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Implications of Increased SST on Sula Dactylatra in Rapa Nui Marine Park

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Abstract

Marine protected areas are a relatively new conservation tool intended to remove harmful anthropogenic practices and influences to enable ecological processes to occur normally, but they cannot protect ecosystems from global impacts like climate change. One such MPA, Rapa Nui Marine Park in Chile, is home to the Masked Booby, Sula dactylatra. Though not currently endangered, their population numbers decrease annually, and seabirds are among the most threatened species in the face of climate change. This study seeks to examine the spatial ecology of the Sula dactylatra against the context of the MPA and examines whether increasing sea surface temperatures (SST) will render the protected area insufficient. This study used statistical analyses in R using open datasets from the World Database on Protected Areas, Movebank, and NOAA. Our findings indicate that on average, SST increased 0.1 degrees per year from 2010 to 2020, culminating in a 1-degree increase over that decade. There is no indication this pattern will subside. The global nature of climate change, evidence of local SST increase, and lack of MPA management suggests that the boundaries of Rapa Nui Marine Park do nothing to protect enclosed masked booby foraging range from climate change effects. As climate conditions continue to change, it is likely that the spatial ecology of the masked booby and other species in Rapa Nui will be impacted in some way. There needs to be more research done to evaluate how ENSO or seasonal changes contribute to increasing SST in this area, as well as what effect this may have on the prey species of the Sula dactylatra. It may also be valuable to understand the varying management needs across Rapa Nui, as many islets are subjected to different conditions and may require different oversight. Aside from climactic factors, park effectiveness is still dependent upon funding and to what extent the regulations are enforced.

Keywords

Sula dactylatra, foraging ecology, sea surface temperature, marine protected areas, climate change

Disciplines

Biodiversity | Marine Biology | Oceanography

Comments

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Marine protected areas are a relatively new conservation tool intended to remove harmful anthropogenic practices and influences to enable ecological processes to occur normally, but they cannot protect ecosystems from global impacts like climate change. One such MPA, Rapa Nui Marine Park in Chile, is home to the Masked Booby, *Sula dactylatra*. Though not currently endangered, their population numbers decrease annually, and seabirds are among the most threatened species in the face of climate change. This study seeks to examine the spatial ecology of the *Sula dactylatra* against the context of the MPA and examines whether increasing sea surface temperatures (SST) will render the protected area insufficient. This study used statistical analyses in R using open datasets from the World Database on Protected Areas, Movebank, and NOAA. Our findings indicate that on average, SST increased 0.1 degrees per year from 2010 to 2020, culminating in a 1-degree increase over that decade. There is no indication this pattern will subside. The global nature of climate change, evidence of local SST increase, and lack of MPA management suggests that the boundaries of Rapa Nui Marine Park do nothing to protect enclosed masked booby foraging range from climate change effects. As climate conditions continue to change, it is likely that the spatial ecology of the masked booby and other species in Rapa Nui will be impacted in some way. There needs to be more research done to evaluate how ENSO or seasonal changes contribute to increasing SST in this area, as well as what effect this may have on the prey species of the *Sula dactylatra.* It may also be valuable to understand the varying management needs across Rapa Nui, as many islets are subjected to different conditions and may require different oversight. Aside from climactic factors, park effectiveness is still dependent upon funding and to what extent the regulations are enforced.

