Multi-Agency Annual Southeastern Beach Mouse Habitat Occupancy Monitoring

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Table of Contents

Figures and Tables

Project Description

The southeastern beach mouse (*Peromyscus polionotus niveiventris*, hereafter SEBM), a federally threatened species was identified by Merritt Island National Wildlife Refuge (MINWR) as one of the top five priorities for management. When we began the project, the SEBM was known to occupy sites ranging from Volusia through Brevard and Indian River Counties, but the exact distribution within the Federal lands encompassing the Cape Canaveral Barrier Island Complex (CCBIC) was not well known. The broad range of habitat conditions encompassing the species' historical range and the diversity of sites historically known to contain SEBM required a landscape-scale approach for both monitoring the population and for investigating species habitat relationships. We designed a monitoring plan for the SEBM with the goal of estimating the habitat occupancy of beach mice annually each winter/spring throughout the entire area of suitable coastal habitat (approximately 72 km linear distance along the beach). Methods were tested in a 2008 pilot study, and during 2010-2018 we monitored the proportion of coastal habitat occupied by the SEBM on the CCBIC. Monitoring was focused on using dynamic habitat occupancy surveys with data collected with rapid assessment techniques (i.e., track tubes or live-traps) to detect SEBM occurrence at sampling stations. An important component of the study design was the use of repeated samples that provided the information needed to estimate detectability. Measuring detectability was required to account for the fact that surveys could fail to detect animals at sites at which they were actually present (Mackenzie et al., 2002). This monitoring framework is very flexible, allowing numerous hypothesis to be tested about how various factors influence beach mouse occupancy using habitat, geographic, and environmental covariates.

Our survey has been the longest survey conducted for any of the seven extant beach mouse subspecies and has encompassed nearly the entire remaining range of the SEBM. Although occupancy surveys of other beach mouse subspecies via track tubes have been conducted on the Gulf coast of Florida by Florida Fish and Wildlife Conservation Commission (FWC), United States Fish and Wildlife Service (USFWS), and various universities, we expanded previous methods to fit unique aspects of the SEBM, and thus our study was very different from any of the previous studies. To achieve this specificity, we employed an adaptive approach throughout the study, with all activities aimed at providing managers with information related to environmental compliance and natural resource management on KSC and the surrounding Federal lands.

Progress During the 9 Years (2010-2018) of the Project

A pilot study of SEBM habitat occupancy was conducted in December 2008 along the 10 km beach on KSC/MINWR (**Figure 1**). In 2009, we analyzed the data from the pilot study, had several meetings with stakeholders, and in December 2009 held a stakeholder's workshop. These activities produced a set of hypotheses about how various covariates (geographic, ecological, and meteorological) affected the dynamics of SEBM habitat occupancy on CCBIC. Using this as a starting point, and incorporating the stakeholder's recommendations for allocation of sampling effort, we developed a study design for a Multi-Agency Annual SEBM Habitat Occupancy Survey (**Figure 2,** see also **Appendix A**).

