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Modelling of carrying capacity at komodo national park: system dynamics approach

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Abstract*. Komodo (*Varanus komodoensis*) with its wildlife is the only one in the world that lives in the Komodo National Park (KNP), East Nusa Tenggara, Indonesia. The conservation efforts are carried out by considering the carrying capacity to remain in line with the principles of sustainable tourism management. This study aims to analyze the carrying capacity of the visits carrying capacity on Komodo Island and Padar Island. The method used in this research is system dynamics analysis. The number of Komodo dragons in 2045 is estimated to increase to 4,000–4,500 Komodo dragons in the KNP or around 2,500 Komodo dragons in Komodo Island and Padar Island because the number of prey is still quite available in their habitat. However, without the implementation of low-carbon development, there will be pressure on its population, which can drop to 800–900 Komodo dragons on both Komodo and Padar Islands. Meanwhile, the temperature increase occurs until 2045 which reaches 0.8 °C. In terms of the ideal number of visits to Komodo Island based on the carrying capacity calculation of 219,000 visits/year on Padar Island, the ideal number of visits is 39,420 visits/year, and it can still increase up to 2–2.5 times.*

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INTRODUCTION

The original habitat of the Komodo dragon (*Varanus komodoensis*) that lives in the wild is in the Komodo National Park, East Nusa Tenggara, Indonesia, which is included in the world heritage list. Komodo dragons were first studied and scientifically explained by Owuens in 1912. Komodo dragons are scattered in several parts of Indonesia, especially in the small eastern islands, namely Rinca, Nusa Kode, and Gili Motang (Forth 2013; Sunkar et al. 2020). Komodo is an endemic animal that is protected as it is the only ancient lizard that is still alive. Approximately 4 million years ago, Komodo dragons existed on the Australian Continent and moved to Indonesia, namely on the island of Flores, 900 thousand years ago (Murphy et al. 2015; Price 2016; Shine and Somaweera 2019). Increasingly, Komodo dragon species have been included in the vulnerable category and are currently in the endangered category (Ariefiandy et al. 2021). This is quoted from the International Union for Conservation of Nature (IUCN) that the animal is included in the red-list category and provides information about limited range, habitat, ecology, uses, threats, and conservation actions that may be needed.

Komodo National Park (KNP) was established in 1980 and declared a World Heritage Site and Man and Biosphere by UNESCO in 1986. Initially, the KNP was formed to preserve the unique Komodo dragon and its habitat. The KNP's goal is to protect biodiversity, especially Komodo dragons and commercial fish spawning grounds for the availability of fishing waters around them (BTNK 2016). In addition to the Komodo dragon, the KNP also has various tourism potentials in both terrestrial and aquatic areas. In terrestrial areas, biodiversity tourism potential can be found, such as Komodo dragons, long-tailed monkeys, wallet birds, horses, deer, buffaloes, and wild boars, as well as the natural panorama on Padar Island, which is surrounded by the blue sea as interesting natural tourism. Meanwhile, aquatic areas have tourism potential, such as pink beaches with the charm of the seabed filled with coral reefs and various kinds of fish; therefore, visitors can enjoy them using snorkeling or diving (BTNK 2016).

Considering the high potential of tourism carrying capacity in the KNP area, special attention needs to be paid to the improvement and restoration of conservation in the Komodo ecosystem area. The number of visits in the KNP area in time series from 2013 to 2019 were 63,801; 80,626; 95,410; 107,711; 125,069; 176,834; 221,703 visits (BTNK 2022). The pattern of visits to the KNP area tends to increase, with a decline in the last two years due to the COVID-19 pandemic which limits all activities, including tourism, causing a decrease in the number of visits. Based on existing behavioral data, there will be a significant increase after the pandemic. In anticipation of this, KNP is addressed not only for tourism orientation or mass tourism, but also for survival tourism by seeing the wildlife of Komodo and its natural ecosystem. On the other hand, the increase in the number of visitors 1.33 times (2013–2016) to 2.05 times (2016–2019) and the economic value of West Manggarai by 1.7 times (2013–2016) decreased the ratio to 1.5 times (2016–2019), this shows that economic growth is slower than the growth of visitors.

The concept of carrying capacity is the ability of the environment to support human life and other living things and the balance between the two. While the capacity is the ability of the environment to be able to absorb energy substances and/or other components that enter or are included in it (KLH 2009). The study of the carrying capacity of an area is not limited to determining the actual or current conditions. However, the carrying capacity could be used in the future. Carrying capacity is strongly influenced and mutually influences its constituent factors; therefore, it cannot be projected partially, but it needs to be comprehensive and integrated with other variables. In the context of tourism, carrying capacity is the maximum number of people who can visit a tourism destination without causing any damage to the physical, economic, and socio-cultural environment and unacceptable quality degradation while still paying attention to sustainability both at the level of development (Savareiedes 2000). This study aims to analyze the carrying capacity and limit of visits to Komodo Island and Padar Island, Komodo National Park, both in terrestrial and aquatic areas.

METHODS

Research Location and Time

This study was conducted to see the carrying capacity and capacity of the environment which is affected by tourism activities. Research activities carried out in February–March 2022. The research location is in the KNP area, especially on Padar Island and Komodo Island, as shown in Figure 1.

