An empirical multidimensional analysis on sustainable tourism: the dynamics of carrying capacity

Jonathan A. Uy*, Nemi Lorraine S. Escalante, Hanah Marie M. Tonggol and Amando A. Radomes Jr.

Department of Industrial Engineering,
University of San Carlos – Technological Center,
Nasipit Talamban, Cebu City, Philippines
Email: jonyuy17@gmail.com
Email: imen.nemi13@gmail.com
Email: hanahtonggol@gmail.com
Email: amando.radomes@gmail.com
*Corresponding author

Abstract: Carrying capacity is a framework often used to attain the goal of sustainable tourism. However, current methods to determining carrying capacity are unable to holistically integrate different components that need to be considered in the achievement of sustainable tourism. Due to the dynamic behaviour of tourist attractions, there is a necessity for carrying capacity to be viewed from a systems perspective through identifying and integrating the dynamic relationships between social, ecological, and economic factors that influence the carrying capacity of a tourism system. A simulation model was developed to analyse the dynamic factors that give rise to the sustainability of the Hinagdanan Cave, an ecotourism attraction in the province of Bohol, the Philippines. Simulation results showed that the limiting factor of the cave system is the *crowd level perception* factor and that the cave has a carrying capacity of 27 persons. The determination of carrying capacity through the analysis of different components in a tourism system is possible given that the model can be used as an archetype; and at the same time, it can also be tailored-fit to address the uniqueness of characteristics and attributes of any tourism system.

Keywords: carrying capacity; sustainable tourism; system dynamics; limiting factor; cave tourism.

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Biographical notes: Jonathan A. Uy is an Industrial Engineer who graduated with the honour of Magna Cum Laude at the University of San Carlos, Philippines. He obtained his Master's in Business Management from the Singapore Management University, placing on the coveted Dean's List. He is currently the co-Founder of two companies incorporated in Singapore and the Philippines.

Nemi Lorraine S. Escalante is an Industrial Engineering graduate who recently obtained her Bachelor's with Magna Cum Laude honour from the University of San Carlos. She is currently starting up her career as a Corporate Management Associate in Jollibee Foods Corporation. She is the recipient of the Best Paper Presentation Award during the 28th Annual Heinrich Schoenig Biosymposium.

Hanah Marie M. Tonggol is an Industrial Engineering graduate from the University of San Carlos. Her research work includes systems development, life cycle assessment and system dynamics. She recently presented a paper on system dynamics at the 8th Taiwan Philippines International Conference. Currently, she is working as a Specialist at the Asia Inspection Phils Incorporated.

Amando A. Radomes Jr. is a faculty member of the University of San Carlos Industrial Engineering Department, where he teaches operations research, system dynamics, and research methods. He holds an Erasmus Mundus European Master's in System Dynamics and authored several articles in the field. He is an IE practitioner at the Metro Retail Stores Group, Inc. as a Systems and Procedures Manager.

1 Introduction

Sustainable tourism, as defined by the World Tourism Organization, is "tourism that takes full account of its current and future economic, social and environmental impacts, addressing the needs of visitors, the industry, the environment and host communities (World Tourism Organization, 2005)." In order to attain this goal, many scholars propose the usage of the carrying capacity concept for each tourism destination. This concept was first used in international shipping parlance in the mid-19th century. It was then applied to other contexts such as living organisms and natural systems (Sayre, 2008). Toward the end of that period, the term was formally coined by range managers as indicator of rangeland productivity (Bartels et al., 1993). Its first use in tourism dates to the 1960s when tourists visiting an attraction was limited to cope with the adverse effects brought about by overcrowding (Coccossis and Mexa, 2004). The World Tourism Organization (UNWTO) defines tourism carrying capacity as the limit on the number of visitors that a location can accommodate while sustaining its current desirable state (UNWTO, 1999). The concept had evolved as more aspects of tourism were taken into consideration. For instance, Batta (2000) discussed three aspects: natural (categorised further into either physical or physical); ecological (i.e., social and psychological); and economic. On the other hand, Coccossis et al. (2001) proposed three components of tourism carrying capacity: physical-ecological, socio-demographic, and political-economic. While the existing literatures provide strong grounds on the identification and categorisation of the factors that make up tourism carrying capacity, none are able to focus on analysing the dynamic effects of one factor to another over time. The current study seeks to analyse the endogenous behaviours of the factors that give rise to a tourism destination's carrying capacity using the case of Hinagdanan Cave in the province of Bohol in the Philippines. The issues on carrying capacity determination are discussed first. A systems approach to establish the causalities between economic, social, and ecological factors is explored next. Then, a simulation model is developed to analyse the future states of the cave's carrying capacity determinants. Finally, insights are provided on how the results can aid policy-makers in addressing carrying capacity for sustainable tourism development.

