Demographic carrying capacity model: A tool for decision-making in Rapa Nui

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Abstract: The increase of population in Rapa Nui (Easter Island) has fueled concerns within the community, given the uncertainty of its impacts. These concerns have driven a socio-political process that triggered the enactment of *Law 21,070*, which regulates the access and permanence of visitors in the territory as a way to cushion the pressure on different environmental, social, and infrastructure components that affect the local quality of life. However, for its application, this law requires technical foundations that allow restrictions to be applied and, therefore, knowledge about the demographic capacity of the territory is also needed. To this end, a dynamic model was built, which consists of different variables that are sensitive to population growth and also can be projected into the future, thus delivering timely information for decision-making. This paper describes the socio-political context for the creation of this instrument, as well as its elaboration process and main results.

Keywords: Rapa Nui, Easter Island, carrying capacity, dynamic model, demographic

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Introduction

According to demographic data, the population living on the island of Rapa Nui (Easter Island) has increased progressively over time (Instituto Nacional de Estadísticas, 1982, 1992, 2002, 2014, 2017). The highest inter-census growth occurred between 2002 and 2017, with an increase of 104%, representing the highest growth rate at the national level (Instituto Nacional de Estadísticas, 2002, 2017). This has fueled concerns among community members, who have expressed the need to face the possible impacts of such population increase on socio-cultural and environmental aspects, as well as on the provision of basic services (Cooperativa.cl, 2017; Pojzman, 2016; Rivas, 2015; Senado República de Chile, 2013). The aspects that most concern the community are two: the high migration of people from continental Chile attracted by the economic possibilities offered by tourism (Cabrera, 2017; Silva, 2012), and the high tourism population of Rapa Nui (Calderón & O'Ryan, 2011; Figueroa & Rotarou, 2013; Pérez & Rodríguez, 2011).

Figure 1. Location of Rapa Nui, Chile.

This increase in both resident and transitory populations has urged inhabitants to establish a mechanism for migratory control (Emol, 2015; La Tercera, 2015; Sandoval, 2013; Silva, 2012). At the beginning of her first term (2006), former Chilean President Michelle Bachelet became aware of this concern through the Commission of Development of Easter Island (CODEIPA) corporation. Among other functions, CODEIPA formulates and develops plans and projects that improve the standard of living of the Rapa Nui community and contribute to the conservation of its culture and environment. Based on this, the government signed a commitment document to support these efforts through a series of legislative and administrative measures for the protection of local heritage (Gobernación Provincial de Isla de Pascua, 2017; Ministerio Secretaría General de la Presidencia de Chile, 2016). This action, followed by the approval of the constitutional reform that defines Rapa Nui as a 'special territory', reflects the recognition of the island's ecosystem fragility and vulnerability, as well as the necessity for protecting its culture and flora and fauna heritage (Biblioteca del Congreso Nacional de Chile, 2007). This legal definition established the foundations to set restrictions around people's entry, and temporary and permanent living in such territories to protect the island's uniqueness (Biblioteca del Congreso Nacional de Chile, 2007).

In March 2018, *Law 21,070*, which "regulates the exercise of the rights to live, stay and move to and from the special territory of Easter Island," (Ley nº 21070, 2018, art 1) was published in the Official Gazette. This law stipulates the need for calculating the demographic carrying capacity (CC) of Rapa Nui, considering different variables and defining saturation and latency indicators which will provide the necessary information to develop a management plan that may reduce the risk of exceeding the maximum carrying capacity (Cámara de Diputados de Chile, 2017). To that end, the Sub-secretariat of Regional and Administrative Development signed a framework agreement of cooperation and applied research with The Pontifical Catholic University of Chile to create an instrument estimating carrying capacity, which will be used for decision-making within the framework of the law. This article describes the methodological process that allowed the creation of the measurement instrument for demographic CC on Rapa Nui.

The concept of carrying capacity and its scope for Rapa Nui

In modern contexts, the concept of CC challenges the number of human beings who can make use of space without degrading its natural, cultural, and social environment, with the ultimate goal of maintaining a desired quality of life in the long term (Abernethy, 2001). The concept has been linked to tourism activity because of its positive aspects, such as being an engine of economic growth and development (mainly for developing countries and island territories), including the creation of jobs, improvements in the conservation of natural areas and urban infrastructure, and revaluation of one's own culture, among others. However, tourism becomes self-destructive when it does not respect limits, including limits on the consumption of natural resources, the production of waste, alteration of ecosystems, loss of traditional values and cultural diversity, and migration flows, among others (Arup, 2013; Canavan, 2016; Mai & Smith, 2015; Maldonado, 2006; Marsiglio, 2017).

The consolidation of tourist destinations is a result of the close relationship between the phenomenon and migration (Williams & Hall, 2000; Takahashi, 2019). Among its causes, migration generates movement to satisfy the employment needs of the industry, thus resulting in permanent transfers of friends and family (Takahashi, 2019). At the same time, the migration for amenity (which is defined as the permanent or temporary migration of people to certain places) occurs when there is a perception of better environmental quality and other factors (Moss, 2006). The constant tourist flows can cause problems, given the demographic carrying capacity of the locations and the impact on the environment and quality of life of the residents. As a result, the carrying capacity concept has become a prominent issue in planning and management fields for the guiding of territories where residents take pride in living due to, for example, their environmental quality, convenient transportation, functional urban services, and, in general, because they constitute environments where they feel physically and culturally comfortable (Wei et al., 2015). This can be accomplished through defining growth limits and by balancing natural systems and artificial components, which must ideally be in line with human demands (Wei et al., 2015).

