Breeding success of the masked booby (*Sula dactylatra dactylatra,* Pelecaniformes:Sulidae) at Middle Cay, Pedro Bank, Jamaica

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Abstract: The masked booby (*Sula dactylatra dactylatra)* colony at Middle Cay, Pedro Bank, 60 miles south of Jamaica, has been affected by challenges resulting from anthropogenic disturbances. Despite habitat degradation, the colony displays resilience by remaining extant on the cay. Between June 2008 and June 2009 we investigated the colony's health (mainly breeding success). Data were collected once per month for twelve months and included one day, seven day and 24 hour (day and night continuous observational) sojourns. Forty-four nests were marked and monitored using a novel method for marking seabird nests based on painted seashells. Data collected from the colony included: the presence/absence/number of egg(s)/chick(s) in nests, offspring maturity, adult attendance at nests and the time of data collection. An average of 227 adult birds constituted the colony. Using the Mayfield Method and the "Naïve Estimator" for comparison, the colony's breeding success was determined to be 37.20% despite a hatching success of 40% and a fledgling success of 93%. This is less than the estimated 45.77% success typical of healthy colonies of sulids such as the masked booby elsewhere. Based on the breeding success calculations the long term survival of this colony is at risk and needs active conservation. Rev. Biol. Trop. 62 (Suppl. 3): 159-167. Epub 2014 September 01.

Key words: masked booby, Middle Cay, Pedro Bank, Jamaica, breeding success, sea bird, Mayfield Method.

The Caribbean with its tropical environment provides a variety of unique habitats for avian species which survive with other organisms within undisturbed ecosystems. While information is available on the population dynamics for some avian species within the region, little information exist for others. This may be so since Caribbean ornithology is often focused on birds with direct economic importance, eye-catching appearances or those that exist within habitats which are conveniently accessible. One such avian species within Jamaica for which limited information is available is the seabird *Sula dactylatra dactylatra* (Lesson, 1931); the masked booby (Atlantic). This seabird species is extant in separate colonies on two of three inhabitable cays located at Pedro Bank Jamaica. The cays with established masked booby colonies are known as Middle and Bird Cay. Though historical reports have indicated that the third cay known as Top Cay also served as a masked booby habitat, there has been no recent observation to substantiate the reports.

By serving as a habitat for more than five seabird species, Pedro Bank's Cays (Pedro Cays) are of importance to Jamaica's seabird diversity and also to Neotropical migrants that stopover to rest during their yearly southward journey. The Bank's submerged environment also provides good habitat for a variety of organisms and represents one of Jamaica's last remaining healthy marine ecosystems, supporting c*oral reefs, sea grass beds and coral cays* (Levy & Koenig, 2009). This healthy marine ecosystem makes Pedro Bank an ideal

location for subsistence fishing which is the main economic activity practiced at the location. Fishermen from mainland Jamaica and other Caribbean islands have been reported to reside on Top Cay and Middle Cay instead of returning to their mainland home between fishing bouts (Allen & Webber, 2013). The presence of fisher folk on Top and Middle Cay has resulted in severe disturbances to those cays' environments thus subjecting native species to direct and indirect anthropogenic influences which may affect their fecundity.

This study was designed to provide information on the Middle Cay masked booby colony's health or resilience within its disturbed habitat through the determination of its breeding success and comparisons between the colony's observed success and that of healthy colonies in relatively undisturbed habitats.

MATERIALS & METHODS

Study Area: The Pedro Bank is a seamount which rises abruptly from about 500m and extends more than 160.93km east to west. Located 80km south of Jamaica, with its area of 8 040km^2, the bank is one of the largest offshore banks in the Caribbean Basin (The Nature Conservancy, 2007). Pedro bank is composed of a variety of marine habitats such as sand, coral reefs, deep reefs, sea grass beds and is one of Jamaica's last remaining healthy marine ecosystems (The Nature Conservancy, 2007). The seamount breaks the sea's surface in eight places, four of which are craggy rocks – Portland Rock, Blower Rock, Southwest Rock and the Shannon Rocks – inhabited only by seabirds; the other four form the Pedro Cays (Espeut, 2006).

