Articles

Differentiating Footprints of Sympatric Rodents in Coastal Dune Communities: Implications for Imperiled Beach Mice

Daniel U. Greene,* Donna M. Oddy, Jeffery A. Gore, Michael N. Gillikin, Emily Evans, Shanon L. Gann, Erin H. Leone

D.U. Greene,* J.A. Gore, M.N. Gillikin, E. Evans
Florida Fish and Wildlife Conservation Commission, 3911 Highway 2321, Panama City, Florida 32409

Present address of D.U. Greene: Weyerhaeuser Company, P.O. Box 2288, Columbus, Mississippi 39704

Present address of E. Evans: Florida Fish and Wildlife Conservation Commission, 3377 East U.S. Highway 90, Lake City, Florida 32055

D.M. Oddy, S.L. Gann
Integrated Mission Support Services, NASA Ecological Program, Kennedy Space Center, Florida 32899

Present address of S.L. Gann: Brevard Zoo, Sea Turtle Healing Center, 8225 North Wickham Road, Melbourne, Florida 32940

E.H. Leone
Florida Fish and Wildlife Conservation Commission, 1105 Southwest Williston Road, Gainesville, Florida 32601

Abstract

Identifying techniques for conducting frequent, effective, and inexpensive monitoring of small mammals can be challenging. Traditional approaches such as livetrapping can be laborious, expensive, detrimental to animal health, and ineffective. Passive approaches such as tracking (e.g., from tracks on the ground or footprints collected at a tracking station) have been shown to lessen those burdens, but a problem with tracking, particularly for rodents, is the uncertainty in identifying species from footprints. To address the need for a more accurate method of identifying small mammal tracks, we measured footprints from live-captured rodents and developed a classification tree for distinguishing between subspecies and species using footprint widths treated as having known or unknown identification. We captured rodents within or near the coastal dunes of Florida and Alabama with a focus on areas occupied by threatened and endangered beach mice Peromyscus polionotus subspp., whose populations warrant regular monitoring but whose tracks are not easily distinguished from those of some sympatric species. We measured 6,996 front and hind footprints from 540 individuals across eight species. The overall accuracy of our classification tree was 82.6% and we achieved this using only the front footprint width. Footprint width cutoffs for species identification were < 5.5 mm for house mice Mus musculus, 5.5–6.7 mm for beach mice, and 6.7–8.3 mm for cotton mice Peromyscus gossypinus. We were most successful in confirming the identity of beach mice: we correctly classified approximately 94% of beach mice, while we misclassified fewer than 6% as house mice and fewer than 1% as cotton mice. When we input a beach mouse individual into the classification tree as of an unknown species, we correctly identified 78.1% of individuals as beach mice from their tracks. Most incorrect identifications were of house mouse tracks. Our study demonstrates that researchers can identify sympatric rodent species in coastal dune communities from tracks using quantitative classification based on footprint width. Accurate identification of beach mice or other imperiled species from tracks has important management implications. Not only can wildlife managers determine the presence of a species accurately, but they can monitor populations with considerably less effort than livetrapping requires. Although our study was specific to coastal dune communities, our methods could be adapted for the creation of a classification tree for identifying tracks from suites of species in other areas.

Keywords: beach mouse; endangered species; footprints; passive surveys; Peromyscus polionotus; track tubes

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Identification of Rodents by Footprint Widths

D.U. Greene et al.

Introduction

A challenge to surveying and monitoring small mammals is identifying techniques that are efficient, effective, and low cost. Mark–recapture techniques such as livetrapping are a key component of wildlife management but can be cost prohibitive and labor intensive and may yield few captures due to low densities, low detectability, or patchy distribution of individuals (Greene et al. 2016b). The paucity of data resulting from low capture success can affect the ability to estimate demographic parameters accurately and precisely. Similarly, low detectability increases the probability of false absences in occupancy studies (MacKenzie et al. 2006). Together, these challenges hinder wildlife managers in their assessments of management efforts and achieving conservation and management goals.