Key Words

Sula dactylatra, foraging ecology, spatial ecology, sea surface temperature, Rapa Nui, marine protected areas, climate change, ENSO

Introduction

The masked booby, or *Sula dactylatra*, is a species of seabird which can be found across tropical oceans. While *Sula dactylatra* has a conservation status of least concern and an extensive worldwide distribution, its global population size has not been quantified and appears to be declining (BirdLife International 2021). This gap in knowledge prompts investigation into how much of their habitat and expanse is protected, including areas for foraging and nesting. One example of a habitat is Rapa Nui, a Chilean island home to twelve seasonal nesting species, including *Sula dactylatra* (Plaza et al. 2020). There are thought to be around seventy breeding pairs which seasonally nest on Rapa Nui (Lerma et al. 2020). The number of nesting seabird species has declined in recent years for a variety of reasons, which includes but is not limited to, the geographic isolation of the island, climate and ecological changes present, an influx of visitors and new residents which further promote anthropogenic land degradation, and hunting (Plaza et al. 2020). The ecosystem is already regarded as fragile given its location in the world's 'largest ocean desert', named so for its oligotrophic quality and being situated in the Southern Pacific Gyre (Lerma et al. 2019). Home to the South Pacific garbage patch, the area is subjected to both macroplastics and microplastics, especially from industrial fishing, although there was no evidence of entangled birds in the Rapa Nui Marine Protected Area (MPA) (Luna-Jorquera et al. 2019).

Theoretically, marine reserves remove human predation and direct pollution from the area, allowing species to recover abundance and size. However, this assumption requires that there is enough oversight, financial resources, and local cooperation to ensure the success and vitality of the territory. The existence of such conditions is disputable at Rapa Nui given numerous studies (Roberts et al. 2017). Originally created with an economic motive to restore fish stocks for future capture and consumption, MPAs have been found to be one of the most practical and cost-effective strategies in ocean conservation and marine science when managed correctly (Roberts et al. 2017).

To infer whether the Rapa Nui MPA is sufficient to maintain local populations of masked booby, it is critical to understand the foraging ecology of *Sula dactylatra* in the face of climate change. Much research has already been conducted to investigate foraging behavior of *Sula dactylatra.* Past studies have found that foraging behavior is linked to extrinsic and environmental factors, including the relationship between bathymetry and sea surface temperature (Sommerfeld et al. 2013). Parental roles and body mass are also important considerations, as it has recently been discovered that in connection with reverse sexual dimorphism, females dive deeper than males and spend more time flapping on the water and less time resting, while the opposite is true for males (Sommerfeld et al. 2013). The most concerning study indicates that there were less predictable prey encounters during the period in which there were no local trips to feed the chick and no distant trips to replenish body reserves. Researchers may find it difficult to inform conservation efforts if the masked booby's behavior increases in variability. This is expected to be exacerbated by further climate change (Sommerfeld et al. 2013).

Specific to Rapa Nui, masked boobies travel in a number of different directions and seem to dive haphazardly rather than at specified locations, exploring less than 110 kilometers from the colony (Lerma et al. 2020). The seabirds feed on flying fish, squid, anchovies, and sea chubs (Lerma et al. 2020). To protect *Sula dactylatra* and other seabird species, initiatives have focused on eradicating invasive species, providing fencing, and encouraging pet owners to not allow their dogs and cats to roam freely (Plaza et al. 2020). However, this does not address climactic factors, which can also negatively impact the masked booby, especially in an ecosystem as sensitive as this one. This study seeks to explore the extent to which Rapa Nui Marine Park encapsulates masked booby foraging range, and how spatial protection of this range may not account for the pervasive, unanticipated effects of climate change.

Methods

We acquired MPA polygon data on Rapa Nui from the World Database on Protected Areas (WDPA). The source listed was the Protected Areas System of Chile, and the data was last updated in 2020. The total reported area of Rapa Nui Marine Park was 579,368.0 km^2. We acquired booby tracking data from the Movebank online database. This point data was originally published by Lerma et al. 2020. Foraging movements were recorded using GPS CatLog-S devices attached to chick-rearing birds. Every 4 minutes, the devices recorded time, latitude, and longitude. This data was recorded only during the months of October and November in 2016 and 2017 (Lerma et al. 2020). Sea surface temperature (SST) data was pulled from the 'NOAA_DHW_monthly' dataset using R. Polygon data, foraging data, and SST data were taken and processed in R. SST data was arranged into two datasets. One was grouped by month and year, and it gave mean SST at the scale of a month. The other was grouped by year and gave mean SST at the scale of a year. The packages we used were *rerddap*, which allowed us to pull monthly SST data from the 'NOAA_DHW_monthly' dataset, *rerddapXtracto*, which allowed us to extract data for every point within our polygon of interest, and *ggplot2*, which allowed us to create data visualizations.