From this, one can say that a territory's CC is not fixed, but dynamic. CC can increase or decrease through the improvement or deterioration of infrastructure, use of technologies, preferences of residents, investment, and consumption patterns and lifestyles, among others (Graymore et al., 2010; Navarro et al., 2012; Wei et al., 2015; Wei et al., 2016) and, therefore, it should be understood dynamically. The above idea becomes especially relevant when considering the challenges faced by the territory given its insularity, which relate to aspects such as ecological fragility, limited resources, isolation to markets, and surface scarcity, among others (Bojanic & Lo, 2016). These are vulnerabilities that can be intensified by demographic pressure and, in the case of Rapa Nui, have intensified over the years (AMBAR, Consultoría e Ingeniería Ambiental, 2001; Calderón & O'Ryan, 2011; Di Castri, 1999; Figueroa & Rotarou, 2013), especially because of the close relationship that exists between tourism and migration (William & Hall, 2000; Takahashi, 2019).

The methodology involved in this study addresses the importance of the demographic load on sensitive and fragile island territories, highlighting the profound effects on the quality of life of its resident population and its sustainable development. On the other hand, it recognizes the importance of the formulation of public policies that acknowledge these impacts and act on them effectively. This study is not designed to ensure competitiveness, nor to understand the effects of migration on the quality of the tourist destination, which often tends to be the most relevant for island public policies. Its focus is on the objective of ensuring the sustainability of quality of life of island residents over time.

Developing the demographic carrying capacity model of Rapa Nui

The creation of the measurement instrument for Rapa Nui demographic CC was developed in two stages (see Figure 2): the exploratory stage and the creation of the instrument. A summary of the model results is provided in a later section (see also Table 2).

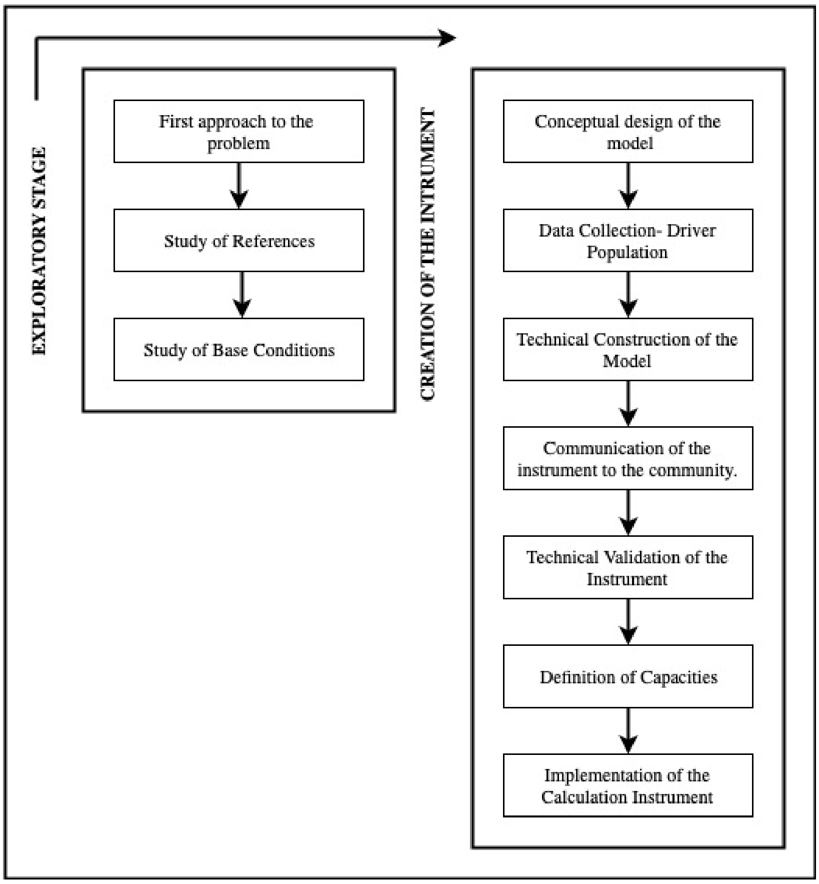


Figure 2. Methodology.

Exploratory stage

First approach to the problem. The research team traveled to Rapa Nui, intending to make contact with the main authorities of the territory, and especially with CODEIPA, which is a corporation that identified and brought the need for instruments of migratory control to the Chilean government, thus representing a local counterpart of the research under development. This first approach allowed the researchers to become familiar with the local needs, and also opened the discussion of what was needed (whether a number or an instrument) to guide local decision-making. From this first approach, the following conclusions were drawn:

- Different variables must be measured and, therefore, it is important to build complex instruments;
- Each variable needs to have its demographic carrying capacities;
- A solid instrument should include sociocultural variables; and
- The instrument must admit that the CC of a territory is not fixed and, therefore, calculating only one number would be obsolete in the short term.

These aspects are pertinent when considering, for example, a situation where we want to establish that a drinking water supply can support a certain number of people in the territory. This number is likely to vary if water consumption patterns increase, the infrastructure of the endowment is improved, or the recharge capacity of the aquifer is diminished. In considering the fourth conclusion in the list, that the instrument must allow for fluctuation, the researchers determined that a dynamic CC model was required.

Study of references. Researchers conducted a literature review and analysis, consisting of the compilation and analysis of academic publications and technical reports from various institutions, in order to identify conceptual and methodological CC aspects. The analysis aimed to address which of these studies could be used to inform the development of a CC model for Rapa Nui.