2 Tourism carrying capacity conundrum

Contradicting viewpoints have long surrounded the concept of carrying capacity. Ever since it was applied in the context of range management (Bartels et al., 1993), carrying capacity was based on the premise that the population growth is logistic in nature, or that it tends to grow until the population reaches its carrying capacity. In this sense, the population growth was limited by different environmental factors. However, due to constant changes to such factors, the determination of a single carrying capacity was proven to be difficult. Moreover, with the inclusion of very diverse ethical and social factors in the determination of carrying capacity, a single number cannot be developed (McCool and Lime, 2001). Butler (1993) takes this concept to the extreme by stating that the carrying capacity concept does not have substantial variables within the tourism system that can be considered to foster sustainability. This is due to the fact that variables acting as significant gauges have a delayed effect that is proven too late for any sustainability efforts to be effective.

Another salient issue concerning tourism carrying capacity is the nonlinear relationships between tourists and biophysical and social elements (Scholtz and Slabbert, 2016; Sun, 2016). Impacts increase greatly with low levels of usage and the rate of increase in impacts decrease as usage level increases. When these impacts become too severe, mitigation may become difficult to sustain. This difficulty arises because of the myriad dimensions that need to be considered (Coccossis et al., 2001). Tourist destinations are complex system, which implies that the segments that comprise it cannot be isolated and analysed myopically.

The UNWTO (1999) argued in its global code of ethics for tourism that in order for an ecotourism spot to be recognised as such, its carrying capacity must be followed. Existing studies on carrying capacity lack the analysis of the tourism systems from a system's perspective. For instance, Cimnaghi and Mussini (2015) and Salerno et al. (2013) focused on the management-side of carrying capacity. Doorne's (2000) study on the Waitomo Caves in New Zealand revolved around the social carrying capacity aspect of the tourism carrying capacity. They focused on the perceptions of overcrowding from the perspectives of different nationalities. It was found out that domestic tourists in the region were more affected by the issue of overcrowding, thus leading to problems from the side of the locals. A study on the Alcatraz Island concentrated on the various factors that affect the quality of customer experience (Manning et al., 2002). Saveriades (2000) took on the social carrying capacity concept from a different perspective as the host community of the tourist destination was also taken into consideration. The socio-cultural deterioration factor was added in line with the thought that a tourist destination can only absorb a certain amount of tourism development before negative impacts were felt by the host community. On the other hand, a study done by Rahmani et al. (2015) investigated various ecological factors such as soil depth and vegetation density to estimate the carrying capacity of Eram Boulevard, a tourist route located in the southwest region of Hamadan city. Although Mai and Smith (2015) introduced systems approach to understanding the sustainable tourism with the case of the Vietnam's Cat Ba biosphere reserve, they were not able to address the reserve's carrying capacity issue. Although the existing studies present a wealth of insights on what factors affect tourism carrying capacity, how each carrying capacity factor endogenously affects every other factor over time is yet to be addressed.

3 Carrying capacity dynamics as a complex system

The multi-dimensional issues of Coccossis et al. (2001); the dynamic behaviour of factors within the tourism system (McCool and Lime, 2001); and the fact that existing studies on carrying capacity determination narrowly focus on selected factors provide an opportunity for the researchers to bridge on the analysis gap on tourism carrying capacity dynamics. One approach in addressing complex systems such as tourism carrying capacity is through system dynamics. System dynamics, incepted in the 1960s, views problems from a systems perspective and deals with understanding the behaviour of complex systems by analysing a system's structure that gives rise to its behaviour (Meadows, 2008; Sterman, 2000). The field of system dynamics has been applied to different carrying capacity studies. A research by Fenling and Dan (2012) focused on railway cargo systems to predict the cargo carrying capacity in China. Cheng (2010) used a system dynamics model to determine the carrying capacity of water resources in Suzhou, China as basis for water carrying capacity improvements. System dynamics has also been applied by Wang et al. (2014) in their study on the ecological carrying capacity of water systems. The current study applies system dynamics to determine the carrying capacity of a tourist destination. It further wishes to use these concepts in a dynamic model to simulate behaviour and mitigate any delayed effects on sustainability as discussed by Butler (1993).

4 A primer on caves

Caves are natural openings in the earth that are large enough to allow humans to enter into. These are formed through different processes and in many types of rocks and sediments. Majority of the natural caves around the world are formed due to the dissolution of limestone and are thereby identified as solution or karst caves. One of the most important features of caves is the speleothems (Davies and Morgan, 1991).

Caves are classified into four zones based on temperature and light. At the outermost part called the light zone, mosses and ferns are found. At the twilight zone, light are dimmer, and bats and swiftlets live around this area. The third zone consists of the area where light turns to dark, and the temperature is not constant. Finally, the innermost part consists of total darkness where troglobites inhabit the area (Culver and White, 2005).