Results

The foraging range of *Sula dactylatra* was completely within MPA boundaries during October and November 2016 and 2017 (Figure 2). A scatterplot displaying the mean SST within MPA boundaries showed seasonal variation across years. From 2000 to 2020, the warmest month in each year was February. A cyclical pattern of seasonality was observed in which mean SST gradually decreased throughout the spring and early summer months, reached a low in late summer, and began to increase after September (Figure 4). In February 2007, a majority of the MPA area was approximately 25 °F. However, in February 2017, there was a notable shift, indicating that a larger area of the MPA warmed to 26 degrees Fahrenheit or above (Figure 5). SST averaged at the scale of a year did not display a significant linear trend from 2000 to 2020 ($b = 0.01$, $p = 0.28$, $r^2 = 0.06$). SST decreased from 2000 to 2010, then increased until 2020. This was best described as a nonlinear temporal trend. The increase in SST from 2010 to 2020 was significant ($b = 0.10$, $p = 0.01$, $r^2 = 0.54$). Over this period, average annual SST increased by about 0.1 degrees per year (Figure 6).

Discussion

The full extent of observed *Sula dactylatra* foraging range was within Rapa Nui Marine Park boundaries (Figure 2). This shows that, on paper, *Sula dactylatra* foraging range was spatially protected by an MPA. However, this is rendered meaningless when removed from the context of changing environmental conditions. Climate change, driven by increasing greenhouse gas emissions, is warming our oceans globally. This sea surface temperature (SST) increase is highly dependent upon time and spatial scales, meaning warming rates vary across ocean basins (Costoya et al. 2015). Our study focused on the spatial scale of Rapa Nui Marine Park, and the time scale of 2000 to 2020. There was a significant increase in mean SST from 2010 to 2020, at the rate of 0.1 degrees per year (Figure 6). This is equivalent to a 1-degree increase per decade. It is unclear whether this trend was driven by general ocean warming as a result of climate change, or by some prolonged warm water event. Marine heat waves are distinct, extended warm water events caused by climate change (Shanks et al. 2019).

No matter the cause, our results suggest that Rapa Nui Marine Park has experienced significant SST increase, and its boundaries are arbitrary in relation to climate change effects. This warming could have major ecological implications, as SST increase has been attributed to species distribution shifts across oceans and taxonomic groups (Weinert et al. 2021). The masked booby could be affected in a similar way, as studies have indicated that masked booby foraging behavior is related to environmental factors, such as SST (Sommerfeld et al. 2013).

Based on significantly increased SST in the span of a decade, Rapa Nui could be subject to prominent climate change effects such as acidification, sea-level rise, escalation of storms, changes in species distribution, and changes to nutrient availability. Sea surface temperature is an important indicator to consider because it reflects the additive, antagonistic, or synergistic effects of climate change previously referred to (Roberts et al. 2017). It is important to note that while climate change and associated effects are driven by increased atmospheric CO_2, this does not mean identical spatial patterns will be observed in the area. One example of direct climate change effects on *Sula dactylatra* could be high SST and reduced nutrient availability, resulting in reduced productivity, negatively impacting food resources. It has been found that in tropical marine environments, prey is concentrated not only in productive areas, but also areas with a lower SST, where seabirds tend to encounter prey more frequently (Lerma et al. 2020).