In total, more than a thousand CC indicators were identified, associated with sociodemographic, environmental, management, and cultural heritage components which could be useful for the developing instrument (Buckley, 1999; Cifuentes, et al., 1999; Shi, et al., 2016; Segrado et al., 2017; Liu, & Borthwick, 2011; Graymore et al., 2010; Dan-lin & Han-ying, 2002; Fang, et al., 2017; *Kang & Xu, 2010;* Wei et al., 2015; Wei et al., 2016; COCCOSISS, 2001; Neuts, 2012; Navarro et al., 2012; Navarro et al., 2012*;* Amer Fernández*, 2009;* Cócola Gant, 2016; Botero et al., 2008; Echamendi, 2001; Hernández, 2000; Abernethy, 2001; Soria-Díaz & Soria-Solano, 2015). Of particular interest in terms of dynamic simulation models were those presented by Banos, Martinez, and Esteve (2013) for the Fuerteventura Biosphere Reserve in the Canary Islands, which integrates social and environmental elements that are built independently but inter-related. Additionally, their model considers the definition of a key variable whose fluctuations determine the dynamics of the rest of the models. The elaboration framework defined the simulation model as an iterative process, which begins with the development of a conceptual model which integrates a series of variables with their interactions validated by experts (Banos et al., 2013).

Considering this methodological approach as a framework for the current study, researchers created a first conceptual approach inspired by dynamic systems and composed of a key variable that affects another series of variables. This key variable corresponds to the population dynamic growth. In this way, dynamic systems would enable the working of different development scenarios based on the demographic trend(s) of Rapa Nui, as well as simulating future changes generated in various components, based on population increase.

Study of base conditions. Once the methodological framework was established, it was necessary to define the variables that would make up the CC instrument. Although the literature review identified several variables and indicators that allow CC to be measured, in order to adapt the model for Rapa Nui, it was fundamental to consider the relevance of each of the variables and indicators according to local needs. To do so, researchers initially carried out a study of baseline conditions based on the variables that allow measuring the CC, as identified in the literature review. Collection of secondary information via various diagnoses and technical reports of the island was also a key factor in identifying the main problems of the territory and their effects on its demographic growth.

The next step was to conduct interviews with stakeholders through participatory workshops, in order to validate and complement the problems identified in the base conditions study. The methodology for selecting interview participants was a combination of theoretical and expert choice, along with 'snowball' method. To prioritize and limit the number of interviewees, the following selection criteria was used:

- Informants with competence in topics related to the island's CC;
- People with decision-making influence; and
- Balancing the number of native Islander informants, for the total number of interviewees. The non-native interviewees will be referred to as 'continental residents'.

Twenty informants linked to areas including archaeology and natural heritage, local management, infrastructure, economy, political participation, environment, and health were interviewed. The interview guideline consisted of two questions:

1) What do you think are the main problems of this territory at present?
2) What do you think are the most influential variables that determine these?

In a second instance, participatory workshops were held for groups of the three key social figures of the island: 1) public service officials, 2) continental residents, and 3) *Honui* (representatives of Rapa Nui families). *Honui*, Rapa Nui's traditional local government, represents the Rapa Nui people and its membership comprises one representative of each of the 36 ancestral families. The objective of these workshops was similar to the interviews; that is, to identify the impacts and incidence of demographic increase.

As a logic process, the variables identified in the literature review that were identified in workshops/interviews or presented in the base conditions study were included in the measurement instrument. Once variables had been identified, a conceptual diagram was created (see Figure 3).

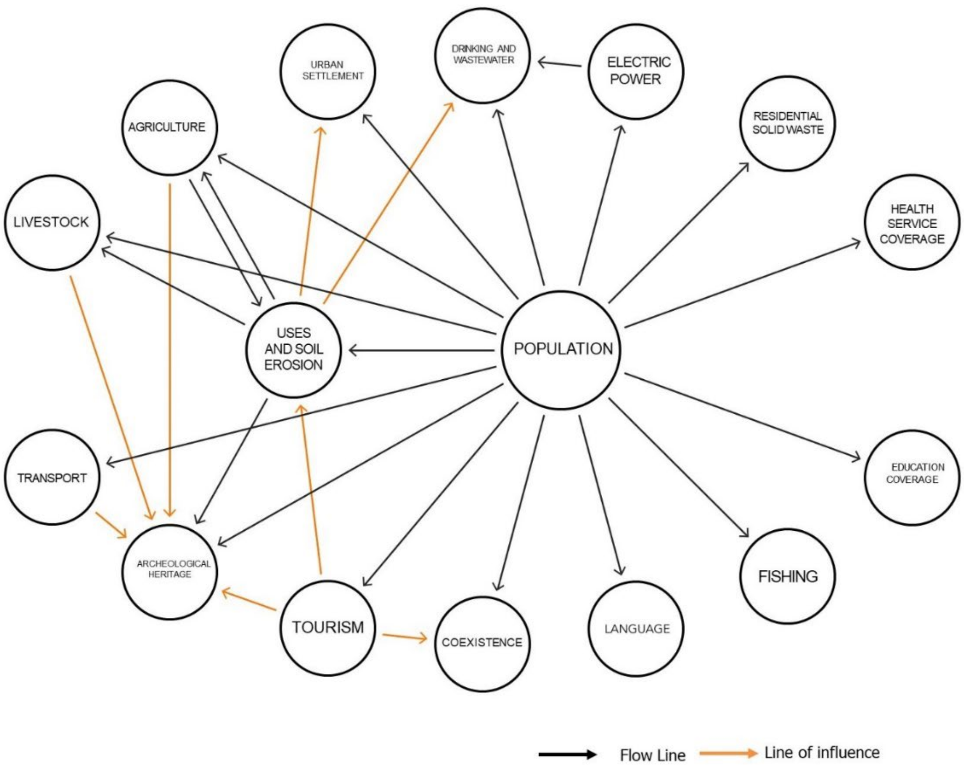


Figure 3. Conceptual diagram.