As time passed, caves have become significantly linked to exploration and other human activities (Klimchouk, 2004). Hamilton-Smith (2004) characterised human interaction with caves into three phases. The first involves human use of caves for shelter, habitation, and ritual purposes. Years after, caves transitioned to become places to be feared because legends spoke of evil spirits that resided in these as opposed to its primary purpose of providing shelter for man. This fear, however, further transitioned into exploration as the natural sciences emerged. Not long after, cave tourism was conceived.

Cave tourism brings about considerable impacts on the cave itself. Several impacts which may result from human activities in caves are the following:

- alteration of the physical structure of the cave
- alteration of water chemistry
- alteration of cave hydrology
- alteration of air currents and microclimate
- introduction of artificial light
- compaction or liquefaction of floors
- erosion or disturbance to cave sediments or their contents
- destruction of speleothems
- destruction of fauna
- introduction of alien organisms or materials (e.g., concrete, climbing aids), pollutants, nutrients, animal species, algae, and fungi
- surface impacts such as erosion, siltation, vegetation change.

It must be noted however that no two caves are the same. Caves are unique to each other thus factors that may affect a cave's natural balance differ from one another. Sunlight, temperature, humidity, water level, carbon dioxide concentrations and biological activities plus human interaction all take a toll on the natural environment of the cave on various degrees (Bosch et al., 1997).

5 Methodology

5.1 Study area

The province of Bohol in the central Philippines has been experiencing an average growth rate of 21% per year in tourist arrivals amidst the occurrences of recessions and natural calamities (Bohol Tourism Office, 2014). This figure not only describes the success Bohol has in its tourism industry, but also the great potential for the province's tourist destinations to become renowned tourist attractions in the country. Among the many tourist attractions in the province, the Hinagdanan Cave is one of the more recently developed and opened to tourists. The cave is an underground ecotourism destination located in barangay Bingag of the Dauis municipality. It is part of the Ecotourism Bohol Program that encourages loyal communities to keep preserve the nature, culture, cuisine, and livelihood of their province. It also aims to strengthen the concept of responsibility and sustainability within the area (The Bohol Chronicle, 2015). As of 2016, the cave is managed by the local government of barangay Bingag and is open for tourists. Visiting hours is from seven in the morning to six in the evening. At the entrance, tour guides are available to accompany and give the visitors a tour around the cave. Visitors' average stay in the cave is about 15 minutes.

The cave has two natural openings from which sunlight can penetrate at some time during the day (Figure 1). The cave path is 54 metres long. A pool with brackish water where swimming is permitted is located at the end of the path. Speleothems such as stalactites, stalagmites, boulders, columns and flowstone sheets are present. The cave is also a habitat to swiftlets birds.

Figure 1 View inside the Hinagdanan Cave (see online version for colours)

5.2 Dynamic model development

This study develops a simulation model of the Hinagdanan Cave tourism system to analyse how the interdependencies among the elements of the system give rise to its carrying capacity. The causalities between the ecological, social, and economic dimensions are shown in Figure 2.

Tourist activities have varying effects on speleothem health, bird population, and water quality. The speleothem health is influenced by the amount of carbon dioxide inside the cave without humans and the amount respired by tourists during the tours. The model also takes into account the rate at which the speleothem naturally grows and the rate at which speleothem degrades as influenced by the influx of tourists. Speleothem growth rate is modelled using Dreybrodt's (2005) equation:

$$R = \alpha(c - c') \tag{1}$$

where:

α reaction constant (cm/s)

c actual calcium concentration ($mmol/cm^3$)

c' actual calcium concentration ($mmol/cm^3$).

Equilibrium calcium concentration is a function of surface temperature as proposed by Baker et al. (1998):

$$c' = -0.01t + 0.72 \quad (2)$$

where:

t temperature (°C)

The bird population is affected by the noise level inside the cave. The noise level is influenced by the average number of tourists in the cave given by the equation:

$$\Psi = 54 + 10 \log N \quad (3)$$

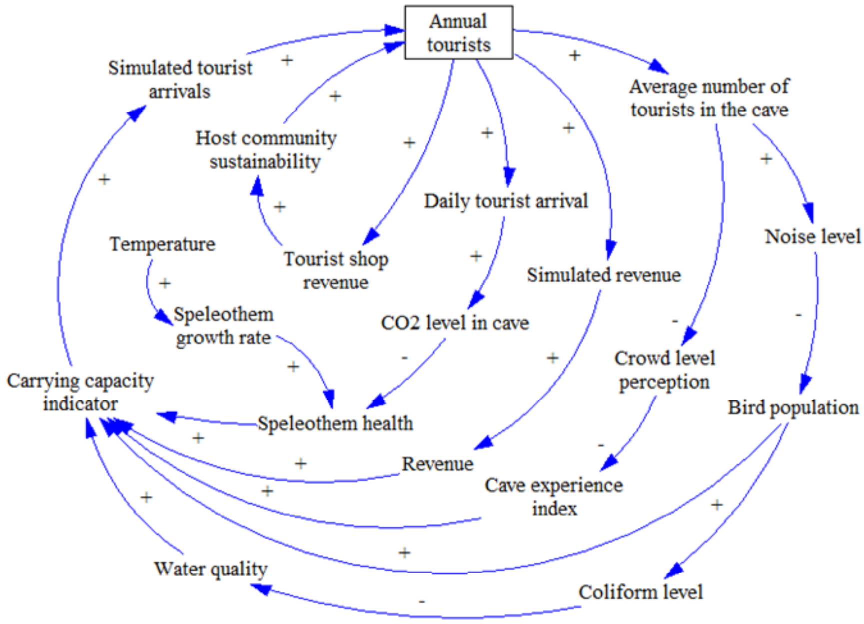
where:

N number of tourists

Initial noise level of relaxed normal speaking is at 54 dBA and this would increase logarithmically when crowd size increases (Hayne et al., 2006). When noise surpasses ambient levels, birds undergo stress and experience other physiological effects. Noise levels at 120 dBA and beyond cause hearing damage (Dooling and Popper, 2007) and drive away all birds.

The bird population also influences the coliform level in the anchialine pool because of the guano they produce. This, in turn, deteriorates water quality and may pose a threat to the biological diversity in the pool.

Figure 2 Carrying capacity model of the Hinagdanan Cave (see online version for colours)



The perceptions and attitudes of tourists toward overcrowding may influence a tourist destination's development (Liu et al., 2016; Nilnoppakun and Ampavat, 2016; Sanchez et al., 2014) and its capacity thresholds (Jurado et al., 2013). Consequently, tourist satisfaction varies greatly due to overcrowding (Rasoolimanesh et al., 2016; Yang, 2016). Walking pathways for tourists inside the Hinagdanan Cave average about one and a half metres in width, which is too narrow to provide a comfortable space to the tourists because they have to enter and exit at the same place, forcing the trail to become two-way path. There are instances when different groups of tourists enter and exit the cave at the same time, thus causing the cave to be overcrowded. The cave experiences tourist influx seasonality. The peak is from April to May each year. This is the period when the surge on visitors significantly increases the cave's humidity level, which consequently provides noticeable discomfort to those who are in the cave. Such crowd level-effect dynamically influences the tourists' satisfaction level in an inversely proportional manner. This satisfaction level is embodied in the cave experience index variable in the model.

An important aspect in the development of sustainable tourism is addressing its short and long-term economic viability (Picard, 2015). Mbaiwa and Stronza (2010), for instance, analysed how tourism development positively affects the livelihood of host communities. The economic factor focused in the current study is on the revenue generated by the tourism. There are two kinds of fees available for visitors: the first is USD 0.6 (as of December 2016) as entrance fee for all tourists; the other is USD 1.7 (as of December 2016) for those who opt to swim on the underground cave pool. Data from 2011 to 2014 provided by the cave management team shows that 16% of the visitors swim. This means that 16% of the population pay USD 2.2, while 84% pay USD 0.6. The revenue generated (as of December 2016) by the cave's fees can therefore be estimated as:

$$\rho = (0.16 \times 2.2 + 0.84 \times 0.6)\ N$$

$$\rho = 0.856\ N \tag{4}$$

where:

ρ estimated revenue

N number of tourists.

The increasing tourist influx in Hinagdanan Cave has become a means of living for the community. Benefits are visible as local residents establish job-generating business opportunities in the area. Currently, tourist shops have been opened around the cave area to cater to the needs of the visitors. The average revenue earned collectively by the shops can be estimated as:

$$\Omega = \mu \times N$$

where:

μ average expenditure per tourist

N number of tourists.

Amount of revenue generated by the tourist shops is highly positively correlated to the sustainability of the host community, implying that the more revenue generated, the more satisfied the host community is due to their economic needs being met. Noting that the case has been done in a developing country, it can be concluded that the host community is generally impacted by tourism in a positive way. Irandu (2004) supports this claim in his study that delved into how the local community of Maasai, Kenya had been impacted by international tourism.

5.3 Carrying capacity determination

Since a systems approach to determining carrying capacity simultaneously considers the behaviour of all its elemental variables, critical factors that directly affect the carrying capacity need to be identified. Once these factors and their respective limits are modelled, they need to be compared. Each factor is then quantified into an index called the carrying capacity index (CCI). The CCI is an indexing system developed by the current researchers to quantify the conditions of different factors within the cave system. CCI has a scale from +1.00 to –1.00. A positive value means acceptable or sustainable condition; a negative value means that the threshold had already been surpassed; and a score of zero means that the threshold has been reached. Once all the critical factors are integrated into the model and simulated, they are compared with the CCI. The lowest scored among the critical factors becomes the system's carrying capacity, which is termed as the limiting factor.

