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Using Programming Languages and Geographic Information System to Determine Spatial and Temporal Variability in a Green Turtle Foraging Population on Liuchiu Island, Taiwan

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Facial photo identification (ID) has proven to be a non-invasive method for identifying individual wild animals, and in recent years it has been effective on megafauna such as sea turtles. However, when processing hundreds of photos over a long period of time, variation in facial scale patterns makes identifying individuals complicated. This means that there is a high possibility that the individual is misidentified, which results in incorrectly determining population sizes. This study used the programming languages Python and SQL to determine green turtle foraging population size in the nearshore waters of a coral island, Liuchiu Island, from 2011 to 2017. The programs determined that the foraging population was 432 turtles, approximately 90% of which resided there one year or less and selected only one foraging site. Those that stayed for more than two years selected two foraging sites. Less than 3% stayed throughout the 7 years. The core residence area was from Beauty Cave to Vase Rock. This study found that the nearshore waters of Liuchiu Island are a temporary development/foraging site for immature green turtles. This is the first study to use Python analysis to determine a foraging sea turtle population in the field.

Key words: Green sea turtles, Liuchiu Island, Foraging population size, Spatial and temporal distribution, Python, GIS.

BACKGROUND

Sea turtles have been receiving high conservation attention world-wide. Studies have been conducted on of sea conservation turtles, including examination of their records and causes of stranding (Sönmez 2018 2019), nesting ecology (Cheng et al. 2009) and the size of foraging populations (Su et al. 2015). Sea turtles are listed as endangered species in Taiwan (Council of Agriculture 1990). There are five species of sea turtle; namely green, loggerhead, hawksbill, olive ridley and leatherback turtles. Among them, the green turtle is the most abundant (Chen and Cheng 1995). Long-term nesting of green turtles have been carried out on both Wan-an Island of Penghu Archipelagos and Lanyu Island of Taitung county (Cheng et al. 2008 2009 2018). There is one island—Liuchiu Island of Pingtung County—however, that host not only a small population of nesting green turtles, but also a foraging population in the nearshore waters (Cheng, unpublished data).

Su et al. (2015) developed a facial photo ID method (modified from Schofield et al. (2008)) to determine the foraging population in the nearshore waters of Liuchiu Island from 2011 to 2013 without

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interfering with underwater tourism activities. However, in order to evaluate the suitability of a habitat and provide proper recommendations for population management, especially for endangered species such as sea turtles, it is necessary to understand the population size, temporal and spatial variabilities, immigration/emigration rate, behavior and habitat status (Crouse et al. 1987; Chaloupka and Limpus 2005; Heppell et al. 2005; Mazaris et al. 2005 2006; Musick 1999). Thus, a long-term monitoring program is needed to determine the spatial and temporal variability of this foraging population. This work is crucial for managing foraging populations.

Even though facial photo ID is a useful tool, it is difficult to apply it to a long-term study. There are eight different facial scale patterns; postocular, temporal, central, tympanic, scale between the second postocular and fourth central scales, smallest scale of the combined postocular and central scales, and special scale, each of which has two to six different combinations of number or size meaning there are a total of 27 different possible combinations for each face. Furthermore, this method results in less than 5% of the turtles having identical facial IDs. Thus, the process of analyzing hundreds of photos for these variables is tedious and yields many mistakes, making this method unreliable for long-term monitoring programs. The problem gets worse when trying to combine the facial ID with other important parameters such as sex, age, behavior and environment. Thus, effective tools are needed to process large datasets. In this study, we analyze a population using the programming language Python, which can handle large amounts of data quickly and effectively. Furthermore, it can easily be combined with the geographic information system to visually determine the spatial distribution of the foraging population.

Python is a free and easy-to-learn programming language. For the data analysis, Python helps get the most accurate results within a short period of time, saving manpower and money. In addition, the language can be automated so that it is not necessary to repeatedly run the data analysis manually. This study used Python to determine the population size, residential longevity, and spatial distribution of this foraging population of green turtles from 2011 to 2017. GIS and Tableau were used to visualize the population's spatial distribution.