Passive survey techniques offer alternative approaches for species that possess characteristics that make them difficult to study using more traditional capture or survey methods. For example, camera traps (O’Connell et al. 2011; Greene et al. 2016b), hair (McDaniel et al. 2000; Harris et al. 2006), and track tubes and track plates (Mabee 1998; Loggins et al. 2010) have been effective in confirming a species’ presence and are less laborious than livetrapping. Wildlife managers may prefer passive approaches when they do not need to handle individuals. Passive methods minimally disturb animals, thereby minimally alter behavior (Morris 1955) and eliminate the risk of stress, injury, and mortality from capture (Romero 2004; Suazo et al. 2005). In addition, many passive survey methods use tools that wildlife managers can deploy for long periods, which makes it more likely that rare or elusive species will be detected than with live capture or visual methods (e.g., distance sampling; Buckland et al. 1993).

For decades, researchers have sometimes used track surveys as an alternative to livetrapping of small mammals, but their accuracy is uncertain, which may be the reason they are not commonly used. Because the presence of heterospecifics can increase the difficulty in identifying a species through track surveys, researchers have expended considerable effort in developing a reliable method for identifying species through characteristics of footprints. Studies have often differentiated species based on subjective visual assessments of footprints, but visual assessment cannot be easily replicated, nor its accuracy quantified (e.g., Mabee 1998; Glennon et al. 2002; Nams and Gillis 2003; Wiewel et al. 2007; Mills et al. 2016). Although some authors have reported quantitative results from identification of tracks (e.g., van Apeldoorn et al. 1993; Mukherjee and Goyal 2004), few estimated confidence in their identifications by determining the probability of misidentification (Palma and Gurgel-Gonçalves 2007; Russell et al. 2009; Stolen et al. 2014).

To allow managers to reliably survey small mammals and to better guide conservation and management decisions for those species, estimates of the margin of error in identifying small mammals from footprint characteristics are needed. This would be especially helpful in the coastal dune communities of Florida and Alabama, where track tubes are the primary technique used in monitoring populations of beach mice Peromyscus polionotus subspp. (Loggins et al. 2010; Stolen et al. 2014), coastal subspecies of oldfield mice that are federally threatened or endangered by both the State of Florida and under the U.S. Endangered Species Act (ESA 1973, as amended). In the past ~35 y, >50% of beach mouse populations on public lands have been extirpated at least once (J. A. Gore, Florida Fish and Wildlife Conservation Commission, unpublished data). This high rate of population loss has required the reintroduction of populations through translocations of wild mice or the release of captive-born animals (Holler et al. 1989; Lynn 2001; Van Zant and Wooten 2003; Austin et al. 2015; Greene et al. 2016a). The risk of extinction for many beach mouse subspecies is high, so frequent monitoring is required. Wildlife researchers periodically livetrap beach mice to confirm presence, estimate population densities, and assess the occurrence of sympatric species, but the high cost of livetrapping, the number of disjoint populations, and the possibility of low detectability make livetrapping impractical for frequent monitoring. Instead, since 2005, researchers have surveyed most populations of beach mice using track tubes (Loggins et al. 2010) every 1–2 mo to assess site occupancy and to monitor population trends. Although these tracking surveys have been logistically efficient, species identification has been subjective and limited to visual assessments, and livetrapping is still occasionally required to inventory species present.

Trapping studies have shown that the beach mouse, where it occurs, is the dominant and sometimes the only rodent species occupying coastal dunes (e.g., Bowen 1968; Humphrey and Barbour 1981; Meyers 1983; Holler et al. 1989; Rave and Holler 1992; Wilkinson et al. 2012). Researchers occasionally detect hspid cotton rats Sigmodon hispidus, cotton mice Peromyscus gossypinus,
and nonnative house mice *Mus musculus* in beach mouse habitat (Loggins et al. 2010), and the tracks of the latter two species are quite similar to those of beach mice. Golden mice *Ochrotomys nuttalii*, Florida mice *Podomys floridanus*, eastern woodrats *Neotoma floridana*, and black rats *Rattus rattus* occasionally occur in the dunes along Florida’s Atlantic coast but typically are present only where trees and other woody vegetation are abundant (D. Oddy, Integrated Mission Support Services, NASA Ecological Program, Kenney Space Center, unpublished data). Recently, Stolen et al. (2014) differentiated beach mice from cotton mice by footprint characteristics along the Atlantic coast of Florida and indicated the footprint widths of the two species overlapped slightly. But researchers have not yet demonstrated the ability to differentiate beach mouse from other sympatric species, particularly house mice. To accurately monitor beach mouse populations, wildlife managers must be able to distinguish beach mouse tracks from those of house mouse. Accurate identification of rodents by footprints could make it unnecessary to live trap concurrently to determine species composition (Lord et al. 1970). Therefore, our objective was to differentiate rodent species using one or a few characteristics of footprints. Although our focus was on rodent species likely to occur in coastal dune habitat, such a method would be applicable to small mammals in other ecosystems.