SST fluctuated seasonally in Rapa Nui, with February being the warmest month each year (Figure 4). Seasonal fluctuation in SST likely leads to predictable fluctuation in productivity that seabirds are adapted to. However, a comparison of the spatial SST overlay for February 2007 and 2017 revealed a concerning development. As a result of climate change, the warmest month of each year became significantly warmer than before (Figure 5). The significant increase in seasonal SST extremes could mean that seasonal productivity lows are also exaggerated, reducing the already low availability masked booby prey. Additionally, the significant overall increase of SST in a single decade (2010 to 2020) is cause for concern, as there is no indication the trend will change. This means the foraging behavior of *Sula dactylatra* could be significantly challenged for years to come, and in unpredictable ways.

Our observation of increased sea surface temperature is consistent with other findings. Given the annual increase in global carbon dioxide emissions during the 20th century, it is no surprise that global sea surface temperatures are rising (Baki Iz 2018). Chile and particularly this area of Rapa Nui are subjected to periodic El Niño Southern Oscillation (ENSO) events, partaking in a positive feedback loop where ENSO initiates SST anomalies, which in turn exacerbate extreme weather events. Studies have shown that significant somatic growth rate decreases in fish are associated with ENSO, and marine organisms on the Eastern Pacific coast experience high levels of mortality during such events (Hernández-Miranda and Ojeda 2006). Together with the Antarctic Circumpolar Current, Antarctic krill have recently witnessed changes in recruitment, survival, and dispersal (Stenseth and Voje 2009). Because krill are designated as a keystone species being so foundational to the food web, their success is pertinent to seabirds and other marine mammal predators (Stenseth and Voje 2009). This is yet another example of impending threats to the masked booby and highlights how designated areas of land will not be able to combat changing environmental factors. However, conclusions based upon these studies contrast with that of a 2020 study analyzing data from seabirds on Clarion Island in Mexico, which also experiences El Niño events. Researchers concluded that in low-productivity waters in tropical areas, the effects of El Niño do not seem to present additional pressure on masked boobies and their predation on flying fish (Lerma et al. 2020). However, the researchers also reveal that Clarion Island is generally environmentally stable and is not as influenced by ENSO-related patterns, which may explain why the ecology of the masked boobies did not change from year to year (Lerma et al. 2020). In the context of our findings, little is revealed about how SST impacts the foraging ecology of *Sula dactylatra,* and we offer several recommendations for future studies to eliminate uncertainty in this area.

Potential impacts driven by SST increase could be mitigated through proper management of Rapa Nui Marine Park. By removing direct anthropogenic disturbances, MPAs can bolster biological processes of ecosystems within their boundaries, helping species adapt to the effects of climate change. However, such benefits are dependent upon effective implementation and management of MPAs (Roberts et al. 2017). Evidence regarding an absence of management shows that Rapa Nui resembles a paper park. 'Paper parks' are MPAs where regulations are not enforced, and little is done to help promote biodiversity (Schéré et al. 2019). A study evaluating the existence and effectiveness of management plans for Chile's protected areas found that only five of 20 MPAs had management plans. Only marine reserves were associated with management plans, and none were managed effectively. Because Rapa Nui is a marine park, not a marine reserve, it had no management plan. However, based on this study's findings, the presence of a plan is no guarantee of its effective implementation anyway (Petit et al. 2018). With no effective management in Rapa Nui Marine Park, species' resiliency to the effects of climate change is not fully supported.

To understand the complexity of climate change and full extent of its impacts, it may be more informative to analyze SST trends regarding changes in seasons or extreme events like ENSO (Costoya et al. 2015). Given that our study used two different data sets, one spanning two decades and another from 2016 to 2017 only, it would also be more insightful to use synchronous recordings of environmental and foraging data. This would help to draw more decisive conclusions rather than predicting a timeline based on observations from a year, as was done here.