MATERIALS AND METHODS

Study area

Liuchiu Island, a coral reef island (22°19'N, 120°21'E), is located approximately 14 km offshore to the south-southwest of Taiwan (Fig. 1; Sue et al. 2015). Among the forty islands in Taiwan, Liuchiu is the only coral island. The other big island, Lanyu Island, is a volcanic island. Liuchiu Island is 6.802 km^2. The island is covered with coral limestone and the coast is surrounded by uplifted coral reefs. The weather is warm and dry, and the water temperature is influenced by the tropical weather and a Kuroshio branch. The seasonal variation in water temperature is small, ranging from 23.7°C in January to 29.6°C in July (unpublished data from the Institute of Marine Biology, Marine Ecology and Conservation Laboratory, 2011 to 2017). The water is less than 20 m deep across 100 m from the shore. Few spots reach depths of up to 30 m (Wu 2008).

Photo ID method

Facial photo ID determination followed the method described by Su et al. (2015). In short, the ID was determined based on specific characters and arrangement of facial scales. First, sex of adult turtle was determined by tail length. Total tail length extending at least 25 mm from posterior margin of supracaudal scale is male [1]. Otherwise, it is female [2] (Casale et al. 2005; Sönmez 2018). Second, the number of postocular scales was determined. Third, the number of temporal scales was determined. Fourth, the largest postocular or central scales was determined; [1] upper one of postocular scales, [2] lower one of postocular scales, [3] upper one of central scale, [4] lower one of

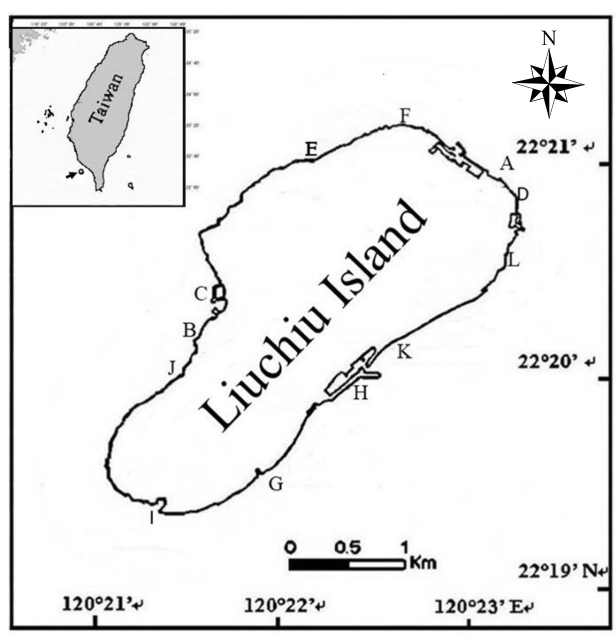

Fig. 1. Map of Liuchiu Island, with the survey sites listed from A to L. The full name for each site is listed in the text. Arrow in Taiwan map on the upper left corner point the location of Liuchiu Island.

central scales. Fifth, the number or the relative size of tympanic scales were determined; [1] one scale, [2] two scales, [3] three scales with the middle one smaller then the others, [4] three scales with the third one larger than the others, [5] four scales. Sixth, whether a scale existed between the second postocular scale and fourth central scale was determined; [1] yes, [2] no. Seventh, the smallest scale of the combined postocular and central scales was determined; [1] upper one of postocular scales, [2] lower one of postocular scales, [3] upper one of central scale, [4] lower one of central scales. Finally, whether there was a special scale (*i.e.*, incomplete scale) or special arranged scale (*i.e.*, small scale surrounded by several large scales) were determined. For example, facial ID can be expresses as "A1B2C1D3E2F2G2H4", in which A1 indicates male turtle, B2 indicates 2 postocular scales, C1 indicates two temporal scales, D3 indicates that the first scale of central scales is largest one in the combination of postocular and central scales, E2 indicates two tympanic scales, F2 indicates there has no scale existed between second postocular and fourth central scales, G2 indicates the second scale of postocular scale is the smallest among the combination of postocular and central, and H4 indicates that there was no special scale arrange on the facial scales. Thus, each side of the face of every turtle had its own personal ID.