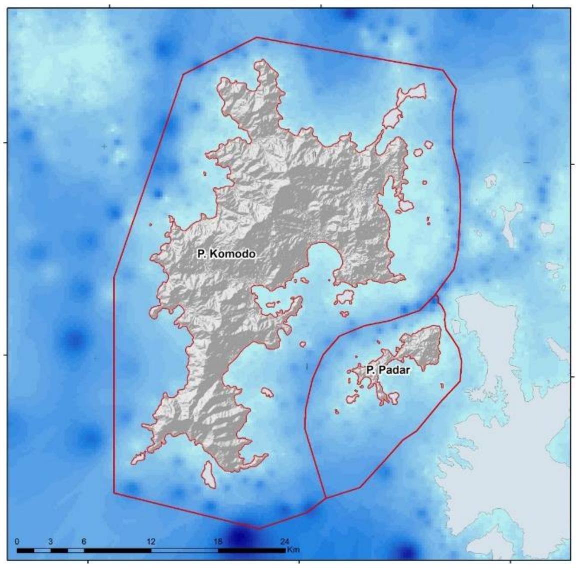

Figure 1 Komodo National Park (Komodo Island and Padar Island)

Data Collection Methods

This study uses a system dynamics approach to examine the relationship between the variables that constitute the carrying capacity model and its projections in the present and future. The system dynamics method has been widely used for various types of research for environmental management (Hassanzadeh et al. 2012), land and water resource planning (Ford 1996; Zarghami and Akbariyeh 2012), ecological modeling (Li et al. 2012), sustainability ecology and economy in urban areas (Zhan et al. 2012), island-based tourism development strategies by considering socio-economic impacts (Aliani et al. 2018), behavioral analysis of tourism destinations related to the number of visitors (Hell and Petrić 2021), analysis about the contribution of ecotourism to conservation and the presence of animals (Lola et al. 2017) and land use change (Firmansyah et al. 2019).

Data Analysis Method

System dynamics modeling was used to obtain an overview of considerations in making decisions that will be carried out by the management of the Komodo National Park (KNP) area. The stages of conducting the system dynamics analysis were developed (Firmansyah 2016), as shown in Figure 2.

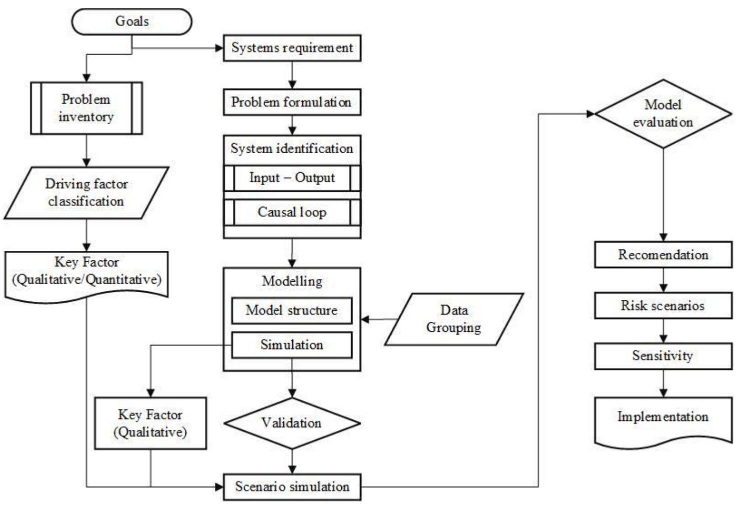

Figure 2 Step of system dynamics

The validation of system dynamics analysis can be accepted at < 10% by using equation AME and AVE (Muhammadi et al. 2001). The calculation of environmental conditions, such as the analysis of water supply and primary production, is obtained from the basis of water sources of the total forest area used as potential water absorption, class of ecosystem services, and the amount of water that has been utilized. The sources of data used in this study were primary and secondary data. Primary data were obtained directly from the results of spatial analysis and quantitative qualitative analysis in the field through questionnaires. Secondary data were obtained from the results of the previous analysis and from related institutions. Tabular time-series data and qualitative data were used. The analysis to determine the limitations of tourism activities is carried out using the carrying capacity approach with the following equation:

$$AME = [(Si – Ai) / Ai]$$

Where:
AME : Absolute Mean Error
Si : Si N, where S = simulation value
Ai : Ai N, where A = actual value
N : Observation time interval

$$AVE = [(Ss – Sa) / Sa]$$

Where:
AVE : Absolute Variant Error
Ss (simulation value deviation) : ((Si – Si)2 N)
Sa (actual value deviation) : ((Ai – Ai) 2 N)

$$CC = f (a.T; b.Tmw; c.Tmv; d.Cm; e.ES1….8)$$

Where:
CC : Carrying capacity
T : Shortest tracking
Tmw : Time walk
Tmv : Time visit
Cm : Comfortable
ES : Ecosystem services

RESULTS AND DISCUSSION

The entire concept of carrying capacity study using a system dynamics approach has causal variables, as shown in Figure 3. The causal loop diagram illustrates the relationships between the factors or variables constituting the model. Forests as land cover will affect many factors, such as ecosystem services, climate change, genetics, biodiversity in Komodo dragons and their habitats, as well as other wildlife, water ecosystem services, primary production, and others. Mangrove forests affect the balance of aquatic ecosystems and coral reefs by reducing the potential for erosion and climate change (Sukwika et al. 2020; Sukwika and Fransisca 2021).