As per the lack of proper management in Rapa Nui Marine Park, future studies should assess management needs in Rapa Nui's islets, as they may require different conservation strategies rather than blanket solutions. This is highly recommended considering each islet has different species assemblage, seasonal changes in species composition, invasive species, and proximity to urban areas (Plaza et al. 2020). For example, Rapa Nui has particularly struggled with domestic pets in an increasingly urbanized area, rendering these cattle, horses, dogs, and cats as invasive (Plaza et al, 2020). It has also been identified that domestic waste attracts upwards of three species of rats which also wreak havoc on nesting behavior (Plaza et al, 2020). In contrast, these species are absent from the more rural Motu Nui, and so the recommended fences and collaboration with residents becomes null. However, management should consider its special morphology which is characterized by caves and other nesting sites (Plaza et al. 2020). Stakeholders are also realizing that the island's isolated and costly location have inhibited long-term seabird studies in this area (Flores et al. 2014). Future research should account for this especially as we come to understand how vulnerable islands, as well as seabirds, are to the effects of climate change.

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Author Contributions

Hayden analyzed data and produced figures using R. She then wrote figure captions, Methods, and Results. She also contributed to the Discussion and found sources.

Flavia wrote the Abstract, Introduction, Acknowledgments, and contributed to the Discussion. She also helped to find sources and proofread the R script.

Literature Cited

Bâki Iz, H. 2018. Is the global sea surface temperature rise accelerating? Geodesy and Geodynamics 9(6):432-438.

BirdLife International. 2021. Species Factsheet: *Sula Dactylatra.* <http://datazone.birdlife.org/species/factsheet/masked-booby-sula-dactylatra> Accessed August 29, 2021.

Costoya, X., M. deCastro, M. Gomez-Gesteira, and F. Santos. 2015. Changes in sea surface temperature seasonality in the Bay of Biscay over the last decades (1982-2014). Journal of Marine Systems 150:91-101.

Flores, M. A., R. P. Schlatter, and R. Hucke-Gaete. 2014. Seabirds of Easter Island, Salas y Gómez Island and Desventuradas Islands, southeastern Pacific Ocean. Latin American Journal of Aquatic Research 42(4):752-759.

Hernández-Miranda, E., F. P. Ojeda. 2006. Inter-annual variability in somatic growth rates and mortality of coastal fishes off central Chile: an ENSO driven process? Marine Biology 149:925-936.

Lerma, M., J. A. Castillo-Guerrero, S. Hernandez-Vazquez, and S. Garthe. 2020. Foraging ecology of a marine top predator in the Eastern Tropical Pacific over 3 years with different ENSO phases. Marine Biology 167.

Lerma, M., J. Serratosa, G. Luna-Jorquera, and S. Garthe. 2020. Foraging ecology of masked boobies (*Sula dactylatra*) in the world's largest "oceanic desert." Marine Biology 167.

Luna-Jorquera, G., M. Thiel, M. Portflitt-Toro, and B. Dewitte. 2019. Marine protected areas invaded by floating anthropogenic litter: An example from the South Pacific. Aquatic Conservation: Marine and Freshwater Ecosystems 29(2): 245-259.

Petit, I. J., A. N. Campoy, M. Hevia, C. F. Gaymer, and F. A. Squeo. 2018. Protected areas in Chile: are we managing them? Revista Chilena de Historia Natural 91.

Plaza, P., J. Serratosa, J. B. Gusmao, D. C. Duffy, P. Arce, and G. Luna-Jorquera. 2020. Temporal changes in seabird assemblage structure and trait diversity in the Rapa Nui (Easter Island) multiple-use marine protected area. Marine and Freshwater Ecosystems 31(2):378-388.

Roberts, C. M., B. C. O'Leary, D. J. McCauley, P. M. Cury, C. M. Duarte, J. Lubchenco, D. Pauly, A. Sáenz-Arroyo, U. R. Sumaila, R. W. Wilson, B. Worm, and J. C. Castilla. 2017. PNAS 114(24): 6167-6175.