Due to the endogenous dynamics between the system's variables, there is a possibility of a shift on limiting factor over time. The limiting factor used to determine carrying capacity is the critical factor that first overshoots the threshold. The corresponding number of tourists at the moment the critical factor surpasses the threshold is the simulated carrying capacity.

6 Model validation

A 25-year time horizon from years 2011 to 2036 was covered in the simulation. Historical data are from 2011 to 2016 and model behaviour is projected 20 years starting at 2017. To establish confidence on the simulation output, the model undergone structural and behavioural tests (Barlas, 1989; Qudrat-Ullah and Seong, 2010). Holding other variables constant, cave experience index increases by approximately 30% when the average tourists variable is isolated and is reduced to 1. This increment is reasonable given that the index weight of this variable is close to 30%. Setting the noise level to extremely high value (e.g., at least 120 dBA, which is already deafening), bird population drops down to zero and, hence, coliform level due to bird guano also becomes zero. Consequently, water quality stabilises at –1.0 because a zero coliform level falls far short of its optimal level at 2,500 most probable number of coliform per 100 mL. The results of the extreme-value tests conducted, therefore, validate the robustness of the model.

7 Results and discussions

This section first discusses the status quo scenario, simulating how the cave system behaves given that no policies are implemented. It then demonstrates how the carrying capacity of the Hinagdanan Cave was obtained. Finally, a scenario where the carrying capacity was implemented is analysed and compared with the status quo scenario.

8 Status quo scenario

Among the several factors that govern the cave system, five factors were identified as crucial to determining carrying capacity:

1 bird population

2 water quality

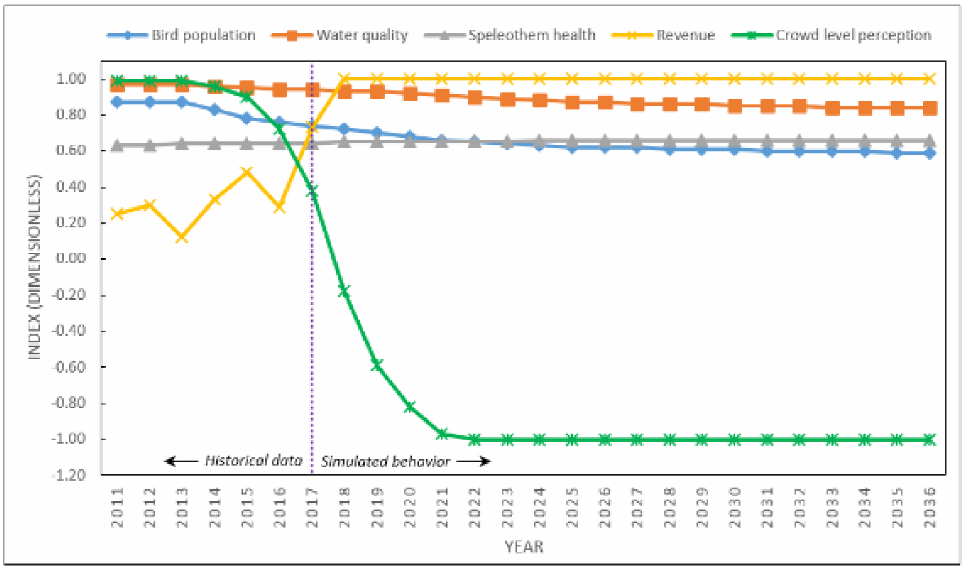
3 speleothem health

4 revenue

5 crowd level perception.

The graphs of these factors are shown in Figure 3.

Figure 3 Status quo CCI (see online version for colours)



Each variable in Figure 3 responds dynamically to the increased tourist activity experienced in the Hinagdanan Cave. Bird population index (blue curve) has a gradual decrease from 0.87 in year 2011 to 0.59 in year 2036. This is caused by the increasing number of visitors in the cave over time. More visitors pose behavioural effects on the birds (Dooling and Popper, 2007), thus causing them to seek alternative habitats outside the cave.

The water quality index (orange curve) has similar behaviour to the bird population since the quality of water in the cave's pool is significantly affected by the guano produced by the birds. Lesser bird guano causes coliform levels in the pool to decrease as well and, in the long run, affect the biodiversity in the cave.

The speleothem health index (grey curve) displays a counter-intuitive behaviour as a slight increase during the simulation period is observed. This is not associated with the increasing tourist activities, though, but with the increased surface temperature due to global warming. As temperature in the region is expected to rise, so does the equilibrium concentration of calcium in the cave (Dreybrodt, 1988). This surge eventually leads to a higher growth rate of speleothems in the cave (Buhmann and Dreybrodt, 1985). Visitors may pose threat to speleothem health; but this is arguably not the case in the Hinagdanan Cave due to the presence of adequate natural ventilation in the cave.

