area for these other land covers in the agriculture area were calculated. The main indicators from this sub-model were the total agriculture land, invasive species area and natural vegetation area (figure 11).

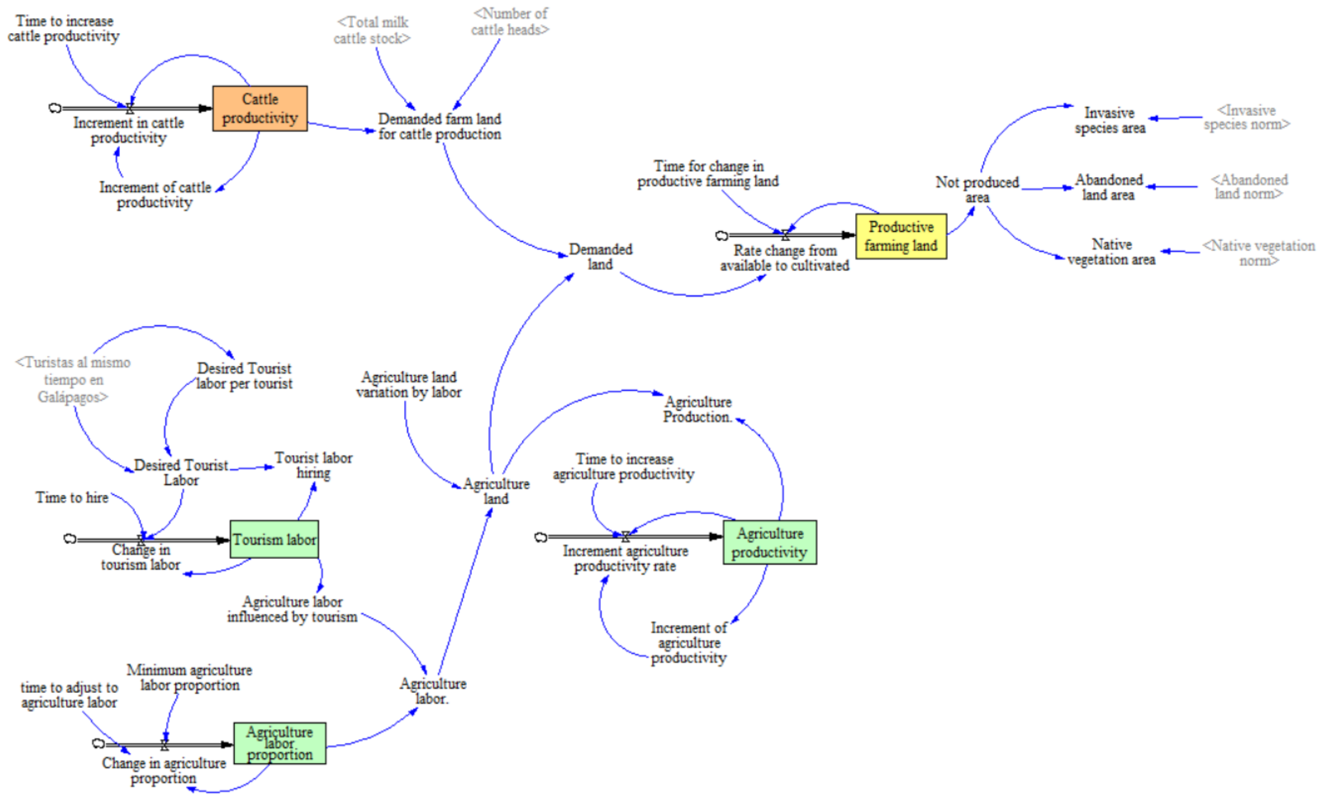


Figure 11. Dynamic diagram from the calculation of the area for agriculture and cattle production, and the remaining trend for invasive species, abandoned land and native vegetation

3 Results

3.1 Scenarios of local population and tourism change

The consumption per capita of agriculture and livestock food in Galapagos is higher than the national average consumption. Namely, 0.3119 for G1 and 0.1319 for G2 measured in tons per year per person, while the national average is 0.2828 and 0.0976 respectively. While the consumption per capita of tourists is higher than the residents consumption in agriculture products with 0.50078 for G1, but lower on livestock products with 0.04569 for G2. The last responds to a higher consumption of sea food than the residents population. As is shown in figure 12, the main consumption of the Galapagos islands corresponds to the residents whom meet their basic needs on a regular basis, which accounts for more than 90% for agriculture products and almost the 98% of livestock consumption. When the three population scenarios were compared, the difference of agriculture and livestock food demand varied in an important way especially for the accelerated growth scenario, which projected until 2036 varies with approximately 32 tons for the G1 and 11 tons for the G2 that are needed to fulfill consumption requirements as opposed to the other two scenarios.