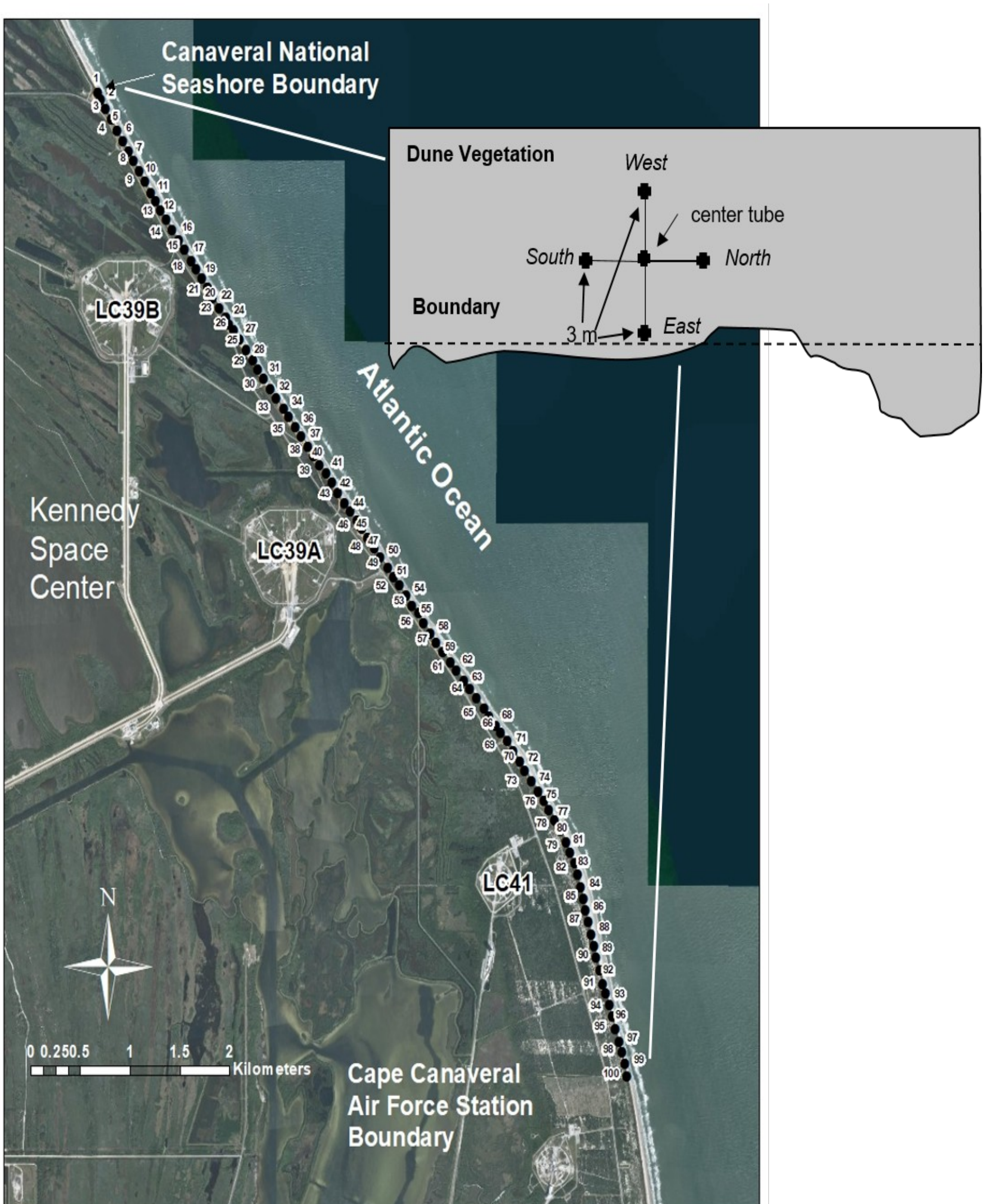

Figure 1. Occupancy Pilot Study in 2008 on KSC and the Track Tube Array Utilized

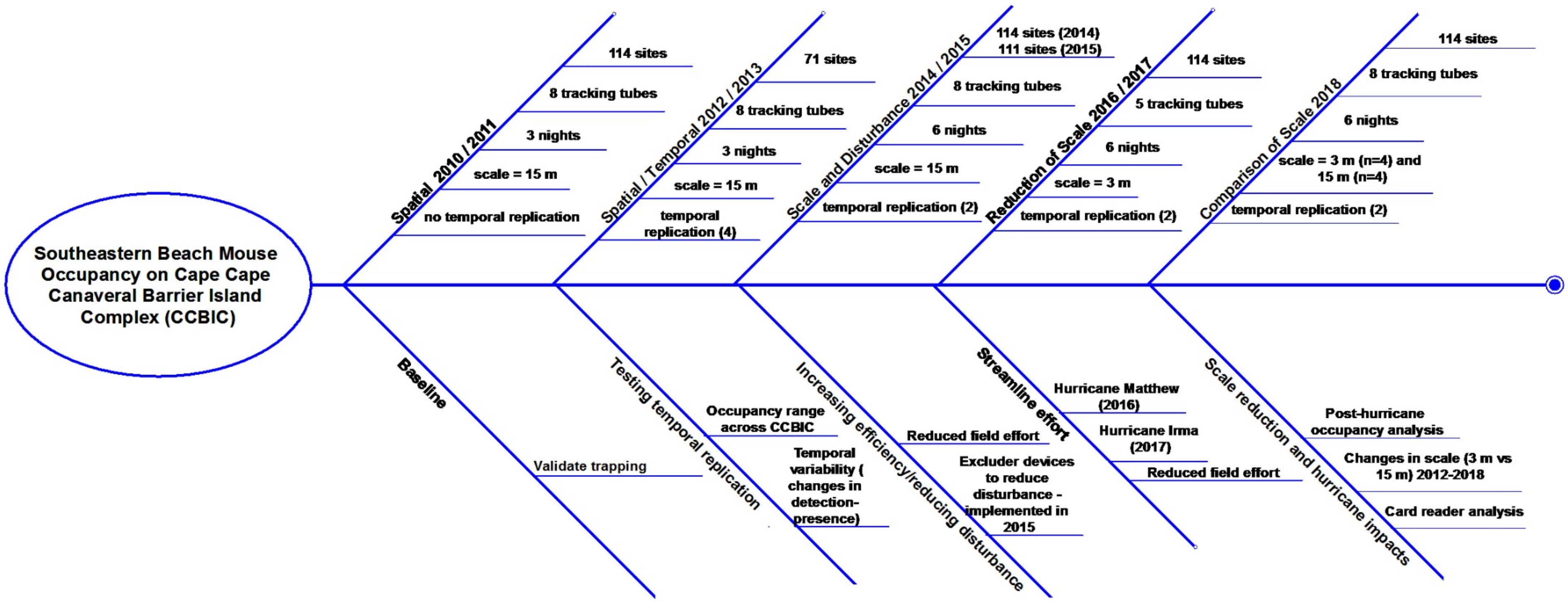

Figure 2. Survey Timeline from 2010-2018

The timeline for the Multi-Agency Annual SEBM Habitat Occupancy Survey on the CCBIC from 2010-2018 is shown along the top spine. The bottom spine shows the adaptive management approach to the changes made during various years of the survey.

In February 2010, a full-scale implementation of the Multi-Agency Annual SEBM Habitat Occupancy Survey was initiated on the nearly 72 km of coastal dunes and strand extending the length of the CCBIC (**Figure 3, Table 1**). The same sites sampled in February 2010 were sampled in February 2011. Baseline footprint collection (from track tubes) and confirmation trapping was conducted between these surveys on KSC and in a region encompassing the northern portion of the sampling locations on Canaveral National Seashore (CNS), which provided improvements to the use of footprints to detect beach mice (Stolen et al., 2014). Results of this trapping combined with patterns of detections between the first and second years of the study raised questions about the scale of occupancy information that was being collected. In February 2012, a third year of sampling was performed at 71 of the original 114 sample points using a modification of the study designed to tease apart questions regarding the scale of beach mouse habitat occupancy being measured. Specifically, the original notion of using replicates in space (i.e., eight track tube locations at each site) as the basic units of replication in occupancy models was expanded to also include replication in time by deploying track tubes during four time periods (four replicates of three-night sample periods). This expanded sampling allowed investigation of the effects of temporary movements at the scale of sample points (15 m radius). In February/March 2013, a fourth year of data was collected from the same locations as in February 2012, also using a combination of temporal and spatial replication.

The combination of spatial and temporal sampling in 2012-2013, while yielding increased detection and occupancy results, required an increased level of effort. As a result, in the summer of 2013 we conducted several track tube experiments designed to increase detection probability, obtain occupancy measurements comparable with previous years, and decrease effort (i.e., less visits) (Oddy et al., 2018). Based on what was learned from these experiments, the February/March 2014 survey employed two, six-night sample periods rather than four, three-night sample periods. By reducing the effort needed for replicated samples, we were able to sample all of the 114 original sites (excluding 3 that were not accessible due to construction). In addition to reducing the level of effort, we wanted to decrease the loss of data observed in previous years due to disturbance of track tubes, papers, ink pads, and unreadable footprints. In summer of 2014, we conducted additional track tube experiments designed to yield increased detection probability by excluding cotton rats (*Sigmodon hispidus*) from the track tubes and decreasing disturbance from raccoons and skunks. Based on the results of these experiments, the design of the 2015 survey had two, six-night sample periods, included all of the 114 original sites, and added a 2.54 cm (1 inch) reducer attached to the tube to reduce disturbance and discourage predators.

To further streamline the survey and to shift effort to analysis of our datasets, the number of track tubes was reduced for the February/March 2016 survey from eight to five, with one tube at the center and the others in cardinal directions at a distance of 3 m from the center (**Figure 3,** middle in-lay). In addition, no track tube covariates were collected this year. Results from the 2016 survey showed there was a decrease in the number of sites occupied by the SEBM on the Cape Canaveral Air Force Station (CCAFS) and KSC. This lower detection was potentially the result of reduction of track tubes at each site to five instead of eight, reduction in area sampled at each site (3 m radius instead of the 15 m radius), a true decline in habitat occupancy, or a combination of these factors.

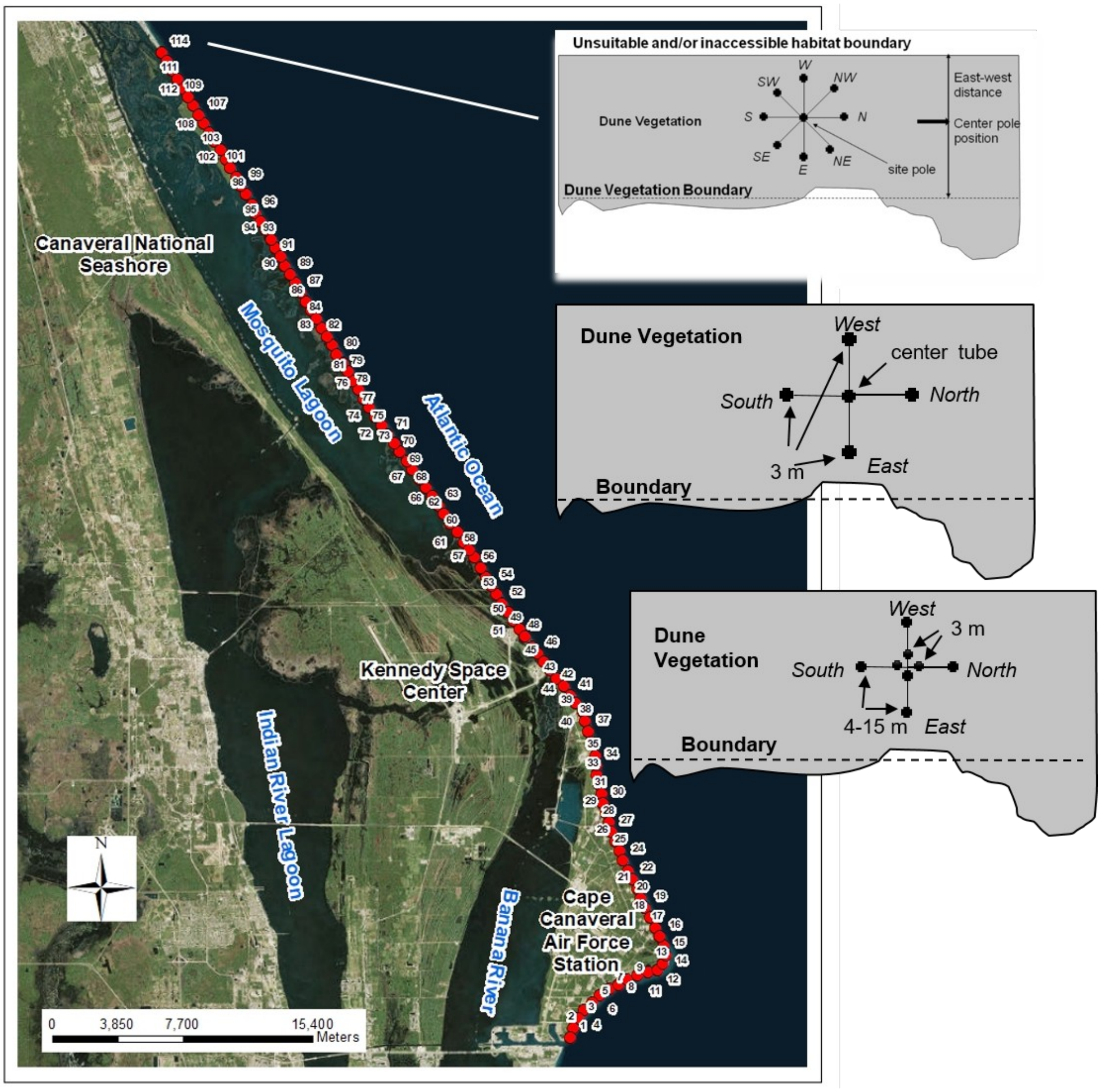

Figure 3. Track Tube Sites from 2010-2018

Location of the 114 track tube sites and the different track tube arrays employed on the CCBIC from 2010-2018 as part of the Multi-Agency Annual SEBM Habitat Occupancy Survey.