An underwater survey was carried out in the nearshore waters every two to three months, with a survey period of 5 to 7 days for each trip. According to Su et al. (2015), most turtles stay in the nearshore waters to forage and perform other activities, such as resting in the early morning (08:00 to 10:00) and in the afternoon (15:00 to 17:00). Therefore, surveys were carried out daily during these two time periods from early July to early September, weather permitting. The survey was also conducted every two to three months between two summers. An underwater survey was done through both snorkeling and scuba diving. A CANON SLR camera, model G12 with a WP-DC24 waterproof housing, was used to photograph either the right, left, or both sides of the turtles' faces. Due to the fact that the nearshore waters around the island are heavily influenced by the weather, *i.e.*, monsoon, typhoon and subsequent southwest winds during the summer. These weather conditions create heavy waves and turbidity in the water column on one side of the island during two thirds of the year. Thus, we only carried out surveys on the side of the island, that weather permitting. The side of the island that permit field survey thus varies from the month to month. Under this logistic limitation, we were not also sure that the turtle(s) photographed during the previous trip are not present on the rough side of the island. Thus, we used the conservative method that only counts the turtles we photographed each time, and determined that yearly counts were a feasible method to calculate foraging population size of the turtles. Prior to each survey, the date and survey site were recorded. The launch and landing points of each survey, as well as the position of each turtle, were recorded by GPS (GARMIN, model Dakota 20).

Twelve sites were chosen as the launch and landing points for underwater surveys: A. Jun-Au Beach, B. Yu-Cheng-Wei, C. Shanfu Fishing Port, D. Dazhai Pin, E. Beauty Cave, F. Vase Rock, G. Thick Stone Reef, H. Daliao Fishing Port, I. Hai Mouth, J. Clam Bay, K. Power Plant, and L. Lobster Cave (Fig. 1). The most suitable site was chosen for each survey depending on the sea conditions (*i.e.*, current direction, tide, waves and underwater visibility) and availability. The most suitable section was chosen for each survey. In cases where all sections were available, the one(s) with the fewest surveys was chosen.

Data analysis

Python and SQL program

Each facial photo ID contained 8 letters and 2 to 6 numbers (*e.g.*, A1B2C1D3E2F2G2H4). Each turtle had two facial photo IDs, one for the right side of the face and the other for the left side. Due to the large dataset and the complexity of the data, Python was used to organize the dataset instead of manually counting the number of turtles recorded. The workflow of data analysis is in figure 2.

A Google Sheets document was used to organize the raw data. Google Sheets is a free Google app that functions similar to Microsoft Excel. It can be used to create a drop-down list for each cell or create a pivot table for the data validation. Once the analyst finished cleaning the data, they were exported as CSV files and stored in the PostgreSQL server. PostgreSQL is a free tool that allows people to store the huge datasets and use SQL to do simple data analyses and manipulations. One can even connect PostgreSQL servers to Tableau for data visualization or conduct ArcGIS for the spatial analysis.

For the data analyzing process, the analyst used Jupyter Notebook to develop Python scripts to answer the research questions. Jupyter Notebook is also a free tool. Compared to other Python script developing tools, one of the big advantages of using this tool is, when conducting data analysis, it shows the analysis results for each step and every result will be saved automatically. Thus, if there is a group of people conducting a big project, it is easy to check where people have made mistakes.

The following is the Python code for the analysis (Fig. 3). One of the big advantages of using Python is that the programmer can build some functions on top of the main Python code, then convert it into the automation system, which can save time and effort.

The logic behind the Python script is showed in figure 4. Due to the complexity of the facial photo ID method, Python v. 2.7 and Jupyter Notebook were