The Pedro Cays are a group of three small low-lying coralline cays, located on the southeastern margins of the Pedro Bank between 16˚57' and 17˚03'N and 77˚46' and 77˚51'W. Historical reports mention a fourth Cay, the South Cay, however it has been eroded and now exists as a shallow shoal with a very small sandy beach (Hay, 2006). Humans reside on only two of the three inhabitable cays, namely, Top Cay and Middle Cay (Zenny, 2005). The situation on the inhabited cays is complex and challenging for management and conservation purposes. An estimated 150 to 1 200 fishers have been reported to operate from the cays (Allen & Webber, 2013). There are no proper toilet facilities or running water and solid waste is burnt, buried or dumped. No masked boobies were observed to nest on Top Cay however masked boobies nest on Middle Cay. According to Zans (1958) seabirds originally nested on all three cays.

Middle Cay located at 17˚1'N and 77˚46'W houses a base for the Jamaica Defense Force Coast Guard and is normally inhabited by hundreds of Jamaican fishermen (Espeut, 2006). Middle Cay, though the smallest of the three cays with an area of 40 000m^2 (Zans, 1958), has been reported to experience a rapid increase in human inhabitants since the 1990s (Hay, 2006). Middle Cay is densely populated and consists mainly of corrugated zinc and wooden shacks (Zenny, 2005). More than 50% of the surface area of the cay is occupied by squatter housings (Hay, 2006).

Sampling: The site was sampled at least once per month between June 2008 and June 2009 with and exception of May 2009 during which no sampling was conducted. Two types of sampling visits were done: day visits and weeklong visits.

Nests were selected for monitoring upon the detection of a laid egg in a nest. Once a nest was selected for monitoring, a conch shell was placed adjacent to that nest with its convoluted tip pointing in the direction of that nest. However before a shell was placed, its convoluted tip was spray-painted in a colour that contrasted with the cay environment and a number depicting the sequence in which the nest was detected and selected written on the inside and outside of the shell using a permanent marker. A map of the colony area showing the general layout of the habitat and the relative locations of each monitored nest was also created and updated each time a new nest was selected for monitoring. Adult masked boobies from

monitored nests were banded with metal bands while their offspring, once at the downy chick stage of development, were temporarily banded with cable ties. All cable ties were removed at the end of the study.

Based on the size of the colony (approximately 227 birds) and a formula from Zar (1999) a sample size of 16 breeding pairs was determined to be a sufficient to obtain statistically sound breeding success values for the colony. Nonetheless twenty-seven nests were monitored through to the offspring's fledgling stage and forty-four nests were monitored through to their offspring's hatchling stage. A core set of data were collected during each visit to Middle Cay, which comprised of the following: nest number, presence or absence of (an) egg(s) in nest, the presence or absence and number of chicks in nests, the monitored offspring's stage of development, the presence or absence of adult(s) at nest, the date and time of data collection. Following each colony visit the data collected were brought back to a lab where they were reviewed and entered into a spread sheet for later analysis.

The hatching and fledgling success of a colony can provide valuable information about that colony's health within its breeding habitat. Hatching success indicates the proportion of that colony with the ability to hatch viable offspring from a set of eggs laid. While on the other hand, the fledgling success of a colony indicates the proportion of that colony with the ability to raise chicks to the point at which they achieve flight. The product of the hatching and fledgling successes of a colony will provide the breeding success of that colony (Priddel, Hutton, Olson & Wheeler, 2005). The breeding success of a colony indicates the proportion of that colony that is able to produce viable offspring which survive to achieve flight. By comparing the breeding success of a colony to the typical level of success obtained from healthy colonies of masked boobies, one can receive an indication of the health or resilience of the colony under investigation. The methods used to calculate hatching, fledging and breeding success are described below.