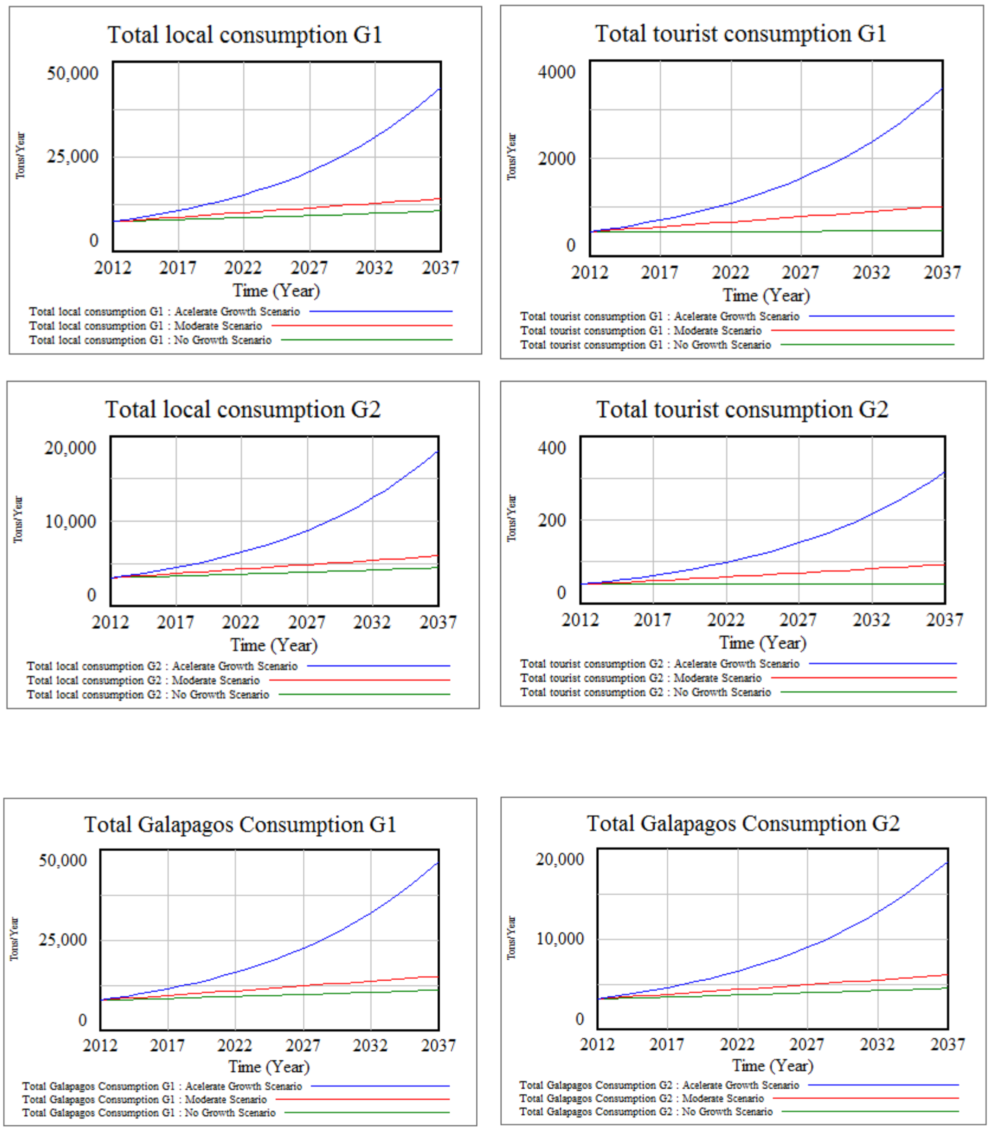


Figure 12. Model outputs – Consumption dashboard

Even though the requirements of agriculture food is increasing, as is shown in figure 13 the local agricultural production does not follow the agricultural food demand trend, no matter which of the population growth scenery is considered. The moderate and accelerated scenarios of tourism growth showed an increment in tourism labor due to higher employment requirements which was reflected as a decrease in agricultural and livestock activities. On the other hand, in the scenario of zero growth, the stock of tourism labor remained constant indicating that no further employments were going to be needed and agriculture and livestock labor remain almost the same. Nevertheless, the trend between agriculture and livestock activities labor determined that even though there is almost no change in general (zero growth scenario for instance), there was still a decrease in agriculture labor. Hence, establishing a tendency of dropping agriculture towards cattle ranching or similar.