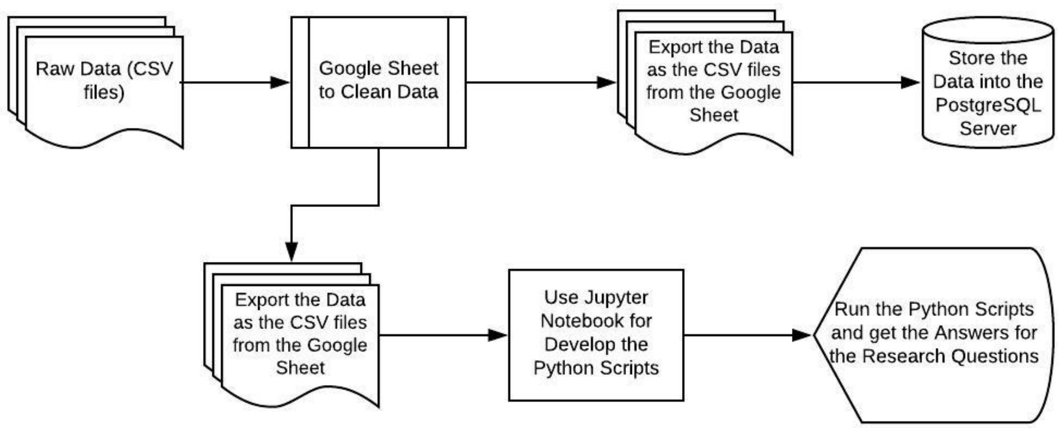

Fig. 2. The workflow of data analysis.

```
import pandas as pd
import numpy as np

#Pat 1: the numbers of patterns in the right-face pattern dataset.
data_right =
pd.read_csv('C:\Users\lavin\Desktop\FACIAL_ID_DATA_SCIENCE\RAW_DATA\RIGHT_FACE_RAW_DATA.csv')
#Here people need to type the file path.
data_right_face = data_right.groupby(['PATTERN']).size().to_frame('NUMBER_OF_OBSERVATION')
data_right_face

#Part2: the numbers of patterns in the left-face pattern dataset.
data_left = pd.read_csv('C:\Users\lavin\Desktop\FACIAL_ID_DATA_SCIENCE\RAW_DATA\LEFT_FACE_RAW_DATA.csv')
data_left_face = data_left.groupby(['PATTERN']).size().to_frame('NUMBER_OF_OBSERVATION')
data_left_face

#Part 3: the numbers of patterns in the both-face pattern dataset.
data_both =
pd.read_csv('C:\Users\lavin\Desktop\FACIAL_ID_DATA_SCIENCE\RAW_DATA\BOTH_FACE_RAW_DATA.csv')
data_both['PATTERN'] = data_both['RIGHT_FACE_PATTERN']+'-'+data_both['LEFT_FACE_PATTERN']
data_both_face = data_both.groupby(['PATTERN']).size().to_frame('NUMBER_OF_OBSERVATION')
data_both_face

#Part 4: list all the possible combinations from the left-face and right-face pattern
list_data1 = data_right['PATTERN']
list_data2 = data_left['PATTERN']
for i in list_data1:
    for j in list_data2:
        combine_results = i+'-'+j
        print combine_results
```

Fig. 3. The Python script for the analysis.

used to count, sort and analyze the turtle population after coding the facial scale. The population size was determined by adding up the number of turtle individuals determined from left, right and both faces, then subtracting the overlap portion from each face. Based on the date and site of the record, facial photo ID was used to determine the spatial and temporal variability of this population. Additionally, Point Density, which is a spatial analysis tool of ArcGIS Pro and Tableau, was used to visualize the spatial distribution of the population.

The data were sorted and organized by the Python script. The computer matched the same ID code from multiple surveys along with the time of each survey. In that way, the computer will provide information on when and where this turtle was "seen", for turtles recorded two or more times during the survey. If we had analyzed the data based simply on matching the eye in the photos or trying to match the ID code manually, it would have created huge errors and the work would have taken significantly longer, especially with more than two years of data.