**Methods**

**Study site**

We conducted livetrapping and collected footprints of rodents in Florida and Alabama from 2009 through 2012. We focused our efforts within the coastal habitat occupied by beach mice at Kennedy Space Center/ Merritt Island National Wildlife Refuge, Tyndall Air Force Base, Grayton Beach State Park in Florida, and Gulf State Park in Alabama. To increase sample sizes of sympatric species that can be less abundant near the coast, we occasionally trapped farther inland (≤ 25 km, at Nokuse Plantation in Walton County, Florida).

**Track collection**

We livetrapped all animals using Sherman live traps (H.B. Sherman Company, Tallahassee, FL) except woodrats and black rats, which we captured using Tomahawk wire-cage traps (Tomahawk Live Trap Company, Tomahawk, WI). We recorded sex, weight (g), and species for all captured animals. We conducted livetrapping following guidelines approved by the American Society of Mammalogists (Gannon et al. 2007; Sikes et al. 2011).

Our goal was to collect tracks from animals and develop a verified reference collection to use for passive identification. For smaller animals, we placed a captured individual into a 37.9-L aquarium; for larger animals (woodrats, cotton rats, black rats) we placed an individual into a 75-L storage bin. The aquarium contained three track tubes made of polyvinyl chloride pipe (30.5 cm long × 5 cm diameter) with a cap on one end; each tube contained a 5 × 28 cm strip of 100-pound card stock shaped to fit the curvature of the tube and an inked 3.8 × 3.8 cm felt pad attached to one end (Loggins et al. 2010). To prevent ink from seeping through onto the paper strip, we attached the ink pad to impermeable contact paper and attached that to a Tyvek credit-card sleeve (Material Concepts Inc., Philadelphia, PA), which we slipped over the strip of card stock. We allowed the mice to move undisturbed between the tubes and thus leave ink tracks on the card-stock strips. The plastic storage bin contained no tubes, only an ink pad clipped to an American letter-size (8.5 × 11 in.) sheet of card stock. The animals moved freely around the bin and left tracks when they crossed the ink pad and paper.

We collected tracks from each individual with a goal of five symmetrical (not skewed or splayed) prints each from front and hind feet (Figure S1, *Supplemental Material*). We measured the width of footprints using a dial caliper with 0.01-mm resolution and 0.02-mm accuracy. We measured all symmetrical front and hind footprints using the distance between the centers of the outer two toe prints (Figure 1). We excluded asymmetrical tracks because stressed mice often place different amounts of pressure on their feet, which can skew and increase the width. To minimize bias from measurement error, we measured each footprint five times and recorded the mean (hereafter referred to as an observation).

**Data analysis**

To determine whether greater variability was introduced by repeat measurements from an individual animal or from different individuals within a species, we built an intercept-only linear mixed model using PROC MIXED (SAS Institute Inc., Cary, NC) to estimate and compare inter- and intraindividual variance components. We performed, for each species, a 1-way ANOVA to compare inter- and intraindividual variance components.
Table 1. Species, subspecies, number of individuals (N), number of footprints measured (Footprints), and footprint widths (mm) of rodents within or near coastal dune communities in Florida and Alabama, 2009–2012. We calculated mean and standard deviation (SD) from multiple measurements within and between individuals of a species or subspecies.