Creation of the instrument

Conceptual design of the model. The model consists of a set of variables, where each of them is a model by itself. For this reason, the variables identified for the creation of the model were called 'modules'. The population module determines and restricts the rest of the modules; that is, it is the model's unifying thread because it impacts all of the other systems incorporated in the analysis. Each of the modules contains processes and interrelations. For example, the population module is formed by the total population that, in turn, includes the resident Rapa Nui population, continental residents, and tourists.

Upon identifying the variables, the researchers implemented the model, which allows information to flow between modules. It is important to note that the model requires that these variables are represented by quantitative information.

Data collection—Driver population. In order to address the creation of a complex model, we used historical data, such as previous consumption rates, demands, and trends, based on the presumption that some historical events, trends, and cycle factors would be likely to repeat in the future.

It is important to recognize that the quality of any dynamic model depends on the quantity and quality of data used to analyze the variables' trends, which build the modules. The larger the time series data, the more accurate the equations that build the model. Unfortunately, there was a relative lack of temporal data available for the current study. An absence of consolidated data can be solved in two ways; gathering additional data (while considering both the cost and relevance), or incorporating demographic data. In this study, we heavily focused on updated demographic data and, accordingly, carried out a survey of the entire resident population of the island (6,952 residents).

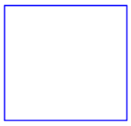
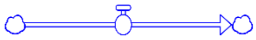
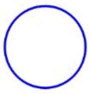
To construct the survey, we standardized the questions associated with demographic and housing characteristics with those of the 2002 and 2012 censuses, as long as they were relevant to the model, to obtain comparable information over the years. Given the opportunity to survey the entire population, we also collected additional data that would allow us to elaborate a general diagnosis of the island's problems.

Technical construction of the model. Once we identified the processes and interrelationships between modules' variables, we transferred these to *Stella*, a software which offers a graphic modeling and simulation environment based on icons (see Table 1). This software allows building, manipulating, correcting, modifying, and validating of a model in a very intuitive and flexible way. In conceptual terms, the software designs a model through stock-and-flow diagrams; that is, processes with elements capable of accumulating material and information over time (stock) and representing historical changes in the system due to different flows and interactions (flows).

For instance, the case of the 'population' module represents the monthly dynamics of the total population (residents and tourists) on the island, distinguishing, within the residents, those of Rapa Nui origin from those who are not. Its purpose is to estimate the behavior of population growth over time, both of its residents and the tourist population. This module has two essential sub-models: that of the resident population and that of the tourist population. The sub-model of the resident population records the number of people resident on the island, which changes with births, deaths, emigration, and immigration. The tourist sub-model records the monthly flow of tourists arriving on the island, using an arrivals vector since the arrival of tourists is different in each month. The sum of both populations delivers the total number of people each month on the island.

Once the model had been built in *Stella*, the researchers defined the connections between the different modules so that the data influenced the final result associated with the module to be analyzed. As an example, the 'population' driver is related to the 'electric power' module through consumption, therefore, the higher the population, the higher the electric consumption rate.

Table 1. Building Blocks Stella software.

ICON	DESCRIPTION
	**Stock:** A stock is a container that accumulates something. It collects whatever flows into it.
	**Flows:** Fills or drains stocks. An arrowhead on the flow pipe indicates the direction of the flow. The flow's equation acts as a valve, controlling the rate of flow.
	**Converter:** A converter holds values for constants, defines external inputs to the model, calculates algebraic relationships, and serves as the repository for graphical functions. In general, they convert inputs into outputs.
	**Connector:** A connector connects model variables to each other.

Communication of the instrument to the community. The objective of this phase was to provide public access to information about the project, by holding events that were open to the entire community. These events provided opportunities for the community to evaluate and discuss the project.. In preparation, we 'translated' the technical information about the project to more simplified language in order to make it more accessible to all interested citizens. One way that this was done was through the use of graphic resources that had local relevance. For this, we worked with a design team who created simplified images ('icons') that explained the conceptual model and each of its modules.

Information about the project was communicated in three formats prior to our arrival on Rapa Nui. The first was a simplified diagram of the model (as described above), in both Spanish and Rapa Nui, that we used to explain the model to the community. The second was a radio news bulletin, in which we invited the community to become familiar with the research work. The third was a booklet explaining the research project's origin, foundations, and purpose in a simplified, accessible way.

Upon arrival, the research team participated in a series of radio interviews to discuss the purpose and relevance of the project for the island. To further engage the island's community, the research team then conducted fieldwork in urban areas of Hanga Roa in the form of community workshops. In these workshops, researchers explained the research project, distributed booklets as explanatory material, and answered questions.

Given the importance of including different Rapa Nui authorities, we also organized information sessions with key organizations of the Island: *Honui*, CODEIPA, Municipal Council, Public Services, and local institutions. These sessions were attended by political and organizational representatives, and consisted of informing the attendees about the structure of the model, its progress, and the fieldwork conducted, as well as asking their opinions on the degree of representativeness of the model compared to the reality of the island.