The revenue index (yellow orange curve) represents the cave management's expectations on the economic impacts of the tourist influx on the overall local tourism industry. The index was pegged at 0.25 in year 2011, showing that the Hinagdanan Cave has much room for improvement economically as a tourist spot. The erratically increasing value of the revenue from 2011 to 2015 is attributed to the 7.2-magnitude earthquake that hit the province in October 2013. Due to safety concerns, the cave had to be temporarily closed for three months for structural integrity and safety assessments by the local government. Another plunge is observed in year 2016 due to the management's decision to establish greater revenue target moving forward, thereafter changing the acceptable revenue threshold. The threshold shift means that the currently set revenue expectation would provide lower utility for the top management. From year 2016 onward, revenue is expected to continue to increase until it stabilises at its maximum value from year 2018 because of the expected increase in tourism activity over the years.

The crowd level perception index (green curve) describes to the perceived overcrowding experienced by the tourists who enter the cave. It starts with an index of 0.99 in year 2011 and slightly decreases to 0.90 in year 2015. A very steep descent is expected from years 2017 to 2021 until it stabilises at –1.00 from year 2022 onward. Given that the cave can accommodate a very limited size of visitors, the significant drop in the crowd level perception index in the coming years may be highly likely.

9 Cave carrying capacity

Table 1 shows the annual index values of the five critical factors. For the first six years, the revenue has the smallest value among the critical factors and is considered as the limiting factor for that period. This is validated empirically because the cave had not been as popular as other destinations in the province in the past.

The salient feature of the cave system's behaviour is that there is a shift in feedback dominance loop. The revenue has become dominant only up to the year 2016; crowd level perception gains dominance from the year 2017 onward. This empirically represents a direct trade-off between the economic (i.e., revenue) and social (i.e., crowd level perception) factors that would require close attention by the cave management. As the cave become increasingly popular to more tourists through word-of-mouth or campaign, tourist influx gains momentum until it surpasses the level that the cave management expects. The revenue index surges up from 0.29 to 0.73 because of the increased inflow of tourist arrivals. While surge on tourist arrivals creates a highly desirable state for the cave management through more collected fees, it has direct inverse relationship with how the tourists perceive the degree of overcrowding. Crowd level perception is expected to drop from 0.72 in the year 2016 to 0.38 just a year after, making it the new limiting factor of the system since then.

Table 1 Hinagdanan Cave critical factors

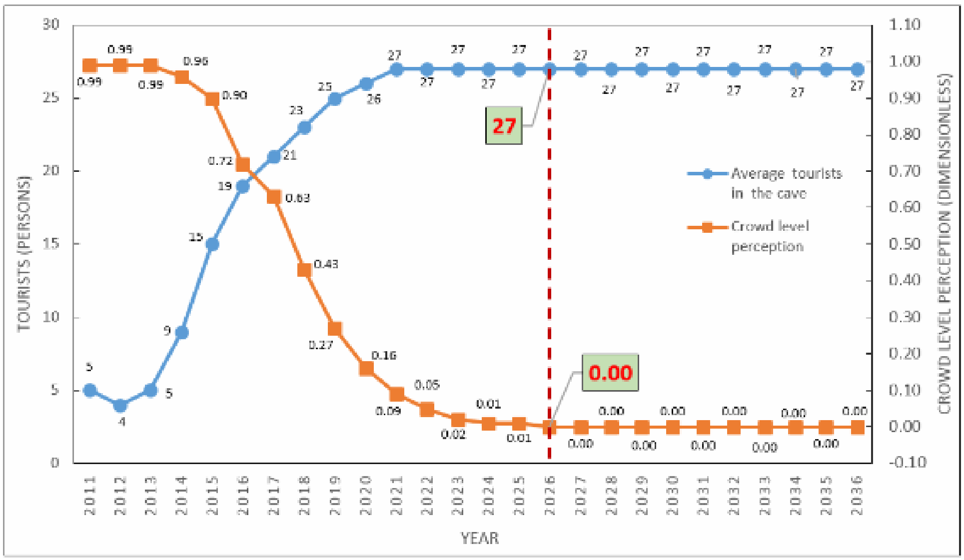
Year	*Critical factors*				
	Bird population	*Water quality*	*Speleothem health*	*Revenue*	*Crowd level perception*
2011	0.87	0.97	0.63	*0.25**	0.99
2012	0.87	0.97	0.63	*0.30**	0.99
2013	0.87	0.97	0.64	*0.12**	0.99
2014	0.83	0.96	0.64	*0.33**	0.96
2015	0.78	0.95	0.64	*0.48**	0.90
2016	0.76	0.94	0.64	*0.29**	0.72
2017	0.74	0.94	0.64	0.73	*0.38**
2018	0.72	0.93	0.65	1.00	*–0.18**
2019	0.70	0.93	0.65	1.00	*–0.59**
2020	0.68	0.92	0.65	1.00	*–0.82**
2021	0.66	0.91	0.65	1.00	*–0.97**
2022	0.65	0.90	0.65	1.00	*–1.00**
2023	0.64	0.89	0.65	1.00	*–1.00**
2024	0.63	0.88	0.66	1.00	*–1.00**
2025	0.62	0.87	0.66	1.00	*–1.00**
2026	0.62	0.87	0.66	1.00	*–1.00**
2027	0.62	0.86	0.66	1.00	*–1.00**
2028	0.61	0.86	0.66	1.00	*–1.00**
2029	0.61	0.86	0.66	1.00	*–1.00**
2030	0.61	0.85	0.66	1.00	*–1.00**
2031	0.60	0.85	0.66	1.00	*–1.00**
2032	0.60	0.85	0.66	1.00	*–1.00**
2033	0.60	0.84	0.66	1.00	*–1.00**
2034	0.60	0.84	0.66	1.00	*–1.00**
2035	0.59	0.84	0.66	1.00	*–1.00**
2036	0.59	0.84	0.66	1.00	*–1.00**