| Species/subspecies          | N  | Footprints | Width | Mean (SD) | Footprints | Width | Mean (SD) |
|-----------------------------|----|------------|-------|-----------|------------|-------|-----------|
| House mouse Mus musculus    | 120| 130        | 4.0–7.3 | 5.4 (0.5) | 607        | 4.2–7.8 | 6.0 (0.6) |
| Golden mouse                | 3  | 43         | 6.0–8.3 | 7.1 (0.5) | 21         | 6.2–8.4 | 7.6 (0.7) |
| Florida mouse P. p. peninsularis | 10 | 142        | 6.0–8.2 | 7.3 (0.4) | 32         | 7.2–9.3 | 8.4 (0.5) |
| Cotton mouse Podomys floridanus | 90 | 589        | 5.7–9.5 | 7.5 (0.7) | 158        | 6.4–10.3 | 8.2 (0.9) |
| St. Andrews beach mouse P. p. niveiventris | 40 | 405        | 4.8–7.0 | 5.8 (0.4) | 113        | 5.0–7.3 | 6.0 (0.6) |
| Perdido Key beach mouse P. p. trissyllepsis | 23 | 457        | 5.0–6.8 | 5.9 (0.3) | 97         | 5.3–7.3 | 6.4 (0.4) |
| Southeastern beach mouse P. p. trissyllepsis | 116| 636        | 4.4–7.3 | 6.1 (0.4) | 127        | 5.3–8.0 | 6.6 (0.5) |
| Hispid cotton rat Sigmodon hispidus | 60 | 515        | 6.3–11.8 | 9.0 (1.1) | 315        | 6.0–13.7 | 10.0 (1.7) |
| Black rat Rattus rattus     | 55 | 725        | 9.8–15.2 | 12.5 (1.0) | 334        | 10.5–17.3 | 14.1 (1.4) |
| Eastern woodrat             | 23 | 314        | 10.4–16.3| 13.3 (1.1) | 203        | 11.4–18.9| 15.1 (1.4) |

Footprint widths varied little among southeastern P. p. niveiventris, Perdido Key P. p. trissyllepsis, and St. Andrews P. p. peninsularis beach mouse subspecies (Figure S2, Supplemental Material), we combined beach mice into a single group (Figure S3, Supplemental Material).

determine whether sex influenced front footprint width for each species. We performed a separate linear regression analysis for each species to determine if there was a relationship between front footprint width and weight. Because footprint widths varied little among southeastern P. p. niveiventris, Perdido Key P. p. trissyllepsis, and St. Andrews P. p. peninsularis beach mouse subspecies (Figure S2, Supplemental Material), we combined beach mice into a single group (Figure S3, Supplemental Material).

To distinguish among rodent species, we developed a classification tree using the rpart package (Therneau and Atkinson 1997) in R v2.15 (R Development Core Team 2012). To avoid overfitting the tree and thus reducing its predictive power, we first formed the tree allowing for the maximum number of fits, then pruned it back to the minimum number of leaves required to achieve the minimum cross-validation error. We also confirmed this optimal tree size by visual examination of complexity parameters relative to the cross-validated error rate (Maindonald and Braun 2010). Predictive variables included in the starting tree were the average front foot width and the average hind foot width for each animal. We used the tree to calculate two percentage classes two ways: first, across all species, we treated individuals as being of unknown species and, using the lower and upper values of leaves in the classification tree, calculated the classified and misclassified percentages based only on footprint widths; second, we treated the individuals as being of a known species and calculated the percentages of individuals that were correctly classified and the percentages classified as each alternate species.

Results

We collected tracks from 540 individuals across eight species (Table 1; Table S1, Supplemental Material). More beach mice were represented, with 179 individuals across the three subspecies. We excluded golden mice (n = 3) and Florida mice (n = 10) from final analyses due to small sample sizes, but they are included in Table 1 for comparison. We collected an average of three track cards per individual (range 1–12) to acquire the minimum five symmetrical prints each of front and hind feet. We measured 6,996 footprints; symmetrical front footprints were more common (N = 4,973) than symmetrical hind footprints (N = 2,023). Hind footprints were also more difficult to collect and were often incomplete. Because our classification tree accurately distinguished between species using measurements of front footprints, which were more common on track cards, we included only the front footprint widths in the tree. Seventeen individuals yielded no clear or complete front footprints, reducing our final data set to 523 individuals.