Technical validation of the instrument. After we elaborated on the model, we sought validation from local experts such as members of political organizations of the island, officials of public services at the local and central level, and other experts in the topics of the defined variables. The objective of this process was to determine the local relevance and accuracy of the measuring instrument. This validation process consisted of two stages. The first sought to explain and give credibility to the research work. For this, we translated the modules from technical language into a colloquial language. In the same way as the previous phase, we worked with a design team who developed images that explained each of the modules (see examples in Figures 4 and 5). We then invited local experts in sociocultural, socioeconomic aspects, and key figures related to environmental issues to attend workshop sessions, which were moderated by the research project leaders. These workshops divided experts and moderators into working groups relating to each of the model's modules. In each working group, the research team explained the modules in a simplified manner, aided by the simplified versions of the model and modules. Participants were then encouraged to give their opinions and provide feedback on potential new variables, relationships, and technical corrections.

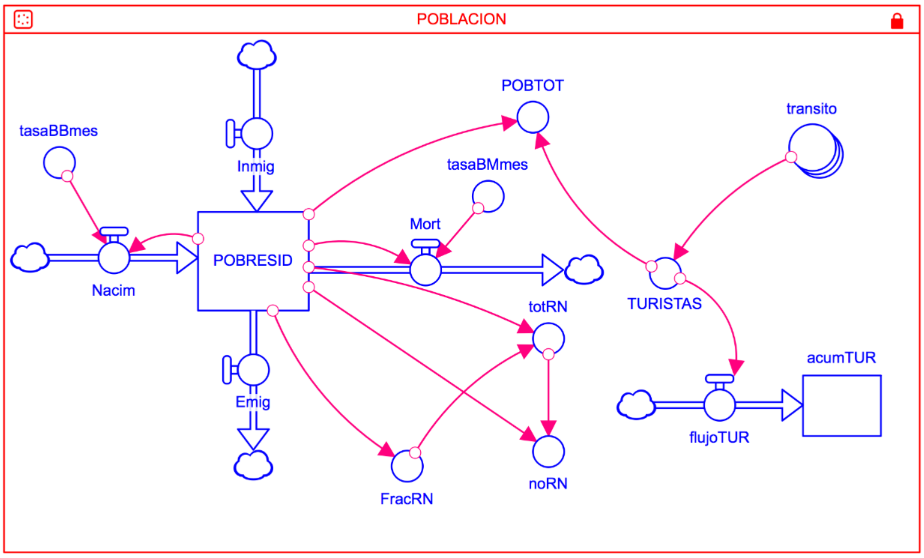


Figure 4. Module 'Population' in Stella software.

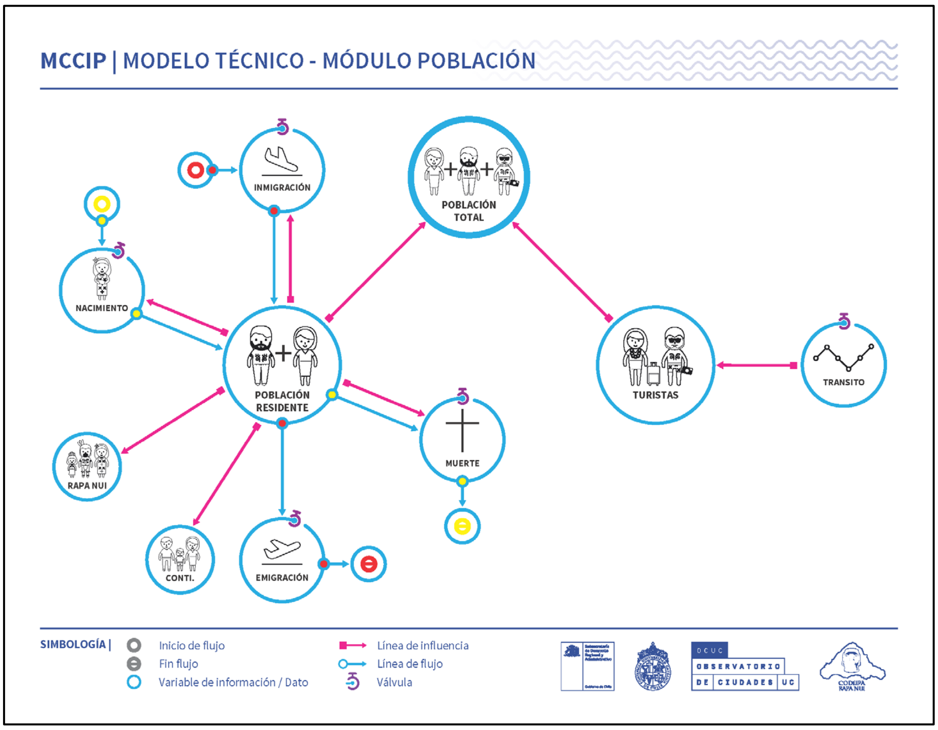


Figure 5. Module 'Population' in colloquial language.

After collating this information, and evaluating emergent themes from the workshop discussions and the availability of relevant data, the technical team made the necessary modifications to the model. Afterward, we conducted a second fieldwork visit. During this visit, we conducted a follow-up workshop where we presented the revised modules to the same attendees from the previous workshop. This visit also involved hosting community workshop sessions, as in the first visit, to communicate information about the research project to political organizations, representatives of the public sector, and figures who would be critical for implementation of the model in the private sector. As in the initial field visit, we collected workshop attendees' opinions, suggestions, and doubts regarding the model. The validated modules, their justifications, and the output variable (OV) of the model, which refer to the results of the modeling, were the following:

1. Drinking and wastewater: The main source of water for the island is groundwater, which rainfall maintains. The main threat of the groundwater contained in aquifers is the lack of sufficient sewer drainage, combined with the increase in population. Thus, the greater the population, the greater the water consumption and the aquifer risk of pollution. OV: 1) Consumption (m3/month) of drinking per person; 2) Production (m3/month) of wastewater per person.