Note: *An index in italic indicates the limiting factor.

From a policy perspective, the focus of the cave management may shift away from stimulating demand from the year 2017 because the targeted tourist influx level is already generating the expected level of revenue. Instead, the other factors (i.e., bird population, water quality, speleothem health, and crowd level perception) may be looked upon. Among the five critical factors, only the crowd level perception reaches below the 0.00-threshold in the simulation. This implies that this factor would already reach an unacceptable level in the year 2018 onward. Moreover, this factor would reach the minimum index of –1.00 by the year 2022. While this may seem alarmingly detrimental to the entire tourism system, sound cave management policies can prevent this from happening.

Figure 4 shows a comparison of the crowd level perception and average tourists in the cave indices. The X-axis of the graph shows the time in years, while the Y-axis has two scales – one for each of the variables. The +1.00 to –1.00 scales taken from the CCI is for the crowd level perception index, and the number of tourists inside the cave from 0 to 200 is for the average tourists in the cave index. From this, the number of visitors resulting from a specific limiting factor score could be attained. As shown in Figure 4, there are 27 tourists that could be accommodated in the Hinagdanan Cave when the crowd level perception index, which is the limiting factor, reaches zero. It can, therefore, be concluded that the cave's carrying capacity is at 27 persons.

Figure 4 Diagram of crowd level perception vs. average tourists in the cave (see online version for colours)

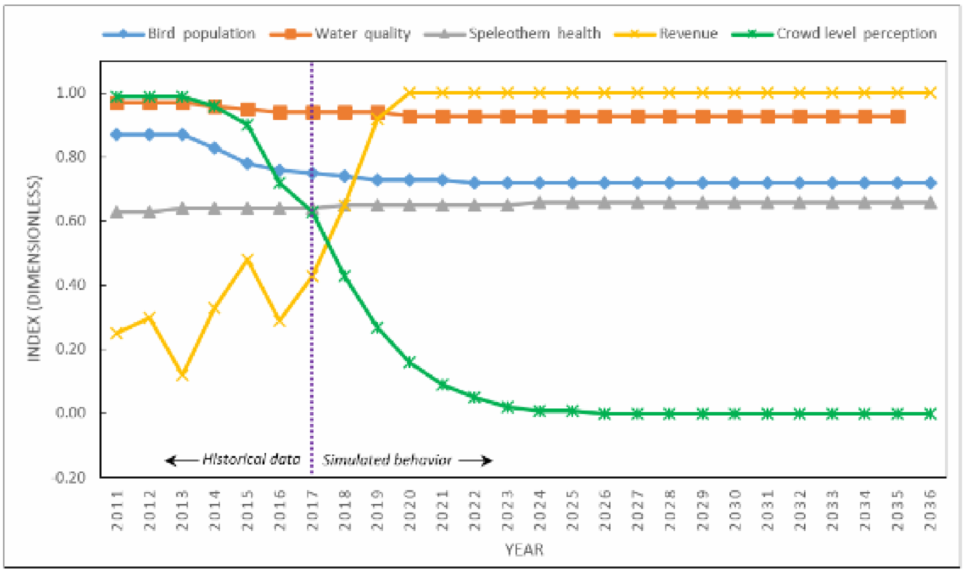


10 Scenario comparison

Different scenarios were developed by varying the values of certain variables in the model. When the carrying capacity switch variable is turned on, the model could simulate the system's carrying capacity. Figure 5 illustrates the behaviour of the five critical factors when the carrying capacity switch is turned on. The carrying capacity in the model has a minor effect on the bird population index. Years 2011 to 2015 give the same results because historical data was used for this period.