Two methods were used to determine the proportion of hatching and fledgling success observed for Middle Cay's masked booby colony; they are:

1. The Mayfield Method (Mayfield, 1961; Johnson, 1979)
2. A "Naive Estimator" (Frank Rivera pers. comm., 2009)

The results obtained from the application of the above methods to the data for hatching success were compared to assess the significance of any difference between the results. The same procedure was then followed for the determination of fledgling success. The result obtained from the Mayfield Method for the hatching success was then compared to the range of hatching successes (53% - 60%) reported by Anderson (1990) from his study on a healthy masked booby colony. For the fledging success, the result obtained from the application of the Mayfield Method to respective data was compared to the average fledgling success (81%) obtained from previous studies done on a healthy colony masked boobies by Kepler (1969).

The breeding success (the product of the hatching success and fledgling success, Priddel et al., 2005) of Middle Cay's masked booby colony was calculated at first using the results from the Mayfield Method and then those from the "Naïve estimator". The breeding successes obtained from both methods were then compared to see if the deviated from each other. Next, the breeding success obtained from the Mayfield Method was compared to the breeding success obtained from the product of the average hatching and fledgling successes observed from healthy colonies in other locations. If the breeding success of Middle Cay's masked booby colony was found to be greater than or equal to that obtained from healthy colonies at other locations, then the Middle Cay colony could be assumed to be in good condition at the time of the study. However, if the breeding success of the Middle Cay colony was found to be below that of healthy colonies

that would suggest that the colony was failing at the time of the study.

In Mayfield (1961) analysis of Kirtland's Warbler (*Dendroica kirtlandii*) he encountered various discrepancies in his data that could not be rectified using customary methods. One of his most serious problems came from the fact that many of the nests used in his sample had not been detected until after incubation had begun. In his attempt to make his results more accurate Harold Mayfield proposed a new method to analyse this type of data. The new method became known as the Mayfield Method (Mayfield 1961, 1975).

For the Mayfield Method the following information must be known:

- The sample size (number of nests being monitored).
- The stage of development of the offspring within each nest.
- The time taken for the species to hatch, fledge or successfully breed must be known.
- The fate of each monitored offspring.
- Days between visits to sample site.
- Exposure time of offspring in each monitored nest (Following Johnson (1979) that when days between visits are > 15 days, 40% of exposure time must be used instead of 50%)
- Total exposure time of monitored offspring within the sample.

The method incorporates the exposure time of sample nests in its determination of success and thus is believed to be more accurate than other methods. To use this method the daily mortality (dmr) rate of the colony must be determined. This is done by dividing the number of nests to fail at hatching (fh) by the total exposure time (tet) of the sample nests within the colony (summation of the exposure time of all sample nests). The daily survival rate (dsr) may then be determined by subtracting the dmr from 1. The Mayfield Method allows for the calculation of the amount of variance contained in the data with the use of the following formula:

$$v = (1)/(((tet)^3)/((tet-fh)fh))$$

Where "v" is the variance. The standard error (SE) many now be determined by finding the square root of the variance: $SE=\sqrt{v}$

In the context of this research, hatching or fledgling success (S) of the colony may now be determined by raising the daily survival rate to the power of the total time taken by the species to hatch or fledge respectively, so $S=(tth): dsr^{tth}$. The resulting success (S) may be reported as a percentage ranging from 0% to 100%. The upper and lower limits of success may also be calculated from the results and reported with the proportion of observed success. This is done for the upper limit by using the formula: $(dsr + (2SE))^{tth}$. And for the lower limit using the formula: $(dsr - (2SE))^{tth}$.