Within-individual variability for front footprint width was 0.18 whereas it was 6.52 within species (between individuals). These values indicate that there was 37 times greater variability among individuals in a species than among repeated measurements for a given individual and, because the variability in measurement of a given individual was small, that repeated measurements for a single print were unnecessary. We found no difference in front footprint width between the sexes for any species (P > 0.05; Table S2, Supplemental Material).

Although the effect of weight on the width of the front footprint was significant for all species (P < 0.05) except the Florida mouse and St. Andrews beach mouse (Table S3, Supplemental Material), relationships were weak, with R² values < 0.45 (Figure S4, Supplemental Material).

For the six species for which we sampled > 10 individuals, we identified species from footprint widths with accuracies ranging from 63 to 92% (Table 2). Footprint widths for Florida mice and golden mice, underrepresented in our samples, were similar to those for cotton mice (Table 1). The root node error for our classification tree was 0.658 and the cross-validated error rate prediction was 0.299, resulting in an absolute cross-validated error rate of 19.69%. Across all species, the overall accuracy of our classification tree correctly classifying individuals to their species was 82.6%. Our classification tree yielded five total leaves with which to
identify the six common species using front footprint width (Figure 2). Our classification tree was most accurate in identifying beach mice. When we used measurements from all species but treated species as unknown, 78% of the individuals that we identified as beach mice were beach mice; we misclassified 19% as house mice and 3% as cotton mice (Table 2). When we used measurements only from beach mice, we correctly classified 94% of the observations as beach mice, and misclassified 6% as house mice. We misclassified a beach mouse only once as a cotton mouse, the native sympatric species closest in body size and weight, but we misclassified cotton mice as beach mice 8% of the time. We misclassified house mice more often (33%) than any other species, but confused them only with beach mice (Table 2).

### Discussion

The local distribution of small mammals has typically been determined via live-trapping, which is labor intensive and may affect the health and behavior of the animals under study. The ability to readily detect and identify individuals to species from tracks allows conservation managers to survey safely and efficiently across broad spatial scales (Russell et al. 2009), which is important for beach mice or other species that are vulnerable to extinction. Our study demonstrates that researchers can differentiate native rodent species in coastal dune communities based upon empirically determined categories of front footprint width. A quantitative indicator of accuracy of track identification, such as that obtained from our classification tree, will also help avoid poor management decisions resulting from misidentification of species.

Several tracking studies of small mammals have used subjective methods to identify individuals to species from footprint characteristics, but those methods can be difficult to learn and replicate (e.g., van Apeldoorn et al. 1993; Mabee 1998; Glennon et al. 2002; Nams and Gillis 2003; Wiewel et al. 2007). Moreover, errors in subjective identification are possible because some species’ footprints are similar. Quantifiable track characteristics, such as footprint width, have been employed to identify small mammals more easily and objectively (Palma and Gonçalves 2007; Russell et al. 2009; Stolen et al. 2014). In addition to providing measures of accuracy of species identification, we achieved this through an uncomplicated approach of using just one type of measurement. While this meets the goals of the present study, other studies still may more accurately identify animals using more complex approaches. For example, Russell et al. (2009) developed an automated imaging system for identifying small mammal tracks to species. This system correctly identified a high percentage of tracks, and it may complement or be a useful alternative.

