Measuring Metapopulation Characteristics of the Southeastern Beach Mouse on Kennedy Space Center using a Dynamic Habitat Occupancy Approach

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Medical and Environmental Division
Environmental Management Branch

INTEGRATED MISSION SUPPORT SERVICES
A Herndon-InoMedic Joint Venture

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Figures and Tables

1.0 Project Description:

The Cape Canaveral Barrier Island Complex (CCBIC) represents the largest (72 km) continuous coastal habitat supporting the core population of the threatened southeastern beach mouse (*Peromyscus polionotus niveiventris*) in Florida. Despite protection throughout the subspecies' remaining range, storm activity during the past two decades has de-stabilized coastal dune and coastal strand habitat required for beach mouse survival. Our long-term goal is to provide information to the management process to ensure a sustainable population on the CCBIC in light of sea-level rise, extreme storm events, and continued land development supporting the multi-user spaceport.

Because beach mice populations are affected by storms (hurricanes, tropical storms, nor'easters), it is important to understand the species-habitat relations during periods with and without storm impacts. Conventional wisdom is that coastal dune and coastal strand are the preferred habitats, but coastal scrub habitat may be important because it is less affected by storm impacts (e.g., overwash, escarpment, sand deposition, etc.) and thus may serve as a refugia. In addition, genetic studies have shown some evidence for reduced dispersal between regions on CCBIC (Kalkvik et al., 2012; Zimmerman et al., 2015). We compared site occupancy dynamics for coastal dune, coastal strand, and coastal scrub habitat over three quarters (seasons) and determined the pattern of spatial correlation in habitat occupancy dynamics for locations at a range of distances in coastal dune, coastal strand, and coastal scrub habitats along the Kennedy Space Center (KSC) coastline (**Figures 1 and 2**). Although habitat occupancy is very useful for understanding species-habitat relationships, in its simplest form it ignores differences in abundance between sites. Because information on abundance may inform management efforts and provide knowledge regarding status of the population, we tested measuring abundance state based on the number of detections in tracking tubes. Small mammal populations often fluctuate in a cyclic manner over time. These fluctuations make populations more susceptible to extinction and make trend detection more difficult. Efficient methods of measuring abundance across time and space are needed for monitoring trends.

The purpose of this project was to:

1. Estimate southeastern beach mouse habitat occupancy parameters in coastal dune, coastal strand, and coastal scrub habitats using a combination of tracking tubes and traps;
2. Model the spatial relationships of the effect of habitat (coastal dune, coastal strand, and coastal scrub) on parameters as a function of distance; and
3. Compare the reliability and efficiency of our survey methods and evaluate the potential to develop an abundance index.

2.0 Progress during the Year on Questions Developed during the Project Review Advisory Board (PRAB):

This project was approved by the PRAB on January 18, 2018, and included two components.

1. Multi-agency annual southeastern beach mouse habitat occupancy survey.
2. Measuring metapopulation characteristics of the southeastern beach mouse on KSC using a dynamic habitat occupancy approach.

This document focuses on the second component. The Multi-agency annual southeastern beach mouse habitat occupancy survey was previously addressed in a separate report. This project was designed to be four quarters but only three occurred (see **Section 8.0**, FY2018 – 2019 Activities). The project was expected to begin in 2018 and extend to 2019, although because we employ an iterative approach in long-term monitoring, our timeline for this project was planned to be extended if required. The following scientific questions were not expected to be answered within the first year but rather to evaluate the ability of the study to produce evidence to answer the questions.

1. How do dynamic habitat occupancy rates (colonization/extinction and occupancy) differ between coastal dune, coastal strand, and coastal scrub habitat?
   a. We expect that occupancy rates will be highest in the coastal strand, lower in coastal dune, and lowest in coastal scrub.
   b. We expect that habitat colonization and extinction will be highest in the coastal dune, lower in coastal strand, and lowest in coastal scrub.
2. Over what distance is there spatial correlation in habitat occupancy parameters (colonization/extinction and occupancy)?
   a. We expect to detect spatial correlation in habitat occupancy parameters (colonization/extinction and occupancy) within 30-600 m.
   b. We expect that correlations will be strongest for sites closer together and in similar habitat.
3. Can we reliably determine the abundance state of a site based on the number of detections in tracking tubes?
   a. We expect to find a correlation between the number of prints and/or the number of detections in tracking tubes and the number of unique individuals captured in live-traps at sites.
   b. We expect to observe dispersal of individuals between habitats.
4. How does beach mouse habitat occupancy fluctuate over time?
   a. We expect to see fluctuations in habitat occupancy between quarters (3-month periods) of less than 25% and larger fluctuations over longer time periods (years).

3.0 Current Progress Towards Addressing Proposed Scientific Questions:

This project was designed with an iterative approach to allow us to analyze the data and determine as we proceeded if the study design was working as expected. We also expected to refine hypotheses as we learned from this study, and that the first year of data would allow us to determine if more surveys were needed or if changes to the design, frequency, etc. were needed. Through the analysis of the data thus far, it is evident that the data we collected has merit and shows promise for providing future answers to the questions we posed as more data is collected. Information learned from this study will allow us to be more efficient in future efforts (i.e., study design, sampling frequency, targeting disturbance events, etc.).

The study included 15 sites along the KSC coast (**Figure 1**). For each site, a station was established in each of the three habitat types (coastal dune, coastal strand, and coastal scrub) for a total of 45 stations (**Figures 1 and 2**). Each station was set up with five tracking tubes (tubes) and five Sherman live-traps (traps) randomly positioned at a distance of 1-15 m in the four cardinal directions (N, E, S, W) and at the center (C), for a total of 225 tubes and 225 traps. Traps and tubes were to be deployed for 23 days (22 nights) during each quarter. The tubes were to be active for 7 nights followed by 3 non-consecutive trap nights and then a second 7-night tube deployment (see **Section 8.0**, FY2018 – 2019 Activities). This sampling structure allowed the collection of data that was utilized to answer each of the scientific questions starting with the first question below. Each of the four scientific questions are listed followed by what we learned in our efforts to address each question for this project.

1. *How do dynamic habitat occupancy rates (colonization/extinction and occupancy) differ between coastal dune, coastal strand, and coastal scrub habitat?*

For southeastern beach mouse occupancy modeling we treated the stations as the sampling units and pooled all five of the detectors. Traps and tubes were both considered as potential detectors. For tubes, a detection occurred if any footprints were recorded; this meant that at least two of three independent readers recorded a footprint less than 7.2 mm on a tracking tube card (Stolen et al., 2014). For traps, we treated any capture of a beach mouse as a detection. The dynamic occupancy model estimates the initial occupancy rate of sampled area for the first quarter, then estimates an area extinction and colonization rate for the subsequent quarter. The rate of occupancy can be calculated for all quarters after the first, using information from the model.

Results of the model show that none of the parameters except detection can be estimated, because in the data we observed they were essentially fixed (**Table 1**). In other words, all but a very few of the stations had at least 1 detection during all quarters resulting in an initial occupancy rate of 1.0, extinction rate of 0.0, and a colonization rate that could not be estimated (because it was never observed). In conclusion, we estimate that all of the habitat was occupied during the study. This study has demonstrated that we have the power to measure these parameters, but more observations of occupancy changes across time and space is needed to determine what influences these dynamics.

Table 1. Dynamic Habitat Occupancy Parameters Estimated from data collected during three quarters on KSC. Note the estimate for colonization is not informative due to the fact that colonization was not observed because all stations were occupied during the time period.

Parameter	Predicted	Standard Error	Lower	Upper
Occupancy (psi)	1.000	0.001	0.000	1.000
Detection	0.652	0.018	0.615	0.687
Extinction	0.000	0.000	0.000	1.000
Colonization	----	----	----	----

More details about habitat use can be gleaned from the trapping data results. For example, when sites and stations were combined, the coastal dune sites had the highest number of individual beach mice captures in July, but was lower than coastal strand in both October and March. As expected, the coastal scrub sites had the least captures in all three quarters (**Appendix B, Figure B-13**).

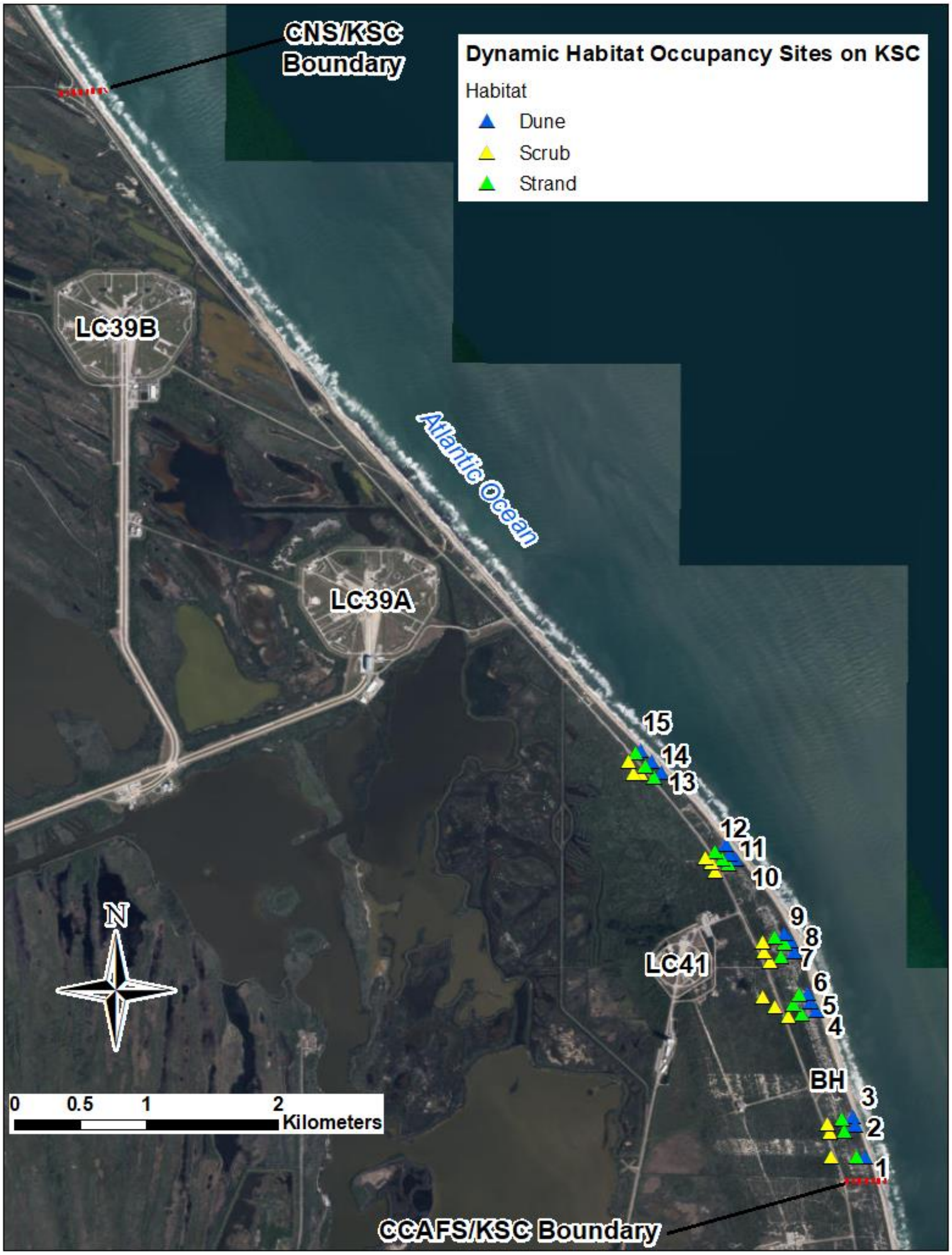

Figure 1. Location of the 15 Dynamic Habitat Occupancy Sites (45 Stations) in Coastal Dune, Coastal Strand, and Coastal Scrub on KSC in 2018 – 2019.

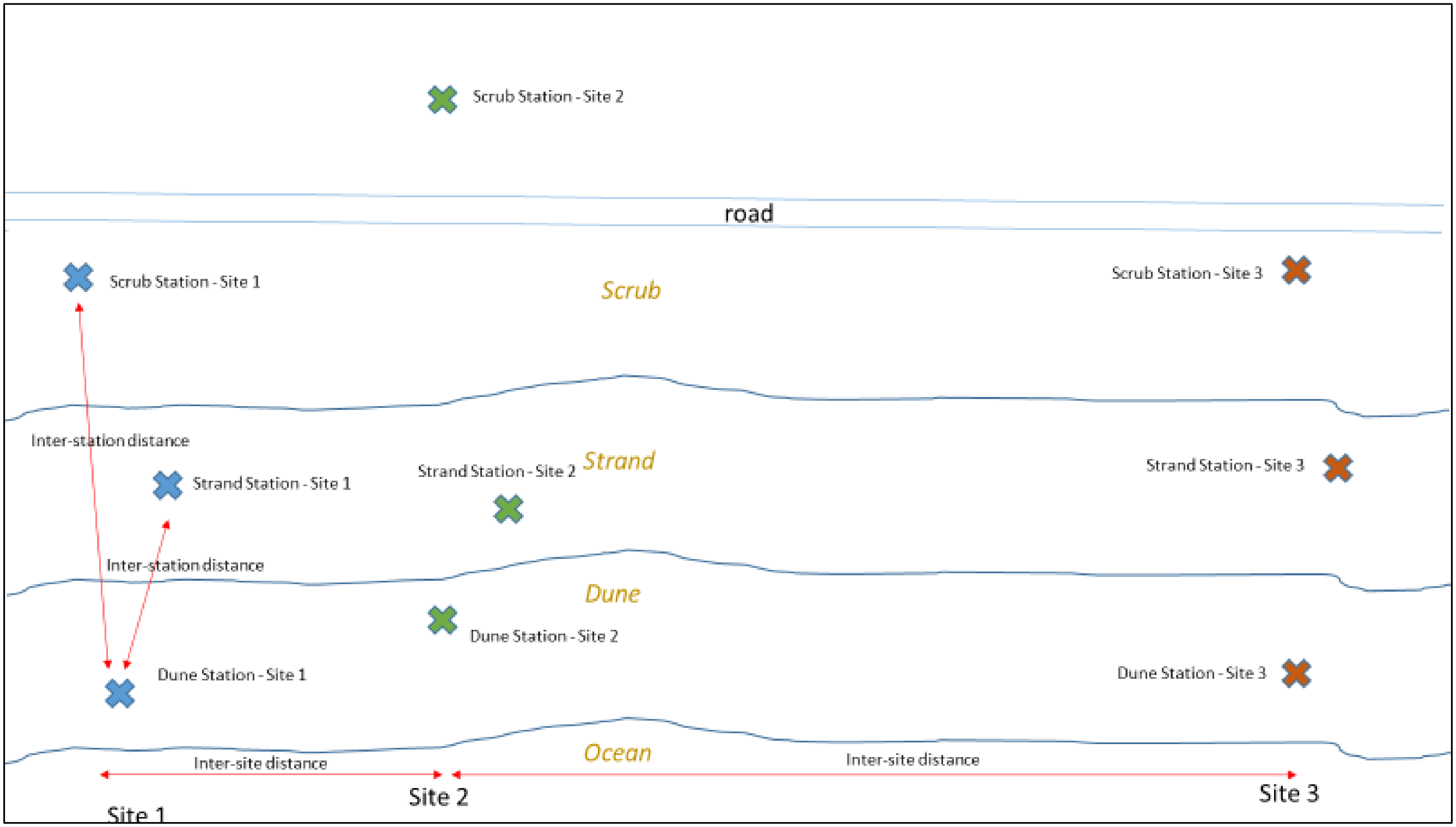

Figure 2. Theoretical Arrangement of the Dynamic Habitat Occupancy Sample Sites and Stations within Sites on KSC.

2. Over what distance is there spatial correlation in habitat occupancy parameters (colonization/extinction and occupancy)?

Although the low level of variation observed does not allow us to directly address this question, the data is not inconsistent with a high level of spatial correlation in occupancy parameters across habitats. A more thorough analysis of this and previously collected data will identify these relationships correctly.

3. Can we reliably determine the abundance state of a site based on the number of detections in tracking tubes?

For this analysis we looked at the relationship between the abundance as measured by the number of unique individuals captured at a location and the number of tube detections at the same location. We did the analysis at two spatial scales. The first was the level of the individual station locations at which five tubes and five traps were deployed during each of the three quarters (N=135). The second level was broader, and we repeated the analysis combining all of the data for each site (N=45). We tested the hypothesis that there was a positive relationship between abundance and detection rate by regressing the number of individuals versus the number of detections at each scale. Because the data were counts, we used Generalized Linear Models (GLMs) with the logit link and Poisson error distribution (often referred to as Poisson regression models). In exploratory data analysis, we found that this type of model performed better on the data than did ordinary least squares regression models with log-transformed data. We also tested for an interaction between tube detections and quarters and tube detections and habitat (for the station scale); such interactions would mean that the relationship between abundance and detection was different across habitats or time. In addition, we tested to see if the effect of habitat (for the station scale) or quarter (for both scales) explained a significant amount of the variation in abundance. For each analysis, we began with the full model with all interactions and then used model reduction to see if simpler models produced adequate fits, testing each step using a likelihood ratio test. We stopped model simplification when the likelihood ratio test indicated that removing a term produced a model with a significantly worse fit.

For the first analysis at the scale of the station, model simplification resulted in the model that predicted abundance as a function of the number of detections with a separate effect for quarter (**Table 2**). The amount of deviance explained by the model was 47% (this is a measure for GLMs that is similar to the R-squared value of ordinary least-squares regression models).

Table 2. Results of Regression Model at the Scale of the Station.

Coefficients	Estimate	Standard Error	Z value	Pr (>|z|)
Intercept	-1.323	0.481	-2.749	0.006
Detections	0.225	0.049	4.567	0.000
March 2019	0.526	0.126	4.157	0.000
October 2018	-0.182	0.176	-1.033	0.302

For the second analysis at the scale of the site (lumping habitat within sites), model simplification also resulted in the model which predicted abundance as a function of the number of detections with a separate effect for quarter (**Table 3**). However, the effect for detections was very small and broadly overlapped zero, indicating that there was no evidence for an effect. The amount of deviance explained by the model was 53%.

Table 3. Results of Regression Model at the Scale of the Sites.