Table 1. Survey Progression on CCBIC from 2010-2018

Progression of the Multi-Agency Annual SEBM Habitat Occupancy Survey on the CCBIC from 2010-2018. The pilot study in 2008 was conducted entirely on the KSC.

Year	No. Sites	No. Tubes	Scale (m)	Temporal Replicates	Excluders	Covariates Collected	Additional prints	Study	Month
2008	100	5	3	1	no	no	no	KSC only	Dec
2010	114	8	15	1	no	yes	yes	CCBIC	Feb
2011	114	8	15	1	no	yes	yes	CCBIC	Mar
2012	71	8	15	4	no	yes	yes	CCBIC	Feb
2013	71	8	15	4	no	yes	yes	CCBIC	Feb/Mar
2014	111	8	15	2	no	yes	yes	CCBIC	Feb/Mar
2015	114	8	15	2	yes	yes	yes	CCBIC	Feb/Mar
2016	114	5	3	2	yes	no	yes	CCBIC	Feb/Mar
2017	114	5	3	2	yes	no	yes	CCBIC	Mar
2018	114	8	3 & 15	2	yes	no	yes	CCBIC	Feb/Mar

On October 6-7, 2016 Hurricane Matthew, a Category 3 hurricane hugged the Brevard County coastline with the eyewall just grazing the coast along the CCBIC (approx. 24 miles offshore). The storm caused increased precipitation (43.20 cm total) and high sustained winds averaging between 58 and 81 mph (93.3–130.4 kph) with gusts of 101 mph (162.5 kph) at ground level and 132 mph (212.4 kph) at the 500-foot level (National Weather Service personal communication). The combination of high storm surge (3-4 ft) and wave action caused moderate to severe erosion in many locations along the coast of CCBIC. In addition, wave run-up, and large breaking waves caused major overwash, extensive escarpment of dunes, and inundation of many of the dunes, resulting in moderate to extensive damage to the sea oats and other dune vegetation. These impacts affected sections of the beach differently, although most sections of the beach and track tube sites did experience some adverse effects.

In March 2017, an eighth year of data was collected from the 114 sites using two, six-night sample periods and five track tubes located at a distance of 3 m at the four cardinal directions and center pole and a 2.54 cm (1 inch) PVC reducer. Results from the 2017 survey also showed a decrease in the number of sites occupied by the SEBM on the CCBIC. This lower detection was potentially the result of the following factors or a combination of them: the design change in 2016 that reduced the track tubes at each site (five instead of eight) and reduced the area sampled at each site (3 m radius instead of the 15 m radius), impacts to the primary dune and surrounding habitat due to Hurricane Matthew which may have resulted in mortality or emigration of the mice from the tracking area, or a decline that had been occurring since 2015.

On September 10-11, 2017, 5 months before the 2018 survey Hurricane Irma, a Category 4 hurricane made landfall along the southwestern coast of Florida (approximately 65 miles from the CCBIC at its closest distance) and traveled across the State. The storm caused increased precipitation (19.53 cm total) and high sustained winds averaging 67-94 mph (107.8-151.3 kph) at ground level and 90-116 mph (144.8-186.7 kph) at the 458-foot level (Patrick Air Force Base 45th Weather Squadron personal communication). The combination of high storm surge (3-5 ft maximum) and wave action caused moderate to severe erosion in several locations along the coast of CCBIC. In addition, wave run-up and large breaking waves caused overwash, extensive escarpment of dunes, and inundation of many of the dunes, resulting in moderate to extensive damage to the sea oats and other dune vegetation. These impacts affected sections of the beach differently, although most sections of the beach and track tube sites did experience some adverse effects, and at some sites the impacts were additive to those from Hurricane Matthew.

To determine if the decline in SEBM habitat occupancy observed 2016 and 2017 could be attributed to changes in sampling methods (five versus eight tubes and 3 m versus 15 m radius), we made the following changes to the February/March 2018 survey: the number of track tubes/site was increased to eight with four of the track tubes placed at a distance of 3 m in the cardinal directions, and the other four placed at a random distance from 4 – 15 m, also in the cardinal directions (**Figure 3,** bottom in-lay). All else remained the same as the 2017 survey.

Near the end of the Multi-Agency Annual SEBM Habitat Occupancy Survey, we developed a new study (the Dynamic Habitat Occupancy Survey) that builds on what we learned from the Multi-Agency Annual SEBM Habitat Occupancy Survey. This study, begun in July 2018, uses a combination of track tubes, live-traps, and cameras (**Figure 4**), and allows us to expanded measurement of SEBM habitat occupancy beyond the coastal dune into coastal strand and coastal scrub habitats. If successful, this study will allow us to model spatial and temporal dynamics of these habitats. We will also obtain data to compare the reliability and efficiency of the three detection methods and evaluate the potential to develop a method of using track tubes to estimate abundance states (absent, low abundance, high abundance).

Figure 4. Location of the Dynamic Habitat Occupancy Sites (n = 15) and Track Tube/Live-Trap Array Employed on KSC in 2018-2019

Each site had one station located in each of the three habitats. The blue triangle represents coastal dune, the green triangle coastal strand, and the yellow triangle coastal scrub.

Key Information Learned from the 9 Years of the Study

Since this work began in 2008, we employed an adaptive scientific approach in which we incorporated what we learned into our continued investigations. As new questions and problems arose, we implemented experiments to test our methods and made modifications to the track tubes, (e.g., addition of excluders), the frequency of sampling (i.e., from one, three-night sample period to four, three-night periods and finally to two, six-night periods), and the number and position of the track tube arrays (reducing the number and spatial extent). When new information indicated it was appropriate, we implemented these changes to our annual survey methods. Examples of this approach and the changes made to the survey are listed below.

- Confirmed the presence of SEBM on KSC and CNS coastal dune habitat to the northern boundary near New Smyrna Beach, FL.
- Compiled baseline footprint database for small mammals on CCBIC. In cooperation with FWC, published a manuscript to communicate these findings (Greene et al., 2018).
- Determined (validated) cut-off size of 7.2 mm, which was smaller than that the previously used 7.5 mm footprint size, resulting in more useable data for our survey. Published a manuscript to communicate these findings (Stolen et al., 2014).
- Decreased disturbance to the track tubes, cards, and ink pads from other mammals (raccoons and skunks) and excluded cotton rats from the track tubes through the addition of a 1" PVC reducer (e.g., excluder). Published a manuscript to communicate these findings (Oddy et al., 2018).
- Documented the amount of impact or change to the dune line (includes established and forming dunes) of the CCBIC between pre- and post-hurricane Matthew (October 6-7, 2016) using a Geographic Information System (GIS) to compare aerial imagery from National Oceanic and Atmospheric Administration (NOAA) flown directly after Hurricane Matthew and aerial imagery from August 2015. Conducted post-hurricane site visits at all 114 sites and identified additional areas of impact such as blow outs, overwash, and inundations. This information was provided to land managers and was correlated to the occupancy survey conducted 5 months later.
- Determined that the reduction in the area sampled (from 15 m to 3 m) in 2016-2017 survey impacted the detection and scale of occupancy estimates of the SEBM. Specifically, when sampling a smaller area, both the occupancy and detection rates were lower (**Figures 5 and 6**). This is both an important theoretical finding for occupancy methods and key information for our monitoring plan study design.
- Found that the agreement between card readers was fairly high, making it possible to change the criteria for beach mouse detection to a probabilistic measure based on our knowledge of footprint size distribution across species in the future. This will further reduce effort associated with using track tubes to sample habitat occupancy.
- Designed the Dynamic Habitat Occupancy Survey (our current ongoing survey on KSC) to include past and current scientific and management, hypotheses, and lessons learned and

problems solved in the 9 years of the Multi-Agency Annual SEBM Habitat Occupancy Survey.