In this regard, the decrement in agricultural labor impacts on agricultural farming land showing a decrease in extension. Even though the productivity has an increasing trend, it also reflects a decrease in production and an increase in agricultural imports. These effects appeared in a more drastic way when the accelerated scenario was analyzed while the no growth scenario showed very subtle changes. In this regard, with an accelerated scenario is expected that for 2036 the amount of agricultural food imported will raise in a 78% from 8.879 tons per year in 2017 to 44.467, while local production for consumption is expected to decrease a 10% than 2017 values of 1.929 tons per year.

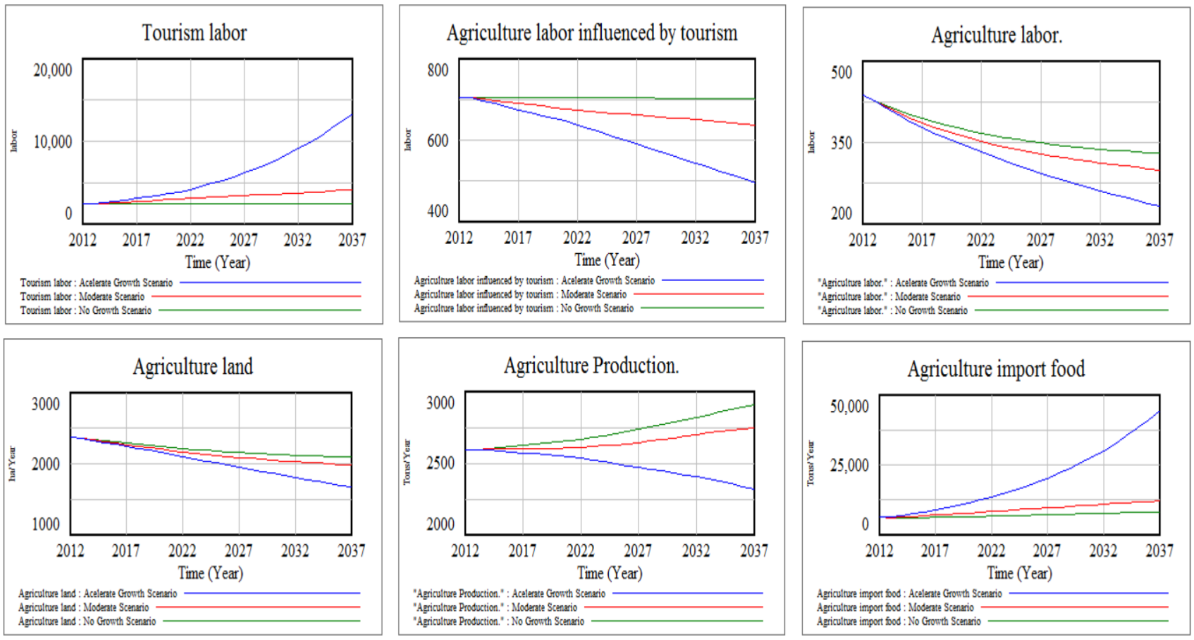


Figure 13. Model output – Agricultural production and importation dashboard

On the other hand, accounting with the meat imports restriction, is expected that under any population growth scenery, when the population of Galapagos residents and tourists increases, the demand for food will increase. Thus, as cattle and pork meat production were based on the population demand it will increase accordingly. As it was expected, as is shown in figure 14, the accelerated scenario raised in high proportions the numbers of cattle and pig heads needed to satisfy the food requirements. On the contrary, when the moderate and zero growth scenarios were contemplated the number of heads raised with a moderate slope. In these sense, for 2036 under an accelerated scenario more than 26.000 cattle heads will be necessary for assuring a sustainable production and guaranteed the demand fulfillment. While in the moderate and no growth scenario almost 9.000 and 7.000 cattle heads will be needed respectively. On the other hand, pig production must increase an 75,4% for the accelerates scenario and a 35,1% for the moderate scenario from 2017 to 2036.

Meanwhile, poultry production is affected, as well as cattle and pigs, by demand, but also by the permission to import frozen chicken from the continent. Consequently, according to the increment on demand, a proportional increment on local production and importations is seen in figure 14, based on the relationship established between production and import in 2014. Hence, poultry production and importation will increment in a 34.5% for the moderate scenario and in a 75.6% for the accelerated scenario, reaching to 563.645 and 1.772.885 poultry heads respectively.