Coefficients	Estimate	Standard Error	Z value	Pr (>|z|)
Intercept	1.086	0.788	1.378	0.168
Detections	0.025	0.028	0.891	0.373
March 2019	0.427	0.138	3.091	0.002
October 2018	-0.460	0.233	-1.978	0.048

In conclusion, there is evidence of a relationship between abundance and detection at the level of station but not at the site level. Proposed future analyses will utilize information from the spatial locations of captures and recaptures to estimate density more precisely. We believe this increase in the use of available information will further refine and strengthen these results.

More details about dispersal can be found in trapping data results from the three quarters, which yielded 13 dispersal occurrences. Nine southeastern beach mice and four cotton mice (*Peromyscus gossypinus*) dispersals with distances ranging from 37.6 m to 1043 m were observed (**Table 4**). Ten of the dispersals were between sites and three were between stations (different habitats within sites).

4. How does beach mouse habitat occupancy fluctuate over time?

For reasons discussed in question two, (low level of variability observed), estimates of habitat occupancy do not allow us to completely answer the question at this time. Past data sets likely contain information that will allow us to characterize the dynamics of habitat occupancy parameters. While habitat occupancy of southeastern beach mice did not fluctuate over the three quarters (i.e., almost all sites/stations were occupied) the numbers of detections between quarters, by species and methods (i.e., tubes versus traps versus bucket and trail cameras) did fluctuate (Figures A-1 – Figure A-24, Table 5 and Table C-1).

4.0 Key Information Learned from the Study during the Past Year:

In summary, this work documented high occupancy of southeastern beach mice during the time period sampled. This may represent a high point in a normal cyclical period or may be driven by post-hurricane population expansion or be a combination of both. This is observed in the long-term data showing this cyclical pattern of high and low abundance and in past hurricane related data. Live-traps and cameras are considered to be certain detectors (because you can hold/see the individual) while tracking tubes are considered to be uncertain detectors (the animal enters and leaves the tube without being seen). We have collected baseline footprint on several small mammal species to help us discern them from the southeastern beach mouse by the size of their footprints (Greene et. al., 2018). While we were able to obtain a cut-off footprint size for southeastern beach mice (<7.2 mm; Stolen et. al., 2014) that allowed us to discern southeastern beach mice from other species using the tracking tubes, the tube is still considered to be an uncertain detector. By utilizing traps, tubes, and cameras simultaneously, we collected occupancy and demographic information, which considered together will be used to answer our proposed questions. In addition, this data allowed us to evaluate the effectiveness of each method to recognize strengths and weaknesses for this project and for future efforts (**Table 5**). Additionally, the value of this work was to gauge the use of our detector types to estimate abundance across larger landscapes. The results presented here, show that these methods are promising for accomplishing this goal. One of the important findings of this study was the reaffirmation of southeastern beach mice occupying coastal scrub, which supports the role of scrub as a refugia during catastrophic storms and as alternative habitat in high-density situations. Another key benefit of this study was the expansion of our understanding and observation of dispersal distances (**Table 4**) and rates, both among and within habitats.

Table 4. Dispersal Distances from Trapping Data for Southeastern Beach Mice (*Peromyscus polionotus niveiventris, Pp*) and Cotton Mice (*Peromyscus gossypinus, Pg*) Between Sites (Top) and Stations (Bottom) on KSC during the July and October 2018 and March 2019 Surveys.

Species	Tag #	Sex	Date	Capture Site	Date	Recapture Site	Distance Between
Pg	3356	F	03/14/19	3S-C	03/19/19	2S-S	79.3 m
Pg	3384	M	03/12/19	9S-S	03/14/19	7S-N	145.2 m
Pg	3387	M	07/17/18	9S-S	07/19/18	8S-C	71.1 m
Pg	3391	F	07/24/18	10S-W	03/19/19	12ST-E	151.0 m
Pp	6098	M	10/18/18	2ST-W	03/14/19	4ST-N	934.2 m
Pp	6175	M	10/12/18	3ST-S	03/19/19	1D-S	328.9 m
Pp	6177	M	10/12/18	6D-S	10/18/18	2D-W	1043 m
Pp	6256	F	03/12/19	10S-W	03/14/18	11S-N	62.8 m
Pp	6374	F	03/14/19	13ST-S	03/19/19	14ST-S	100.0 m
Pp	6534	F	03/12/19	5D-E	03/19/18	6D-S	62.7 m
Species	**Tag #**	**Sex**	**Date**	**Capture Station**	**Date**	**Recapture Station**	**Distance Between**
Pp	6406	M	07/17/18	8ST-S	07/19/18	8D-C	46.1 m
Pp	6422	F	07/17/18	3D-C	10/16/18	3ST-N	73.8 m
Pp	6541	F	03/14/19	8D-S	03/19/19	8ST-C	37.6 m

Table 5. Total Number of Detections and Non-Detections by Each Method for Southeastern Beach Mice (*Peromyscus polionotus niveiventris, Ppn*) and Cotton Mice (*Peromyscus gossipinus, Pg*) at the 15 Sites on KSC in April, July and October 2018 and March of 2019. Note the April Survey was a Partial Survey (One 7-night Tube and Cameras Deployment). Proportion of Detections and Non-Detections from the Total Number of Detectors Deployed is in Parentheses.

	Southeastern beach mouse, *Peromyscus polionotus niveiventris, Ppn*				Cotton mouse, *Peromyscus gossypinus, Pg*			
	Apr-18	Jul-18	Oct-18	Mar-19	Apr-18	Jul-18	Oct-18	Mar-19
Total Number of Detections (All Methods)	180 (75.9%)	501 (44.1%)	377 (33.2%)	532 (46.5%)	65 (27.4%)	124 (10.9%)	172 (15.1%)	287 (25.1%)
Total Number of Non-Detections (All Methods)	57 (24.1%)	634 (55.9%)	754 (66.3%)	613 (53.5%)	172 (72.6%)	1012 (89.1%)	965 (84.9%)	858 (74.9%)
Total Number of Detections via Tracking Tubes	169 (75.1%)	422 (93.8%)	337 (74.9%)	411 (91.3%)	57 (25.3%)	100 (22.2%)	163 (36.2%)	242 (53.8%)
Total Number of Non-Detections via Tracking Tubes	56 (24.9%)	28 (6.2%)	113 (25.1%)	39 (8.7%)	168 (74.7%)	350 (77.8%)	287 (63.8%)	208 (46.2%)
Total Number of Detections via Live-Traps	NA	69 (10.2%)	34 (5.0%)	101 (15.0%)	NA	16 (2.3%)	6 (0.9%)	31 (4.6%)
Total Number of Non-Detections via Live-Traps	NA	606 (89.8%)	641 (95.0%)	574 (85.0%)	NA	660 (97.7%)	669 (99.1%)	644 (95.4%)
Total Number of Detections via Bucket Cameras	5 (83.3%)	5 (100%)	5 (83.3%)	10 (100%)	4 (66.7%)	4 (80.0%)	2 (33.3%)	8 (80.0%)
Total Number of Non-Detections via Bucket Cameras	1 (16.7%)	0	1 (16.7%)	0	2 (33.3%)	1 (20.0%)	4 (66.7%)	2 (20.0%)
Total Number of Detections via Trail Cameras	6 (100%)	5 (100%)	6 (100%)	10 (100%)	4 (66.7%)	4 (80.0%)	1 (16.7%)	6 (60.0%)
Total Number of Non-Detections via Trail Cameras	0	0	0	0	2 (33.3%)	1 (20.0%)	5 (83.3%)	4 (40.0 %)

5.0 Long- and/or Short-Term Trends

This project only encompassed three complete quarterly surveys in 2018 – 2019 and as such, there are no long-term trends to report. Listed below are descriptions of additional valuable data collected during this study, which are provided in **Appendices A, B, and C**. Examination of this data allow readers to discern differences in detections between traps and tubes, explore quarterly demographic data for southeastern beach mice, and compare bucket and trail camera data.

- The detection maps (not occupancy) for both the tracking tubes and live-traps for each survey conducted (July and October 2018 and March 2019) are provided in **Appendix A**. The maps show the changes in the detection of southeastern beach mice for the three complete quarterly surveys by site, station and method (tracking tube versus live-traps and individual tracking tube or live-trap).
- Demographic data results for each survey conducted (July and October 2018 and March 2019) obtained via trapping are provide in **Appendix B**. These results provide the following information:
  - Number of potential and actual trapnights for each survey.
  - Number of individuals, recaptures, and total beach mice for each survey with sites and stations combined and by survey and site with habitats combined.
  - Number of individual male and females by survey with sites and stations combined.
  - Number of individual male and females by site by survey.
  - Number of individual adult, subadult, and juveniles by survey with sites and stations combined.
  - Number of individual adult, subadult, and juveniles by site by survey.
  - Number of individual beach mice and cotton mice by habitat by site.

  When sites and stations were combined for each survey the following was observed:

  - Individual numbers, recaptures and total number of beach mice all decreased from July to October and then almost doubled in March.
  - More male beach mice were captured than females in July; the sex ratio was almost equal in October, and more females than males were captured in March.
  - In each survey, adults were the predominant age class of southeastern beach mice captured. Subadults were present in all (lowest numbers in October and highest in March). No juveniles were captured in July, only one was captured in October, while 17 juveniles were captured over eight sites in March.
- A comparison of the data from the bucket and trail cameras is provided in **Appendix C**. We tested bucket cameras versus trail cameras (both passive certain detection methods) and provide examples of photos obtained by both types of cameras for southeastern beach mice and cotton mice at a subset of sites/stations for each survey. A list of other species observed is also provided (**Table C-1**).

- Trail cameras provided more information on the small mammal community assemblage around each trap/tube as well as habitat use by other species (**Table C-1**).
- Both bucket and trail cameras had strengths and weaknesses. Bucket cameras were able to discern differences in pelage, size of the animal and morphometric measurements like tail length (**Figure C-1**). Identification of southeastern beach mice versus cotton mice using a trail camera was heavily dependent on the correct placement, distance and angle of the camera (**Figures C-1 and C-2**).
- More testing of each camera type in different situations is needed to determine which camera system will work the best on the CCBIC.

6.0 Recommendations

Future work in consultation with National Aeronautics and Space Administration's (NASA's) Environmental Management Branch (EMB) may include consideration of the following:

- Target episodically disturbed habitats (storm events, created dune, and managed areas) for sampling.
- Tailor study design through adaptive sampling to maximize information obtained from the data and utilize resources more efficiently.
- Continue the use of multi-type detection (tube, trap, camera, genetics, etc.).
- Continue to focus on the connection between coastal and inland southeastern beach mouse habitat.
- Engage stakeholders to jointly address progress, identify data gaps, and plan and prioritize species recovery goals (genetics, management, monitoring, and translocation) for southeastern beach mice on the CCBIC.

7.0 Current or Foreseeable Concerns:

- **Southeastern beach mouse population decline without continued monitoring.** Gaps in knowledge are riskier with an r-selected species (short life cycle, high reproductive rate), because such populations are highly variable and without regular monitoring important rapid changes may go undetected. When populations become small, data becomes much harder to obtain (more expensive). It is better to maintain a long-term monitoring effort for this reason, and because species recovery is much more expensive than species maintenance.
- **Lack of information about the impact of continuing storm events on southeastern beach mouse functions after storms.** Possibly the greatest threat to the persistence of the southeastern beach mouse over the next 50 years is the likelihood that a severe storm or series of severe storms will result in its extinction (Frank, 1996). The severe storms in 1995, 2000, 2004, and most recently 2016 and 2017 showed that severe storms impact the beach mouse populations on CCBIC. Future storms will occur and these events may be more severe and more frequent due to climate change.

8.0 FY2018 – FY2019 Activities

- Four surveys were planned; three were completed, and one was partially completed.
- The tubes were active for 7 nights. Trapping occurred for 3 trap nights with a break of 1 night between trap nights (except for 2 nights to account for the weekend) followed by a second 7-night tube deployment. One bucket camera and one trail camera were placed at a subset of sites and deployed for the whole 23 days of the survey.
- The April survey began as planned but was suspended due to demand for personnel and equipment by the Created Dune work, shifting FY2019 to two planned surveys. We were able to complete one 8-night tube survey as well as collect data from the trail and bucket cameras for the same period. The October survey began as scheduled but trapping and card retrieval for part of the survey had to be delayed for 2 days due to Hurricane Michael, which shifted the remainder of the schedule by 2 days.
- January's survey (winter) was canceled due to the Government shutdown which occurred in December 2018/January 2019. Due to the loss of this quarter's survey, the planned April survey was moved to March in order to decrease the length of time between the data collection.
- Six bucket and trail cameras were deployed during the April survey, 5 each for the July survey, 6 each for the October survey, and 10 each for the March survey
- Trap data from each survey was entered. Tracking cards (n = 450 per survey) were sorted and the reading process begun. Cameras were downloaded, and the process of reviewing the images was begun.

9.0 Literature Cited

Frank, P. A. 1996. Ecology and conservation of the Anastasia Island beach mouse (*Peromyscus polionotus phasma*). Ph.D. dissertation, University of Florida Gainesville.

Greene, D. U., D. M. Oddy, J. A. Gore, M. N. Gillikin, E. Evans, S. L. Gann, and E. H. Leone. 2018. Differentiating Footprints of Sympatric Rodents in Coastal Dune Communities: Implications for Imperiled Beach Mice. Journal of Fish and Wildlife Management 9:582-590.

Kalkvik, H. M., I. J. Stout, and C. L. Parkinson. 2012. Unraveling natural versus anthropogenic effects on genetic diversity within the southeastern beach mouse *(Peromyscus polionotus niveiventris*). Conservation Genetics 13:1653–1664.

Stolen, E. D., D. M. Oddy, M. L. Legare, D. R. Breininger, S. L. Gann, S. A. Legare, S. K. Weiss, K. G. Holloway-Adkins, and R. Schaub. 2014. Preventing tracking-tube false detections in occupancy modeling of southeastern beach mouse. Journal of Fish and Wildlife Management. 5:270-282.

Zimmerman, M., D. Oddy, E. Stolen, D. Breininger, and C. L. Pruett. 2015. Microspatial sampling reveals cryptic influences on gene flow in a threatened mammal. Conservation Genetics. 16:1403-1414.

Appendices Figures and Tables

Appendix A. Detection Maps for Each Quarter by Sites and Methods (Tubes vs. Traps)

Figure A-1. Southeastern Beach Mouse Detection by Tracking Tubes for July 2018 at KSC Dynamic Habitat Occupancy Sites 1-3. Each site consisted of five tracking tube stations in coastal dune, coastal strand, and coastal scrub habitats.

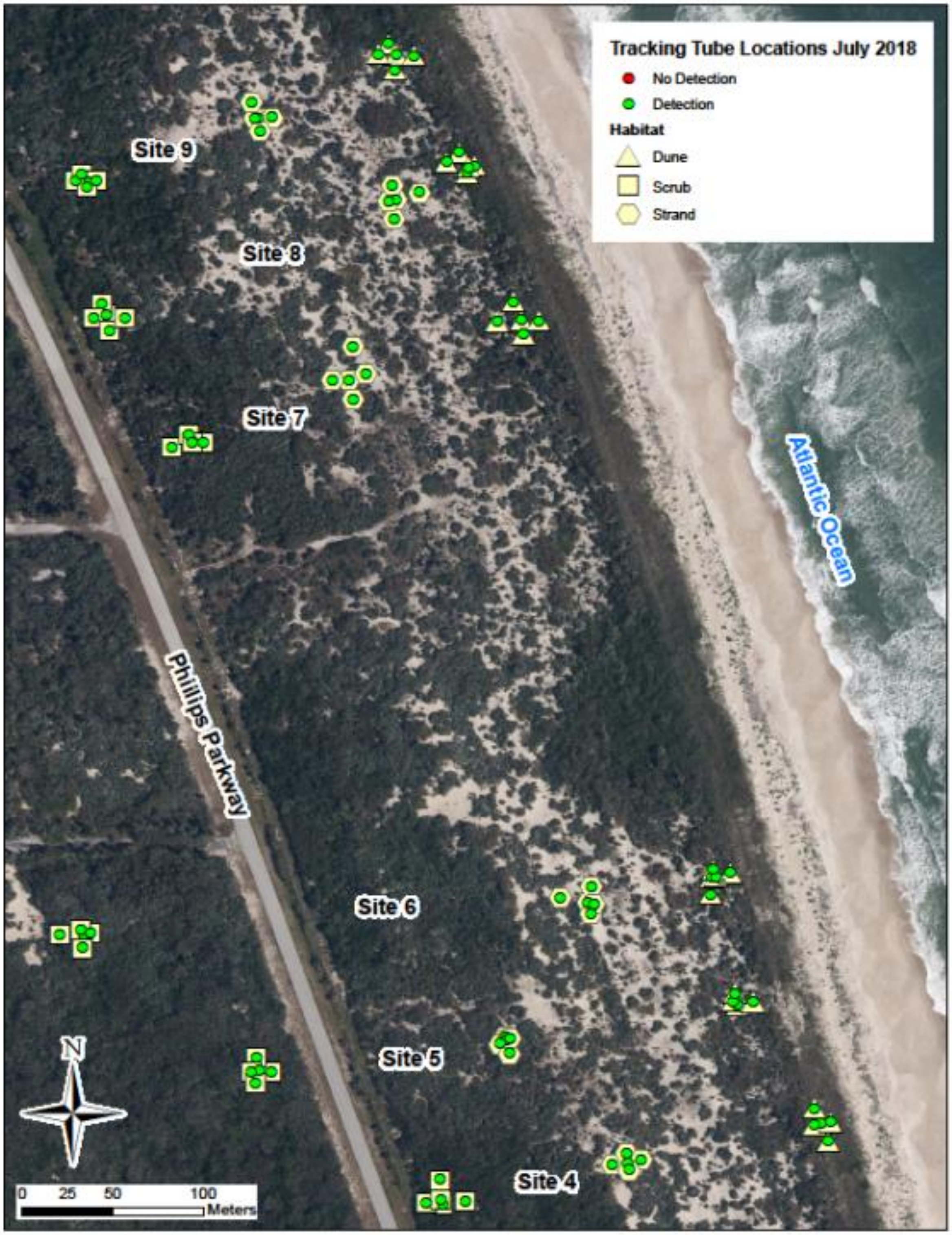

Figure A-2. Southeastern Beach Mouse Detection by Tracking Tubes for July 2018 at KSC Dynamic Habitat Occupancy Sites 4-9. Each site consisted of five tracking tube stations in coastal dune, coastal strand, and coastal scrub habitats.