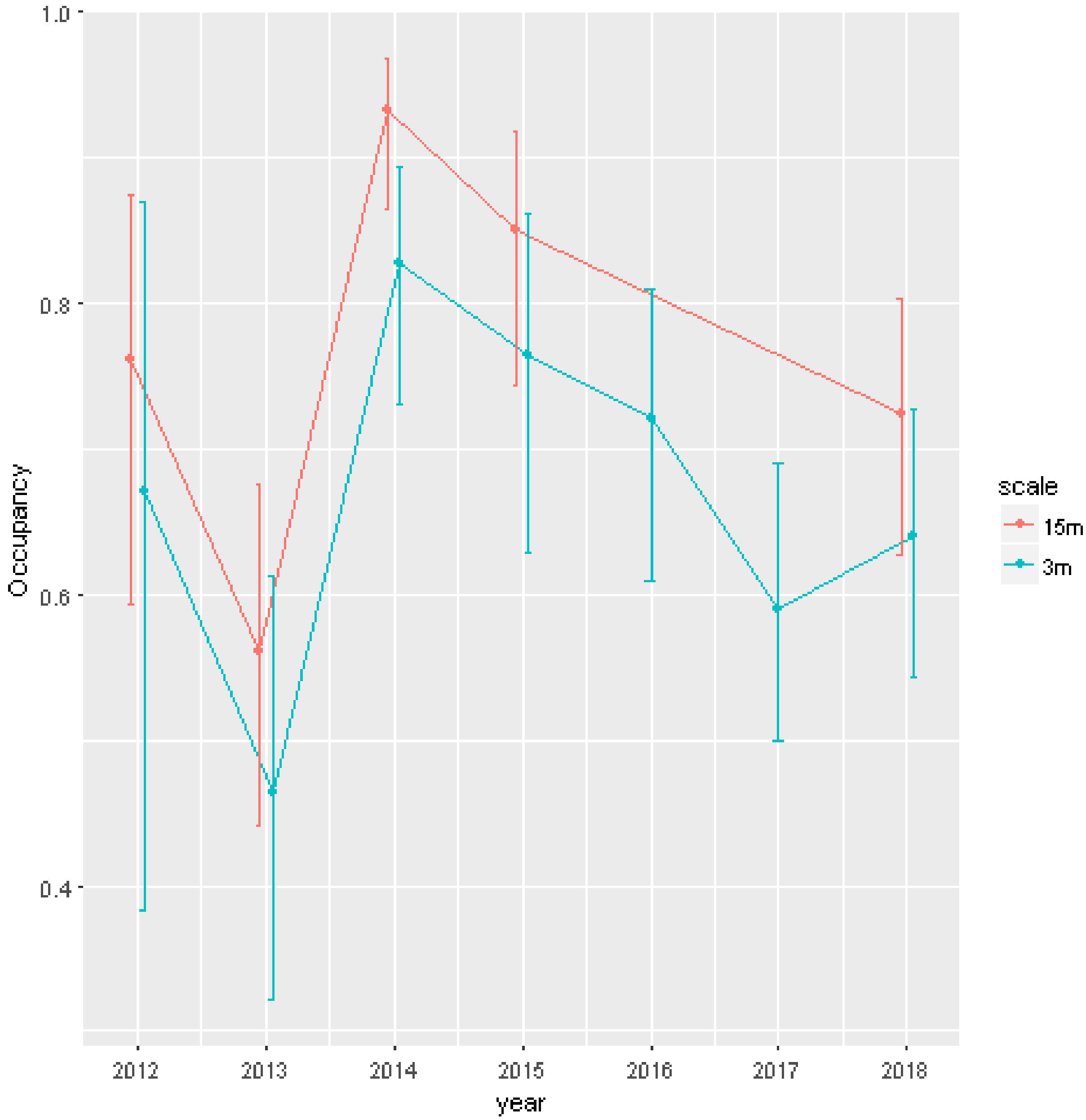

Figure 5. Habitat Occupancy of SEBM in Coastal Habitat on the CCBIC from 2012-2018
Estimates are based on single season habitat occupancy model with one shared estimate of detection rate for both seasons. Separate estimates are given for two different study design scales (3 m versus 15 m).

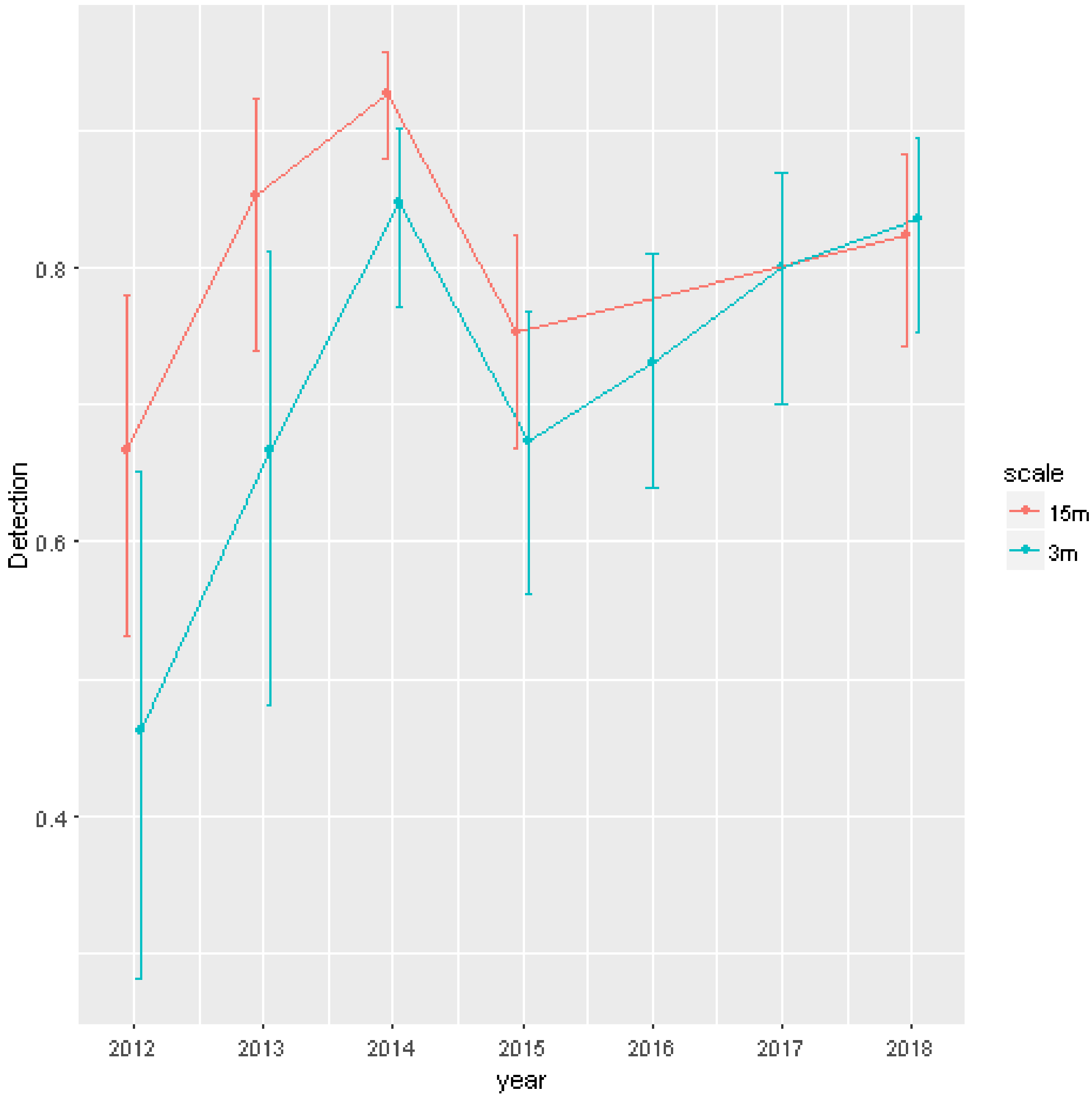

Figure 6. Detection Probability Comparison

Detection probability comparison between study design scales (3 m versus 15 m) for SEBM in coastal habitat on the CCBIC for 2012-2018. Estimates are based on single season habitat occupancy model with one shared estimate of detection rate for both seasons.

Long- and/or Short-Term Trends

The large amount of effort used to detect SEBM in the Multi-Agency Annual SEBM Habitat Occupancy Survey has resulted in a robust estimate of beach mouse habitat occupancy dynamics in coastal habitat across the core species range. Preliminary analysis provides a clear picture of occupancy dynamics (more detailed analysis is underway and will be published in peer-reviewed literature).

- The estimated rate of coastal habitat occupancy of SEBM on the CCBIC was 0.59–0.91 during 2010-2018 (**Table 2**, single season models). Because of the random placement of the sites, this can be interpreted as indicating that 59-91% of coastal habitat on CCBIC was occupied by the SEBM during the time period sampled.
- Site level detection rate was generally between 0.49-1.00 (**Table 2**, single season models), resulting in a power to detect the presence of SEBM at sites during two surveys of 75-100% (i.e., the chance of finding mice at a site if present). This indicates that the study design was functioning as planned.
- Although interpretation of the patterns are complicated by changes in study design, a decline in occupancy rate over recent years is evident (**Figure 5**). However, there is some indication of a slight increase in occupancy rate in 2018, and the overall level of occupancy for the 3 m scale has remained above 0.5 (half of all habitat occupied) for all years except 2012.
- Trends for the three Federal properties are different, with habitat occupancy on CNS remaining fairly stable while that of KSC and CCAFS show a decline over the last several years (**Figure 7**).
- The scale of sampling (3 m vs. 15 m) had an effect on both occupancy and detection in the direction expected (**Figures 5 and 6**). Specifically, when sampling a smaller area, both the detection and occupancy rates were lower. This makes sense if individuals encounter the track tubes as they move around their home ranges, which are larger than the track tube arrays, so sampling larger sites would allow a higher encounter rate. This also sheds light on the meaning of habitat occupancy as measured by this study. It is a measure of the probability that at least one SEBM has a home range that overlaps the track tube array, and also that at least one mouse with such a home range moves into the site during the track tube deployment period.