The population influences each variable forming the model, either directly or indirectly. Directly, the population affects the increased volume of waste, which causes a high accumulation of waste, a decline in water quality caused by the discharge of domestic liquid waste, and an increase in the profession of fishermen. Indirectly, the population will also affect the decline in non-settlement land use caused by the increasing number of residents, which means the potential of increasing residential areas. Visitors' visits have a direct effect on the number of tourist boats, emissions, waste piles due to tourism activities, and the decline in seawater quality caused by discharge from ship waste.

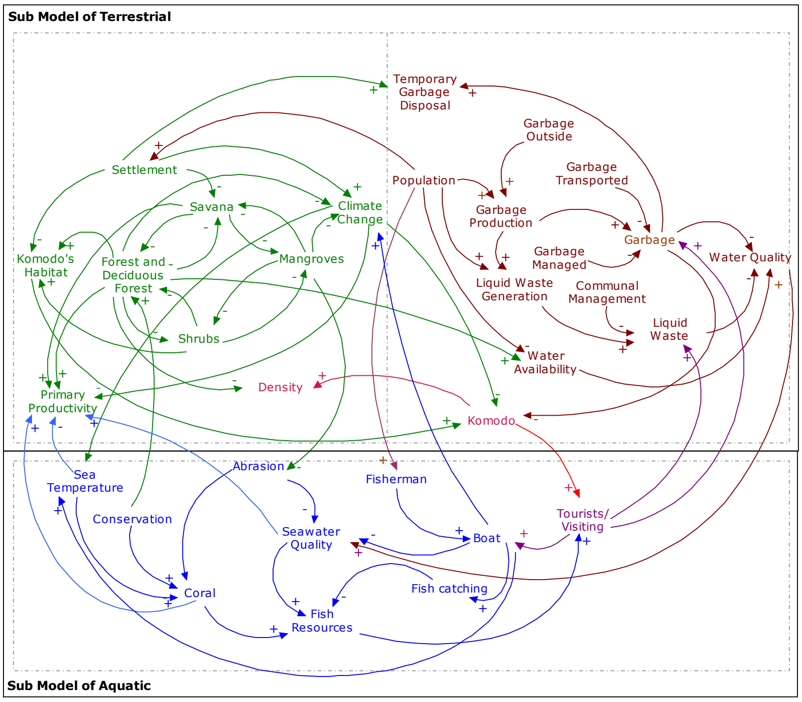

Figure 3 Causal loop diagram model of carrying capacity

The Carrying Capacity Terrestrial

The analysis of the carrying capacity in terrestrial areas focuses on land use, absorption, water supply, and primary production. The factors that cause land use change are the climate change process continues to occur and human activities that accelerate the rate of climate change. Some impacts of climate change include land use changes in the forest, desertification, extinction of species and habitats, loss of biodiversity, forest and land fires, reduced oxygen levels, changes in rain patterns and storm frequency, reduced water quality and quantity, emergence of new critical areas, and rising sea levels (IPCC 2022; Zhang et al. 2015). The results of the projection analysis in the Komodo Island and Padar Island areas show a temperature increase of 0.8 ^{o}C until 2045, which already includes a low-carbon development scenario. Although climate change is occurring globally. It is certainly the nearest area that contributes to the emission of greenhouse gases from transportation, energy use, agricultural activities, and other human activities.

Increases in temperature and land-use changes influence each other. The results of the land use change projection analysis showed that there was a change in forest land use. The changes in forestland use in 2013, 2017, 2021, 2030, and the projection until 2045 show a total area of approximately 7,321 ha; 6,925 ha; 6,012 ha; 5,878 ha; and decreased to 5,619 ha. This occurs because the area enters a dry climate; thus, land use changes will easily occur both naturally and because of pressure from human activities (Jones et al. 2018), including economic needs activities (Sukwika et al. 2022), as well as an increasing population (Zhu et al. 2014).

The performance of the model can be seen from the AME and AVE values, which are still below 10%. The visitor variable has AME and AVE values of 2.62% and 1.89%, respectively; the population variable has AME and AVE values of 1.45% and 4.56%, respectively; and the Komodo variable has AME and AVE values of 0.54% and 9.12%, respectively. This result shows that the developed model is close to the actual structure; in other words, the model contains valid data.

The Projection on Komodo and Its Habitat

By 2045, the number of Komodo dragons is estimated to increase to 4,000–4,500 Komodo dragons in KNP. This is in line with the number of prey that are still quite available in their habitat, while the utilization zone is only a small part. These Komodo dragons breed by preying on buffaloes, deer, and wild boars. There is a slowdown in 2029, because the balance slowly approaches the maximum stability of the number of Komodo dragons with their food. There may be a decline in Komodo dragons if their habitat and feed are reduced because of climate change and illegal hunting. The current condition that declines is its abundance, because the habitat is also decreasing due to climate change. This is in line with the research conducted by Jones et al. (2020) and Sunkar et al. (2020), where the Komodo dragon (*Varanus komodoensis*) is an endangered island endemic species with a naturally limited distribution, and predicts a wide coverage reduction in Komodo dragon habitat by 8–87% by 2050, which leads to a 25–97% reduction in habitat patch occupancy and 27–99% decrease in abundance across the entire species range. The results of the analysis show the projected number of Komodo dragons on Komodo Island and Padar Island, as shown in Figure 4.