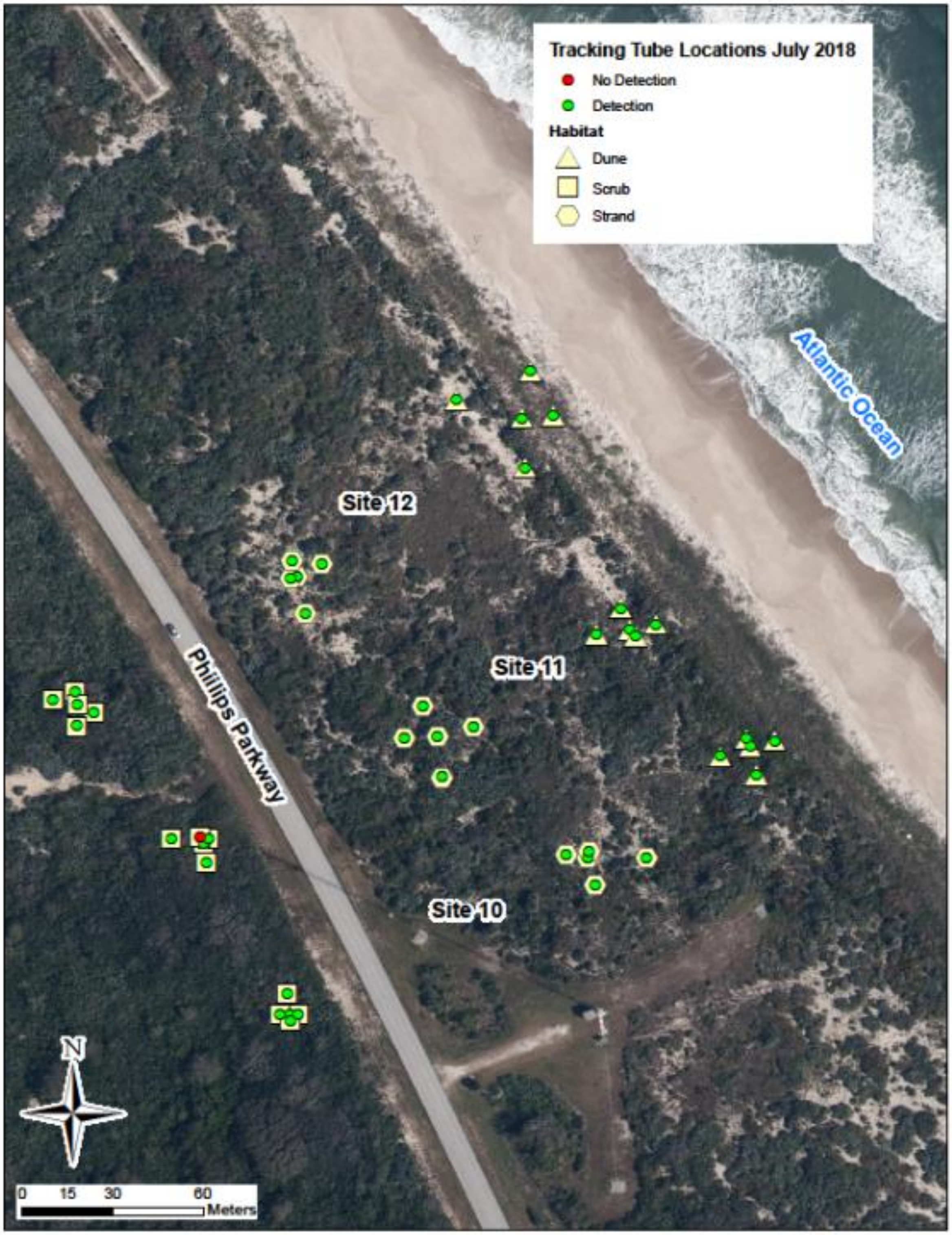

Figure A-3. Southeastern Beach Mouse Detection by Tracking Tubes for July 2018 at KSC Dynamic Habitat Occupancy Sites 10-12. Each site consisted of five tracking tube stations in coastal dune, coastal strand, and coastal scrub habitats.

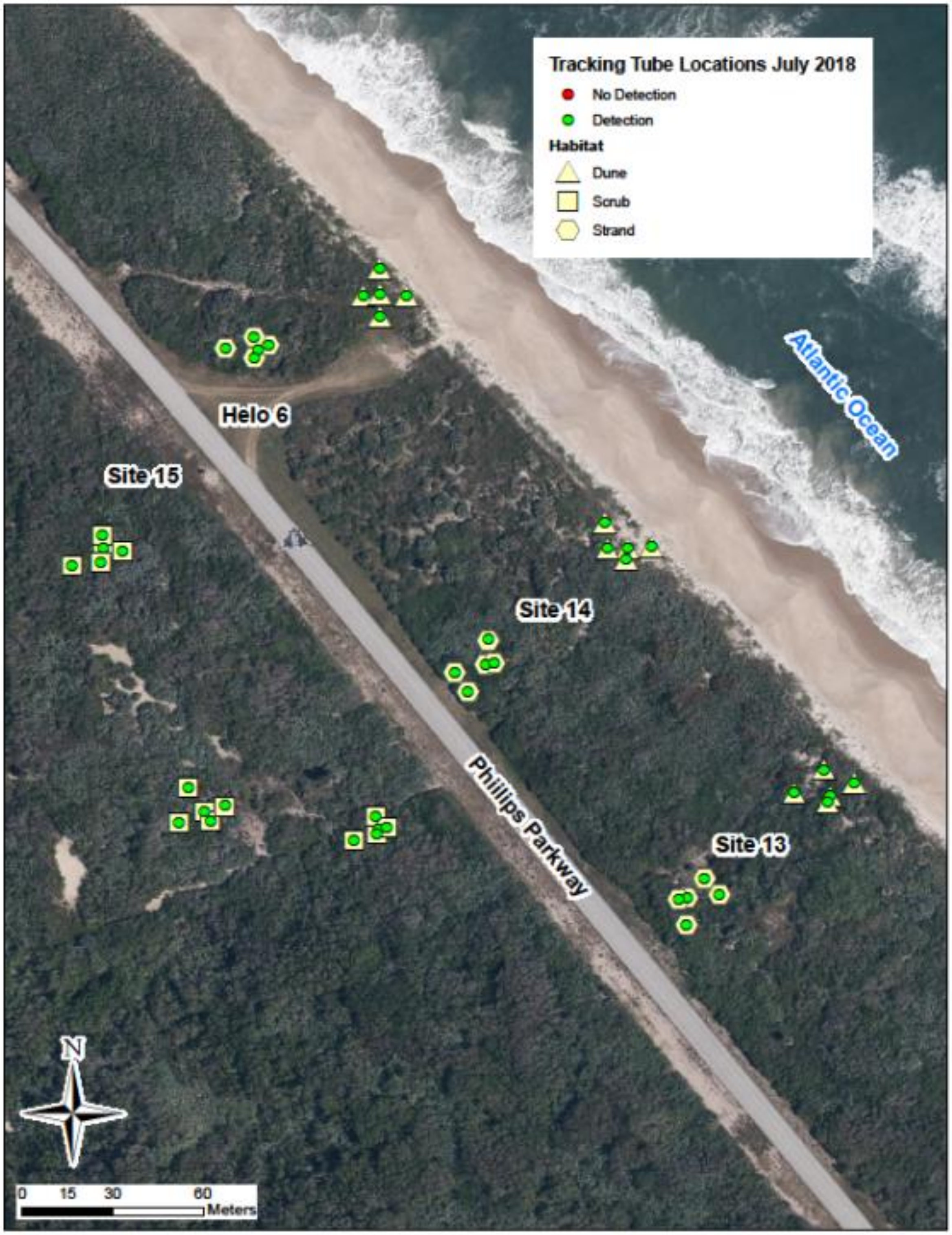

Figure A-4. Southeastern Beach Mouse Detection by Tracking Tubes for July 2018 at KSC Dynamic Habitat Occupancy Sites 13-15. Each site consisted of five tracking tube stations in coastal dune, coastal strand, and coastal scrub habitats.

Figure A-5. Southeastern Beach Mouse Detection by Live-Traps for July 2018 at KSC Dynamic Habitat Occupancy Sites 1-3. Each site consisted of five live-trap stations in coastal dune, coastal strand, and coastal scrub habitats.

Figure A-6. Southeastern Beach Mouse Detection by Live-Traps for July 2018 at KSC Dynamic Habitat Occupancy Sites 4-9. Each site consisted of five live-trap stations in coastal dune, coastal strand, and coastal scrub habitats.

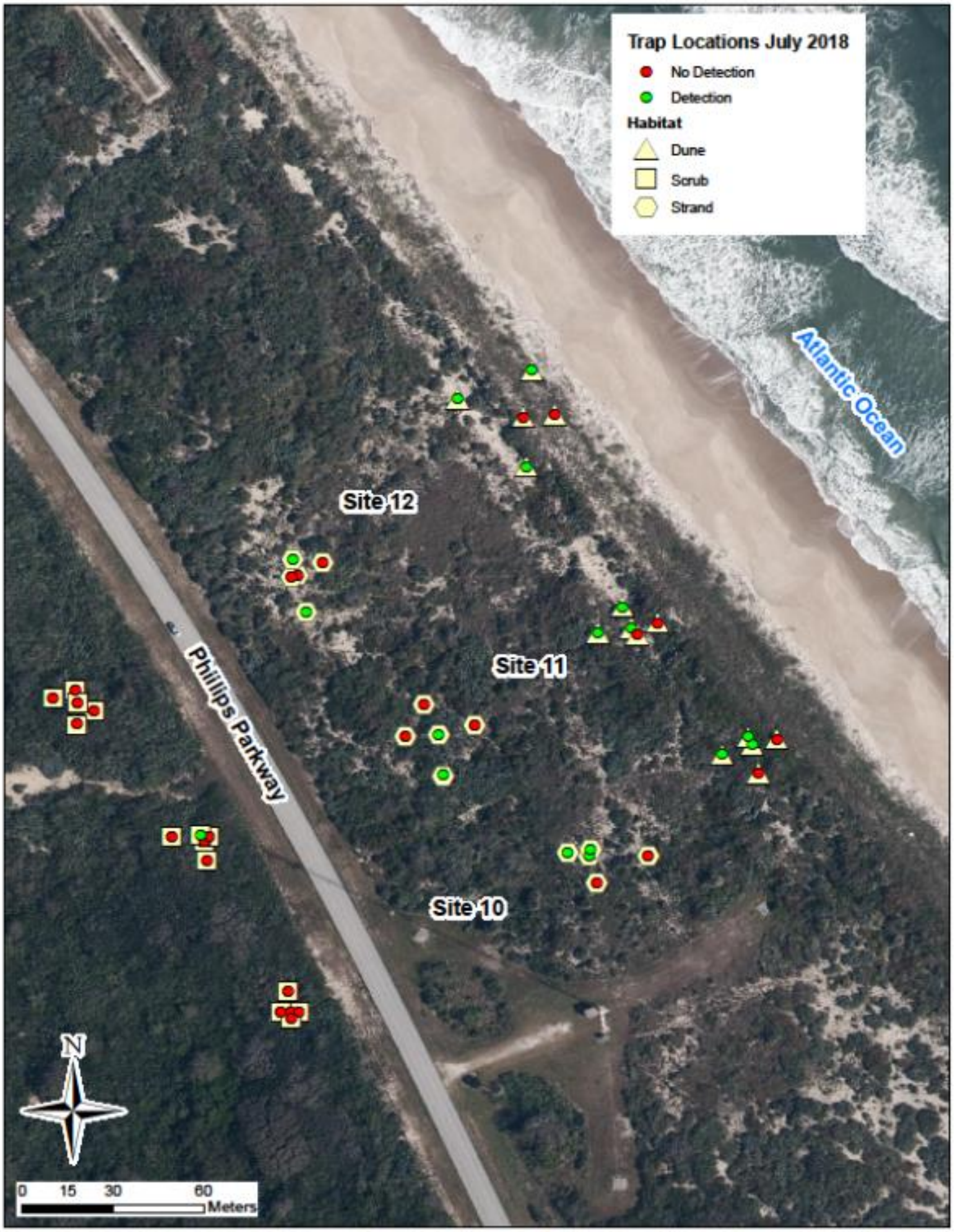

Figure A-7. Southeastern Beach Mouse Detection by Live-Traps for July 2018 at KSC Dynamic Habitat Occupancy Sites 10-12. Each site consisted of five live-trap stations in coastal dune, coastal strand, and coastal scrub habitats.

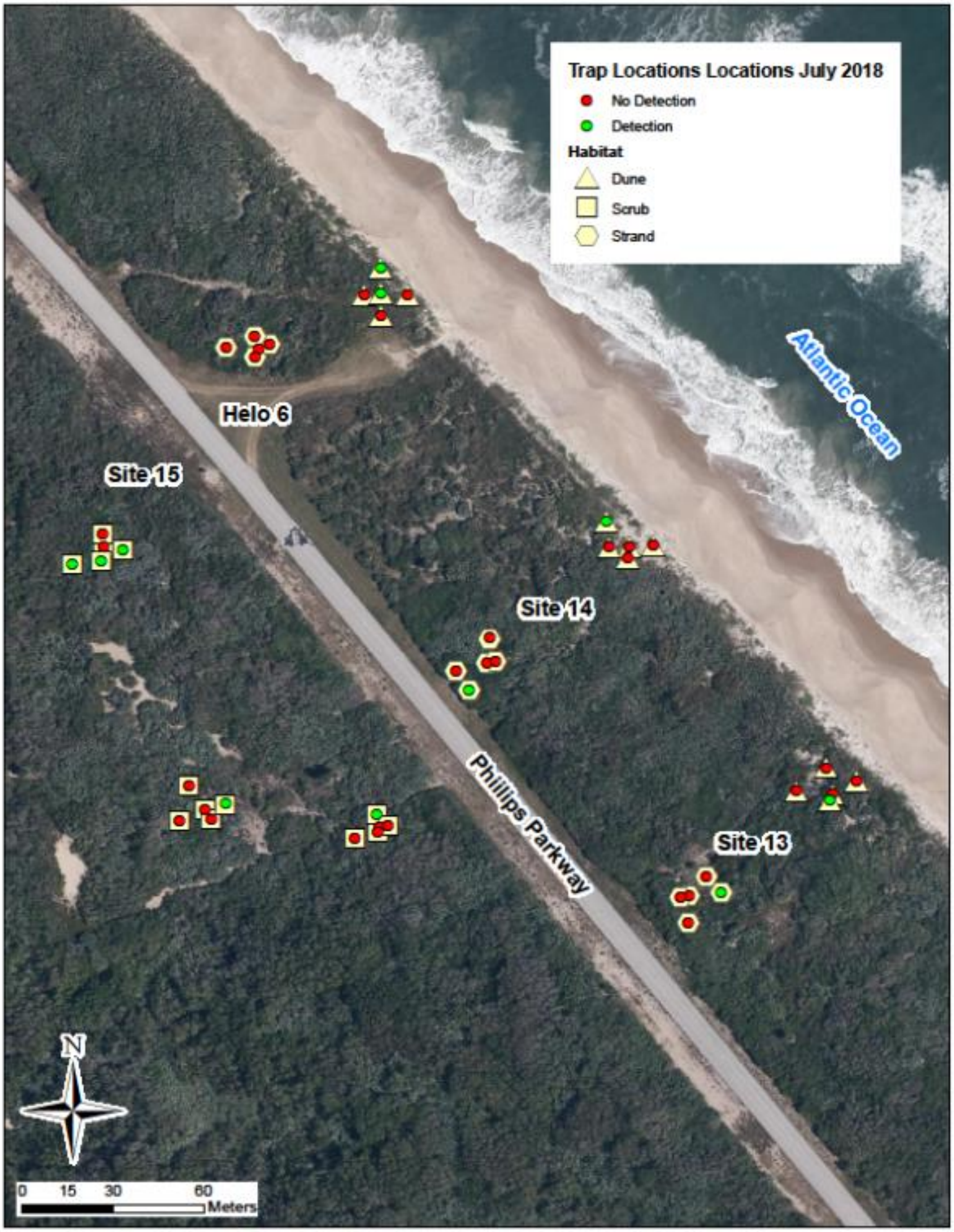

Figure A-8. Southeastern Beach Mouse Detection by Live-Traps for July 2018 at KSC Dynamic Habitat Occupancy Sites 13-15. Each site consisted of five live-trap stations in coastal dune, coastal strand, and coastal scrub habitats.

Figure A-9. Southeastern Beach Mouse Detection by Tracking Tubes for October 2018 at KSC Dynamic Habitat Occupancy Sites 1-3. Each site consisted of five tracking tube stations in coastal dune, coastal strand, and coastal scrub habitats.