A similar behavior is identified towards cattle for milk production and laying hens for egg production. Where, if the accelerated scenario is analyzed and the same market dynamics are considered, almost 8.500 additional milk cattle will be needed to fulffil milk local consumption, and 1.400 tons of imported milk are going to be necesary. While, only 332 additional milk cattle will increment for the moderate scenario, and a decrease of heads will be expected for the no growth scenario, with a range of milk importations that fluctuate from 130 to 190 tons of milk imports for both scenarios. Under the same trend, 51559 laying hens will have to increase from 2017 to 2036 if the population growth happens in an accelerated way, while 7.713 and 3.220 will be expected to rise for the moderate and no growth scenarios respectively. While importations will keep raising accordingly reaching to 68.124, 21.658 and 15.942 tons per year at 2036. In this regard, imports will increment accordingly in moderate amounts for the first and third scenario, and in a high number of tons for the accelerated scenario. This means that as actual trends show, the more the demand grows, the more difficult it is for domestic production to supply the necessary products, so dependence on imports becomes stronger.

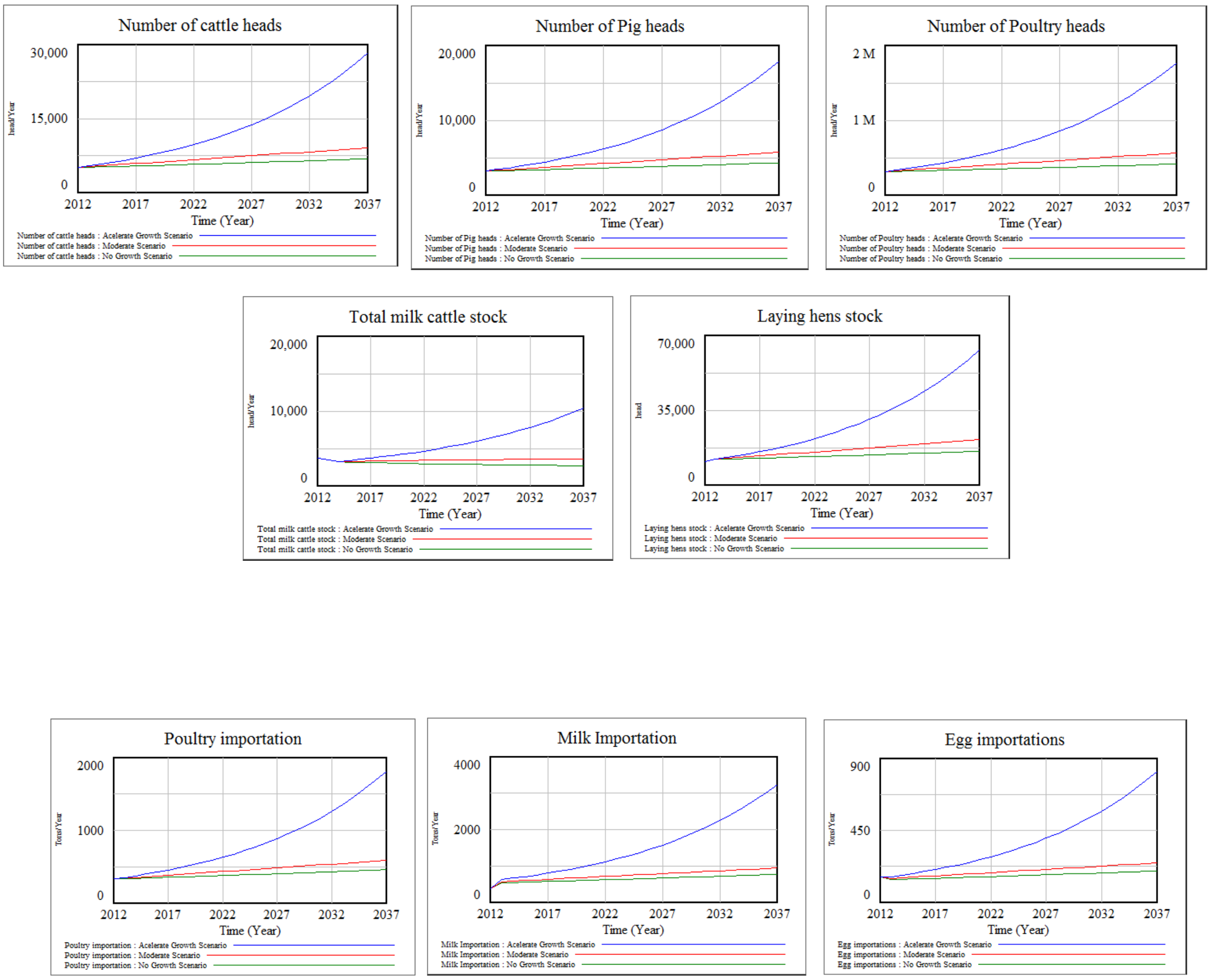


Figure 14. Model output – Livestock products dashboard

The use of the agricultural area of the Galapagos Islands is regulated by the agricultural and livestock production, being the later the one that have a greater impact in the total extent of the agricultural area. Hence, even though the area occupied by agriculture production is decreasing, if the cattle ranching activity, either intended for meat or for milk production, is increasing its extent, the agricultural lands will increase as well. Productivity have a main role in these dynamics, and a trend of incrementing productivity is considered in the model, however, if productive practices continue as today, for the accelerated growth will be needed 38.638 ha, while only 25.059 ha are available. While for the other two scenarios, the farming land occupied will vary around half the total available extension.