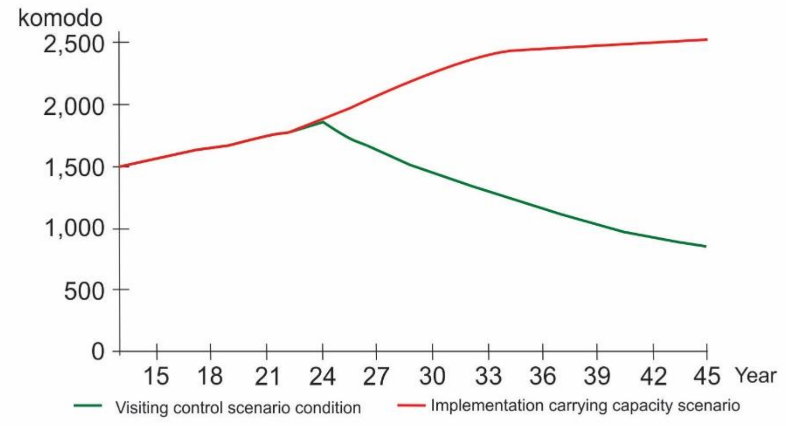

Figure 4 Komodo in Komodo Island and Padar Island

The result of the system dynamics projection shows that there will be an increase in the Komodo dragon population from 1,700 in 2021, reaching 2,400 in 2045 if the habitat is still sufficient and the feed is still available, then it grows slower as it approaches the natural balance. The trend of decreasing numbers of Komodo dragon populations can occur in 2029 on Komodo Island and Padar Island to around 1,750 Komodo dragons if there is significant climate change due to human activities without controlling for physical development and other low-carbon activities. The decline of Komodo dragons also occurs because of the decreasing number of prey owing to illegal hunting, and its habitat is becoming limited. In addition to illegal hunting, in line with the research conducted by Hufbauer et al. (2015), other influencing factors include the loss of genetic diversity, demographic changes, environmental changes, and climate change. Thus, it is necessary to create a water point to maintain the sustainable habitat of the Komodo dragons and other animals. When there is an increase in the abundance of Komodo dragons and wildlife, it is necessary to relocate these animals to other areas around the KNP Area. This is necessary to achieve a ratio between the number of dragons and the area of habitat in the wild. Another necessary measure is planting endemic plants to maintain microstability in view of climate change.

Water Provisions and Primer Production

One way to determine the carrying capacity of an environment is to use a water supply and demand approach (Ojea et al. 2012; Mori et al. 2017). The power of the water supply is influenced by rainfall, temperature, and area of forage land cover as a water storage medium. Figure 5 shows the power of the water supply, as illustrated by the absorption area and projection of the water demand.

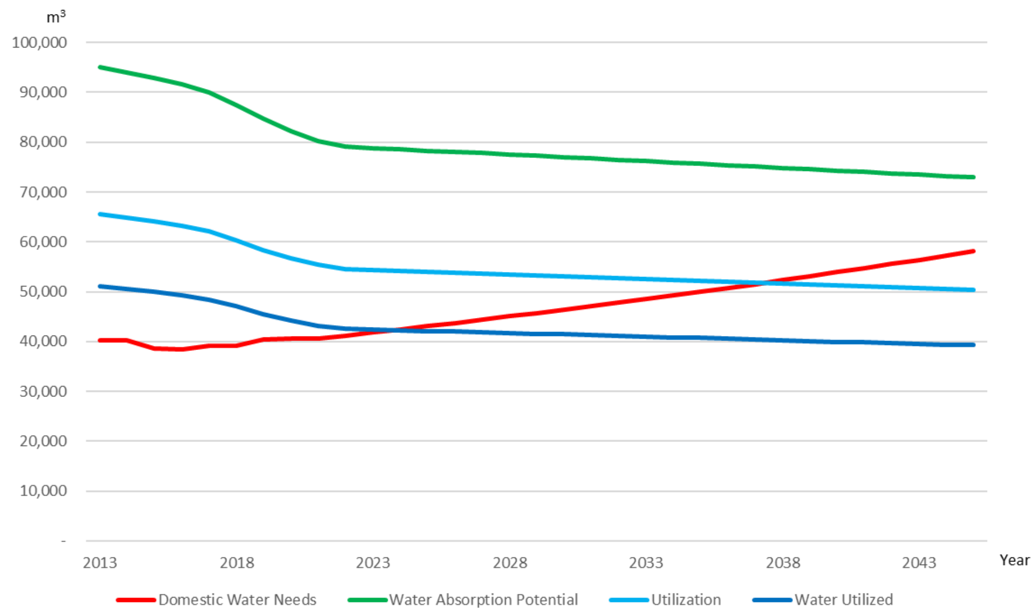

Figure 5 Water potential

Water availability in the Komodo and Padar Island areas decreased. The projection results show that in 2021 and 2045, the water demand will reach 40,622 m³ and 58,070 m³, respectively. The water absorption potential that can be utilized in 2021 and 2045 is 43,226 m³ and 39,251 m³, respectively. The increasing domestic water demand indicates an increase in total residents in Komodo Village, as well as water needs from both the KNP itself and visitors to the KNP. In those years, land use changes have occurred quite significantly, especially in forest, savanna, and mangrove land cover.