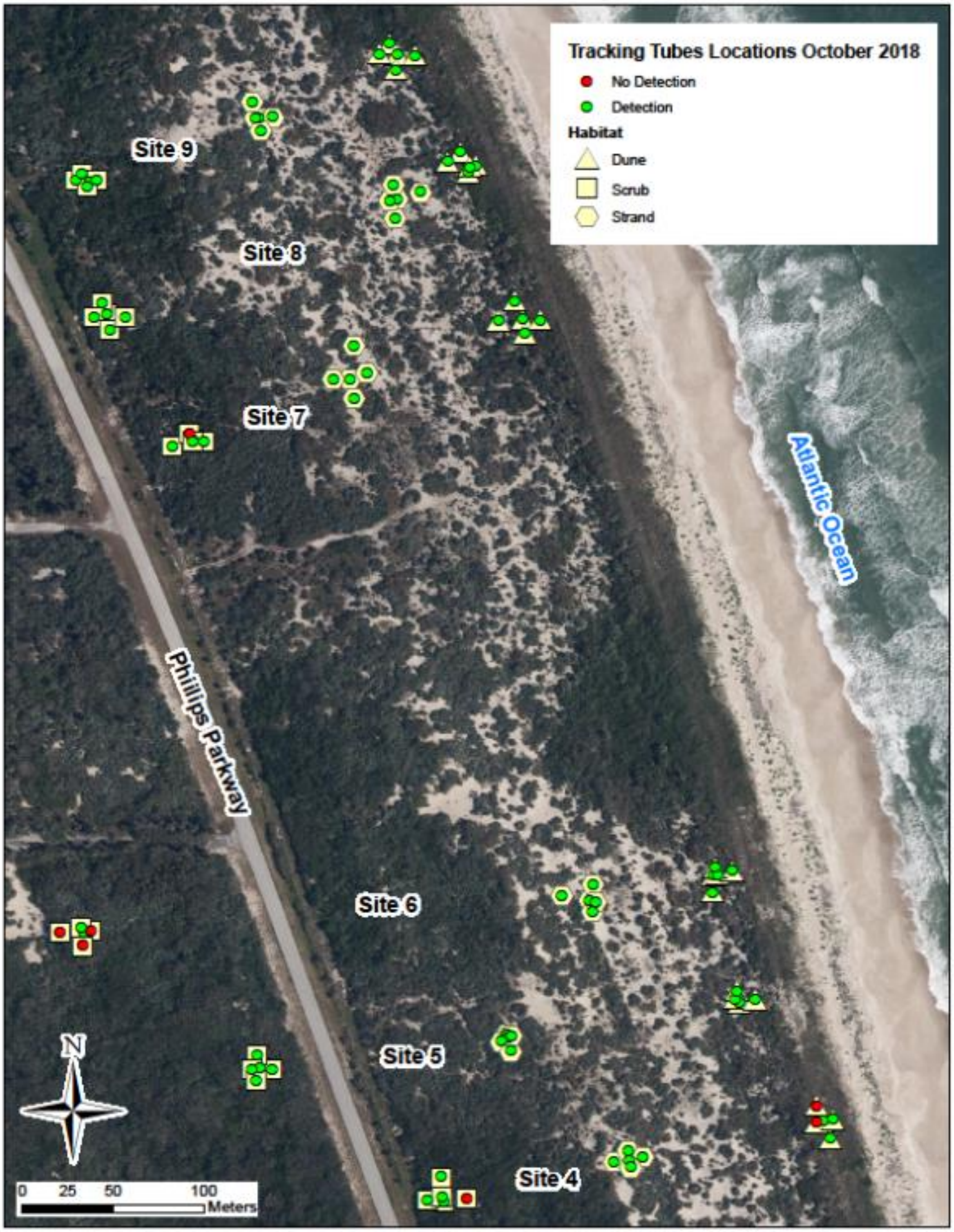

Figure A-10. Southeastern Beach Mouse Detection by Tracking Tubes for October 2018 at KSC Dynamic Habitat Occupancy Sites 4-9. Each site consisted of five tracking tube stations in coastal dune, coastal strand, and coastal scrub habitats.

Figure A-11. Southeastern Beach Mouse Detection by Tracking Tubes for October 2018 at KSC Dynamic Habitat Occupancy Sites 10-12. Each site consisted of five tracking tube stations in coastal dune, coastal strand, and coastal scrub habitats.

Figure A-12. Southeastern Beach Mouse Detection by Tracking Tubes for October 2018 at KSC Dynamic Habitat Occupancy Sites 13-15. Each site consisted of five tracking tube stations in coastal dune, coastal strand, and coastal scrub habitats.

Figure A-13. Southeastern Beach Mouse Detection by Live-Traps for October 2018 at KSC Dynamic Habitat Occupancy Sites 1-3. Each site consisted of five live-trap stations in coastal dune, coastal strand, and coastal scrub habitats.

Figure A-14. Southeastern Beach Mouse Detection by Live-Traps for October 2018 at KSC Dynamic Habitat Occupancy Sites 4-9. Each site consisted of five live-trap stations in coastal dune, coastal strand, and coastal scrub habitats.

Figure A-15. Southeastern Beach Mouse Detection by Live-Traps for October 2018 at KSC Dynamic Habitat Occupancy Sites 10-12. Each site consisted of five live-trap stations in coastal dune, coastal strand, and coastal scrub habitats.

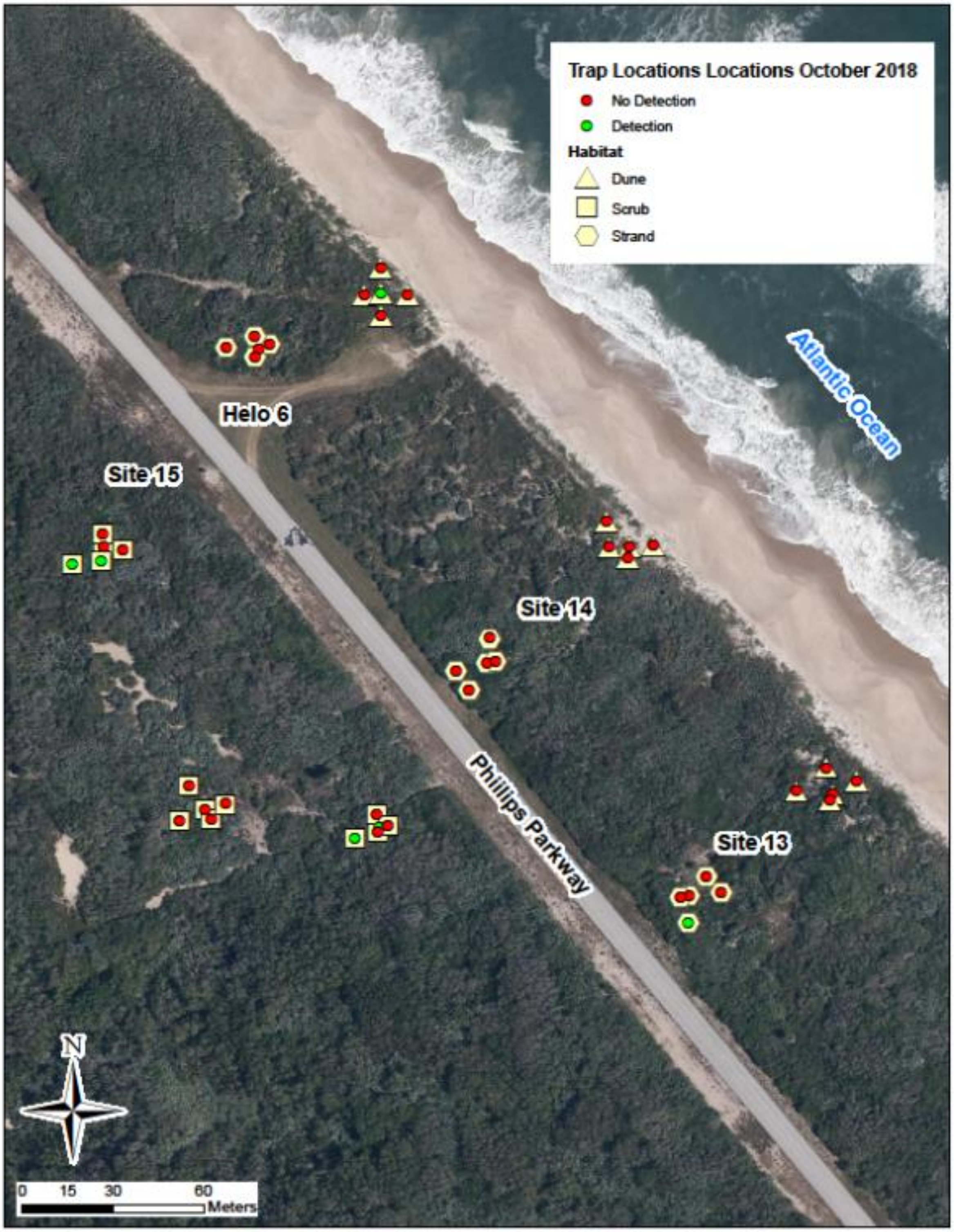

Figure A-16. Southeastern Beach Mouse Detection by Live-Traps for October 2018 at KSC Dynamic Habitat Occupancy Sites 13-15. Each site consisted of five live-trap stations in coastal dune, coastal strand, and coastal scrub habitats.

Figure A-17. Southeastern Beach Mouse Detection by Tracking Tubes for March 2019 at KSC Dynamic Habitat Occupancy Sites 1-3. Each site consisted of five tracking tube stations in coastal dune, coastal strand, and coastal scrub habitats.

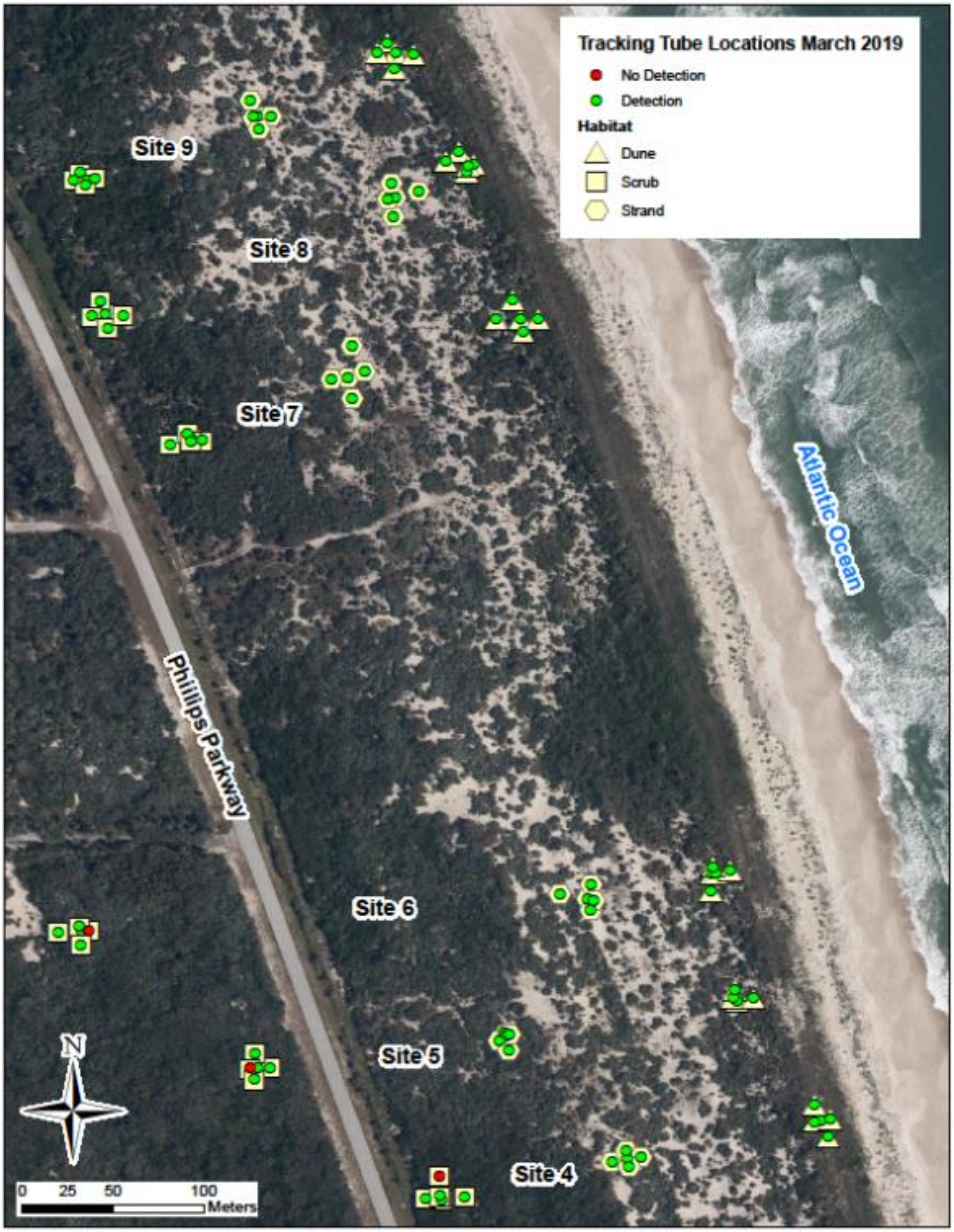

Figure A-18. Southeastern Beach Mouse Detection by Tracking Tubes for March 2019 at KSC Dynamic Habitat Occupancy Sites 4-9. Each site consisted of five tracking tube stations in coastal dune, coastal strand, and coastal scrub habitats.

Figure A-19. Southeastern Beach Mouse Detection by Tracking Tubes for March 2019 at KSC Dynamic Habitat Occupancy Sites 10-12. Each site consisted of five tracking tube stations in coastal dune, coastal strand, and coastal scrub habitats.

Figure A-20. Southeastern Beach Mouse Detection by Tracking Tubes for March 2019 at KSC Dynamic Habitat Occupancy Sites 13-15. Each site consisted of five tracking tube stations in coastal dune, coastal strand, and coastal scrub habitats.

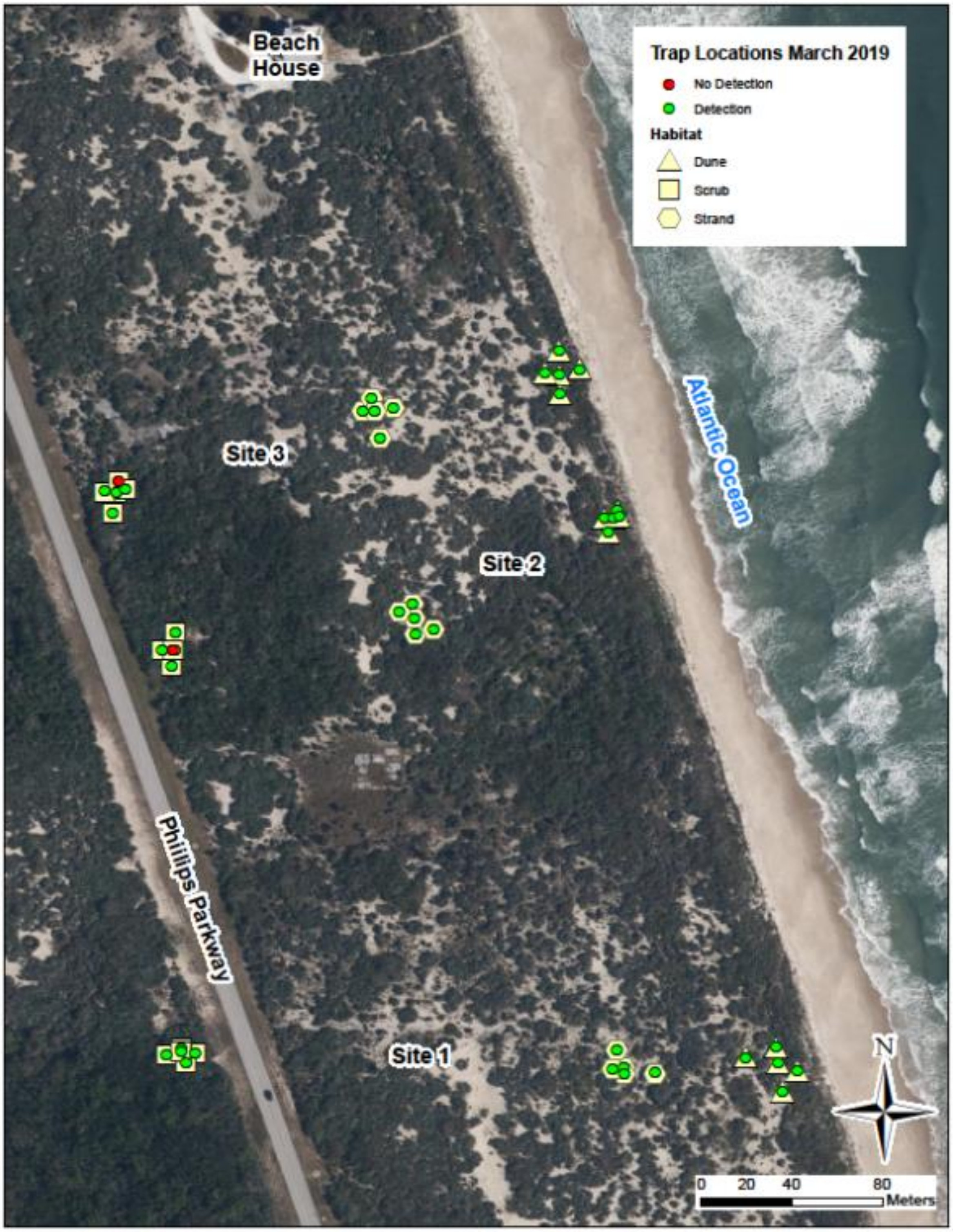

Figure A-21. Southeastern Beach Mouse Detection by Live-Traps for March 2019 at KSC Dynamic Habitat Occupancy Sites 1-3. Each site consisted of five live-trap stations in coastal dune, coastal strand, and coastal scrub habitats.

Figure A-22. Southeastern Beach Mouse Detection by Live-Traps for March 2019 at KSC Dynamic Habitat Occupancy Sites 4-9. Each site consisted of five live-trap stations in coastal dune, coastal strand, and coastal scrub habitats.

Figure A-23. Southeastern Beach Mouse Detection by Live-Traps for March 2019 at KSC Dynamic Habitat Occupancy Sites 10-12. Each site consisted of five live-trap stations in coastal dune, coastal strand, and coastal scrub habitats.

Figure A-24. Southeastern Beach Mouse Detection by Live-Traps for March 2019 at KSC Dynamic Habitat Occupancy Sites 13-15. Each site consisted of five live-trap stations in coastal dune, coastal strand, and coastal scrub habitats.

Appendix B. Demographic Data from Live-Trapping

Table B-1. The Number of Potential and Actual Trap Nights for the 15 Sites at the KSC in July and October 2018 and March 2019. Stations (coastal dune, coastal strand, and coastal scrub) were combined at each site.