"**Naïve Estimator**"**:** This method was dubbed the "Naïve estimator" by Rivera (pers comm., 2009). This was done because unlike the Mayfield Method that used exposure time to calculate its results thus making them more accurate, the "Naïve Estimator" does not. Due to this the results obtained by the "Naïve Estimator" may be considered as less accurate since it does not consider variation in its calculation. The information needed for the use of the "Naïve estimator" is as follows:

- The number of nests in the sample
- The number of failed nests.

Using the "Naïve Estimator" hatching mortality (hm) would be calculated by dividing the number of nests that failed to hatch (fn) by the number of monitored nests (n), as shown in the formula: hm=fn/n. The hatching success (hs) could then be calculated by subtracting the hatching mortality from 1, as shown in the formula: hs=1-hm. Because the results of the "Naïve Estimator" are not corrected for errors, its results were only used in comparisons with

the results of the Mayfield method and not to draw conclusions from this study.

RESULTS

The results of the one year field assessment are reported as observations, in tables and as calculated hatching success, fledgling success and breeding success. Population counts revealed an estimate of 227 total boobies forming the colony from which 44 nests were monitored to provide the below results.

Hatching success: Two nests within the colony received eggs during the June 2008 to August 2008 period. These two nests were monitored and labelled sample Nests 1 and 2. However both nests failed to produce a hatchling. A third nest (Nest 3) received eggs in August 2008 and was monitored (Table 1). Sample Nest 3 also failed to produce a hatchling. In September of the same year there was a 100% increase in the number of eggs laid in nests over previous nest monitoring months; three nests became active in September 2008. Of the three nests two were successful in producing hatchlings. Most colony nests received eggs in October 2008 (Table 1). Twenty-one nests with eggs were marked and monitored from October 2008. These nests were monitored to their offspring's fledgling developmental stage, at which point the fate of a monitored offspring could be determined. Of the twenty-one nests, nine failed to produce a hatchling while 12 were successful. In April 2009 a second mass laying of eggs at the colony was observed. Seventeen of the nests from the second colony breeding attempt were monitored. These seventeen nests were monitored to determine their hatching success. Of the seventeen nests two successfully produced hatchlings; Nests 28 and 39 (Table 1). Therefore, of the forty-four monitored nests, sixteen successfully produced hatchlings. Despite the size of a nests' clutch only one chick was raised by the adults of successful nests. No dead chicks were observed in failed monitored nests where un-hatched eggs were absent.

The results obtained by using the "Naïve Estimator" and the Mayfield Method are presented in Tables 2 and 3 respectively. While the "Naïve Estimator" produced a proportion hatchling success of 0.36/36%; corrected to 2 decimal places (Table 2) the more reliable Mayfield Method produced a hatchling success of 0.4/40% (Table 3). The Mayfield Method also provided lower and upper 95% confidence interval spread of 0.29/29% at minimum and 0.57/57% at maximum.

Fledgling success: Data were collected from twenty-seven nests (Nests 1 to 27) for the determination of the colony's fledgling success. Of the 14 nests that successfully produced a hatchling, 13 were successful at producing a fledgling (Table 1). According to the "Naïve Estimator" the fledgling success was found to be 0.93 (Table 4); corrected to 2 decimal places, which was the same as the result produced by the Mayfield Method (Table 5). The lower 95% confidence interval spread was found to be 0.79 while the upper 95% confidence interval spread was 1.0. The daily survival rate was found to be 0.99936 thus indicating that almost no fledgling mortality occurred on a day to day basis.

Breeding success: The breeding successes obtained from the two methods employed (Table 6). to determine the breeding success of Middle Cay's masked booby colony the product of the observed hatching and fledgling successes was found. The colony's breeding success was determined to be 37.20% according to the Mayfield Method and 33.81% according to the "Naïve Estimator". These two successes were determined to be significantly similar (p=0.05) according to the 95% confidence intervals produced by the Mayfield Method. Both methods produced slightly different results but with the same implication.