	2010				2011				2012				2013				2014				2015				2016				2017				2018			
	est	SE	lcl	ucl	est	SE	lcl	ucl	est	SE	lcl	ucl	est	SE	lcl	ucl	est	SE	lcl	ucl	est	SE	lcl	ucl	est	SE	lcl	ucl	est	SE	lcl	ucl	est	SE	lcl	ucl
single season models																																				
constatnt p occupancy									0.86	0.04	0.76	0.93	0.82	0.05	0.71	0.90	0.91	0.03	0.84	0.95	0.80	0.03	0.72	0.86	0.72	0.05	0.61	0.81	0.59	0.05	0.50	0.69	0.72	0.05	0.63	0.80
constatnt p detection									0.73	0.03	0.66	0.78	0.72	0.03	0.66	0.78	0.93	0.02	0.88	0.96	0.89	0.04	0.79	0.94	0.73	0.05	0.64	0.81	0.80	0.04	0.70	0.87	0.82	0.04	0.74	0.88
survey specific p detection1									0.49	0.06	0.37	0.61	0.52	0.07	0.39	0.64																				
survey specific p detection2									0.69	0.06	0.56	0.79	0.65	0.06	0.52	0.76	0.87	0.03	0.79	0.92	0.66	0.05	0.56	0.75	0.61	0.06	0.49	0.72	0.67	0.06	0.55	0.78	0.76	0.05	0.65	0.84
survey specific p detection3									0.85	0.05	0.74	0.92	0.81	0.05	0.69	0.89																				
survey specific p detection4									0.88	0.04	0.77	0.94	0.93	0.03	0.83	0.97	0.99	0.01	0.93	1.00	1.00	0.00	0.00	1.00	0.92	0.04	0.80	0.97	0.98	0.02	0.86	1.00	0.90	0.04	0.80	0.96
survey specific p occupancy									0.86	0.04	0.76	0.92	0.82	0.05	0.71	0.89	0.90	0.03	0.83	0.95	0.85	0.03	0.77	0.91	0.69	0.05	0.59	0.77	0.57	0.05	0.48	0.66	0.72	0.04	0.62	0.80
multi-season models																																				
constatnt p occupancy	0.31	0.05	0.23	0.40	0.44	0.05	0.35	0.53	0.42	0.06	0.31	0.54	0.42	0.06	0.31	0.54	0.81	0.04	0.73	0.87	0.56	0.05	0.47	0.65	0.42	0.05	0.33	0.51	0.39	0.05	0.30	0.48	0.54	0.05	0.45	0.63
constatnt p detection	0.30	0.03	0.24	0.36	0.40	0.03	0.35	0.46	0.55	0.01	0.53	0.58	0.62	0.01	0.59	0.64	0.72	0.01	0.70	0.74	0.70	0.01	0.67	0.72	0.69	0.02	0.65	0.73	0.67	0.02	0.62	0.70	0.68	0.01	0.65	0.71
constatnt p extinction									0.10	0.03	0.06	0.17	0.03	0.02	0.01	0.09	0.01	0.01	0.00	0.07	0.00	0.00	0.00	0.98	0.08	0.04	0.03	0.20	0.02	0.02	0.00	0.18	0.10	0.04	0.04	0.20
constatnt p colonization									0.42	0.05	0.32	0.52	0.30	0.05	0.21	0.39	0.62	0.11	0.40	0.80	0.66	0.07	0.52	0.78	0.42	0.06	0.31	0.55	0.30	0.06	0.20	0.42	0.35	0.07	0.23	0.48
survey specific p occupancy									0.44	0.06	0.32	0.56	0.43	0.06	0.32	0.55	0.81	0.04	0.73	0.87	0.56	0.05	0.47	0.65	0.42	0.05	0.34	0.52	0.39	0.05	0.30	0.48	0.54	0.05	0.45	0.63
survey specific p detS1									0.36	0.03	0.30	0.43	0.44	0.03	0.38	0.51																				
survey specific p detS2									0.59	0.03	0.53	0.64	0.58	0.03	0.52	0.63	0.65	0.02	0.62	0.69	0.63	0.02	0.59	0.67	0.68	0.03	0.61	0.73	0.64	0.03	0.57	0.70	0.67	0.02	0.62	0.71
survey specific p detS3									0.60	0.02	0.56	0.65	0.65	0.02	0.60	0.70																				
survey specific p detS4									0.58	0.02	0.53	0.63	0.71	0.02	0.66	0.75	0.78	0.01	0.75	0.81	0.74	0.02	0.71	0.77	0.70	0.02	0.65	0.75	0.69	0.03	0.63	0.73	0.70	0.02	0.66	0.73
survey specific p extinction									0.10	0.03	0.06	0.17	0.04	0.02	0.01	0.09	0.01	0.01	0.00	0.07	0.00	0.00	0.00	1.00	0.08	0.04	0.03	0.20	0.02	0.02	0.00	0.17	0.10	0.04	0.04	0.20
survey specific p colonization									0.41	0.05	0.31	0.52	0.29	0.05	0.21	0.39	0.62	0.11	0.40	0.80	0.66	0.07	0.52	0.78	0.42	0.06	0.31	0.55	0.30	0.06	0.20	0.42	0.35	0.07	0.23	0.48

Table 2. Estimated Probability of Occupancy and Detection from 2010-2018

Estimated probability of occupancy and detection for various site occupancy models for SEBM in coastal habitat on CCBIC during 2010-2018. SE = standard error, lcl = lower confidence level, ucl = upper confidence level.