On the other hand, no matter at which scenario we look at, the area of native vegetation showed a decreasing trend, while the invasive species-area kept growing until the point there is no free land in the agriculture area, because the need of local production occupied the whole agricultural territory. This would be the case of the accelerated growth scenario. Nevertheless, at the moderate and no growth scenarios the invasive species reach to occupy the 28% and the 36% of the agricultural area each, just as presented in figure 15.

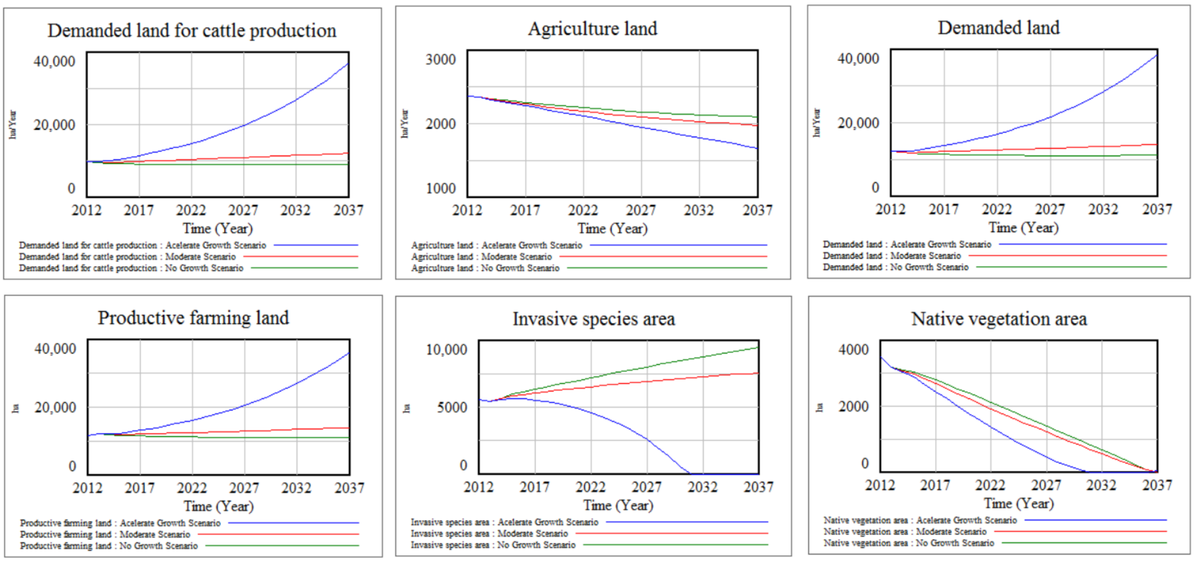


Figure 15. Model output – Agricultural land dashboard

3.2 Alternative Scenarios

According to the interview with key stakeholders in the production sector, Galapagos accounts with the local production capacity to fulfill current demand on poultry meat, eggs and milk. Nevertheless, importations and market dynamics regulates production. In these sense, if in 5 years, imports restrictions were implemented for these specific items, the growth in demand would corresponds to approximately 38.7% for meat poultry, 38.8% for laying hens and 20.9% for milk cattle production for each year as is presented in figure 16. Accordingly, the impact on the increment of milk cattle production would increase the land farming utilization on about a 9% requiering 3198 additional hectars, which therefore would decrease the invasive species area. On the other hand, these means that local producers need to be in the capacity to produce 381.164 additional poultry heads to assume the imports share just for 2022, getting to an additional number of 1.098.270 at 2036. While for egg production, it will be needed 14.741 additional laying hens for 2022, which is more than the 12.500 laying hens registerd on 2014 (Consejo de Gobierno del Régimen Especial de Galápagos, 2014).

Figure 16. Model output – Considering the scenario of the restriction of importations for poultry meat, eggs and milk.