2. Electric power: One of the key examples to prove the impact of demographic growth in the territory is the pressure on the generation of electrical energy, as power cuts have become increasingly recurrent. In addition to this, the high dependence on the continent due to the island's power system's reliance on oil as the primary generation source is also a relevant aspect to consider. Despite the possibilities, there is little participation in renewable energy. OV: 1) Electricity consumption (kWh/month) per person.

3. Residential solid waste: As a consequence of demographic increase, the production of waste has increased, which has in turn increased pressure on the current landfill. It is important to note that because this is a landfill site rather than a sanitary landfill, the current waste collection system and the possibility of percolation infiltration puts water tables at risk. OV: 1) Volume (ton/month) of waste deposited in a landfill; 2) Volume (ton/month) of recycling entered into the Recycling Center.

4. *Agriculture:* This module describes the dynamics of supply and consumption of agricultural products, considering the island's production and food imports. The model forecasts local production based on the yields per agricultural land unit. It allows identification of the time when local food production will no longer be able to meet local demands, thus requiring food importation. OV: 1) Gap (ton/month) between supply and demand of agriculture products.

5. Livestock: This module denotes the estimation of animal loads (cattle and horses), to allow for comparison against a desirable or maximum standard. OV: 1) Animal units (horses and cows) in Rapa Nui.

6. Fishing: This module stands for the dynamics of fish supply and consumption on the island. The data show a dramatic decrease in the records of some species, such as tuna. Although there are no precedents to prove it, it is possible to assume that this decrease may be due to the overuse of resources. OV: 1) Gap (ton/month) between supply and demand of Fish.

7. *Tourism:* This module represents the dynamics of accommodation for tourists on the island. In this sense, the model considers the growth of formal and informal accommodation and their use by tourists. It also takes into account the level of acceptance of tourist activity.

OV: 1) Number of tourists per month; 2) Percent of the population having a negative perception of tourism.

8. Archaeological heritage: This module draws concern about archeological sites' vulnerability due to urban expansion, tourism, and livestock pressure, which has affected sites' conservation status. OV: 1) Indices to measure the general state of archaeological sites; 2) Number of complaints and traffic to archeological sites; 3) Indices to National Park Management.

9. Housing and urban settlements: This module addresses the concern about the increase of housing density, as well as urban expansion, including areas without the feasibility of basic services, such as drinking water and electricity. OV: 1) Urbanized area (km2); 2) Housing units in the urban area.

10. Transport capacity: The problem arises from the progressive rise of the vehicle fleet, which has caused an increase in traffic congestion, accidents, deterioration of streets, and generation of junk. OV: 1) Number of vehicles.

11. Coverage of education considers the availability problem of school enrollment over time. OV: 1) The ratio of the number of enrollments and the enrollment capacity.

12. Health service coverage reflects the impacts on the demand for health services, expressed in the ratio between the number of doctors and the population. OV: 1) Number of people.

13. Soil erosion and uses: This module reflects the local community's concern regarding erosion levels and changes in land use. OV: 1) Percentage of land at different levels of erosion; 2) Changes (hectares) in *land uses*.

14. Language: This module depicts the interest regarding the loss of use and knowledge of the vernacular Rapa Nui language. This loss directly impacts the patterns of traditional life, explained by the increase of Spanish-speaking daily conversations, as the continental resident population increases. OV: 1) Number of Rapa Nui speakers of the vernacular language.

The discarded modules and the reasons for their omission are the following:

- After considerations with experts in the area and community organizations, we decided to exclude the module 'cultural expressions' from this instrument, due to the significant difficulty to quantify such information. Also, we posed that the native 'language' module is the unifying thread of cultural expressions. Therefore, as long as native language preserved, music, arts, dance, and all other expressions can be developed since they all transmit a cultural legacy.
- We decided to not develop the 'biodiversity' module for three reasons. Firstly, there is no reliable information on the conservation categories of emblematic 'species'. Secondly, when asking in the participatory workshops what species are emblematic of the island, people listed invasive species (which are without conservation threats). And thirdly, with the available data, we were not able to develop a biodiversity module that worked dynamically with the "population" module.
- We did not include the 'communal living' module, which aimed to measure the level of the perceived conflict between the Rapa Nui resident population and the non-resident and tourist populations. Although, during the initial phases of the project, the island's population emphasized its relevance, we found it to be a non-quantifiable topic.
- Other potential modules were excluded because of the lack of information or because they were too qualitative. For example, we did not develop a module for 'tourism coexistence' because they are not variables that require mathematical modeling,

in turn, 'health service coverage' and 'archeological heritage' did not have the necessary information to be modeled.