In the entire simulation period, the score of the bird population index dropped from 0.87 to 0.72. The 0.15 descent was an improvement from the 0.28 decrease simulated in the status quo scenario.

Figure 5 Index when carrying capacity is implemented (see online version for colours)



Adhering to the 27-person limit (i.e., the carrying capacity) would approximately limit the noise level as well at 68.31 dBA, which is better compared to the initial ceiling level of 74.41 dBA. Birds in the cave would be exposed to lesser disturbance level and would, therefore, be expected not to eventually leave the cave as their natural habitat.

A minute increase in water quality is observed as another effect of the carrying capacity implementation. Since there are more birds in the cave, there would also be more guano produced. This would result for coliform levels to sustain at a higher level, thus sustaining the biological diversity in the pool.

The speleothem health index exhibits identical behaviour in the two scenarios. It had a score of 0.60 the start of the simulation and a score of 0.66 at the end. This is expected because in the status quo scenario, increase in carbon dioxide level resulting from tourist respiration was not high enough to affect speleothem health. The same premise holds true for the second scenario since a decrease in carbon dioxide level occurred. Surface temperature, an exogenous variable, was not affected by limiting the number of tourists in the cave.

Revenue is directly affected by the carrying capacity policy implementation because it is a function of the number of tourists in the cave. The behaviour of the revenue index remains the same in the two scenarios: it has a score of 1.0 by the year 2036. The difference, however, is the time it took for each scenario to reach that value. In the status quo scenario, the revenue score obtained the 1.00 value at year 2018. High sales volume was gained this early on because the number of visitors was not limited. In the carrying capacity scenario, nevertheless, revenue increased at a slower pace to achieve the 1.00 score at year 2020 due to the restriction imposed. Despite having lower sales, however, the carrying capacity scenario is seen to be more advantageous due to the improvements on the values the other variables.

The crowd level perception index is the variable that is most affected by the carrying capacity policy. Without its implementation, it would take a mere 11 years for the score to go from a near perfect score of 0.99 to –1.00, the lowest score attainable on the index. By 2018, this is expected to reach a negative value, surpassing the acceptable condition. With carrying capacity being implemented, a decrease in score still occurs; but instead of reaching a –1.00 score by 2022, a 0.05 value was reached. It would take another four years to decrease the value to the threshold level (i.e., zero). Moreover, the score stabilises at the zero value until the end of the simulation period. The slower growth in tourist arrivals contributes to the steady decline in the limiting factor. Carrying capacity is also the reason why negative value was not obtained. Simulating a scenario that establishes strong feedback dominance through carrying capacity as presented in the current study provides a benchmark on how a sustainable tourism can be achieved.

11 Conclusions

A sustainable tourism system can be viewed as a network of social, ecological, and economic dynamic factors that endogenously interacts with each other over time. This study introduced a novel technique in determining carrying capacity by applying systems thinking to bridge the knowledge gap on the multi-dimensional approach to the analysis of the complexity of tourism systems. The case study on the Hinagdanan Cave located in the province of Bohol in the central Philippines had shown that quantification of a tourism carrying capacity is possible by simultaneously analysing the varying degrees of feedback dominance on the dynamic factors in the tourism system through system dynamics simulation model. Sustainable tourism management is seen as a key in balancing the overlapping, and sometimes conflicting, interests of tourism system stakeholders. Therefore, there is a need for experts and stakeholders to collaborate to create a shared understanding on how a tourism system works, like in the case of tourism development in Cat Ba Island, Vietnam (Mai and Smith, 2015); green tourism economy in Sharm El Sheikh, Egypt (Law et al., 2012), and tourism planning in Guimaraes, Portugal (Malek and Costa, 2015).

12 Limitations of the current study

The current research focused on the interdependence of three fundamental tourism carrying capacity factors: social, ecological, and economic. Future researchers may explore other soft variables, such as the impacts of the tourists' willingness to pay to enjoy sustainable destination (e.g., Lopez and Pulido, 2016); the disparate perceptions of the stakeholders (e.g., Sanchez et al., 2016; Larson and Poudyal, 2012); and tourism politics (e.g., Wesley and Pforr, 2010) and how their behaviour would dynamically affect sustainable tourism and tourism carrying capacity. Climate change and its long-term effects on cave flora and fauna (e.g., Scott, 2011) may also be endogenously explored. Furthermore, other biodiversity indices, such as the Shannon's diversity and Simpson's diversity, may be considered. However, the use of these indices must be compatible with the specific case taken for study, as the choice of index can significantly affect biodiversity results (Morris et al., 2014). Finally, knowing that various systems are interconnected, further research can cover the impacts of a specific tourism system on other biological, economic, and ecological systems.

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