4 Discussion

This research applied an SD model approach to address the food supply system in the Galapagos Islands through the analysis of its main variables and interactions. The construction of the flowchart model was able to establish the relationships between population growth and food consumption in the Galapagos Islands, and to demonstrate the influence of food demand on the supply dynamics of the islands. It was shown that agriculture local production is not able to provide the food demand on the island, due the decrement of labor on the agriculture sector caused by the tourism industry, and low productivity rates, hence imports are filling the production gap, showing an increasing trend.

The data of consumption of the inhabitants of the Galapagos Islands was the basic information used for the construction of the SD model. Through, it was noticed that the consumption per capita of food in Galapagos is higher than the national average. In addition, a decrement trend on consumption on agricultural food has been identified (INEC, 2009, 2014) accompanied by an increment on processed food, which also is higher than the national average, with 0.6792 tons per year per person in Galapagos versus 0.2512 in continental Ecuador. The reasons of this high consumption trend for the Galapagos Islands is not within the scope of this analysis, but certain hypothesis can be mentioned to be addressed in future investigations. For instance, according to personal interviews with local residents, they may prefer processed foods over fresh ones because highly processed ones have a longer shelf life thus allowing them to have a personal stock in their households in case of shortage of supplies or an increase in the prices. Furthermore, according to Kearney (Kearney, 2010)**,** poverty is a reason for consuming highly processed foods, nevertheless it could be discuss that in Galapagos income levels do not seem to play a decisive role in the choice of consumption, and other drivers such as consumer attitudes, urbanization, women in employment and food availability may be influencing in a stronger way such behavior (Øvrum, Alfnes, Almli, & Rickertsen, 2012) (Kearney, 2010). Though, this statement has been contradicted by a market study developed by Zapata (Zapata, 2009), who assures that income levels become a restriction for residents at the time to buy processed food. Anyhow, the Galapagos islands is facing a nutrition transition, which according to Gerbens-leenes, Nonhebel, & Krol (2010) consist on the shift from local markets towards external trade. Another reason that could be explored involves the level of food waste in the populated islands (Granda et al., 2012). Where as well as countries with high consumption levels, high percentages of food waste has been registered at the consumer level, due people tend to consume more but also throw away more of the purchased products due to leftovers or unused products (Williams, Wikström, Otterbring, Löfgren, & Gustafsson, 2012).

The consumption behavior together with the population growth prompted by tourist industry and immigration are responsible for the annual increment of food demand in the islands. However, the SD model trends suggest that agricultural production is decreasing in spite of local demand increments, and policy and programs that encourage its growth (Jaramillo, Cueva, Jiménez, & Ortiz, 2014; MAGAP, 2013, 2016). This behaviour is closely tight with tourism industry growth, who has act as a destabilizing force in the islands dynamic, due in few years became the most important mobilizer for the Galapagos economy, through the generation of direct and indirect new job positions with higher wage. Agricultural labor was attracted to this new economic dynamic (Espín, 2016), and coupled with the growing trend of the shift from the agriculture to livestock activities, was calculated in the SD model a decrement of agricultural labor of a 40% from 2017 to 2036, within the accelerated growth scenary. Which generate abandonment of farming lands and therefore the decrement of agricultural production, accounting for the decline in the production of 255 tons in the same period.

These tourism-agriculture phenomenon has been discussed mostly in the 1980´s and 1990´s within Caribbean islands whose suffered a similar shift in their economies shocked by an aggressive tourism industry growth. Both of the main researchers on tourism in the Carribean islands, McElroy & Albuquerque (1990) argue that labor extraction from agricultural sector, large-scales immigration and rural land competition are the three main factors that influence agriculture decrement in small islands under economic restructuring toward tourism industry, resembling very similar characteristics to the Galapagos Islands. Several authors agree with this asseveration considering tourism as an agent of negative changes towards agriculture (Loumou, Giourga, Dimitrakopoulos, & Koukoulas, 2000; Telfer & Wall, 1996). Nevertheless, it is also recognized that under the right circumstances and a good public policy it can also provide new opportunities to boost agriculture production (Cox, Fox, & Bowen, 1995; Loumou et al., 2000). For the Galapagos food supply SD model, urbanizations was not included due competition for land can be considered as marginal, which are similar to other islands situations as is stated by Latimer (Latimer, 1985).

According to Hollenstein et al. (Hollenstein, Arrazola, Yumbla, & Almagro, 2016) other factors that influenced agriculture decrement in the Galapagos Islands is the disconnection of agricultural production and local market dynamics, as it is implicit in the SD model. Due local distributors are the ones that define the prices of local products in comparison with the imported ones (Hollenstein et al., 2016). Belisle (1983) has named this characteristic as “market obstacles”, thus he considers that the lack of marketing, storage facilities and the direct contact between the producers and the consumers have a negative impact on food distribution and prevent the food from getting to the consumer, as well as the producer to connect with consumers necessities.