Looking at some impacts of climate change, the decrease in ocean oxygen is the most serious impact due to human activities on the Earth’s environment in the last 50 years, while the increase in areas with minimal oxygen in the sea has increased by four times; estuaries, bays, and coastal areas have low oxygen levels up to 10 times (GO2NE 2016). Climate change will influence primary production (oxygen) within the limited carrying capacity of the region in the future. The primary production value is calculated based on the amount of oxygen from the forest area of 91.1 kg/tree/year (Nowak et al. 2017); the savanna area is 540 kg/tree/year (Septriana et al. 2004), the coral reef is 11,607.46 kg/hectares/year and the pelagic water area is 12,267.48 kg/hectares/year.

In 2021, primary production is 2,198,677,815 kg/year sourced from the forest area, savanna, coral reefs, and availability of pelagic zones; in 2045, it will decrease to 1,099,338,907 kg/year. Currently, it may still be able to support the convenience of visitors’ activities, compared to the need for the tourism busiest year before the pandemic in 2019, with a use value of 966,798,714 kg/year. However, more visitors without restrictions will pressure these primary production ecosystem services because their use value is estimated at 1,244.968,306 kg/year in 2045. Primary production is needed for 2,898,073 kg/year residents, 919,131,874 kg/year visitors, and 1,222,603,200 kg/year transport. This needs to be a concern in the future regarding the restrictions on Padar Island with its environmental limitations.

Land Use for Settlement

The carrying capacity is inseparable from land use to ensure that the number of residents and settlement area can be accommodated in one stretch of land. The carrying capacity analysis is more focused on residential land use in Komodo Village. The results of the projection analysis show that there is a tendency to increase land use for settlements, with a projected population of 1,855 people in 2021 to 2,652 people in 2045. This is also true if the villagers enforce the customary law about the restrictions on villagers who have families outside the village, then they must leave the village. Meanwhile, if the villagers do not apply customary rules, then it is estimated that the population will increase rapidly to 3,322 people by 2045.

The increase in settlement area is caused by population growth factors and movements from outside Komodo Village. Meanwhile, an increase in settlement area will occur in 2045, covering an area of 17.11 hectares. This area shows that the capacity of the land for settlements is still below the provision of the zone that should exist which is 26.68 hectares. However, it should be noted that as the population continues to increase, there will be an explosion in settlement demand in the future, both approaching and exceeding the specified area. The population growth graph can be seen in Figure 6 (a) and settlement needs can be seen in Figure 6 (b).

The village area is allocated to settlements, farming, and public facilities such as public fields and schools. Every newly married couple in Komodo Village occupies a house yard measuring (9 m x 12 m = 108 m²). Therefore, if each household consists of two 4–5 people, the allocation of residential land in 2021 will be around 9.91 hectares of the available 26.68 hectares, including other needs for social and public facilities. An increasing need for settlements will occur, equivalent to the settlement zone available in 2046, without applying the customary law. On the contrary, if customary law is still running, an increased need for settlements will appear in 2077.

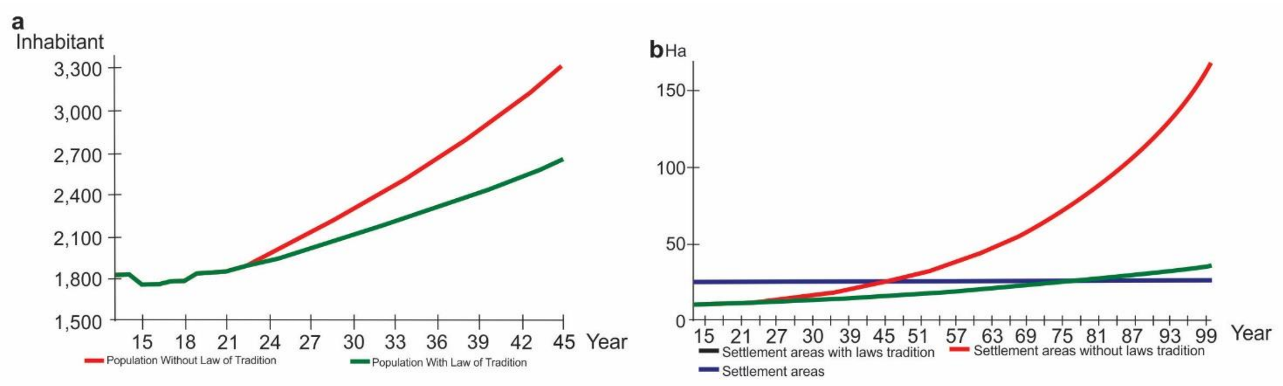

Figure 6 The population growth and settlement needs

The Projection of Waste

The waste comes the most dominant from residents in Komodo Village as much as 0.7 tons/day, waste from visitors as much as 0.01 tons/day (BTNK 2017), and waste carried by currents is estimated at 0.25 kg/day. The projection of waste piles in the KNP area is shown in Figure 7.