Site #	July		October		March	
	Potential #	Actual #	Potential #	Actual #	Potential #	Actual #
1	45	43	45	41	45	36
2	45	42	45	45	45	40
3	45	43	45	43	45	38
4	45	42	45	44	45	37
5	45	41	45	43	45	34
6	45	42	45	45	45	39
7	45	44	45	42	45	32
8	45	42	45	41	45	35
9	45	44	45	43	45	40
10	45	42	45	41	45	34
11	45	41	45	42	45	39
12	45	39	45	44	45	37
13	45	39	45	44	45	43
14	45	42	45	40	45	37
15	45	44	45	43	45	38
	675	**630**	**675**	**641**	**675**	**559**

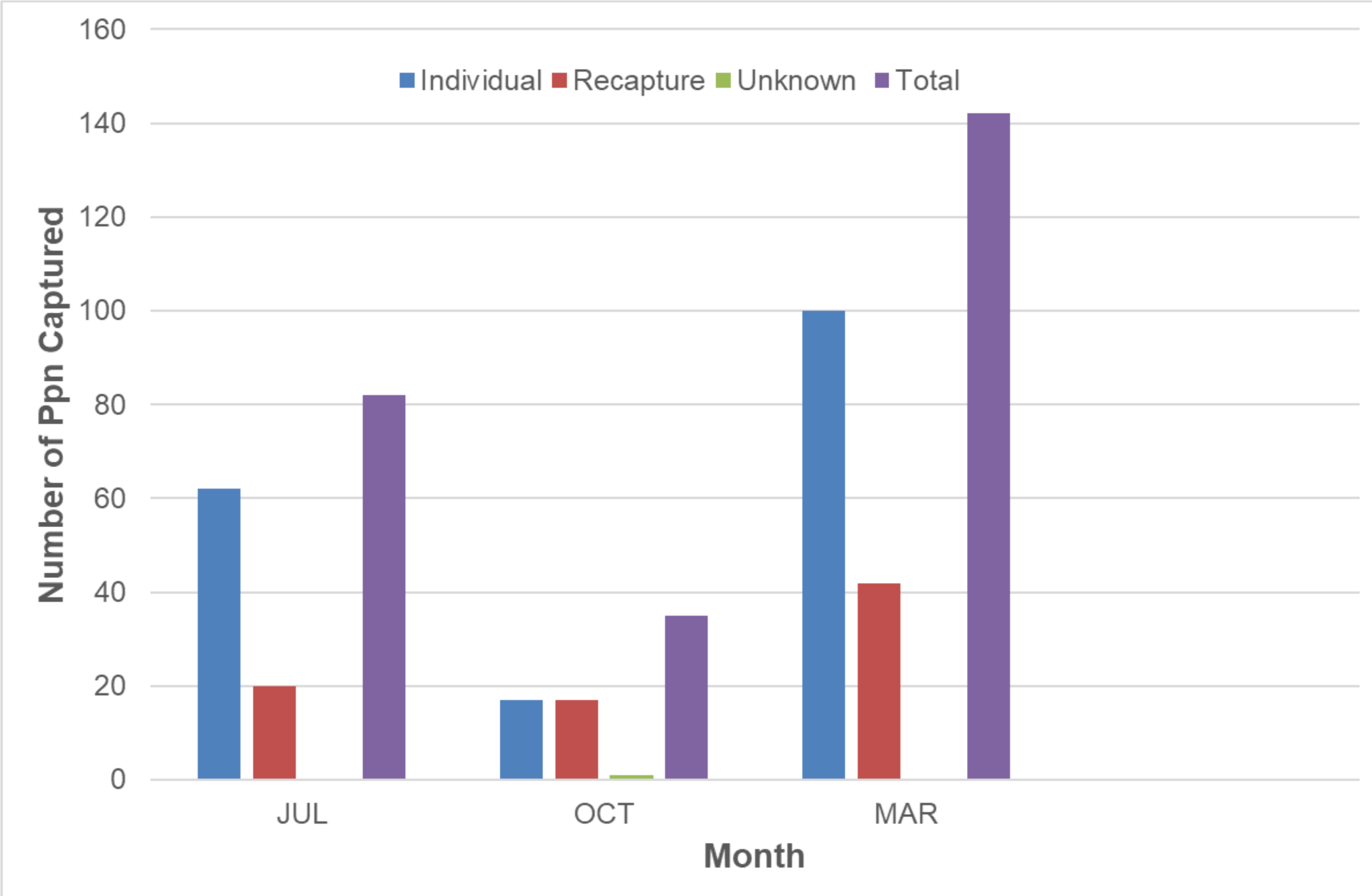

Figure B-1. Number of Individual, Recapture, Unknown, and Total Southeastern Beach Mice (Ppn) Captured at the 15 Sites Combined on KSC during the July and October 2018 and March 2019 Surveys.

Figure B-2. Number of Individual, Recaptured, and Total Southeastern Beach Mice (Ppn) Captured at the 15 Sites (45 Stations) on KSC in July 2018.

Figure B-3. Number of Individual, Recaptured, and Total Southeastern Beach Mice (Ppn) Captured at the 15 Sites (45 Stations) on KSC in October 2018.

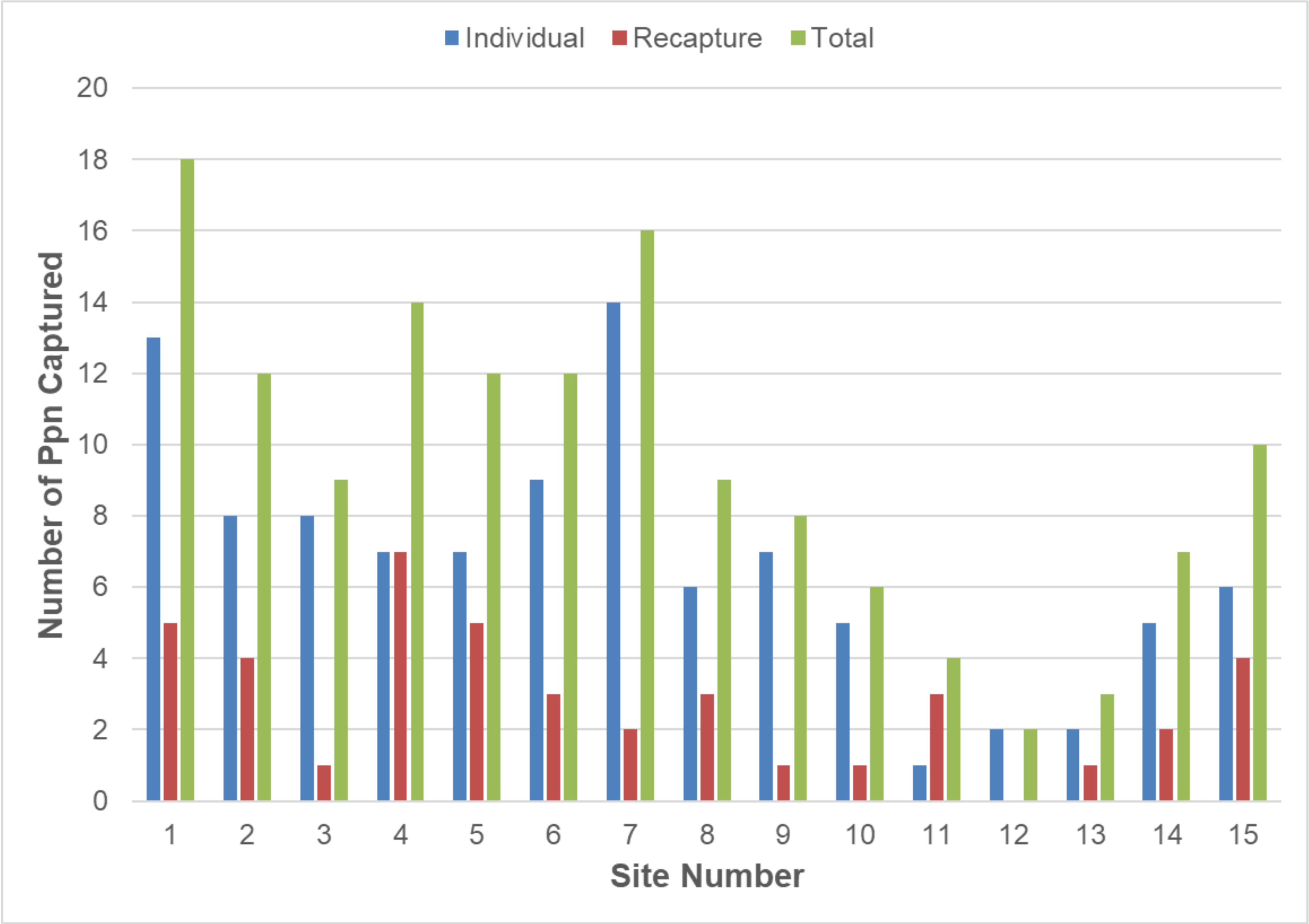

Figure B-4. Number of Individual, Recaptured, and Total Southeastern Beach Mice (Ppn) Captured at the 15 Sites (45 Stations) on KSC in March 2019.

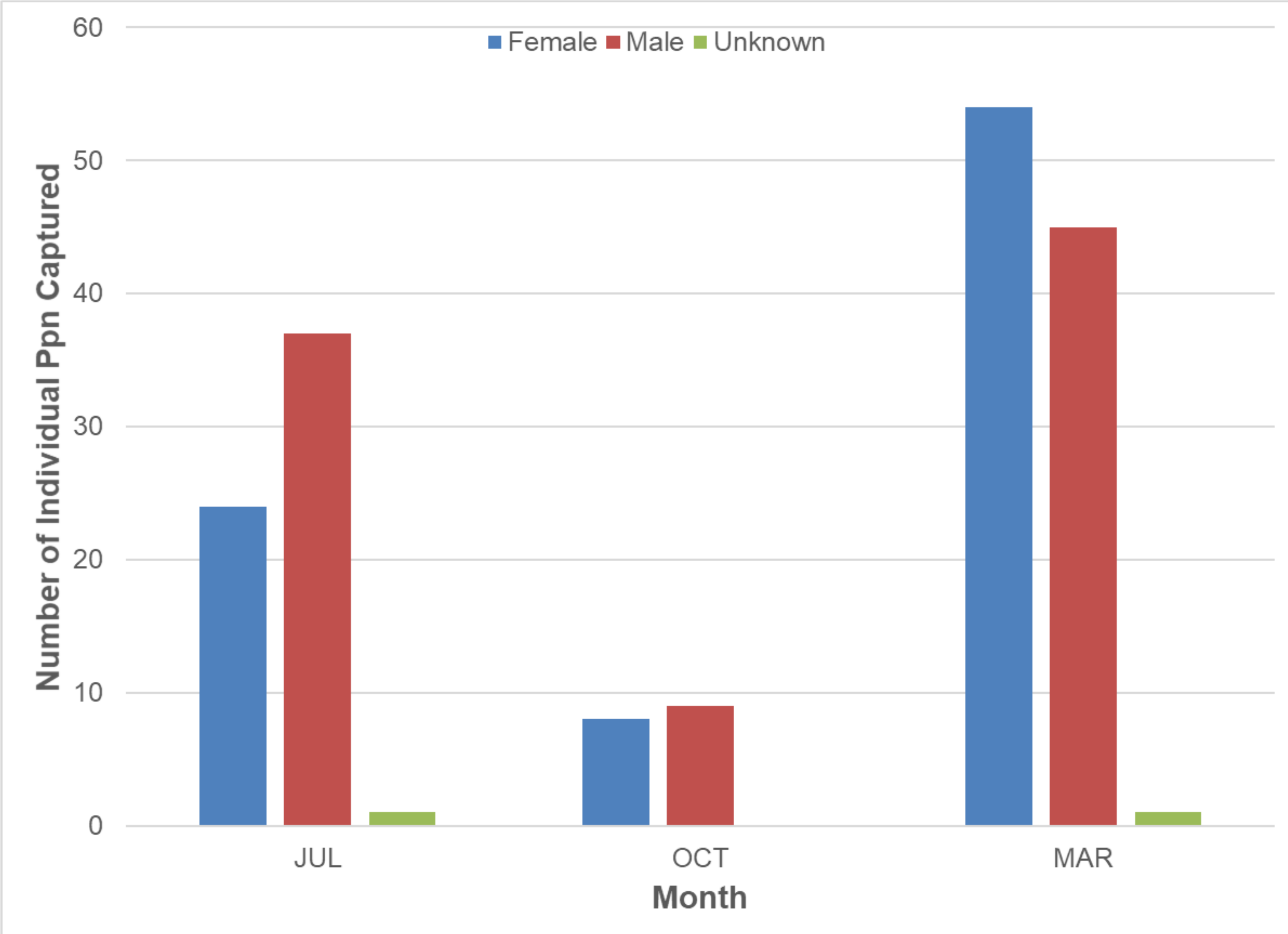

Figure B-5. Number of Individual Female, Male, and Unknown Sex Southeastern Beach Mice (Ppn) Captured at the 15 Sites Combined on KSC during the July and October 2018 and March 2019 Surveys.

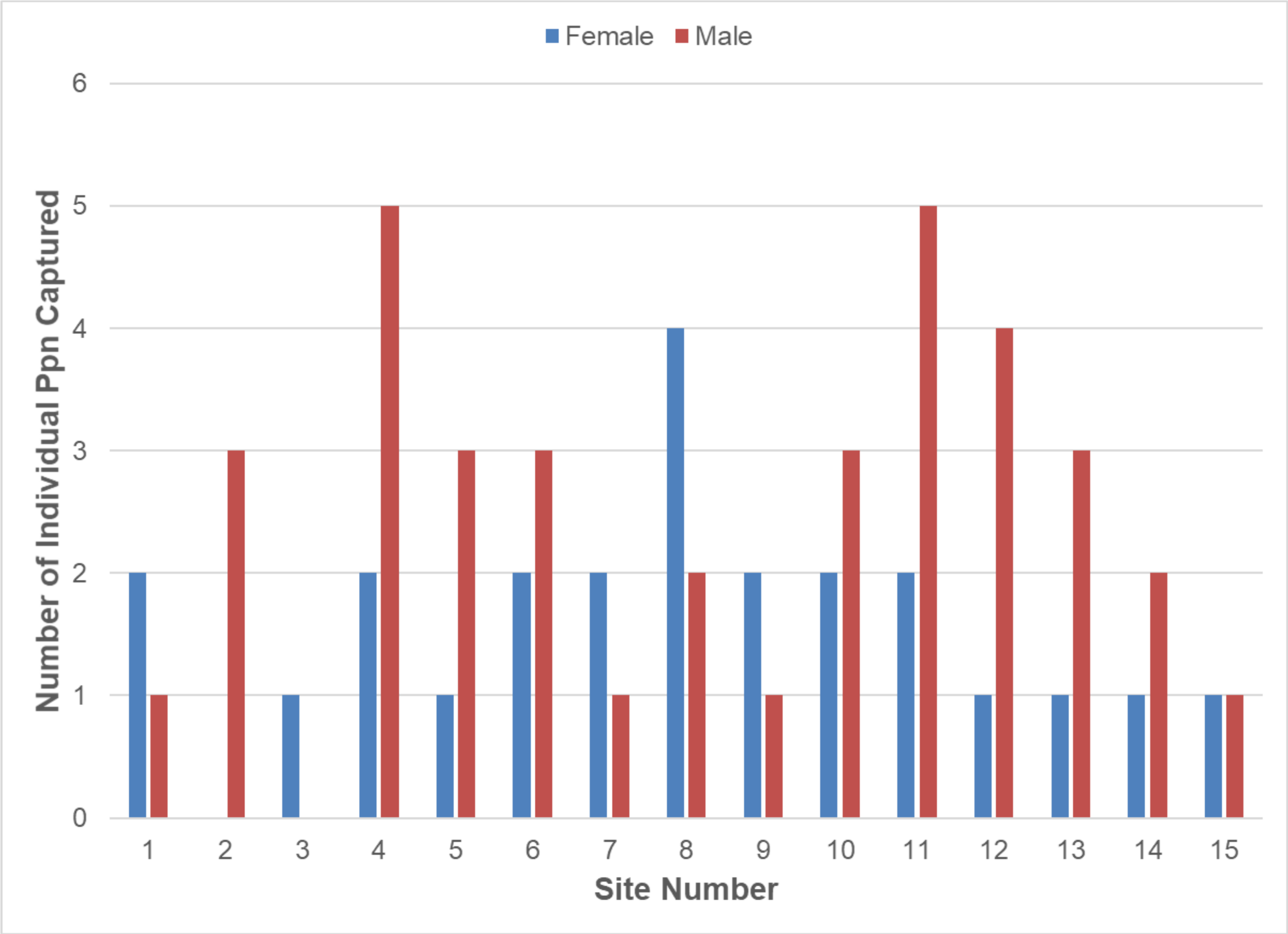

Figure B-6. Number of Individual Female and Male Southeastern Beach Mice (Ppn) Captured at the 15 Sites (45 Stations) on KSC in July 2018.

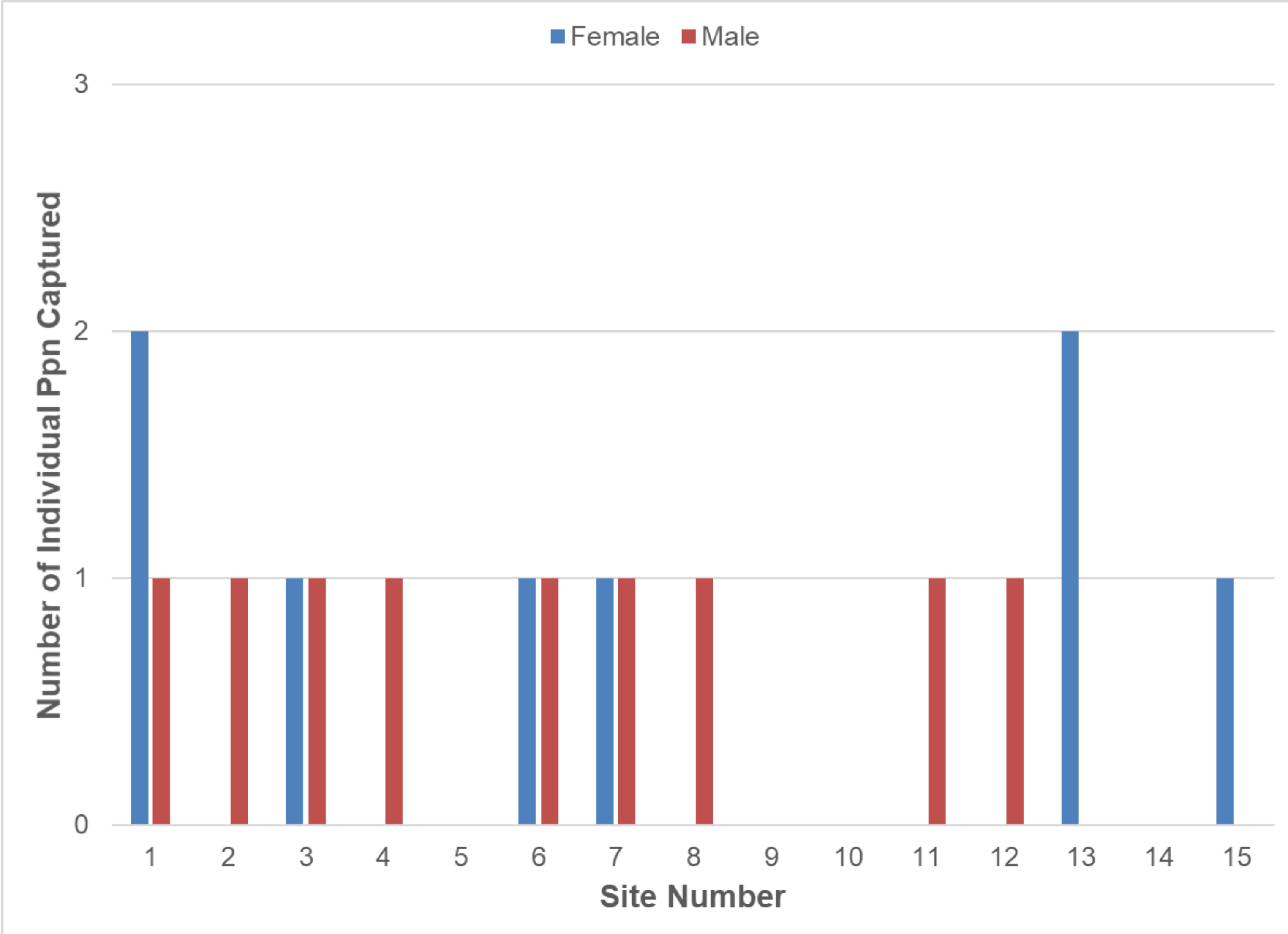

Figure B-7. Number of Individual Female and Male Southeastern Beach Mice (Ppn) Captured at the 15 Sites (45 Stations) on KSC in October 2018.