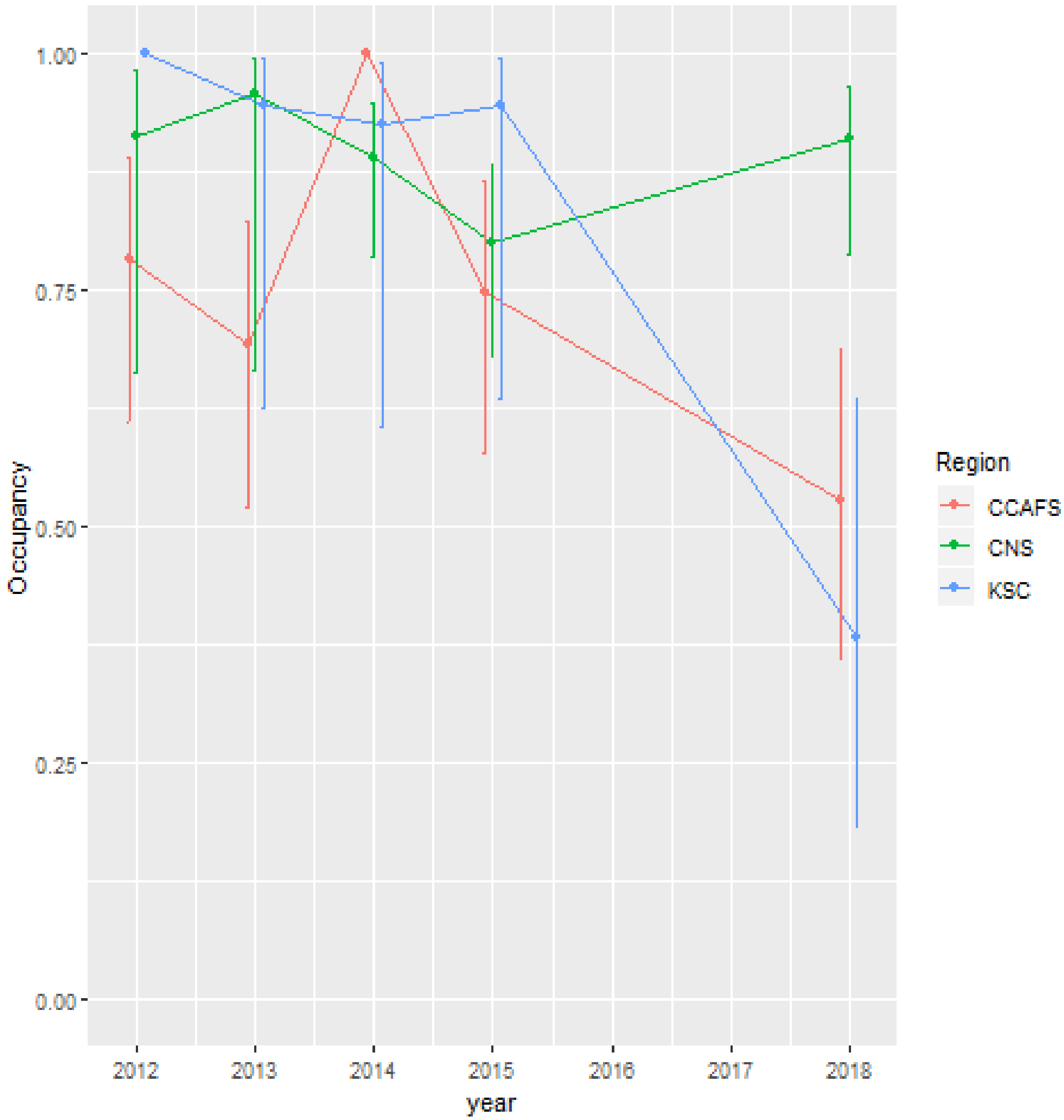

Figure 7. Estimated Habitat Occupancy by Property

The estimated habitat occupancy by property: CCAFS, KSC, and CNS for the full scale (15 m). Note that 2016 and 2017 are missing, because data was only collected at 3 m scale in these years. For KSC in 2012 and CCAFS in 2014, the error bars are not shown because occupancy was nearly 1.

Recommendations

1. **Conduct workshops with stakeholders and community of practice.** A workshop will help facilitate stakeholders to jointly address progress and discuss specific future needs for the SEBM on the CCBIC. One of the main tasks will be to identify and discuss data gaps for our community of practice (USFWS, FWC, Brevard Zoo, etc.) and how to fill these gaps. This will include planning and prioritizing for specific species recovery goals (i.e., genetics, management, monitoring, and translocation).

2. **Analyze KSC Ecological Monitoring historic SEBM data sets (e.g., trapping, telemetry, multi-agency habitat occupancy survey) to answer management questions.** During this study and in others, we have analyzed historic datasets, utilized personal observations, and implemented the knowledge learned into our questions, hypotheses, study designs, and methodologies. For example, home range information from our telemetry dataset helped explain movement patterns and space use, and the information was incorporated into the Multi-Agency Annual SEBM Habitat Occupancy Survey. These datasets need to continue to be analyzed in order to yield more valuable information to aid in future study designs and to fit missing pieces into the puzzles of our knowledge.

3. **Continue exploring the use of other monitoring methods including cameras, drones, and the combination of methods like the Dynamic Habitat Occupancy Survey.** Passive methods of certain detection (bucket camera traps and trail cameras) should be used in conjunction with other passive uncertain detection (track tubes) and active methods of certain detection (live-traps) to test their efficacy as in the current Dynamic Habitat Occupancy Survey. In addition recent imagery collected from drones along the KSC coastline in 2018 showed promise. These drones could be used to fly the coastline of the CCBIC after severe storm events (hurricanes, tropical storms, and nor'easters) and also on a regular basis. This could provide us with the opportunity to document changes to the dune line and vegetation from erosional processes, track the creation of forming dunes, view management actions (i.e., prescribed fire), and map habitat changes.

4. **Consider adding some population demography monitoring.** Monitoring SEBM demography should be continued on KSC and expanded to include the whole CCBIC. Monitoring should be targeted at understanding how habitat conditions affect key vital rates. Beach mice are small, nocturnal, secretive animals that could easily become extinct without notice. For this reason, regular monitoring of population demography should be conducted to assess the health of the population and guide future management actions. Vulnerabilities include catastrophic storms, sea-level rise, climate change, habitat fragmentation, introduced predators, and loss of suitable habitat and corridors to movement due to lack of management or other activities. Maintenance of the most extensive geographic range will provide the spatial separation of populations needed to decrease the chance of extinction resulting from a single storm event. Monitoring methods should involve live-trapping, track tubes, and/or cameras and be focused on answering specific questions (e.g., habitat specific survival).

5. **Work with stakeholders to explore the effects of management activities (burning, mechanical treatment, and translocation).** Limited information is currently available on responses to management strategies. A single study by Suazo et al. (2009) on CCAFS

showed a positive correlation between SEBM and the Florida Scrub-Jay with prescribed fire. It also showed that neither mechanically cut/chopped nor fire-suppressed habitat benefited either species. While this may suggest that both species benefited from the same management practices, the SEBM may require further management at the microhabitat level. Federal agencies on whose land the remaining viable populations of the SEBM exist may benefit from combining management with population monitoring to learn how management affects SEBM habitat use.

6. **Begin to understand the connection between coastal and inland SEBM habitat.** SEBM have been collected from relict dunes and swales and inland scrub systems west of their primary coastal habitat. It is believed that such habitat can serve as a source of colonists after a storm event has caused a local extirpation of beach by providing a surviving population from which recolonization of the frontal dunes can take place (Holliman, 1983; Sneckenberger, 2001; Swilling et al., 1998; Oddy, 2000). Information is needed on how such inland habitat is used by SEBM, and about the corridors that allow movement between coastal and more inland habitats.

7. **Establish regular aerial imagery and a set of hurricane photo-documentation reference sites to monitor SEBM habitat changes.** Managers would benefit from information on the effects of land management activities or extreme events (hurricanes and tropical storms) on SEBM habitat. Mapping of the established and forming dunes along the coastline of the CCBIC would allow areas and intensity of erosion to be identified and monitored over time. To capture impacts from individual storm events on SEBM population, a set of photo-documentation sites could be established. These tools could be used to monitor changes to SEBM habitat pre- and post-hurricane, or as a result of management activities.

Current or Foreseeable Concerns

1. **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. This difficulty coupled with lowering statistical power to detect trends in SEBM habitat occupancy may be of concern. Currently we are working on methods to quickly derive the abundance state (none, few, or many) from track tube data. An interruption in habitat occupancy monitoring data collection may diminish our ability to extrapolate density in time and space limiting this effort. When populations become small, data becomes much harder to obtain (more expensive). It is in our best interest to maintain a monitoring effort for this reason, and because species recovery is much more expensive than species maintenance.

   Impacts of continuing storm events without continued monitoring. In the absence of a catastrophic storm or series of storms, the SEBM population on the CCBIC is likely to persist as long as the background ecological conditions remain relatively unchanged. However, the ability of the subspecies to survive a severe storm has been compromised because the original range has been greatly reduced, mostly to the CCBIC. Two major hurricanes (Matthew and Irma) have impacted SEBM habitat on the CCBIC in the last 3 years; either of these storm events could have had a catastrophic impact for all or most of the population. A few short-term studies have shown that SEBM are not always abundant along the entire stretch of coastline and that the species can occur much further inland on both Cape

Canaveral and Merritt Island. More information is needed about how such habitat functions after storms. Possibly the greatest threat to the persistence of the SEBM over the next 50 years is the probability 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 do 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.

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Appendix A. Additional Details of Methodology

Study Design

To determine the optimal study design for the Multi-Agency Annual SEBM Habitat Occupancy Survey, it was necessary to decide how to allocate the total effort (number of track tubes) between sites and replicates within sites. It was decided, based on available personnel and previous experience during the pilot study, that the effort available for the entire occupancy survey on the CCBIC was 950 tubes (± 50 tubes). The pilot study indicated that the average detection probability for a track tube was expected to be between 0.2 and 0.3, and the overall occupancy was expected to be around 0.44. Based on these results it was determined that seven or eight replicates at a minimum of 106 sites should be deployed to achieve the desired level of precision of between 0.1 and 0.15% Coefficient of Variation (MacKenzie et al., 2005). Theoretical considerations suggest that more replicates (i.e., track tubes) within sites, at the expense of fewer sites, would lead to better precision of the estimate of occupancy. The final study design had 114 sites with eight replicates (track tubes) placed randomly within a radius of 15 m (**Figure 3**; area of site = 707 m^2) at each site. All track tubes were deployed for 3 nights (4 days).