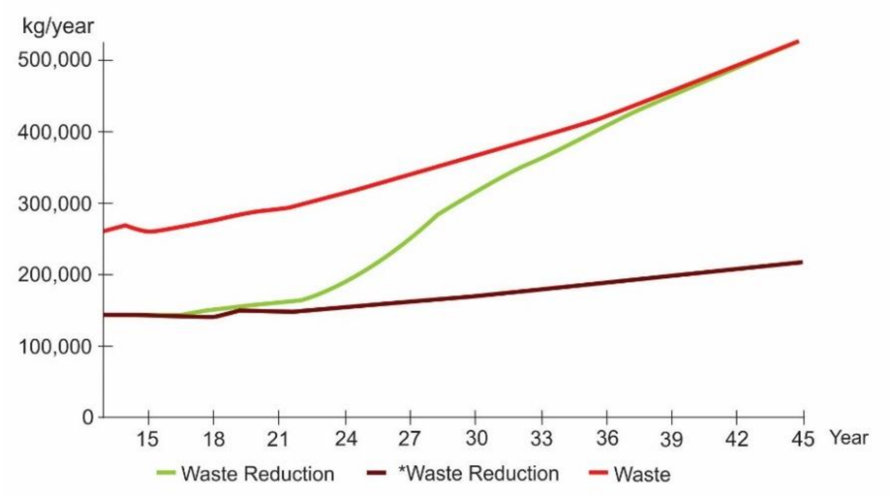

Figure 7 Waste projection

The amount of waste in 2045 will tend to increase by approximately 528,026 kg/year. The scenario analysis shows that applying a waste reduction program and starting waste management efforts in 2022 to overcome the waste pile problem can reduce existing waste piles. Waste reduction efforts can be in the form of reduce-reuse-recycle temporary garbage disposal management, waste management with eco enzyme techniques, composting, and other processed waste. Therefore, it is necessary to conduct training, empower people, and collaborate with other stakeholders. However, the environmental ability will only be capable of cleaning itself in 2039. This can be seen in Figure 7. The figure is the result of the system dynamics modeling, which shows that the environment will not be able to clean itself until 2039.

The Carrying Capacity for Visitors

The growth behavioral data on visits showed a significant increase from 63,801 visits in 2013, then 107,711 visits in 2016, to 221,703 visits in 2019. Despite the COVID-19 pandemic, it is estimated that the growth will return in 2–3 years post-pandemic and show behavioral growth to normal, reaching 479,240 visits by using projection analysis until 2045. If the management applies the restriction-free visit policy, it will cause high-density levels of visitors and result in discomfort during travel, both from the availability of facilities, security, and the accumulation of visitor numbers. This will automatically cause the number of visitors to decrease due to inconvenience. In addition, pressure on the environment and its ecosystem services has been lost because they exceed their maximum capacity. The growth behavioral data for the visits and projections are presented in Figure 8.

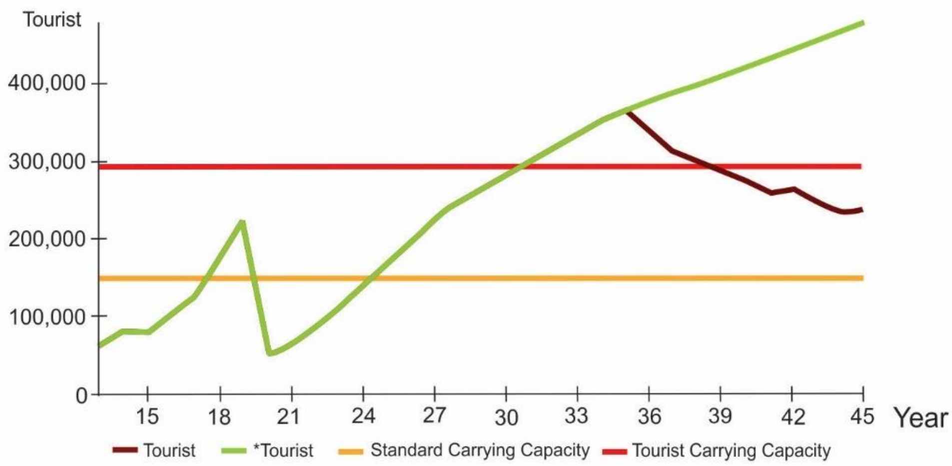

Figure 8 Visitor projection

The analysis of the capacity of visits on Padar Island, which considers the average daily visits based on the feasibility of capacity in terms of security and service standards multiplied by the number of visits and the ecosystem services availability, indicates that in one day there are 108 visits and in one year there are 39,420 visitors per year. It can be increased up to 2–2.5 times by improving services, safety, and facilities until it reaches 98,550 visitors per year. The number of visits to Komodo Island and Padar Island are described in Tables 1 and 2.

The capacity of visits to the terrestrial area on Komodo Island was analyzed based on the length of the shortest tracking path, the average length of the walk, the length of visit, the level of comfort during the travel of the visitors, and considering the Ecosystem Services (ES), biodiversity, water supply, air, and other ecosystem services. The environmental capacity throughout the terrestrial area of Komodo Island shows that the ideal number of visits is 219,000 visitors per year, with a maximum range of 292,000 visitors per year, and a standard range of 146,000 visitors per year.