Definition of capacities. For each output variable, we carried out a group discussion with a key actor of the validation process on how to define the latency and saturation states, and documented the perceptions and suggestions when proposing the definition of each of these limits. With this information, our team set the saturation thresholds for each of the model's variables. Likewise, to define a latency state, we considered the necessary time a decision-maker needs in order to coordinate the management around said variable before it is entering a saturation level. Therefore, in each case, we pose the importance of considering the response capacity of relevant organizations and institutions. For example, in the case of the 'drinking water and sewage water' module, the primary source of water for the island is groundwater contained in the volcanic aquifer, whose storage volume is estimated between 30 and 150 million m^3. In turn, studies indicate that the availability of water in the aquifers has remained stable over the years. On the other hand, the provision of drinking water is limited based on the capacity of its infrastructure, so its limit is set based on this value. The main concern regarding water resources on Rapa Nui is the possibility that the aquifer becomes contaminated due to wastewater, coming from household discharges, but also from the landfill that does not have a system of collection of percolated liquids. While existing drilling shows that contamination of the aquifer due to wastewater infiltration from individual sewage without treatment is still far away, we found that the aquifer is still vulnerable. However, we could not define a threshold concerning the production of wastewater, that is, to determine the volume that can affect the health of the aquifer. In turn, it is essential to continue monitoring the water quality of the aquifer to ensure that runoff does not contaminate the vital resource.

Implementation of the calculation instrument. The results obtained by the implementation of the model will vary according to the existence and quality of available data. Some output variables of the CC model's present numerical results are reflecting trends, as they have more than three pieces of data available, which enables modeling over time.

As an example of this modeling, Figure 6 shows how the increase in population also increases residential solid waste deposited in landfill. The landfill will reach its saturation level in May 2025, when the gathering capacity of the landfill will become saturated (85,085 tons). The model indicates that the latency of this variable would have been reached in May 2018, because the model is designed to alert seven years before to the actual saturation date, thus allowing time to take action and go through the technical processes of landfill construction on the island (design, approval, and construction).

Other output variables, such as the fraction of people that have a negative perception of tourism, the proportion of Rapa Nui speakers of the vernacular language/non-speakers of the vernacular language, planning of benefits portfolio (health service coverage), urbanization and housing, have a static outcome at present, i.e., they are fixed over time (only one piece of data available).

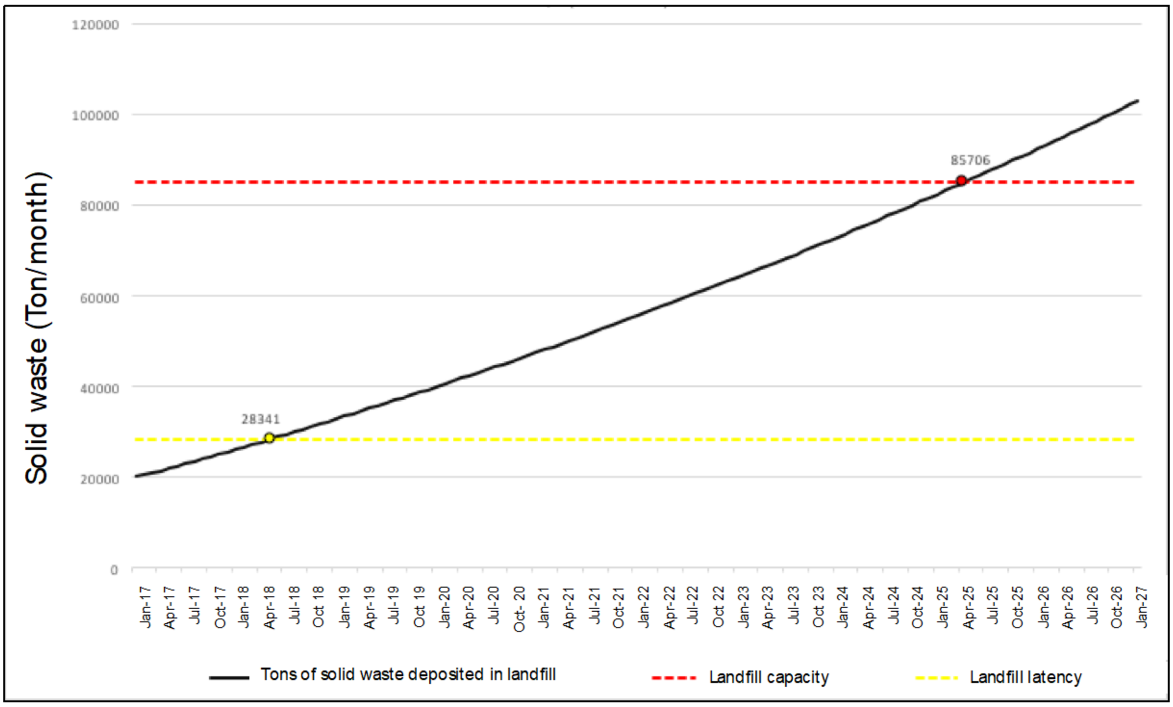


Figure 6. Modeling results of solid wastemodule.

Finally, at the present time, there are output variables for which we lack the data required for their modeling and determination of their current state. One of the advantages of dynamic simulation is that it offers the possibility of a representing a variable in a simple way, without data or the possibility of modeling over time. To the extent that the information will be available in the medium or long term, it will be possible to propose more complex representations, so that some modules will run out of information. Still, they can complement each other in the future, whenever data generation is considered necessary.

Model results

From all output variables (including those that can be modeled over time and those that currently have static results), we were able to define CC thresholds of saturation and latency for only a few of them, which the table below presents.

Table 2. Results of the demographic carrying capacity model of Rapa Nui.

Module	Output Variable	Saturation Threshold Value	Qualification of the Saturation Threshold	Month of Saturation	Definition of Latency Threshold	Model Results
Drinking Water & Sewage Water	Drinking water consumption.	103,610 m^3/month	Maximum installed capacity of drinking water production.	February 2023	Period required to implement increased production of drinking water (3 years).	Optimal.
Electric Power	Electric power consumption.	842,602.5 kWh/month	Maximum installed capacity of electrical system.	February 2017	Period required to implement increased production of electric power (3 years).	Saturated.