In this context, the agricultural decrement is the main concern in all the specialized reports about food management in the islands (Berube, 2014; MAGAP, 2013; SIPAE, 2006; Zapata, 2009), which emphasize that in order to guarantee food security, local production must increase. Meanwhile, in the Galapagos the gap of demand generated by the poor local production is compensated by food imports which has become the largest source of food, due the model calculated that about 75% of agriculture food supply is transported from the continent in 2017, with a trend to increment to 95% in 2036. This is a common problem in small islands in developing countries, which show a common trend towards import increase which in change threatens food security (FAO, 2014). Due, there are no large storages of food in the islands, and local interviews have stated that supermarkets and food distributors may have around four weeks of supply of food in their shelves and warehouses, which in an extreme situation may compromised food availability. Though McGregor et al. (2009) research argue that the dependence on imports is not necessarily correlated with food insecurity, due he considers that while governments and individual households are in the capacity of paying for the food they import, food insecurity may be mitigated. Nevertheless, from the above, Kearney (2010) research concord that the goal should be to focus on collaborative efforts to build locally-based and self-reliant food economies. Moreover, the increment of imports are the most important source of the arrival of more invasive species in the Galapagos (Cremers, 2002; González et al., 2008), which is an world wide trade according to Margolis et al. (2005).

According to McElroy & Albuquerque (1990), islands environments have to deal with different types of constrains, and one of the broader categories corresponds to natural limits. Even though land availability is not mentioned in his research, it is the case for the Galapagos Archipelago, due its particular characteristic of its ecosystem uniqueness. The area destined for production activities have its limits on 25.059 ha, while the rest of the islands territories are part of the National Park protected areas. This condition according to Latimer (1985) may result in competition between agricultural production and tourism, and in this specific case also with conservation, which agree with the SD model results. In these sense, from the area destined for production purposes, the 53% was occupied by agriculture and livestock activities in 2014 (Consejo de Gobierno del Régimen Especial de Galápagos, 2014), from which the 82% is used for cattle ranching. The SD model showed an increasing trend in the area destined for cattle ranching activities, which is correspondent with the increase of cattle heads that will be needed to fulfill meat and milk demand. It is expected that with an accelerated growth escenary more than 20.000 cattle heads will be needed just for meat production, while in a moderate growth scenary only 3.184 additional heads will be required. In these sense, when the accelerated population growth scenario is considered, the maximum area that can be used for local production, if an extensive method of cattle ranching persists, is esteemed to be reached at 2030. These happens because the import restriction of meat products incentive local production, as they must produce the Islands total demand, due production is determined by population increment.

The poultry meat and eggs production are part of a growing production sector, as in 2000 most of poultry and laying hens where raised in farms, while for 2014 the 90% were produced in poultry farms. Thus, poultry industry was quick to meet the demand for broiler chicken meat and egg production, which according to Latimer (1985) resembles to the pattern of the poultry industry in Caribbean islands as was the case of Jamaica. Moreover, it was mention that local production in the Galapagos can fulfil the current demand but because of poultry meat and eggs imports, the industry has been not exploited in its full potential. Following the later, the SD model showed that the poultry industry will need to increment its production for 2036 in 563.645 poultry heads in the moderate scenery and 1.772.885 in the rapid scenery if the imports persist with the same proportion as 2014. Nevertheless if the restriction in importations take place in 5 years a 38.7% additional production will be required, hence the trend of rapid growth stablished in the past must be maintained.

As mentioned previously, food consumption and food production dynamics are closely linked to the use of agricultural land and in turn, both influence land use dynamics in the highlands. In 2014 the 47% of the agricultural land was abandoned, invaded by foreign invasive species and occupied by natural vegetation (Consejo de Gobierno del Régimen Especial de Galápagos, 2014). Moreover, according to the satellite image classification of 2016, 44% of the agricultural area is affected by invasive species which prompt the abandonment of agricultural activities, thus increasing its presence and encouraging its dissemination (Jaramillo et al., 2014). In addition, invasive species have managed to become the largest threat to terrestrial biodiversity (Snell, Tye, Causton, & Bensted-Smith, 2002; Trueman, Atkinson, Guézou, & Wurm, 2010), decreasing the abundance of native plants (Jäger, Kowarik, & Tye, 2009) and vastly detrimental to local production. Despite efforts form several institutions and organizations to invest in projects control and eradication of invasive species (González et al., 2008; Coello & Saunders, 2011; Ministerio del Ambiente, 2013), it is expected that numbers will only rise in years to come because of the relationship between the presence of invasive species and population size

(Trueman et al., 2010). Nevertheless, the SD model shows that if land use increment, the area left for invasive species will reduce, which may be considered as an efficient invasive species control, as mention in the bio agriculture plan of the islands (MAGAP, 2013).