Table 1 Number of visits on Komodo Island

Activities	**Value**	**Unit**
Shortest trek		
Step time average travel time	40	Second
Length of visit	1	Hour
Number of visitors (standard)	50	People
Number of visitors (maximum)	100	People
Total visit time	8	Time
Number of visitors/year (standard)	146,000	Visitor/year
Number of visitors/year (maximum)	292,000	Visitor/year
Average number of visitors ideal	219,000	Visitor/year

Table 2 Number of visits on Padar Island

Activities	**Value**	**Unit**
Number of visitors per visit	12	People
Total visit time	9	Time
Number of visitors per day	108	Per day
Number of visitors per year	39,420	Visitor/year
Number of visitors with improved service, health and safety	98,550	Visitor/year

The capacity of the tourism area is not seen by the number of visitors queuing along the track but by the availability of comfortable space for traveling. On Padar Island, it was also calculated that each person takes selfies at post points or shelters. Indeed, it is not recommended that visitors stand or walk outside the available track or post/shelter because it can endanger their safety. Especially on Padar Island, after 8 o'clock, the sun is quite hot due to the condition of the area being quite dry and lack of trees, and a buildup of queues can reduce the comfort and safety of visitors. Visitors will perform high activity under hot temperature conditions; meanwhile, if the average ambient temperature increases, they will experience more heat stress. Excessive heat can lead to disorders, such as dehydration, heat rashes, heat cramps, fatigue, fainting, and heatstroke (Gauer and Meyers 2019). This condition is more likely to occur if there are no restrictions on visitors until 2045, with a high density and lower primary production.

The addition of public service facilities on Padar Island is highly recommended to ensure the security, safety, and comfort of visitors. For example, additional infrastructure such as rest shelters and 3–4 additional stairs in the middle of the trail path that protrudes 40 cm deep, to anticipate if there are visitors who pass by, both going down and up. These stairs are used when someone wants to stand and rest for a while on the journey between the shelters. Another service facility is the provision of clean water to other areas or shelters. There are already three toilets available for bath wash toilets. Ideally, more visitors need more male and female toilets to add and improve according to the minimum service standard where one toilet can be used for approximately 10–20 people separately for men and women. In addition, the area needs special first aid rooms and medical personnel that are not yet available as a precaution for visitors with a vulnerable health history. To provide better facilities, management capability is needed by strengthening human resources such as rangers and medical personnel. Strengthening these human resources can provide better services for visitors (Wahjono 2015).

Limiting the number of visits as a conservation effort does not mean that it will reduce the visitors' interest in visiting; otherwise, it can increase their length of stay on Komodo Island and in the Padar Island areas. Strengthening tourism destinations in other locations, as well as integrating local tourism destinations in Labuan Bajo and West Manggarai, is another way to maintain the harmony of the total number of visitors.

The Carrying Capacity of Aquatic Area

The potential for aquatic tourism in Komodo National Park is very high. Several location points for diving and snorkeling were determined based on the results of the zoning and bathymetry overlays by taking the deepest point of the seabed fault/seabed back. The aquatic area for calculating the carrying capacity is 70,344.12 ha, divided into the water zone area of Komodo Island is approximately 57,667.98 hectares and Padar Island is about 12,676.14 hectares. The points taken among others are Indihalang Island, Amjama, Broken Hill, Tukoh Serikaya, Wizard Hut, Toro Moncong, Castle Rock, Cristal Rock, Lighthouse, Cauldron Passage, Karang Makassar, Batu Tiga, Three Sisters, Pilarsteen, Batu Gaja, Tanjung Lelok Sera, Manta Alley, German Flag, Twins, Lengkol Rock, and The End of The World Eta. The distribution of diving points is shown in Figure 9.

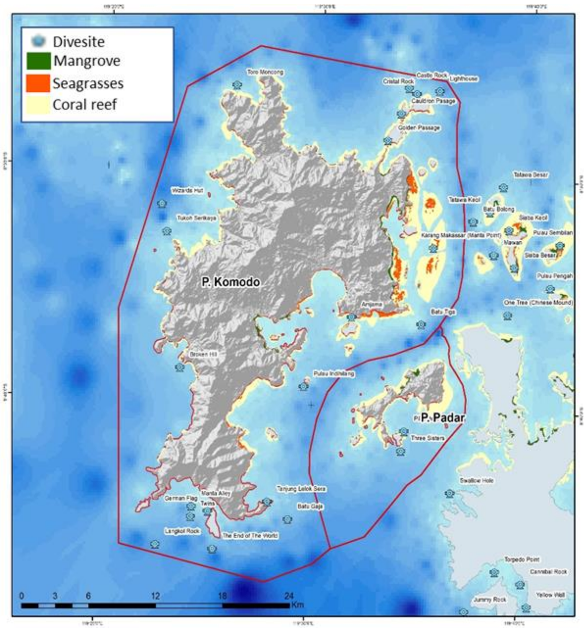

Figure 9 Diving point

The graphic simulation shows that coral reefs exhibit a declining trend. This is due to several pressures, such as fishermen using bombs or fishing nets that can damage coral reefs, as well as significant climate change. A projection of the coral reef is shown in Figure 10. The scenario in the projection of coral reefs is transplantation of the coral reefs. If the area of coral reefs is transplanted at 150 ha every three years, it will minimize the potential for coral reefs to decrease by 1,419 hectares from the original 6,251 hectares to 4,832 hectares. This means that coral transplantation will maintain the sustainability of coral reefs.