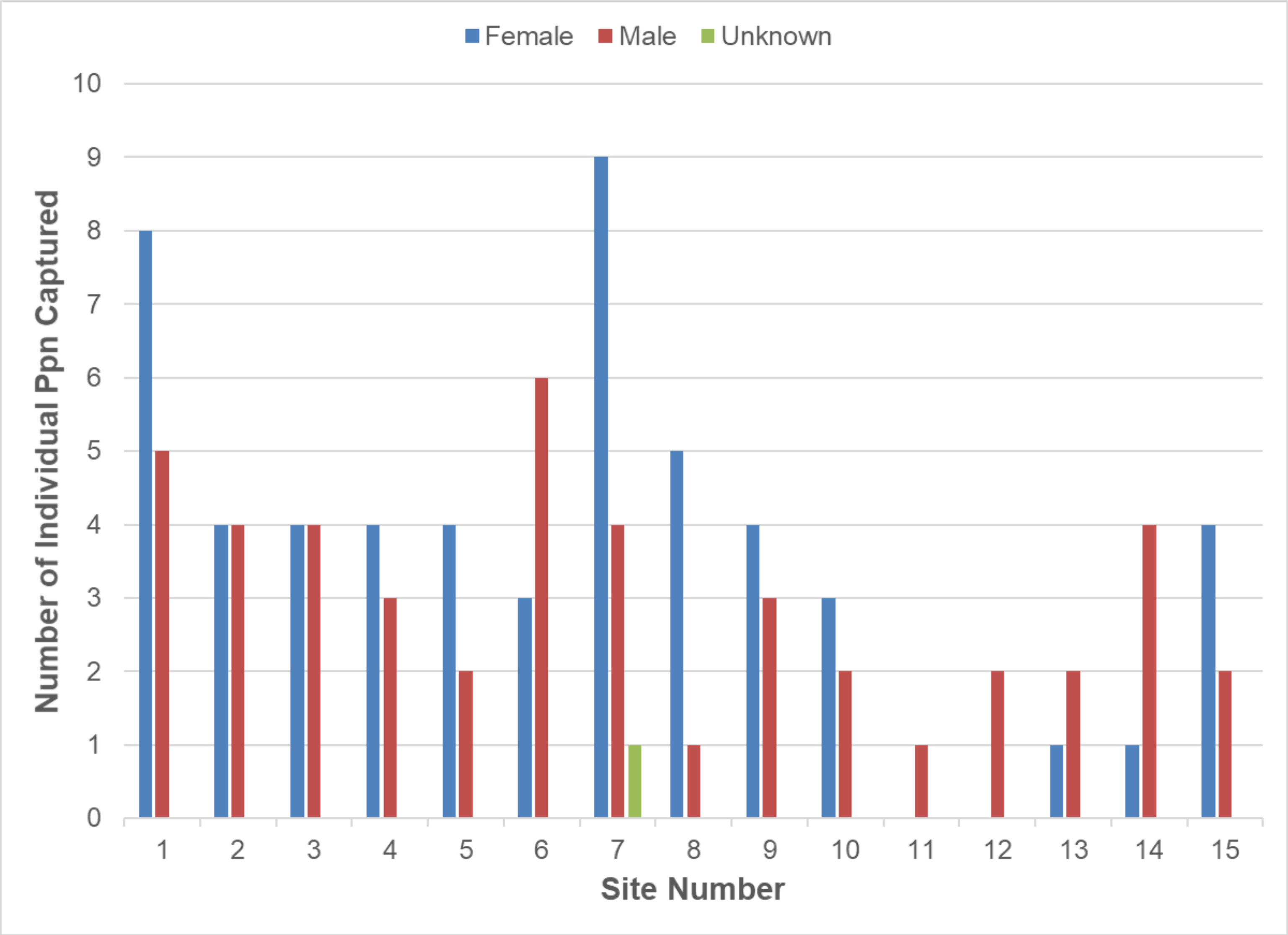

Figure B-8. Number of Individual Female, Male, and Unknown Sex Southeastern Beach Mice (Ppn) Captured at the 15 Sites (45 Stations) on KSC in March 2019.

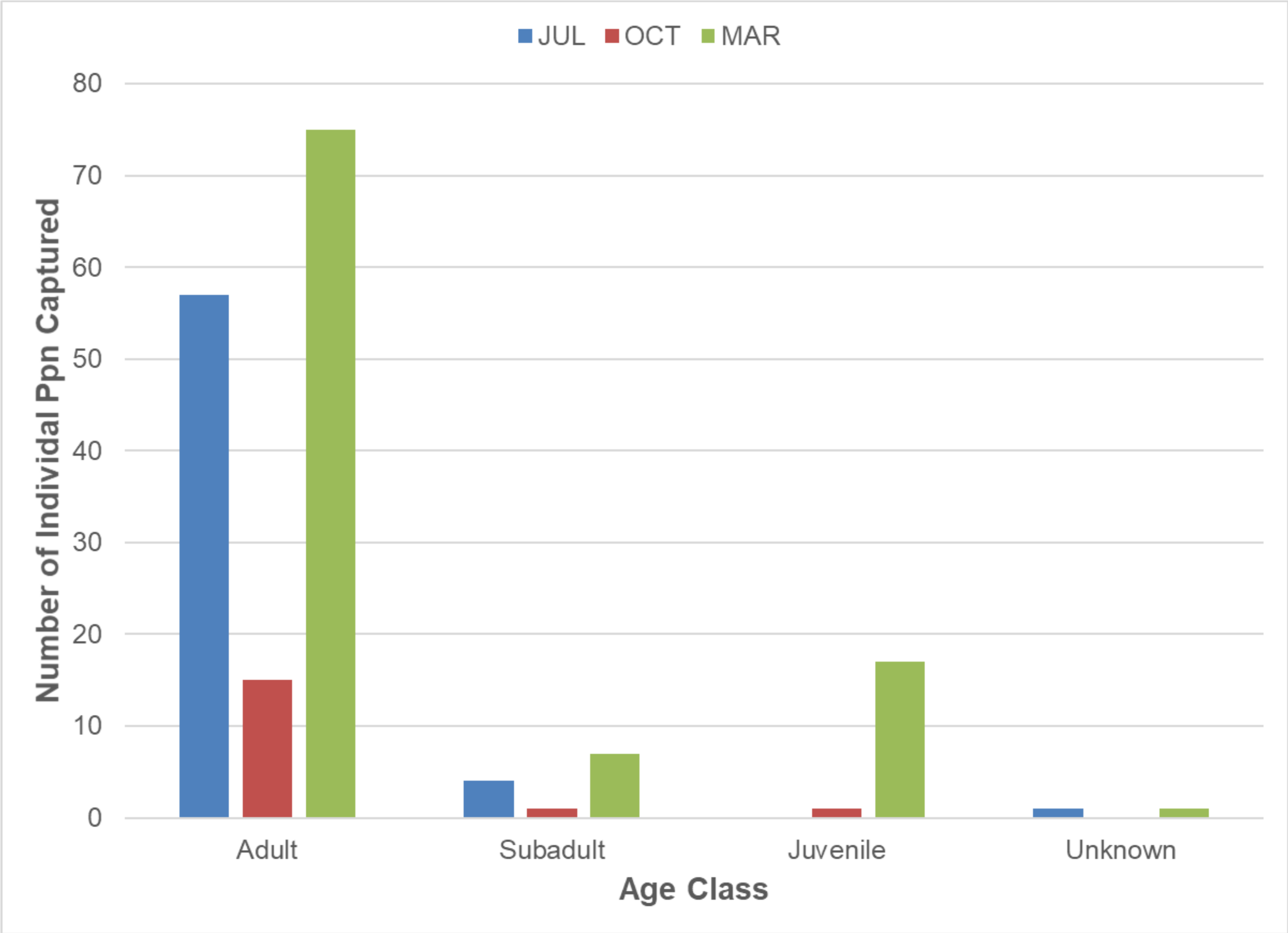

Figure B-9. Number of Individual Adult, Subadult, Juvenile, and Unknown Age Southeastern Beach Mice (Ppn) Captured at the 15 Sites Combined on KSC during the July and October 2018 and March 2019 Surveys.

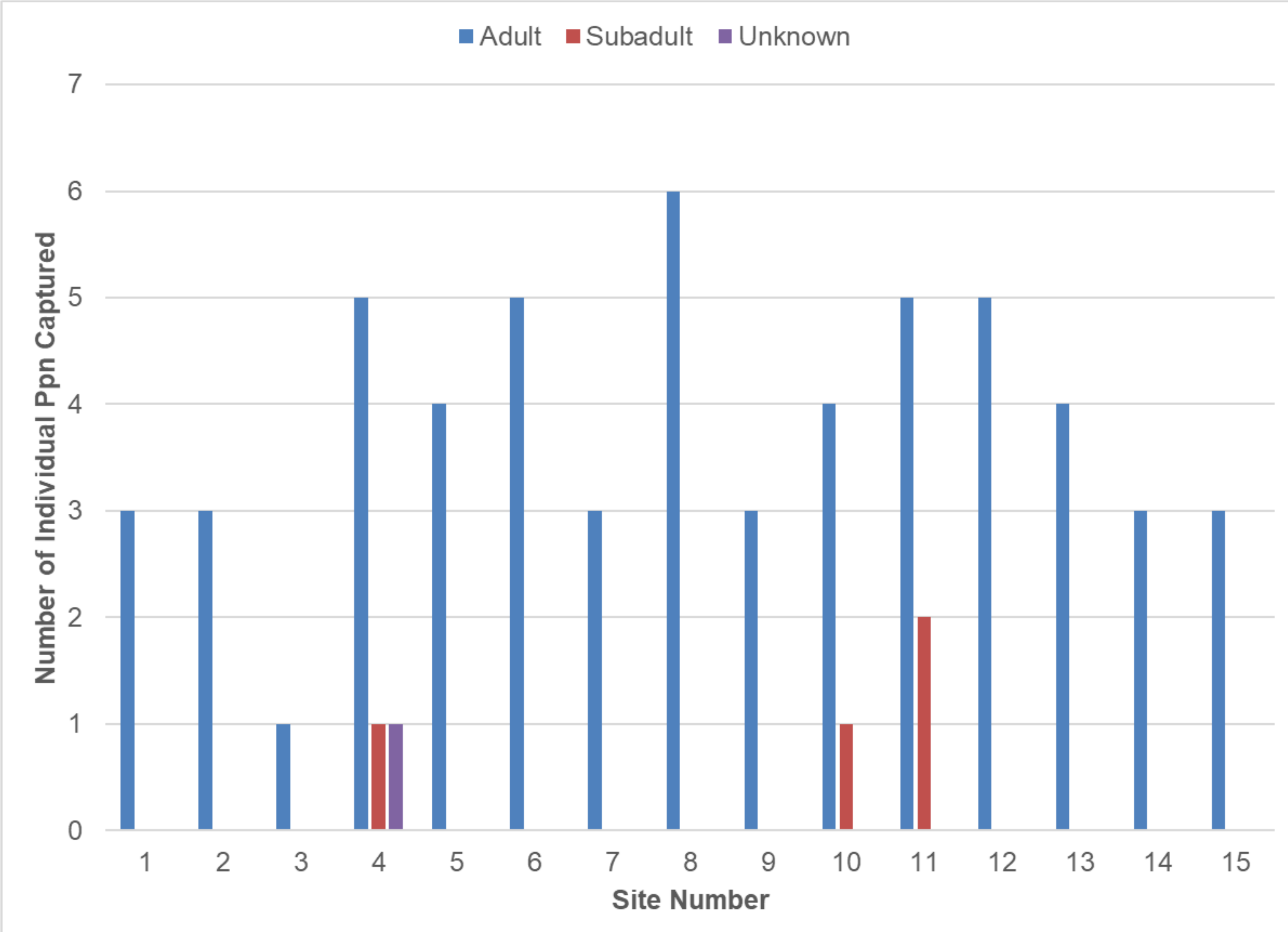

Figure B-10. Number of Individual Adult, Subadult, Juvenile, and Unknown Age Sex Southeastern Beach Mice (Ppn) Captured at the 15 Sites (45 Stations) on KSC in July 2018.

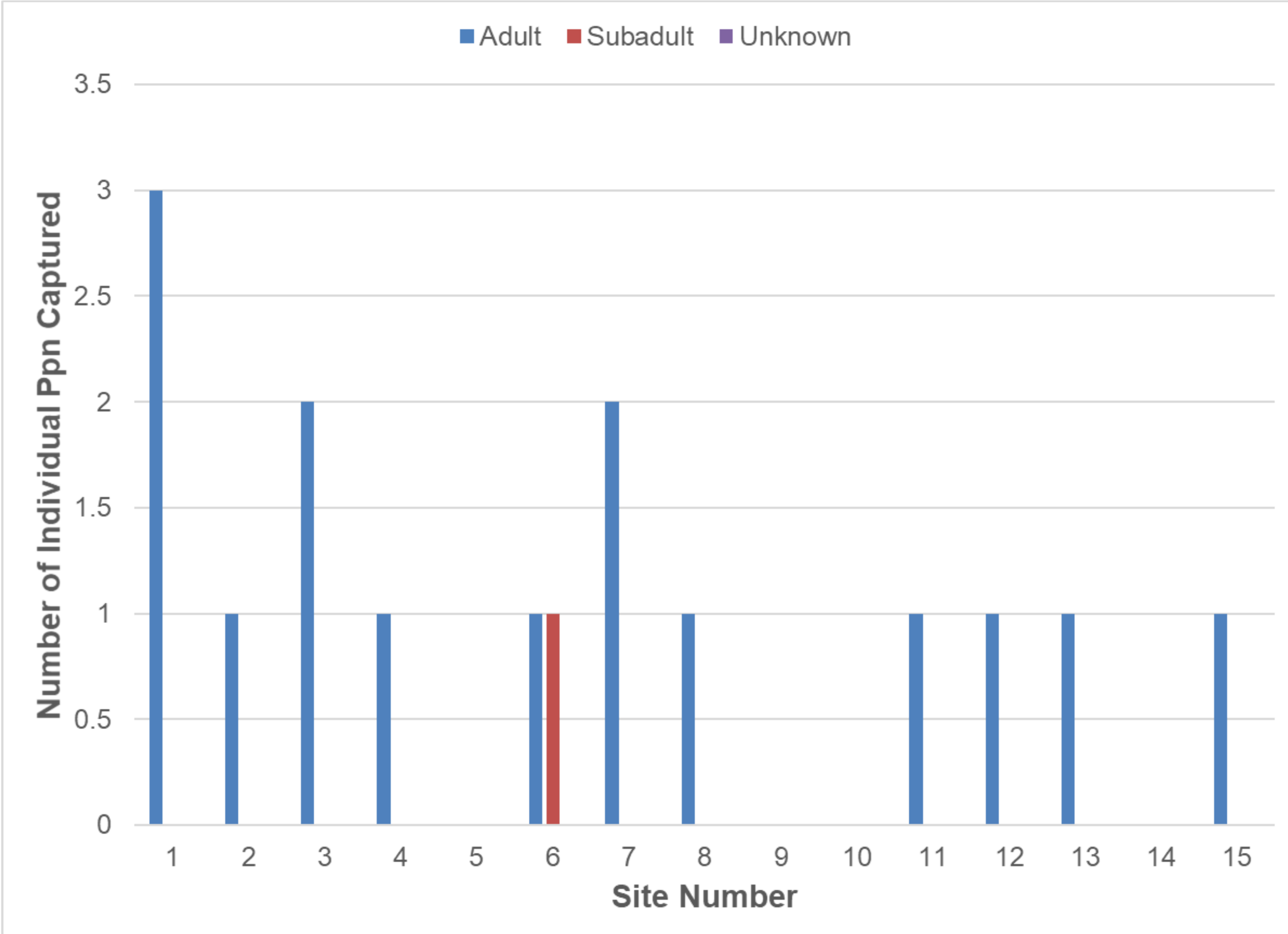

Figure B-11. Number of Individual Adult, Subadult, Juvenile, and Unknown Age Southeastern Beach Mice (Ppn) Captured at the 15 Sites (45 Stations) on KSC in October 2018.