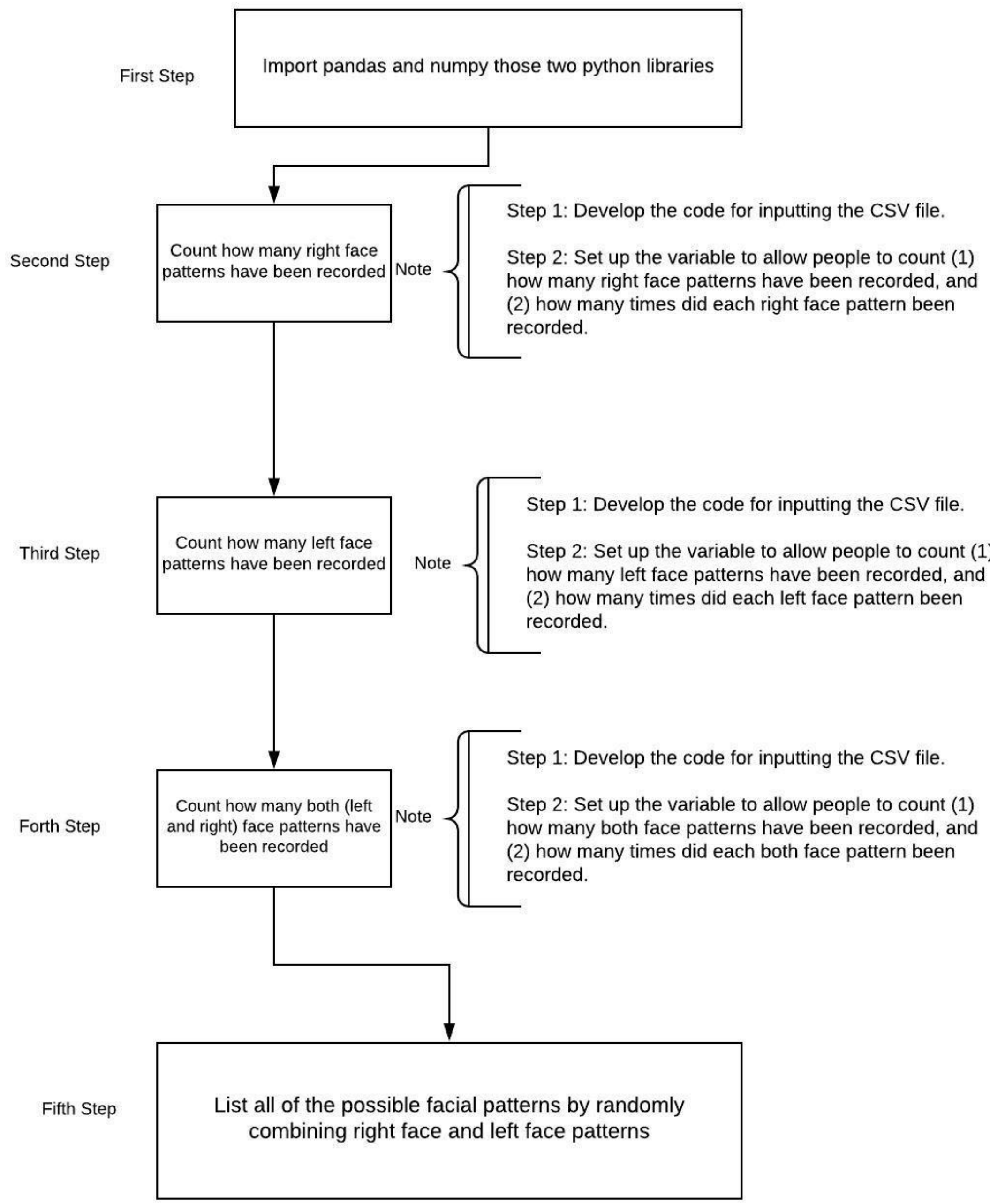

Fig. 4. The logic for developing the Python script.

RESULTS

Population size estimation

A total of 891 photos were identified in this study, 331 from the left face, 343 from the right face and 165 from both faces. Among them, 198 turtles were identified from the left face, 212 from the right face and 100 from both faces (Table 1). On average, 61% of the photos could be identified as individual turtles.

Estimation of the foraging population's residential period

The facial ID data over these 7 years showed that 85% from left face, 89% from right face, and 91% from both faces were identified only in one year. The average proportion was 88%. That is, we calculated that about 380 turtles resided in these nearshore waters for one year or less. For those that stayed two years or more, analyses showed that 15% from left face, 27% from right face and 56% from both faces, with an average of 33%, were identified. For those that stayed three or more years, 59% from left face, 40% from right face and 44% from both faces, with an average of 48%, were identified. For those that stayed throughout the entire 7 years, the analysis identified 23% from left face and 21% from right face. Since photo ID on both faces was not carried out prior to 2015, no data were available on both faces and this variable was excluded from the analysis. Results showed that on average 22%, or about 11 turtles, stayed throughout the entire survey period.

Spatial distribution of sea turtles in the nearshore waters

The spatial distribution based on all GPS positions is shown in figure 5. The study found that the main foraging site in the nearshore waters of Liuchiu Island was Beauty Cave to Vase Rock. There were no records between Vase Rock (F) and Jun-Au Beach (A) and between Daliao Fishing Port (H) and Power Plant (K) because these two sites are ferry/fishing ports. There was also no record from Hi Mouth (Site I) to Clam Bay (Site J) for logistical reasons.

The next question was how many turtles remained in one or more sites during their residential period. The Python analysis showed that, for those turtles that resided in the nearshore waters for one year or less, 88% on average stayed only in one site (Table 2). For the turtles that stayed two years or more, 59% on average selected two sites and 17% on average selected three sites or more (Table 3).