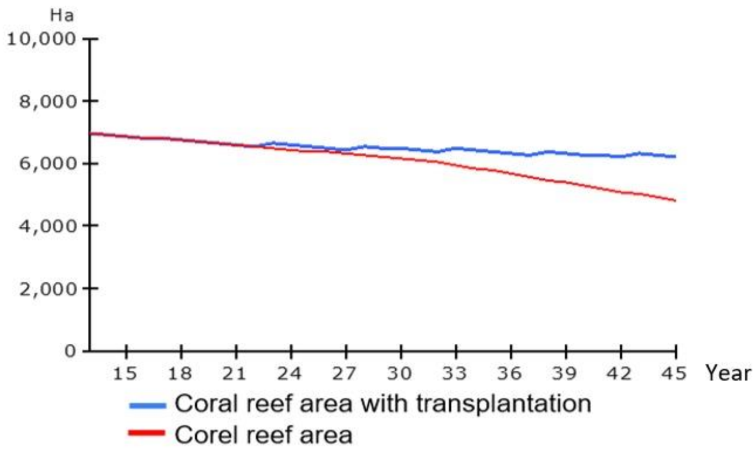

Figure 10 Corel reef projection

The capacity to visit the water area was divided into visits for divers and snorkelers. The capacity of visits for diving attractions is analyzed by considering the number of dive points, the area of coral reefs or other spots such as fish observations including depth, the closest distance between points, and the time of diving (Giglio et al. 2015; Lelloltery et al. 2018). The analysis of the capacity of visits to the water area for snorkeling is presented in Table 3, and for diving is presented in Table 4.

Table 3 Snorkeling potential

Snorkeling potential	Value	Unit
Beach length	5,315.07	Meter
Distance per group	300	Meter
Snorkeling point	18	Points
Snorkeler beach area	12.42	Hectares
Snorkel	15	People
Long snorkeling	2	Hours
Time snorkeling	2	Times
Total snorkeler	197.100	Snorkeling

Table 4 Diving potential

Diving potential	Value	Unit
Diving point	8	Points
Other diving point	14	Points
Coral reef area	397.09	Hectares
Smallest area coral reel (diving point)	5.56	Hectares
The closest distance between points	1	Km
Coral reef divers	15	People
Other divers	15	People
Distance per group	500	Meter
Long diving	2	Hours
Time diving	3	Time
Diving per divers	6	Time
Maximum number of dives	361.350	Divers/years

The projection of coral reefs is influenced by other variables such as climate change, tourist pressure, and natural factors from the aquatic environment. A little change in sea water temperature will cause reduction of quantity and quality of coral reefs because they are no longer suitable for their habitat. The extreme temperature increase can make Zooxanthellae react (Baird et al. 2018). Every 1–3 degree of sea temperature increase causes coral bleaching, coral death, decrease coral cover and shifts in populations of other coral-dwelling organisms (Moreno et al. 2012; Sheppard et al. 2017).

Likewise, the number of the visitors also influences the coral reefs since the more visitors who do snorkeling and diving, the potential for damage to coral reefs will be even greater. Damaged coral reef ecosystems are caused by human activities, especially tourism activities such as in Nusa Penida, Bali, which showed an increase in damage of 4% (Jubaedah and Anas 2019). On the other hand, the ignorance of ship operators which still anchor in the waters needs a better understanding related to coral reef areas. In addition to this, it is also necessary to minimize the number of ships staying in the waters.

The projection of coral reefs is influenced by other variables such as climate change, tourist pressure, and natural factors from the aquatic environment. A little change in seawater temperature will cause a reduction of the quantity and quality of coral reefs because they are no longer suitable for their habitat. Likewise, the number of visitors also influences coral reefs because the more visitors the snorkel and diving, the greater the potential for damage to coral reefs. This is in line with research conducted by Jubaedah and Anas (2019), who stated that tourist pressure and natural factors from the aquatic environment, such as a decrease or increase in seawater temperature, will disrupt coral reef development. However, the ignorance of ship operators who still anchor in the waters requires a better understanding of coral reef areas. In addition, it is necessary to minimize the number of ships staying in aquatic waters on both Komodo and Padar Island.

CONCLUSION

The number of Komodo dragons in 2045 is estimated to increase to 4,000–4,500 Komodo dragons in the KNP or around 2,500 Komodo dragons on Komodo Island and Padar Island because the amount of prey available in their habitat is adequate. However, without restrictions on tourism activities, there will be pressure on the Komodo dragons to become 800–900 Komodo dragons on both Komodo Island and Padar Island because of the effects of climate change. In terms of the ideal number of visits to Komodo Island based on the calculation of the carrying capacity of 219,000 visitors per year on Padar Island, the ideal number of visits is 39,420 visitors per year and can still be increased up to 2–2.5 times.

Likewise, the carrying capacity of the aquatic area is under pressure from aquatic tourism and fishing activities, such as fishing with bombs, causing massive coral reef damage. Therefore, it is necessary to transplant 150 ha of coral every three years. Capacity, infrastructure, and ecosystem services were used as the basis for calculating the carrying capacity. Globally, climate change is dominated by surrounding activities, both of which have an impact on transportation emissions and visitor activity density.

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