The sites were located using a combination of systematic and random selection of sampling locations. Sites were placed systematically along the 72 km north-south distance of the CCBIC starting at the southernmost point on CCAFS and spaced approximately 600 m apart (based on telemetry to achieve independence between adjacent points). Then at each site, we randomly selected a distance westward to locate the station (based on the width of the beach mouse habitat at the site), which was placed randomly within one of three distance zones perpendicular to the beach. This design allowed the stations to fall within several additional types of habitat, which were not sampled during the pilot study, which was restricted to habitat directly adjacent to the beach. In addition, because part of the focus of the study was to document the geographic range of the population along the CCBIC, we chose a systematic location of sites along the north to south extent rather than randomly selecting the initial eight location of sites. Finally, the eight track tube locations were arranged in cardinal compass bearings (e.g., 0°, 45°, 90°) around the center pole, each 1-15 m from the center (**Figure 3,** top in-lay), using a pre-defined table of random distances. Covariates taken at both the track tube locations and at the site as a whole are listed below.

Covariates

Track tube location covariates and their descriptions

The following is a list of the covariates collected during the 2010-2018 Multi-Agency Annual SEBM Habitat Occupancy Survey:

1. The percent of bare sand within a 1 m radius.
2. The presence/absence (and the number of burrows if present) of burrows consistent with SEBM burrows within 1 m radius.
3. The distance (m) to the nearest sea grape (*Coccoloba uvifera*).
4. The condition of saw palmetto (*Serenoa repens*) coverage within a 1 m radius, recorded as absent, patchy, or continuous with the surrounding area.

5. The presence/absence of food plants within a 1 m radius (primary food plants were based on [Keserauskis, 2007] and were beach sunflower [*Helianthus debilis*], shoreline sea purslane [*Sesuvium portulacastrum*], sea oats [*Uniola paniculata*], beach pea [*Canavila rosea*], ground cherry [*Physalis walteri*], and varnish leaf [*Dodonaea viscosa*]).
6. The height of the vegetation (m) within a 1 m radius.
7. The composition of habitat within a 1 m radius recorded as herbaceous, woody, or mixed.

Characteristics of the sites measured from existing land use and land cover classification using a GIS:

1. The proportion of unvegetated habitat within 15 m of each site center position.
2. The distance (m) to nearest hard infrastructure (e.g., train track, paved road).
3. The distance (m) to nearest water barrier (e.g., ditch, estuary, large pond).
4. The distance (m) to adjacent beach habitat (open sand to the east).
5. The distance (m) to the nearest oak scrub.
6. The amount and the land use and land cover classification code of habitat within buffers around the central points at each of three distances (15 m, 100 m, and 200 m).
7. The distance from the center of the point to the nearest dune crest.
8. The direction from the center of the point to the ocean (i.e., was the point landward of the dune?).
9. The elevation of the center of the point.
10. The elevation of the nearest primary dune.
11. The degree of erosion or accretion of the dune adjacent to the point 1969–2015.
12. Width of suitable habitat westward of the point.

Mapping Detection Rate as a Proxy for Habitat Occupancy

A simple way to look at habitat use is to quantify the number of years SEBM were detected at each site. This is potentially misleading, since it ignores non-detection and the potential confounding of detectability with occupancy. However, since we had fairly high detection rate across years, this may provide some insights into patterns of habitat suitability. **Figures A-1 and A-2** show how often SEBM were detected at each of the 114 sites over the 9 years of the survey. Since not all the sites were sampled for all 9 years, we calculated the proportion of years with detection over the surveyed years for each site. Looking at the proportion of years with detection, we can see some areas on each Federal property that seem to have detection in all or nearly all years, and other areas with consistently low detection rate. These patterns may lead us to question hypotheses of what factors cause these differences between sites that can be tested with existing and future data.

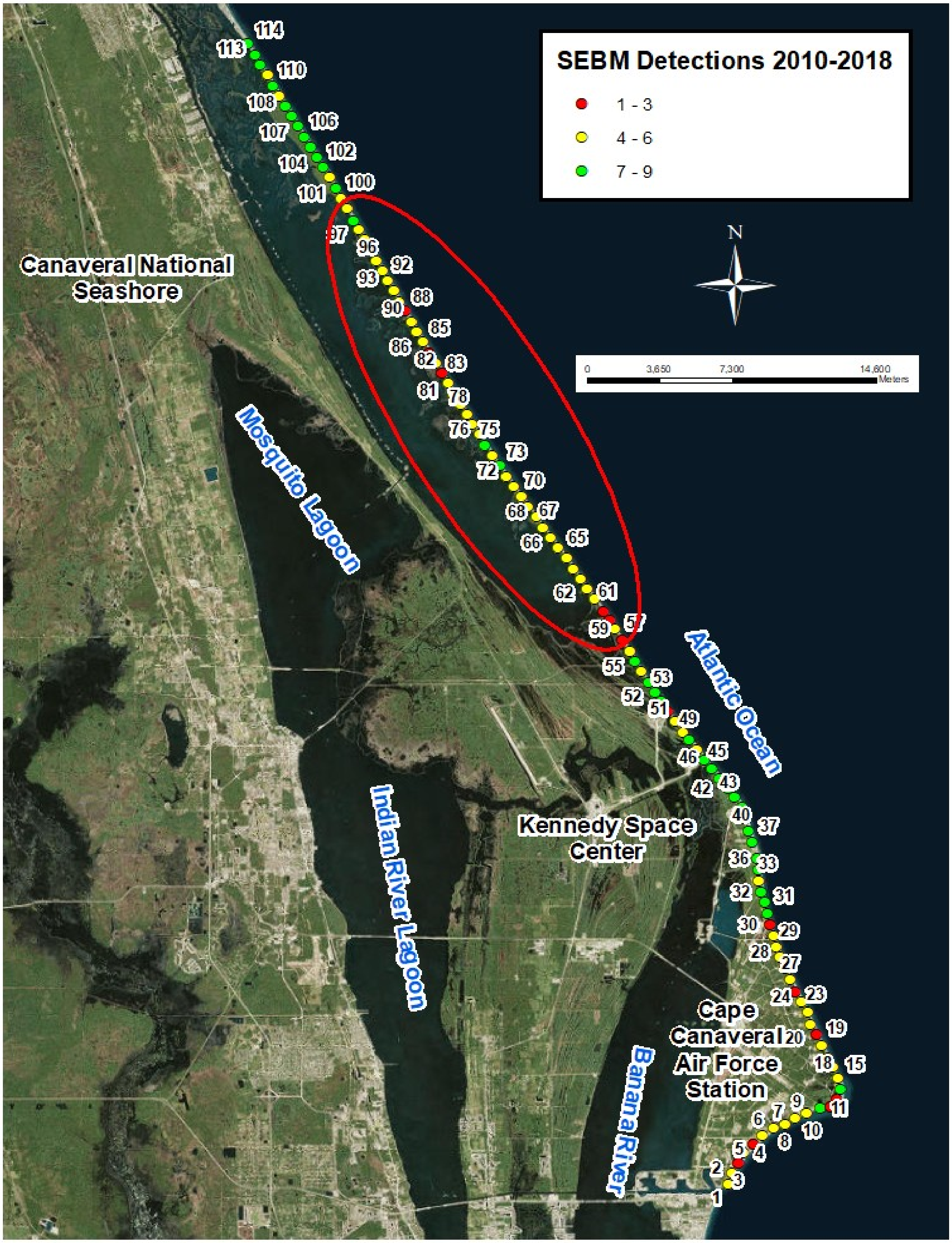

Figure A-1. Number of Years Sites Were Occupied by SEBM on the CCBIC (2010-2018).
Sites 56-98 located in the red oval were not sampled during the 2012-2013 surveys.