The Galapagos consumption behavior has a direct impact upon the social, economic and environmental systems through the increase of exploitation of resources such as a higher demand of agricultural products and livestock production which in turn demands for land, water and energy resources (Jaramillo et al., 2014). Also to be mentioned is the growing trend on the import of food products which according to several authors is considered the main driver for the entrance of invasive species to the islands (Gardener, Atkinson, & Rentería, 2010; Trueman et al., 2010; Watson, Trueman, Tufet, Henderson, & Atkinson, 2010). Not to mention the increment in the footprint of transportation CO2 (Pizzitutti et al., 2016), and the additional economic expenditures for the population and local authorities (Llive, 2016). Furthermore, import of food products creates the need for the increase of the capacity for waste management (Buzby & Hyman, 2012) and impacts on public health (Freire et al., 2014). Thereby, the importance of analyzing consumption patterns should be addressed through adequate mechanisms, either for consumption guidance or for adequate provision of food. The same is argued for food supply, which in accordance to McElroy & Albuquerque (1990) arguments measures that emphasizes only on mitigating natural and economic constraints do not necessarily act upon long-term institutional and structural difficulties. Hence, concluded that agricultural policy must be integrated into overall economic planning to account for sectoral imbalances. And for doing so, the institutional structure and information infrastructure must be strength (FAO, 2017).

5 Conclusions

The consumption profile of the inhabitants of the Galapagos Islands is on average higher than the consumption of Ecuador mainland population. This factor plus the rapid growth of local population fueled by the tourism industry development and the decrement in per capita food production, due the rapid rate of agricultural hand labor loss, has prompt over the last years the increment of food import dependence. In addition, the local agricultural production is not connected to the islands food demand, so there is no tangible incentive to stimulate production. Besides, invasive species spreading into the agricultural area of the islands generate a negative impact on farming production due the demand of additional labor.

On the other hand, livestock and pork production in the islands are in capacity of meeting the population meat demand, nevertheless local production should be prepared for a growing demand tendency, through the implementation of practices intended to increase productivity. The meat import restriction stimulates local production, but not only fulfilling the demand should be the goal, also an increment in quality is a key element for demand satisfaction, and for decreasing the illegal meat importation. Additionally, the production capacity for poultry products is capable of satisfying the current demand, nevertheless still local institutional capacity for local organizations management and policy implementation is needed to improve. In this regard, poultry local producers are in the capacity of supersede poultry meat and egg imports, and are looking forward a restrictive policy for this matter. Nevertheless, rather if this happens or not, production must expect an increment in demand.

The increment in cattle production is the activity that demands the highest proportion of agricultural land. Therefore, depending on the population growth trend, if the current production model continue, an over demand of the available agricultural area is expected. Consequently, while farming land increases, the decrement of areas occupied by invasive species is expected, as well as the areas of native vegetation. This is anticipated because the increment of demand will incentive local production, and farming lands that are currently not used will be needed for production. Hence, the incentive on agriculture and livestock production is considered as an effective approach for invasive species control.

In this regard, Galapagos food security depends on a decreasing local farming and an increasing dependence on food imports, what in turn increases the vulnerability of the islands food security. Therefore, self-reliance in local production is a goal to pursue as a food security policy. Several actions must be considered in order to achieve the increase of local production, for instance technology improvement, technical assistance, economic incentives, and price and import regulations. Thus, policies to promote agricultural growth should be the coarse part of the strategy to reduce food insecurity. On the other hand, primary information concerning these matters is almost inexistent. In the last few years some efforts and resources have been invested into the generation of data about consumption, income, prices, land production and imports but there is not yet an appropriate system for data collection and analysis. Consequently, information that allows policy makers to act upon these matters is of vital importance and any effort towards that direction is a step forward. It is essential for Governmental authorities and other stakeholders to access reliable information regarding social and ecological dynamics so that an adequate monitoring and assessment of the islands production and consumption dynamics can be performed.

This research has focused on representing the dynamics of the food supply system in the Galapagos Islands. However, this is only a small part of what food security represents in the whole sense of the concept. In this regard, future research should focus on extending this theoretical exercise towards the implementation of new subsystems that make up food security in the Galapagos Islands, such as the food and environment system, market interaction system, and nutrition and health systems. However, information availability acts as a restrain, due collection and systematization of local data is imperative for further efforts.

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