DISCUSSION

Ultimately, breeding success is the product of hatching and fledgling successes and these

TABLE 1
Data collected for the determination of the Middle Cay masked booby colony's breeding success

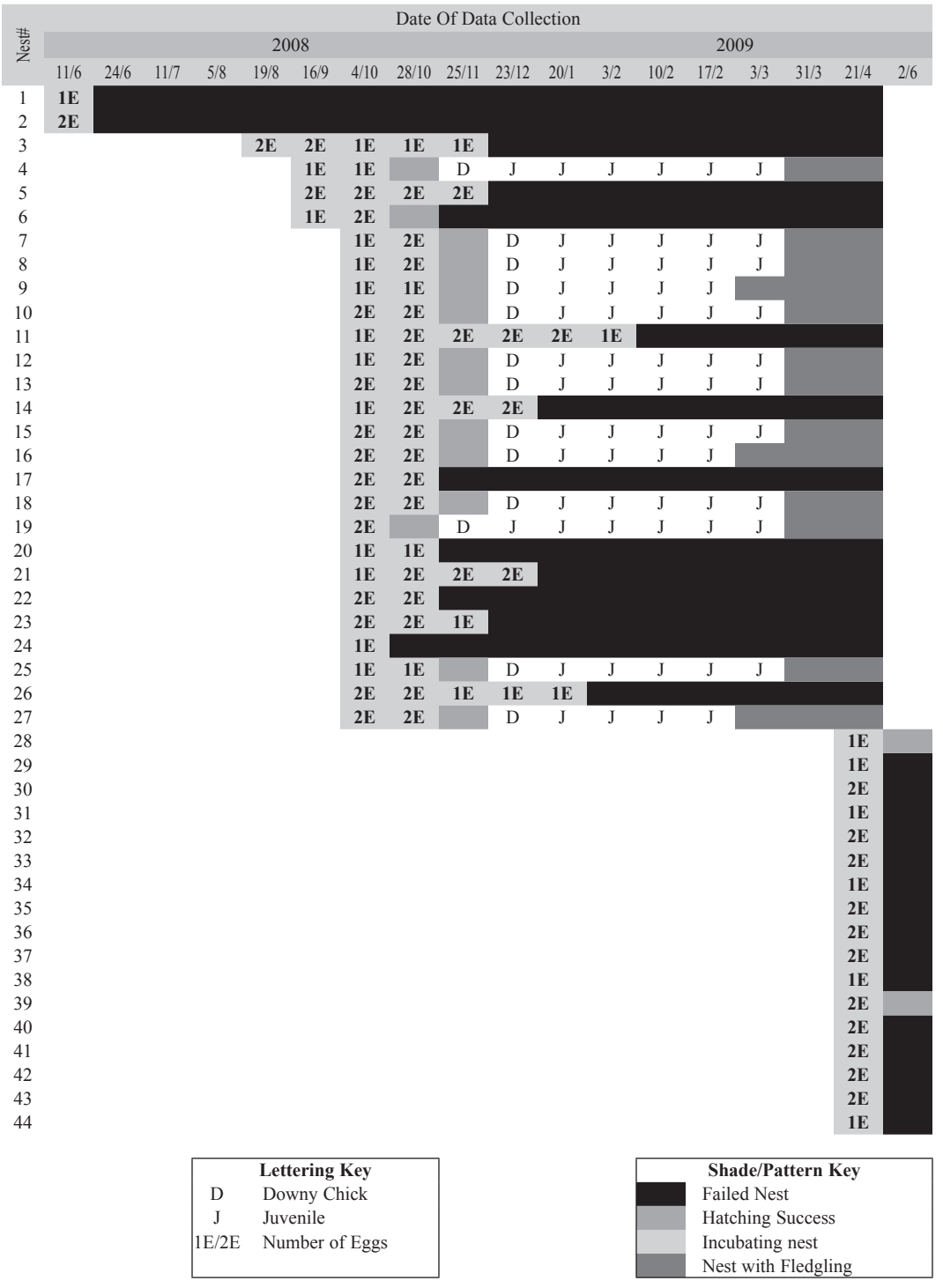

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TABLE 2
Results of calculations done on the data to determine the colony's hatching success using the "Naïve Estimator"