Table 1. The total, confirmed and proportion of confirmed numbers of total green turtle face photos from Liuchiu Island, 2011 to 2017

	left face	right face	both faces
total number	331	342	165
confirmed number	198	212	100
proportion confirmed	60	62	61

Table 2. The number of sites turtles stayed at when residing in the nearshore water for one year or less based on the left, right and both sides of the face. Data are presented as the percentage of total turtles

	Left Face	Right Face	Both Faces
Same Site	86	78	100
Two Sites	11	22	0
More than Two Sites	3	0	0

Table 3. Number of sites turtles stayed at when residing in the nearshore water for two year or more based on the left, right and both sides of the face. Data are presented as the percentage of total turtles

	Left Face	Right Face	Both Faces
Same Site	9	39	100
Two Sites	78	39	0
Three sites of more	13	21	0

Fig. 5. Distribution of the foraging population of green turtle in the nearshore waters of Liuchiu Island based on records per square km.

DISCUSSION

Population size estimation

Because each turtle was identified from right, left and both sides of the face separately, some were identified on two or three occasions. This portion must be determined before the population size can be determined. Python was used to determine the overlapping number of turtles determined by left, right and both sides of the face. The results in table 4 show that the overlapping number identified from the left and both sides was 47, 54 from the right and both sides and 21 from the left, right and both sides. The total abundance of the foraging population during the survey period was then calculated by summing the turtles identified from the left, right and both sides, then subtracting the overlapping number from the left and both sides, as well as the right and both sides, then adding up the overlapping number from left, right and both sides. The total abundance in these 7 years was then calculated as 432 turtles. In a previous study (Su et al. 2015), 106 to 142 turtles were identified in nearshore waters based on photo ID from 2011 to 2013. In that study, the Python program was not applied and the overlapping portion could not be determined. Thus, they only presented a range of turtles identified from facial photo ID. With this technique, we were better able to determine the foraging population size. Williams et al. (2017) posed a caveat about the stability of the sea turtle facial scale over a long period of time. Even though the turtle may change its pigmentation pattern over time, the scale arrangement remains unchanged. This is the first study to apply Python analysis to a long-term study of a foraging sea turtle population in nearshore waters.

Estimation of the foraging population's residential period

The results of the facial photo ID analyses showed that almost 90% of the foraging population resided in this nearshore waters for one year or less, and less than 3% resided throughout the 7 years. We also found that the majority of the turtles were juvenile to sub-adult sized (Laboratory personnel observation). These suggest that the nearshore waters of Liuchiu Island are a temporary development/foraging site for the immature green turtle. It is possible that, because Lichiu is a small island, with an area of only about 6.8 km^2 in size, the habitat may not be large enough to sustain a large foraging population.

Table 4. The number of turtles identified from left, right, both sides of the face, overlap from left and both sides, right and both sides, and left, right and both sides

	item	number
1	left face	198
2	right face	212
3	both faces	100
4	left and both faces	47
5	right and both faces	52
6	left, right and both faces	21

Spatial distribution of sea turtles in nearshore waters

This study found that the Beauty Cave (E) to Vase Rock (F) is the core foraging area for the nearshore water population (Fig. 5). This is consistent with the previous study of Su et al. (2015). However, we also found that most turtles reside for a year or less, tending to select only one site. About 60% of the turtles that stayed two years or more tended to select two sites. These suggest that some turtles that stay for a longer period will shift their residence site. Some turtles were found to utilize multiple foraging sites (*e.g.*, Carman et al. 2016; Mingozzi et al. 2016; Senko et al. 2010; Shaver et al. 2013), while others showed high fidelity to one site (*e.g.*, Shimada et al. 2016). However, the results of this study show that the core area is determined by turtles that stayed a year or less. Certain portions of the longer residential turtles do show habitat changes. More studies are needed to determine the mechanism of the habitat selection of residential turtles.

CONCLUSIONS

This is the first study to use Python analysis to determine a foraging sea turtle population in the field. However, in order to determine the dynamics of a foraging population, more information is needed. For example, the mechanism of habitat selection, seasonal variation, immigration and emigration rate etc. The results of this study provides the basic knowledge for the population dynamics in the field without disturbing the animal in the field.

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Availability of data and materials: Additional data are available upon request.

Consent for publication: Not applicable.

Ethics approval consent to participate: Not applicable.

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