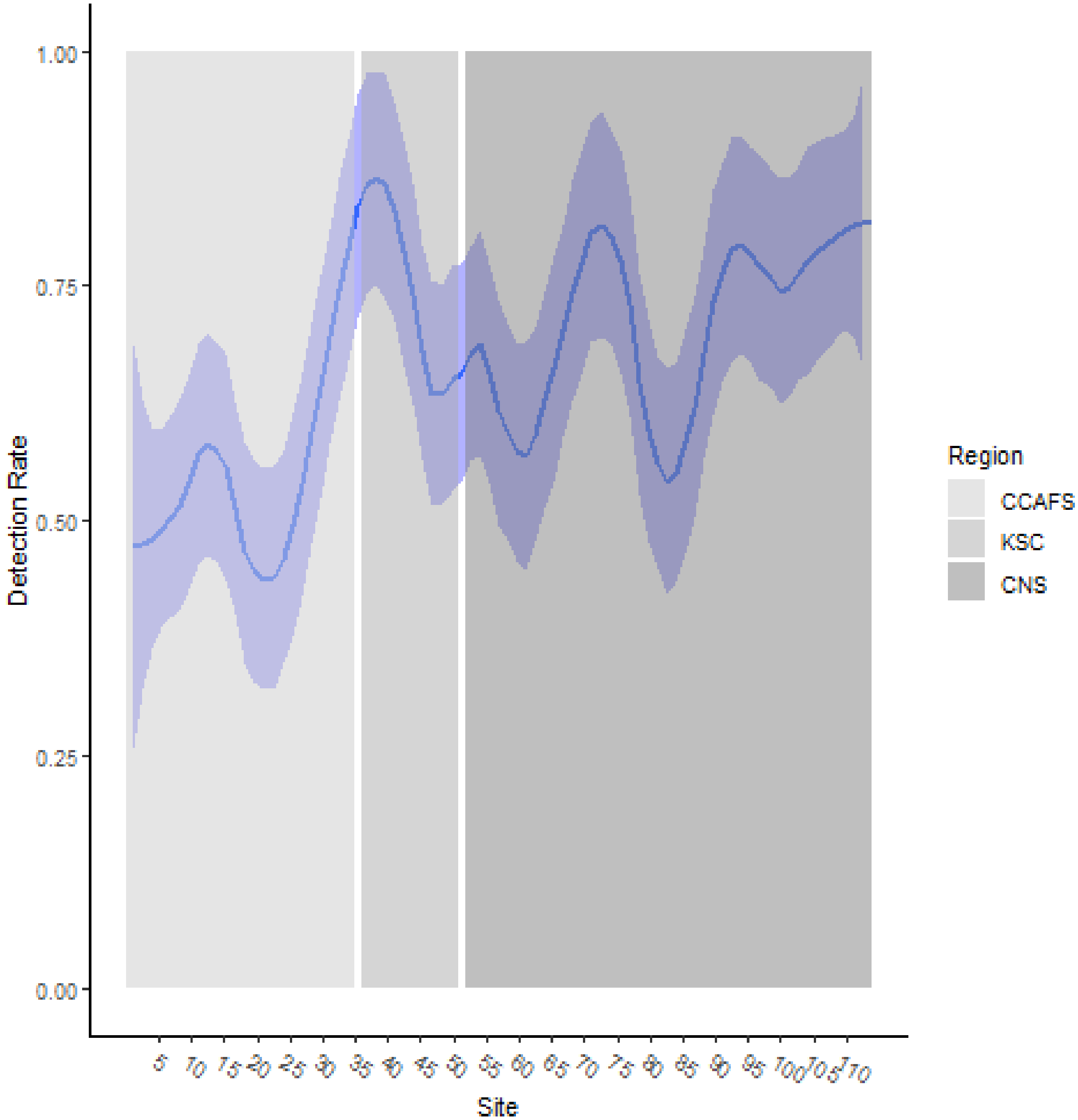

Figure A-2. Plot of the Proportion of Years with Detections

Plot of the proportion of years with detections (detection rate) for 114 sites during the Multi-Agency Annual SEBM Habitat Occupancy Survey. The blue solid line shows a smoothing function fitted to the data and the blue shaded area indicates the 95% confidence interval of the locally weighted estimate for each site. The sites 1-114 are arranged from south to north, with CCAFS, KSC, and CNS indicated by grey shaded regions.

Table A-3. Detections of SEBM in All Years Sampled Based on the 7.2 mm Size Criterion

An "X" indicates a SEBM was detected (at least two of the three track tube card readers recorded a footprint <7.2 mm in width) at each site in at least one of the track tubes over all sampling periods. A summary column was used to show which sites had detections during any of the 9 years sampled. Note that different methods were used across years: 2010-2011 used 1 sample period of 3 nights with 8 track tubes, 2012-2013 used 4 sample periods of 3 nights each with 8 track tubes, 2014-2015 used 2 sample periods of 6 nights each with 8 track tubes, 2016-2017 used 2 sample periods of 6 nights each with 5 track tubes, and 2018 used 2 sample periods of 6 nights each with 8 track tubes. A "—" indicates the site was not sampled that year.

Station	2010	2011	2012	2013	2014	2015	2016	2017	2018	Any Year
1			X	X	X				X	X
2	X		X	X	X	X			X	X
3				X	X	X				X
4				X	X	X	X	X		X
5				X	X	X				X
6			X	X	X	X				X
7			X	X	X	X			X	X
8	X		X		X	X				X
9	X		X		X	X	X			X
10		X			X	X			X	X
11	X	X	X	X	X	X	X		X	X
12			X	X	X					X
13			X	X	X					X
14		X	X	X	X	X	X		X	X
15	X		X		X	X	X		X	X
16			X		X	X	X	X	X	X
17		X	X		X	X			X	X
18			X		X	X			X	X
19					X	X				X
20				X	X	X	X			X
21	X			X	X		X			X
22			X	X	X	X				X
23				X	X					X
24		X	X		X				X	X
25	X	X	X	X	X	X	X	X		X
26	X		X	X	X		X		X	X
27		X	X		X	X				X
28			X	X	X			X	X	X
29			X		X					X
30	X	X	X	X	X	X	X			X
31	X		X	X	X	X	X	X	X	X
32	X		X	X	X	X	X		X	X
33		X	X	X	X	X			X	X

Station	2010	2011	2012	2013	2014	2015	2016	2017	2018	Any Year
34	X	X	X	X	X	X	X	X	X	X
35			X	X	X	X	X	X	X	X
36	X	X	X	X	X	X	X			X
37	X	X	X	X	X	X	X			X
38		X	X	X	X	X	X	X	X	X
39	X	X	X	X	X	X	X		X	X
40	X		X	X	X	X	X	X		X
41		X	X	X	X	X	X	X		X
42	X	X	X	X	X	X	X	X	X	X
43	X	X	X	X	X	X	X			X
44		X	X	X	X	X	X	X		X
45			X	X	--	X	X	X		X
46		X	X	X	--	X	X	X	X	X
47		X	X	X	--	X				X
48			X	X	X	X				X
49	X		X							X
50			X	X	X	X	X	X	X	X
51	X	X	X	X	X	X	X		X	X
52			X	X	X	X	X	X	X	X
53	X			X	X	X	X	X		X
54	X	X	X	X	X	X	X	X	X	X
55				X	X	X	X	X	X	X
56			--	--	X				X	X
57		X	--	--	X	X	X	X	X	X
58			--	--	X	X			X	X
59			--	--		X		X	X	X
60			--	--	X	X		X	X	X
61			--	--	X		X	X	X	X
62	X		--	--		X	X	X	X	X
63	X		--	--	X	X			X	X
64			--	--	X		X	X	X	X
65		X	--	--	X	X	X		X	X
66		X	--	--	X	X	X		X	X
67		X	--	--	X	X	X	X	X	X
68		X	--	--	X	X		X		X
69			--	--	X	X	X		X	X
70		X	--	--	X	X	X	X	X	X
71		X	--	--	X	X	X		X	X
72		X	--	--	X	X	X	X	X	X
73	X	X	--	--	X	X	X	X	X	X
74		X	--	--	X	X	X	X	X	X
75	X	X	--	--	X	X	X	X	X	X

Station	2010	2011	2012	2013	2014	2015	2016	2017	2018	Any Year
76			--	--		X	X	X	X	X
77		X	--	--	X	X			X	X
78	X	X	--	--			X	X	X	X
79			--	--	X	X		X	X	X
80			--	--		X	X	X	X	X
81	X		--	--	X	X	X	X	X	X
82			--	--					X	X
83			--	--	X	X	X	X	X	X
84			--	--		X		X	X	X
85			--	--	X	X		X	X	X
86		X	--	--	X			X	X	X
87		X	--	--	X	X	X	X	X	X
88	X		--	--	X				X	X
89			--	--	X	X	X	X	X	X
90		X	--	--	X	X	X	X	X	X
91			--	--	X	X	X	X	X	X
92		X	--	--	X	X	X	X	X	X
93		X	--	--	X	X	X	X	X	X
94			--	--	X	X	X	X	X	X
95		X	--	--	X	X	X	X	X	X
96			--	--	X	X	X	X		X
97	X	X	--	--	X	X	X	X	X	X
98			--	--	X	X	X	X	X	X
99			X	X	X	X		X	X	X
100	X	X	X	X	X	X		X	X	X
101			X	X	X	X	X			X
102		X	X	X	X	X	X	X		X
103			X	X	X	X	X	X	X	X
104			X	X	X	X	X	X	X	X
105			X	X	X	X	X	X	X	X
106			X	X	X	X	X	X	X	X
107		X	X	X	X	X	X	X	X	X
108		X	X	X	X	X	X	X	X	X
109			X	X	X	X	X	X		X
110	X	X	X	X	X	X	X	X	X	X
111	X		X	X	X	X	X			X
112			X	X	X	X	X	X	X	X
113		X	X		X	X	X	X	X	X
114		X	X	X	X	X	X	X	X	X