Hatchling survival (success)	0.364
Hatchling mortality (failure)	0.636
Number failed hatching	28
Number survived to fledge	16
Number monitored nest (n)	44

TABLE 3
Results of calculations done on the data to determine the colony's hatching success using the Mayfield Method

Daily mortality rate	0.02083
Daily survival rate	0.97917
Variance	1.5178E-05
Standard error	0.00390
Hatching survival (success)	0.40
Number survived hatching	16
Number monitored nests (n)	44
Lower 95% confidence interval	0.29
Upper 95% confidence interval	0.57

TABLE 4
Results of calculations done on the data to determine the colony's Fledging success using the "Naïve Estimator"

Fledging survival (success)	0.928571429
Proportion of chicks that died	0.071428571
Number failed hatching	1
Number survived to fledge	13
Number monitored nest (n)	14

TABLE 5
Results of calculations done on the data to determine the colony's Fledging success using the Mayfield Method

Daily mortality rate	0.00064
Daily survival rate	0.99936
Variance	4.1065E-07
Standard error	0.00064
Fledging survival (success)	0.93
Number survived to fledge	13
Number of monitored nests (n)	14
Lower 95% confidence interval	0.79
Upper 95% confidence interval	1.08

are calculated estimates which account for a researcher's observations at the nests as well as a researcher's time away from the nests with no observations. The three successes therefore need to be considered in the final analysis.

Hatching success is a potentially important fitness component for avian species (Knape et al., 2008). Due to this, the determination of a colony's hatching success may provide critical information about a bird colony's resilience within its habitat. Table 2 shows that successful sample nests produced only one offspring despite the observation that a maximum of two eggs were laid in nests. This observation is characteristic of the species and is due to the persecution of the younger chick by its older sibling; a process known as siblicide (Nelson, 1978). Consistent with the biology of the species, each monitored nest which produced one chick was reported as being successful at its attempt. According to the Mayfield Method, the colony was determined to have a hatching success of 40%, while the "Naïve Estimator" suggested a success of 36.4%. The confidence limits produced by the Mayfield Method indicated that the two results were not significantly different when tested at the 90% Confidence Interval.

According to Anderson (1990) the proportion of the hatching success observed from obligately siblicidal species, such as the masked booby, should fall within the range of 53% to 60%. By comparing the hatching success observed for the colony, which was 40%, to the range of successes presented by Anderson (1990) it is evident that the observed success did not fall within the range of successes

TABLE 6
Calculated breeding success of the masked booby colony nesting on Middle Cay, Pedro Bank, Jamaica

Method	Hatching	Fledging	Breeding	% Breeding Success (2d.p.)
"Naïve Estimator"	0.364	0.93	0.338	33.81
Mayfield Method	0.4	0.93	0.372	37.20

expected. It was therefore deduced that at the time of the study, middle cay's colony was not achieving a level of success which is associated with that of a healthy masked booby colony. Despite this, the upper 95% confidence limit determined for the colony's hatching success fell within the range of successes representative of healthy colonies and so the success, at the upper limit, obtained for the Middle Cay colony was not significantly different from that of fit colonies. Though a significant difference was not detected between the previously mentioned statistics, the results still suggest that the colony would benefit from scientific intervention to increase its hatching success. The range of hatching successes observed by Anderson (1990) for siblicidal Sulids was a good statistic to use for this analysis since hatching success tends to vary between colonies of Sulids found in different locations.