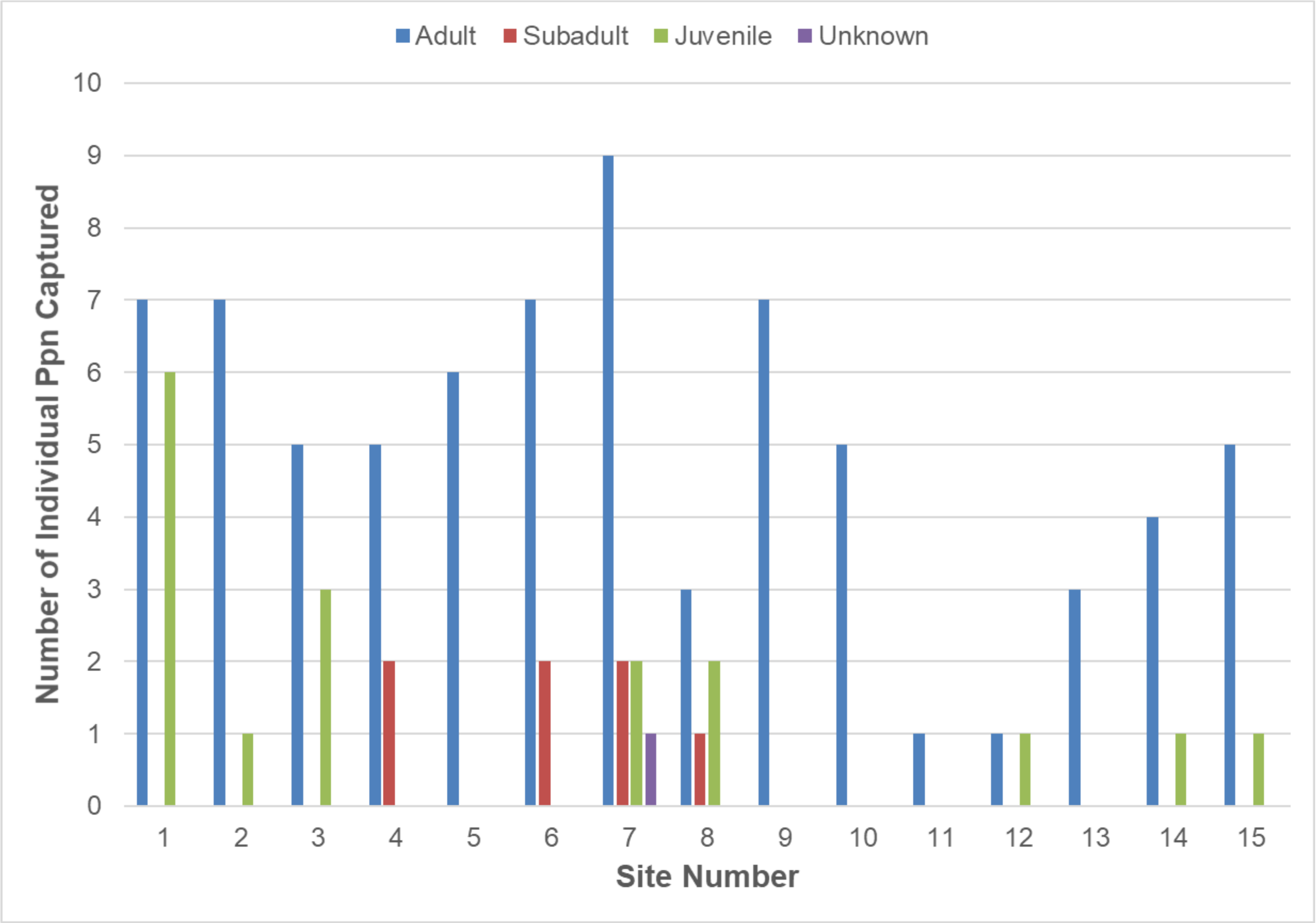

Figure B-12. Number of Individual Adult, Subadult, and Juvenile Southeastern Beach Mice (Ppn) Captured at the 15 Sites (45 Stations) on KSC in March 2019.

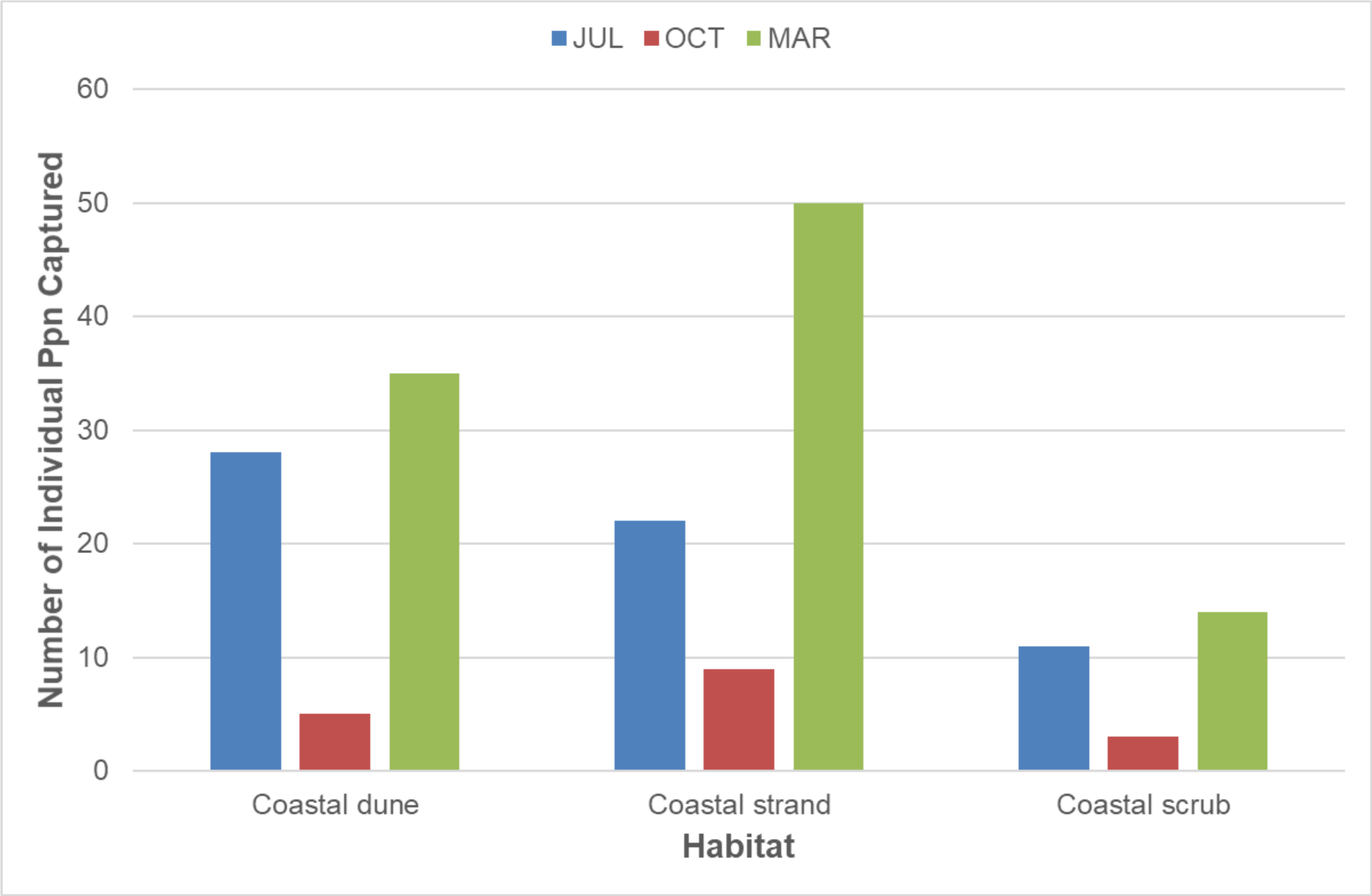

Figure B-13. Number of Individual Southeastern Beach Mice (Ppn) Captured in Coastal Dune, Coastal Strand, and Coastal Scrub Habitat at the 15 Sites Combined on KSC during the July and October 2018 and March 2019 Surveys.

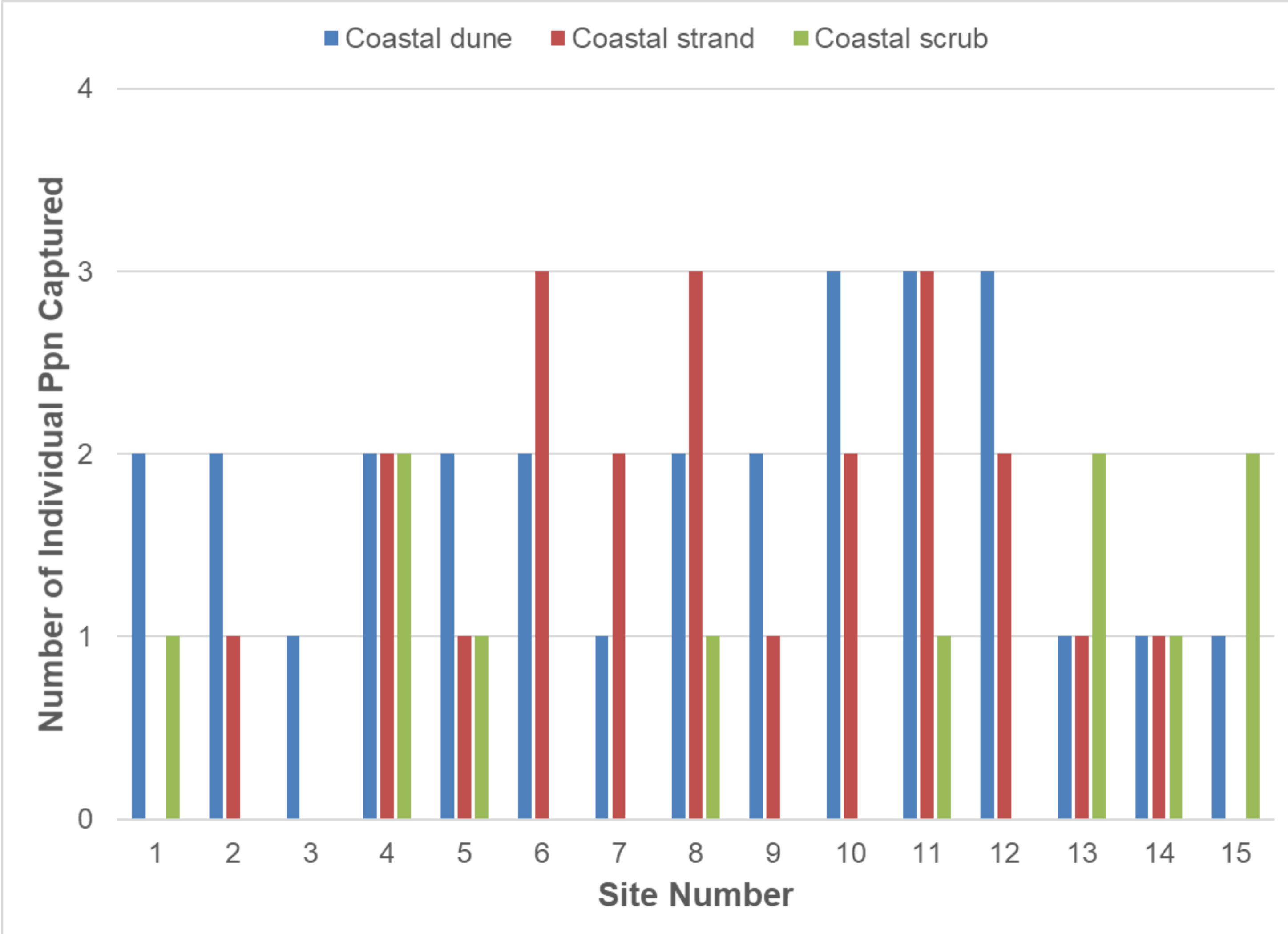

Figure B-14. Number of Individual Southeastern Beach Mice (Ppn) Captured in Coastal Dune, Coastal Strand, and Coastal Scrub Habitat at the 15 Sites (45 Stations) on the KSC in July 2018.

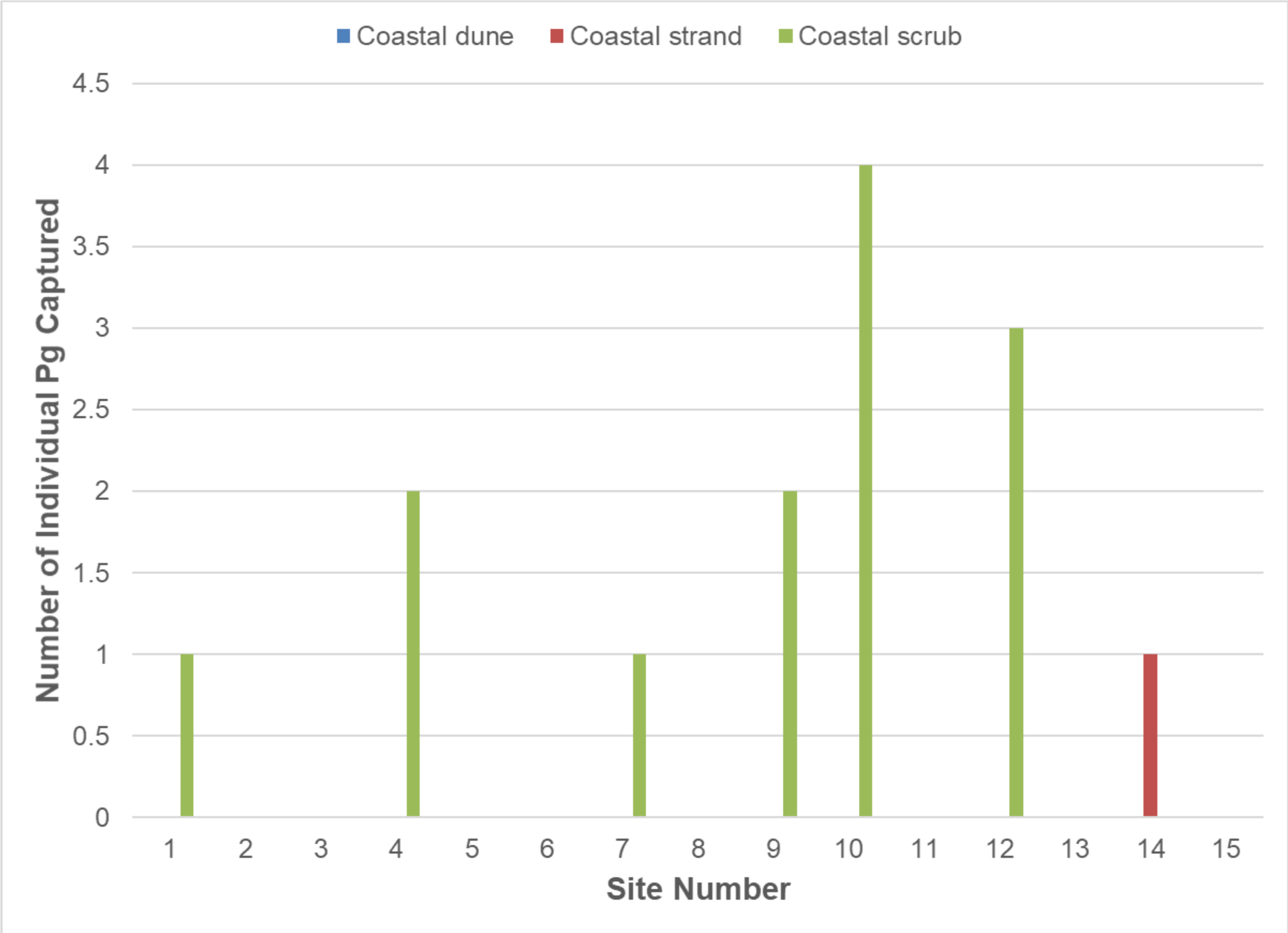

Figure B-15. Number of Individual Cotton Mice (Pg) Captured in Coastal Dune, Coastal Strand, and Coastal Scrub Habitat at the 15 Sites (45 Stations) on KSC in July 2018.

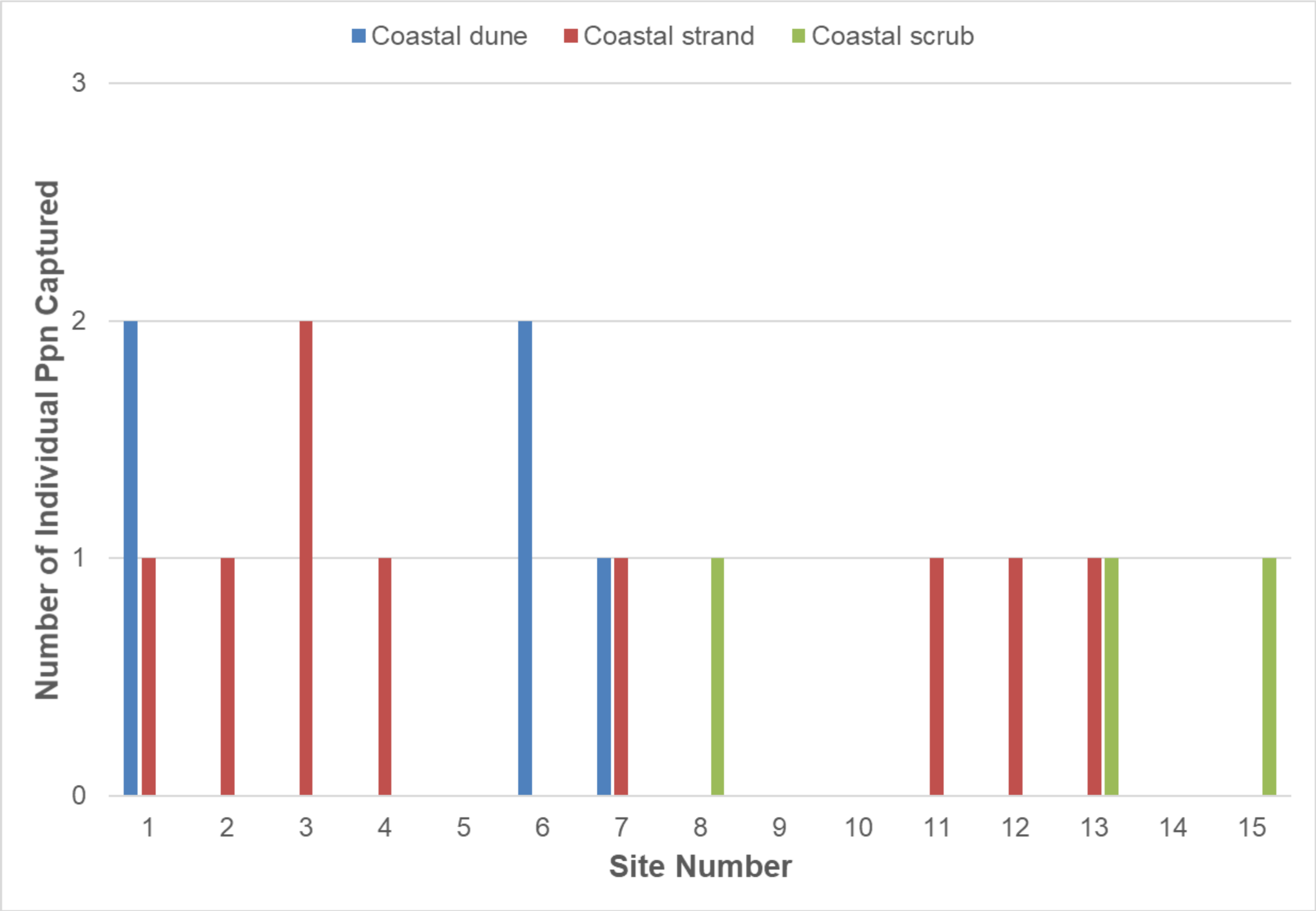

Figure B-16. Number of Individual Southeastern Beach Mice (Ppn) Captured in Coastal Dune, Coastal Strand, and Coastal Scrub Habitat at the 15 Sites (45 Stations) on the KSC in October 2018.