Schéré, C. M., T. P. Dawson, and K. Schreckenberg. 2019. International Journal of Sustainable Development & World Ecology 27(7): 596-610.

Shanks, A. L., L. K. Rasmuson, J. R. Valley, M. A. Jarvis, C. Salant, D. A. Sutherland, E. I. Lamont, M. A. H. Hainey, and R. B. Emlet. 2019. Marine heat waves, climate change, and failed spawning by coastal invertebrates. Limnology and Oceanography 65(3): 627-636.

Stenseth, N and K. Voje. 2009. Easter Island: Climate change might have just contributed to past cultural and societal changes. Climate Research 39(2): 111-114.

Sommerfield, J., A. Kato, Y. Ropert-Coudert, S. Garthe, M. A. Hindell. 2013. The individual counts: within sex differences in foraging strategies are as important as sex-specific differences in masked boobies *Sula dactylatra.* Journal of Avian Biology 44(6):531-540.

Weinert, M., M. Mathis, I. Kroncke, T. Pohlmann, and H. Reiss. 2021. Climate change effects on marine protected areas: Projected decline of benthic species in the North Sea. Marine Environmental Research 163.

Figures

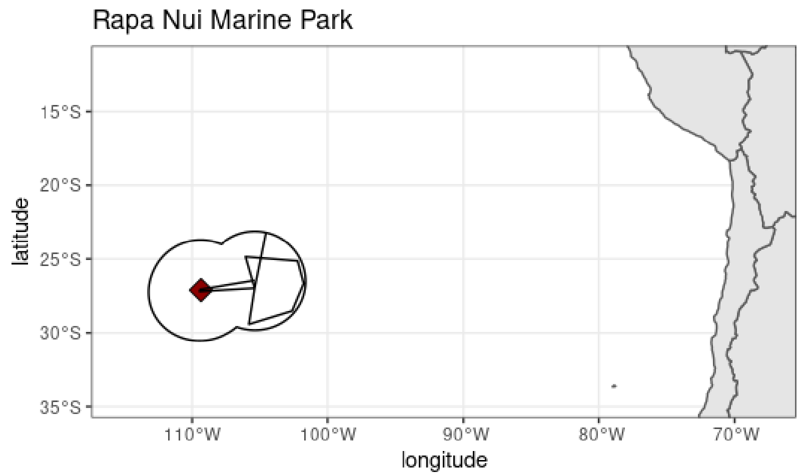

Figure 1. Map displaying the orientation of Rapa Nui Marine Park. Located off the coast of South America, Rapa Nui (Easter Island) is a Chilean territory (Lerma 2020). Polygon data was sourced from the Protected Areas System of Chile.

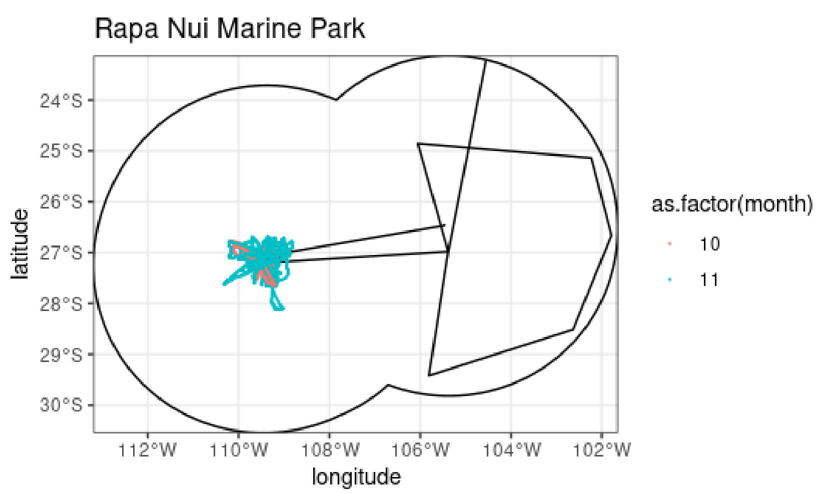

Figure 2. Map displaying the layout of Rapa Nui Marine Park and local, recorded foraging range of the masked booby (*Sula dactylara*). Data points are grouped by month, orange being October and blue being November. Data was collected at Motu Nui, an islet located southwest of the island of Rapa Nui. Nine chick-rearing birds were tagged in 2016, and 14 chick-rearing birds were tagged in 2017.