The fledging success of Middle Cay's masked booby colony was determined to be 93% by both the Mayfield Method and "Naïve Estimator". Kelper (1969) observed a fledging success of 79% from a study done on 43 boobies in 1964 and a success of 83% from a study done on 30 boobies the following year (1965) at Green Island, Kure. The results from Kelper's 1969 study were used in the analysis because the Green Island colony was not exposed to adverse disturbances such as that of the Middle Cay colony. Using the average of the fledging successes obtained by Kelper, an average expected fledging success of 81% was obtained. From a comparison between the observed fledgling success of 93%, and the average "expected" success of 81%, it was deduced that Middle Cay's masked booby colony was experiencing a more than satisfactory level of fledgling success and so the colony was in no need of scientific intervention in the area of fledgling success.

The acceptable breeding success for siblicidal masked booby colonies was determined to be 45.77%, which is the product of the average "expected" range for the hatching success from Anderson's data (56.5%) and that of the fledgling successes obtained by Kelper (81%). A comparison of the two results (37.20% according to the Mayfield Method and 33.81% according to the "Naïve Estimator") revealed that at the time of the study, the colony obtained a success which was less than that characteristic of healthy colonies. Due to this it may be concluded that the Middle Cay's masked booby colony would benefit from intervention to improve its breeding success.

Greatest error in this calculation of breeding success may be attributable to the hatching success calculation but confidence in the data surrounding fledging success and observations of activities in the colony especially over the 24 hour period support the finding of a colony whose breeding success is less than acceptable for this species. Conservation interventions if considered should surround the improvement of the hatching success by reduction of the environmental pressures observed at Pedro Cays but only after more detailed data collection and analysis. The presence of large and apparently increasing number of fisher folk on Middle Cay has resulted in severe reduction in physical space and modifications of the environments available to the birds. Hourly counts of adult masked boobies at the colony during a one week period, reveled the colony's attendance to peak at an estimated 227 individuals by dawn which left little room for the arrival or departure of colony members. Being now more densely populated, the Sulids at Middle Cay's are encountering species specific triggered habitat reduction as well as intense disturbances from fisher folk. These factors appear to be important contributors to the recorded low breeding success of these sea birds in their natural environment.

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RESUMEN

Determinación del éxito reproductivo del alcatraz enmascarado (*Sula dactylatra dactylatra,* Pelecaniformes:Sulidae) en Cayo Middle, Banco de Pedro Jamaica. La colonis del alcatraz enmascarado (*Sula dactylatra dactylatra)* en Cayo Middle, Banco de Pedro, 60 millas al sur de Jamaica, ha sido afectada por una serie de desafíos resultantes de disturbios antropogénicos a su hábitat. A pesar de la degradación excesiva del hábitat, la colonia muestra resilencia al permanecer en el cayo. Entre junio de 2008 y junio de 2009 realizamos una investigación de la salud de la colonia (principalmente éxito reproductivo). Los datos fueron recogidos una vez al mes durante doce meses e incluyó un día, siete días y 24 horas (día y noche de continua observación). Cuarenta y cuatro nidos fueron marcados y monitoreados utilizando un método novedoso para marcar nidos de aves marinas. Los datos recogidos de la colonia incluyen: presencia/ausencia/número de óvulos/polluelos en nidos, madurez de crías, asistencia de adultos en los nidos y el tiempo de recolección de datos. Un promedio de 227 aves adultas constituían la colonia. Usando el método de Mayfield para analizar los datos y el "estimador Naïve" para la comparación, el éxito reproductivo de la colonia se determinó de un 37.20% a pesar de un 40% de éxito de eclosión y un éxito de pichones del 93%. Esto es menos que el éxito estimado de 45.77% en colonias saludables como la del alcatraz enmascarado en todo el mundo. Basado en los cálculos de éxito la supervivencia a largo plazo de esta colonia está en riesgo y necesita se ejecute conservación activa.

Palabras clave: enmascarados Piquero, medio Cay, Pedro Bank, Jamaica, cría éxito, aves marinas, método Mayfield

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