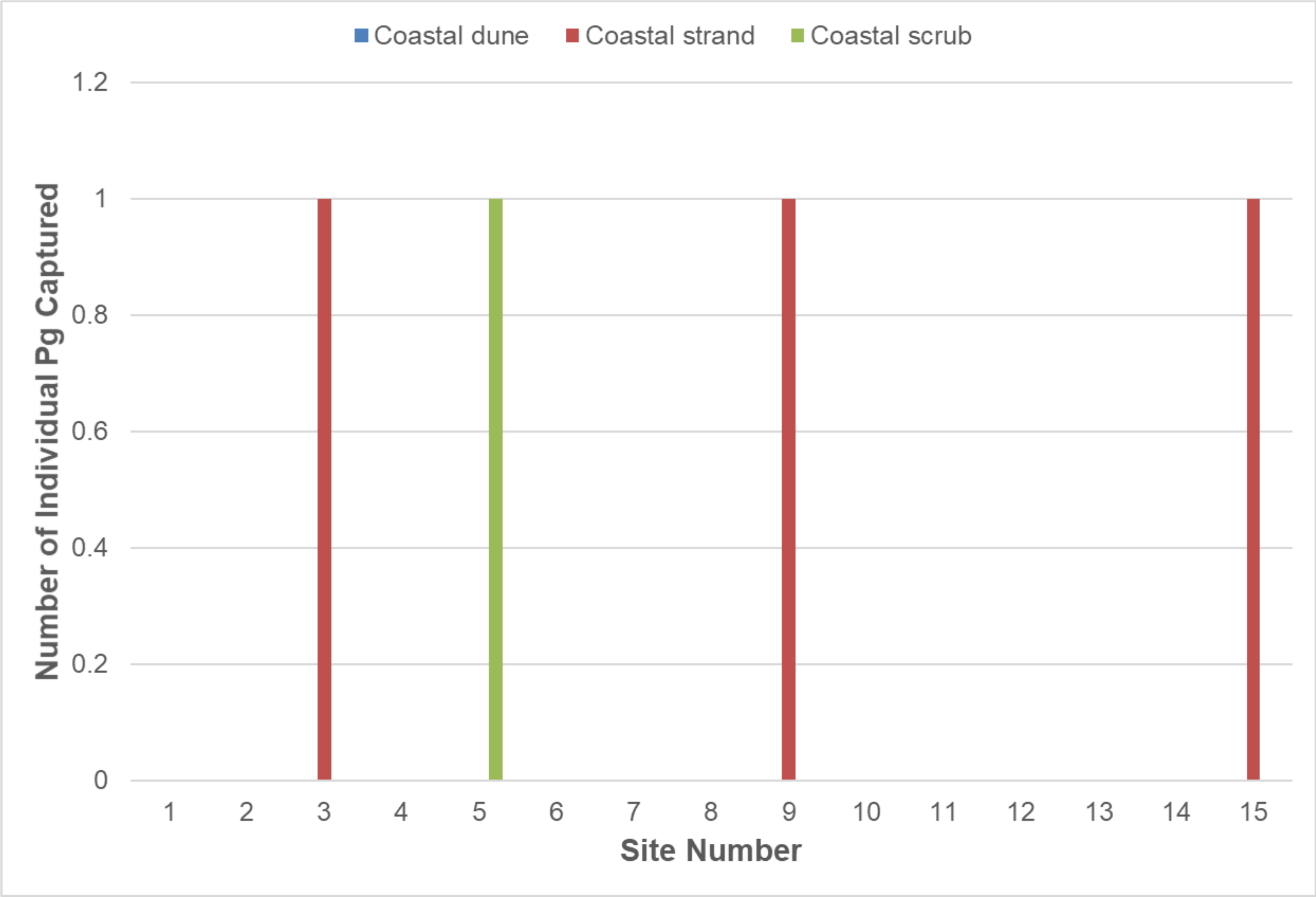

Figure B-17. Number of Individual Cotton Mice (Pg) Captured in Coastal Dune, Coastal Strand, and Coastal Scrub Habitat at the 15 Sites (45 Stations) on KSC in October 2018.

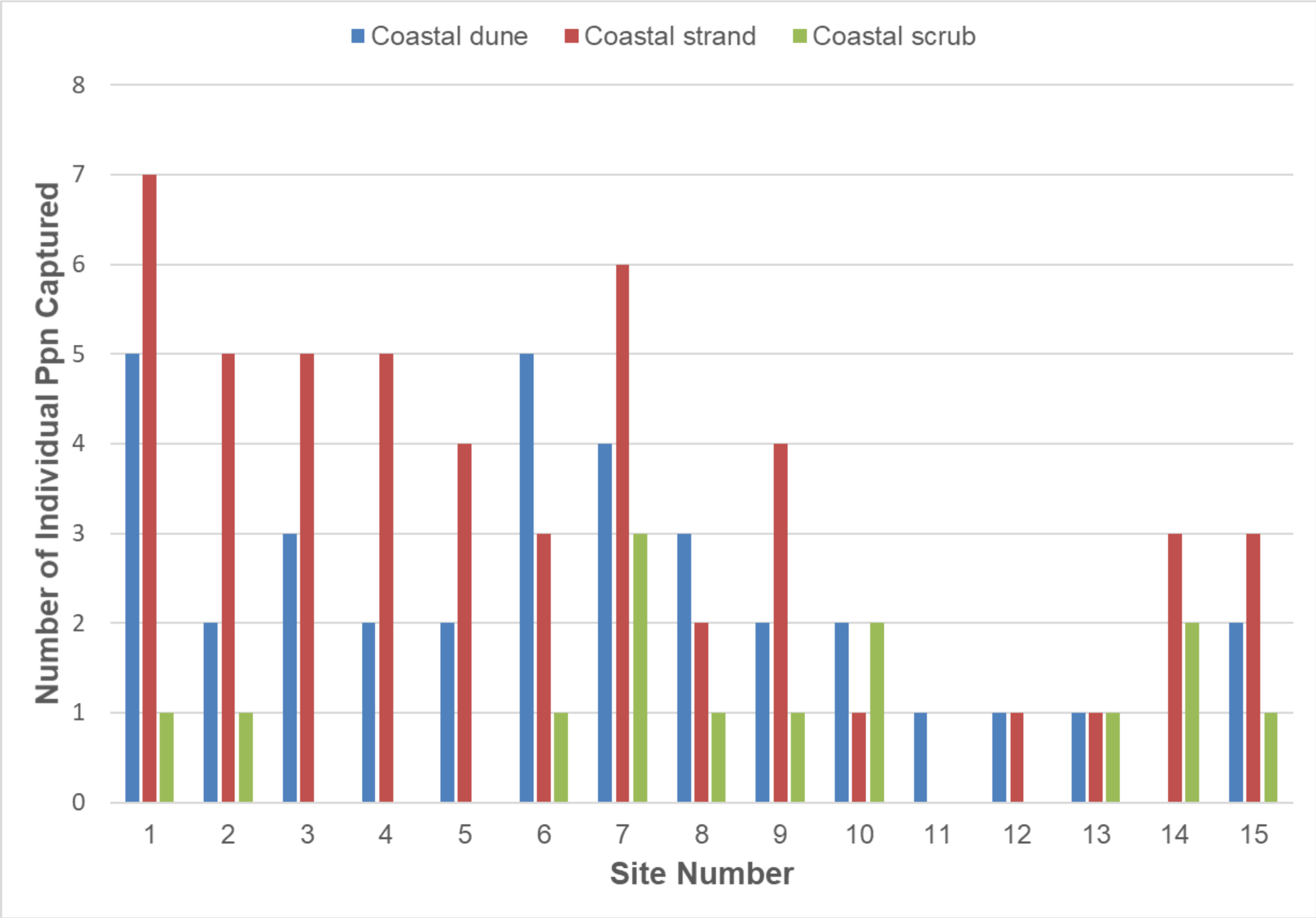

Figure B-18. Number of Individual Southeastern Beach Mice (Ppn) Captured in Coastal Dune, Coastal Strand, and Coastal Scrub Habitat at the 15 Sites (45 Stations) on KSC in March 2019.

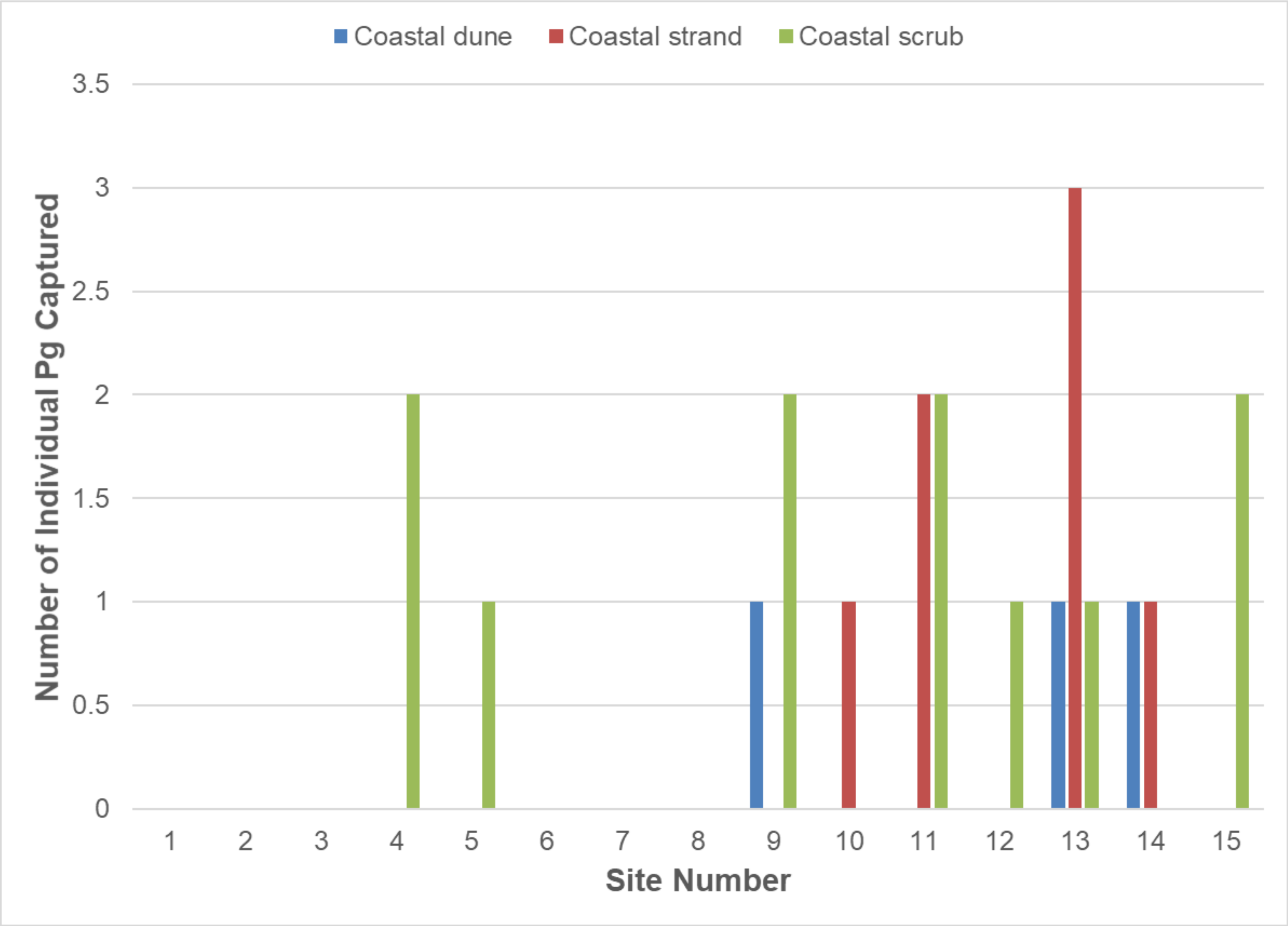

Figure B-19. Number of Individual Cotton Mice (Pg) Captured in Coastal Dune, Coastal Strand, and Coastal Scrub Habitat at the 15 Sites (45 stations) on KSC in March 2019.

Appendix C. Comparisons Between Bucket Cameras and Trail Cameras

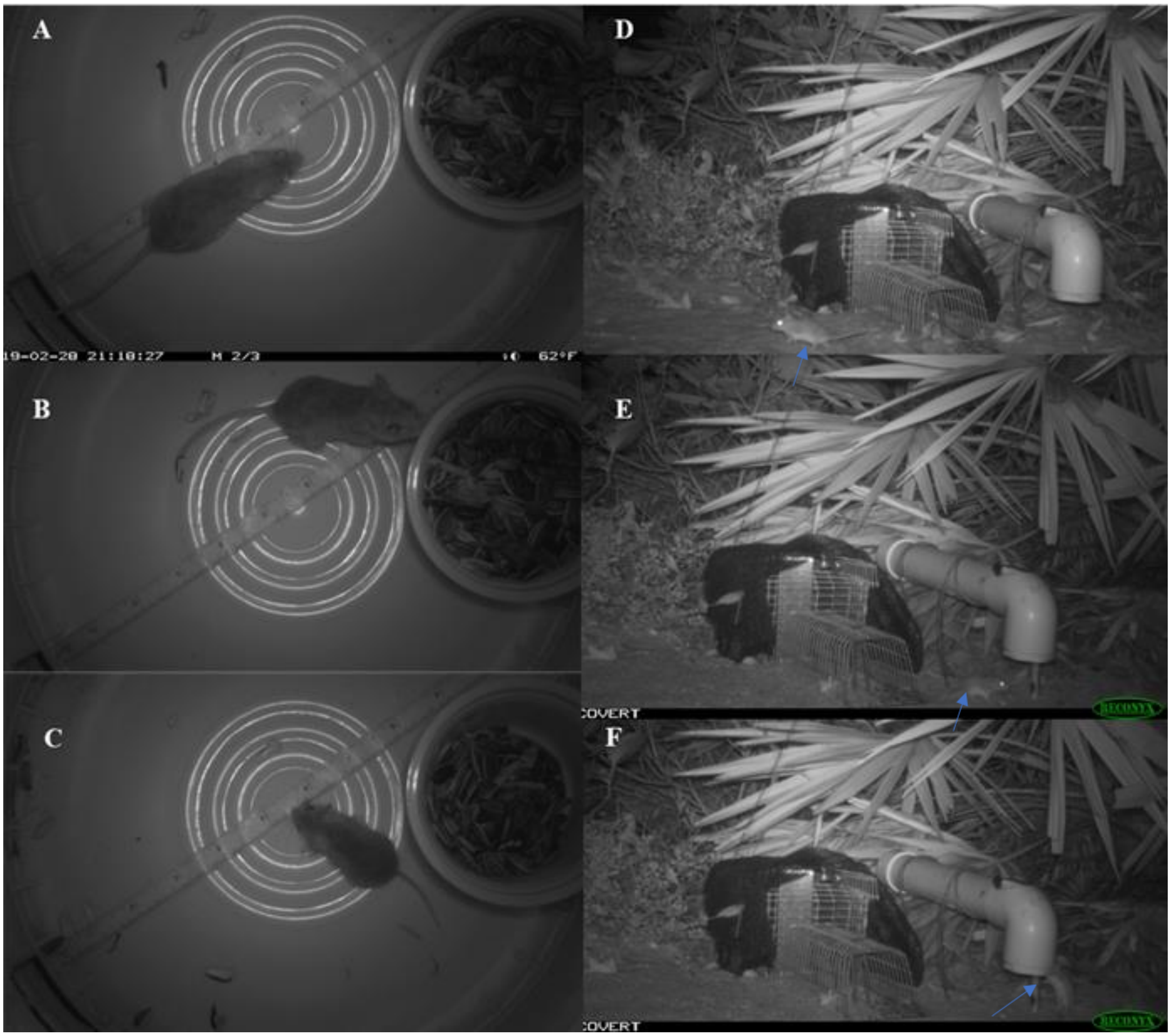

Figure C-1. Photos of Southeastern Beach Mice (*Peromyscus polionotus niveiventris*) via Bucket Cameras (left) and Trail Cameras (right) on KSC. Bucket camera photos A and B shows an adult southeastern beach mouse while C is a juvenile. Trail camera photos D, E, and F are all adult southeastern beach mice observed around the live-trap and tracking tube. Note the blue arrow in trail camera photos that shows the lighter (white) dorsal/ventral line and abdomen of the southeastern beach mouse.

Figure C-2. Photos of Cotton Mice (*Peromyscus gossypinus*) via Bucket Cameras (left) and Trail Cameras (right) on KSC. Bucket camera photos A, B, and C shows an adult southeastern cotton mouse; notice the darker color, larger ears, longer tail, and overall larger size. Trail camera photos D, E, and F are all adult cotton mice observed around the live-trap and tracking tube. Note the darker pelage color on the dorsal side in the trail camera photos that shows the lighter (gray) venter (abdomen), while lighter than the dorsal side darker than that of the southeastern beach mouse.

Table C-1. Species Detected by Bucket Cameras versus Trail Cameras for the Dynamic Habitat Occupancy Survey on KSC in April, July, and October 2018 and March 2019.

	Bucket Cameras				Trail Cameras			
Species Detected	**Apr-18**	**Jul-18**	**Oct-18**	**Mar-19**	**Apr-18**	**Jul-18**	**Oct-18**	**Mar-19**
Southeastern beach mouse	X	X	X	X	X	X	X	X
Cotton mouse	X	X	X	X	X	X	X	X
Cotton rat		X		X			X	X
Eastern spotted skunk	X	X	X	X	X	X	X	X
Southern short-tailed shrew		X						
Raccoon				X				X
Nine banded armadillo					X	X		X
Virginia possum						X		X
Bobcat							X	X
Eastern cottontail				X	X	X	X	X
Feral pig					X			X
Gopher tortoise					X	X	X	X
Black racer		X		X				X
Six-lined racerunner							X	X
Cuban anole				X				
Ghost crab							X	
Eastern towhee						X	X	X
Common grackle						X		
Northern cardinal							X	
Northern mockingbird							X	X
American robin						X		
Gray catbird				X	X			
Florida Scrub-Jay						X		X
Oven bird					X			X
Palm warbler								X
Mourning dove							X	X