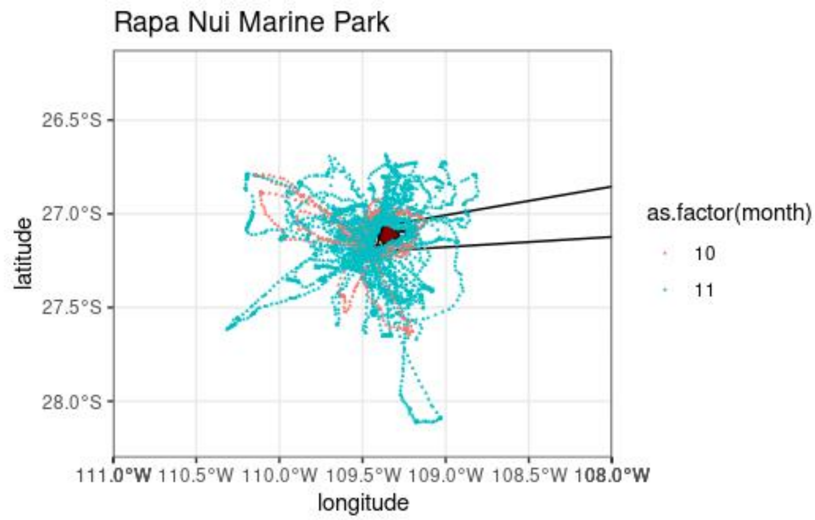

Figure 3. Large-scale map displaying the recorded locations of individual masked boobies (*Sula dactylara*) while foraging. Data points are grouped by month, orange being October and blue being November. Data was collected at Motu Nui, an islet located southwest of the island of Rapa Nui. Nine chick-rearing birds were tagged in 2016, and 14 chick-rearing birds were tagged in 2017.

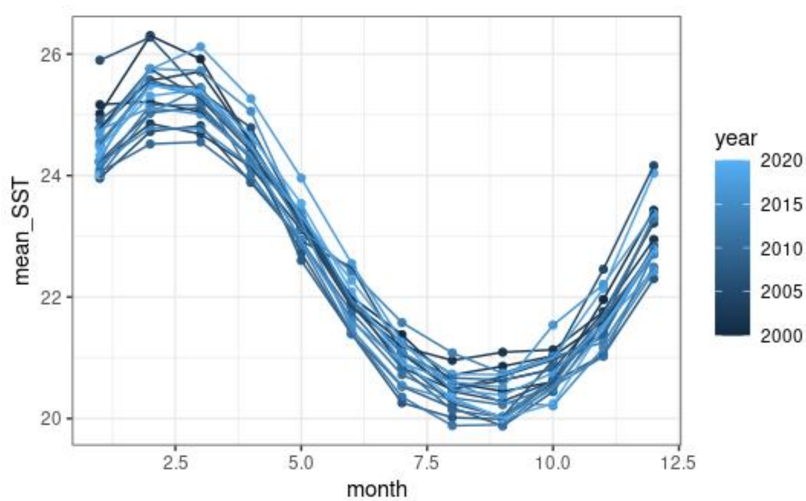

Figure 4. Scatterplot showing seasonal variation in the average sea surface temperature of Rapa Nui Marine Park. This data spans two decades, 2000 to 2020. Across all years, February had the highest mean SST. SST data derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor, which is carried by NASA's Aqua satellite.