Module	**Output Variable**	**Saturation Threshold Value**	**Qualification of the Saturation Threshold**	**Month of Saturation**	**Definition of Latency Threshold**	**Model Results**
Household Solid Waste	Volume of solid waste deposited in landfills.	85,085 ton	Estimated maximum capacity of the landfill.	April 2025	Period required to implement a new landfill (7 years).	Latency.
Fishing	Gap between supply and demand.	3,738 ton caught fish	The threshold indicate the amount of fish caught, i.e., the offer of the resource.	The model starts saturated.	Not defined. Additional specific studies regarding the ecological cycles of species present in the extraction area of Rapa Nui are required. According to experience, it is estimated that 6 years prior to the date is enough time to develop studies and measures linked to the improvement of the condition.	Saturated.
Livestock	Animal units.	2,246 animal units	Animal load capacity, according to the availability of food and deducting the surface sensitive to erosion.	The model starts saturated.	Period required to develop and implement a management plan for animal load (6 years).	Saturated.
Tourism	Variation in the number of formal and informal beds.	2,779 tourists/month	Number of beds available. Annual month average.	February 2024	Period required to implement accommodation service (3 years).	Optimal.
Tourism Coexistence	Fraction of people that have a negative perception of tourism.	50.1% of the population has a negative perception.	More than 50% of the sample perceived a negative impact.	It is not defined on a temporary basis.	Period required to develop and implement a plan of responsible tourism (2 years) or when 30% of the population have a negative perception of tourism.	Optimal.
Language	Proportion of Rapa Nui speakers of the vernacular language/non-speakers of the vernacular language.	50% of the population in Rapa Nui present a high level of linguistic competence.	Less than 50% of the Rapa Nui people have a high linguistic competence.	Not defined on temporary basis.	Less than 80% of the Rapa Nui people have a high linguistic competence.	Latency.
Educational Service Coverage	The ratio of the number of enrollments and the enrollment capacity.	100% of available enrollments.	Available enrollments.	It is not defined on a temporary basis.	95% of available enrollments occupied.	Latency.
Health Service Coverage	Planning of benefits portfolio.	5,000 residents.	Number of people for whom the hospital benefits portfolio is designed.	The model starts saturated.	90% of the benefits portfolio.	Saturated.
Housing & Urbanization	Urbanization.	4.5557 km^2	The area corresponding to the urban limits defined in the PRC.	The model starts saturated.	Period required to define and approve a new PRC (10 years).	Saturated.
	Housing.	3,040 housing units in the urban area.	Urban load capacity according to Ámbar Study.	The model starts saturated.	Period required to define and approve a new PRC (10 years).	Saturated.

Recommendations

The impacts of the sustained increase of the resident and tourist population on Rapa Nui comprise a complex social and environmental phenomenon. The results of the current study show that, for example, the carrying capacity of the landfill is not infinite and, therefore, authorities must understand that urgent action is required. The alternatives include promoting recycling, reducing the amount of waste produced per person, increasing agreements to move garbage to the continent, or implementing a new landfill, among others. Each alternative will have its own economic and social difficulties.

This challenge is not unique to Rapa Nui; it is inherent in insular territories with limited resources and surfaces, isolated areas, fragile ecosystems, and vulnerability to climate change (Gil, 2016; Howell & Fielding, 2019). Accordingly, demographic load must be addressed by public policy at the local and national levels to promote laws that regulate, in a certain way, the impacts on the region's society and ecosystems that are valuable for world heritage.

Decision-making must consider the load limits, prioritizing them according to their importance, as well as their level of urgency. One of the deliverables at the end of the research project on Rapa Nui was to present the Management Plan of the demographic carrying capacity for the island territory, with 155 recommendations for the community. Working groups with representatives from public and private institutions discussed these recommendations in the context of territory-based decision-making, with the objective that they had to have plausible and coherent solutions to carry out in the territory.

Conclusions

In this study, we developed a model that serves as an instrument to predict latency and saturation states of the demographic carrying capacity of various environmental and territorial components on the island of Rapa Nui. This instrument will allow decision-makers to identify future problems in a timely manner, with clarity on the scope for action to formulate plans, strategies, and investments. In turn, the instrument provides the island community and decision-makers with valuable information which can inform their decisions and actions, according to their vision of development. As an example, the 'drinking water' variable is currently expected to reach its saturation threshold in March 2023. This eventuality can be delayed through various measures, such as limiting migration and the number of tourists, encouraging sustainable and efficient use of the resource, building new extraction wells, and improving the infrastructure provision, among others. These are the types of decisions to be made by islands or territories that attract significant flows of visitors and are especially fragile from a sociocultural, environmental, and economic point of view. Otherwise, there is little hope of achieving sustainable development (Marsiglio, 2017).

Another attribute of the model is the possibility that, as long as quantitative data is available, pre-existing modules can be further modeled. Similarly, it is possible to formulate new modules, in cases where the demographic CC of the territory is limited by one or more dimensions than the ones considered in the initial model.

Even though the model developed in the current study has advantages relevant to local management, the relative lack of data is a limiting factor for its use. Therefore, it is essential that information and knowledge is generated according to local priorities in order to provide data for these modules. The goal is to turn this instrument into a tool for developing a territory according to local needs and aspirations, promoting its quality of life in environmental, socio-cultural, and economic terms.

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