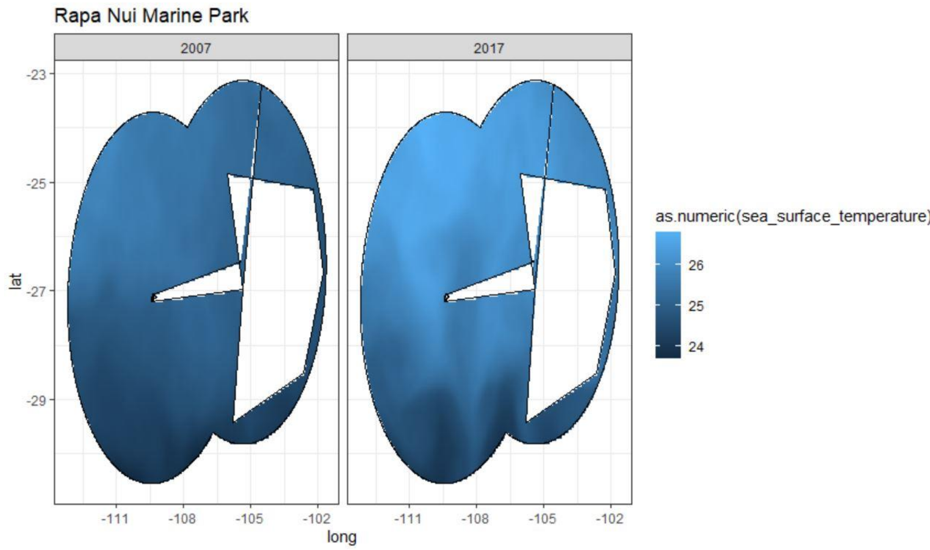

Figure 5. Spatial visualization of mean sea surface temperature data in Rapa Nui Marine Park. SST data is from the month of February in years 2007 and 2017. SST data derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor, which is carried by NASA's Aqua satellite.

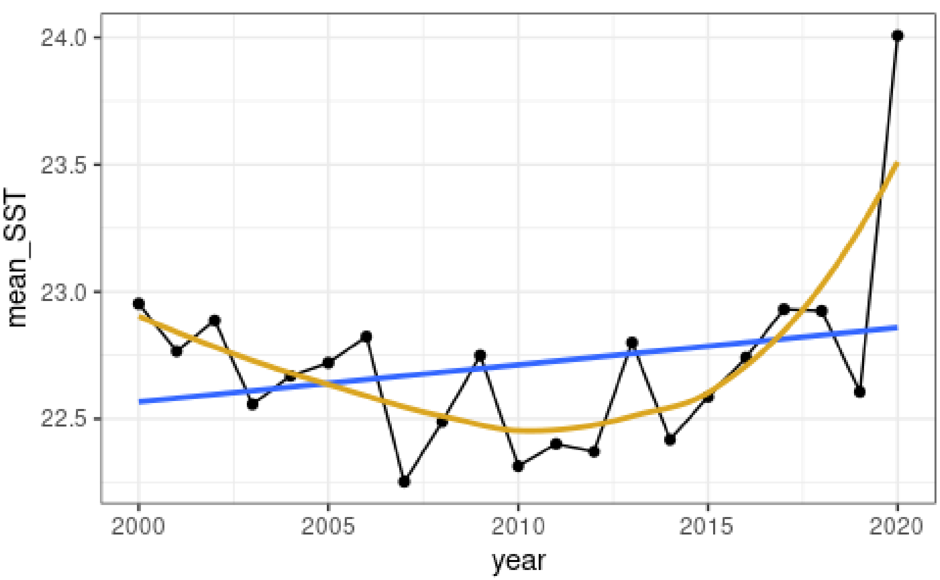

Figure 6. Scatterplot of mean sea surface temperature in Rapa Nui Marine Park from 2000 to 2020. SST data derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor, which is carried by NASA's Aqua satellite.