### Table 2

Percentages of correct and incorrect identification of coastal dune rodent species from front footprint widths in Florida and Alabama, 2009–2012, using our classification tree. We interpreted results in two ways: first, across all species, we estimated accuracies where individuals were treated with an unknown species identification and where individuals were classified to a species using lower and upper cutoffs of footprint widths; second, we estimated within-species accuracies as the percentage of individuals that were classified correctly. For example, using the classification tree, 215 individuals were classified as beach mice. Of those, 168 individuals were beach mice, yielding a 78.1% overall accuracy for the species. However, of the 179 beach mouse individuals, 168 were correctly classified, yielding a within-species accuracy of 93.9%.

| Species | Classified | Actual | BM | HM | CM | CR | BR | EW |
|---------|------------|--------|----|----|----|----|----|----|
| BM      | 215        | 179    | 78.1 | 18.6 | 3.3 | — | — | — |
| HM      | 90         | 120    | 11.1 | 88.9 | — | — | — | — |
| CM      | 92         | 91     | 1.1 | 87.0 | 12.0 | — | — | — |
| CR      | 51         | 60     | — | 7.8 | 92.2 | — | — | — |
| BR      | 48         | 50     | — | — | — | 4.2 | 83.3 | 12.5 |
| WR      | 27         | 23     | — | — | — | — | 37.0 | 63.0 |

Across-species classification % accuracy

| Species | Classified | Actual | BM | HM | CM | CR | BR | EW |
|---------|------------|--------|----|----|----|----|----|----|
| BM      | 215        | 179    | 78.1 | 18.6 | 3.3 | — | — | — |
| HM      | 90         | 120    | 11.1 | 88.9 | — | — | — | — |
| CM      | 92         | 91     | 1.1 | 87.0 | 12.0 | — | — | — |
| CR      | 51         | 60     | — | 7.8 | 92.2 | — | — | — |
| BR      | 48         | 50     | — | — | — | 4.2 | 83.3 | 12.5 |
| WR      | 27         | 23     | — | — | — | — | 37.0 | 63.0 |

Within-species classification % accuracy

| Species | Classified | Actual | BM | HM | CM | CR | BR | EW |
|---------|------------|--------|----|----|----|----|----|----|
| BM      | 215        | 179    | 78.1 | 18.6 | 3.3 | — | — | — |
| HM      | 90         | 120    | 11.1 | 88.9 | — | — | — | — |
| CM      | 92         | 91     | 1.1 | 87.0 | 12.0 | — | — | — |
| CR      | 51         | 60     | — | 7.8 | 92.2 | — | — | — |
| BR      | 48         | 50     | — | — | — | 4.2 | 83.3 | 12.5 |
| WR      | 27         | 23     | — | — | — | — | 37.0 | 63.0 |

* Beach mouse Peromyscus polionotus subssp. (BM), house mouse Mus musculus (HM), cotton mouse Peromyscus gossypinus (CM), hispid cotton rat Sigmodon hispidus (CR), black rat Rattus rattus (BR), eastern woodrat Neotoma floridana (WR).

**Figure 2.** Classification tree used to distinguish six rodent species from front footprint width within or near coastal dune communities in Florida and Alabama, 2009–2012. We input data from individuals into the classification tree with individuals treated as having an “unknown species” identification. Using the classification tree, we assigned individuals to a species though footprint widths, which allowed for testing of the tree’s accuracy (i.e., the percentage of individuals classified correctly to their respective species). Circles represent the size (mm) thresholds for the front footprint cutoff widths; rectangles show the percentage of individuals (%) correctly classified each species under this restriction.
to our method, particularly for animals that leave incomplete prints. But the automated system requires computer expertise, input of enough complete tracks to create baseline information, then development of a template database for pairing incomplete tracks to likely tracks. Palma and Gurgel-Gonçalves (2007) developed an alternative method; they collected and digitized footprints, then compared collected and reference tracks using a discriminant analysis to identify tracks based upon a host of distances between points within the footprint. Although they correctly classified many sympatric species, the classification system requires measurement of numerous points rather than a single character such as footprint width. While this system may be useful for researchers conducting an intensive inventory of a site, like Russell et al. (2009), it may have limited applicability for frequent and repeated surveys by land managers.

Defining footprint size cutoffs precisely is vital in the accurate differentiation of rodent species. Most recently, Stolen et al. (2014) used a Bayesian analysis to produce footprint width cutoff points to distinguish cotton mice from beach mice. They concluded that footprints < 6.1 mm wide were almost certainly from beach mice, prints 6.1–7.1 mm wide were uncertain, and prints > 7.1 mm wide were considered not to be from beach mice. This compares with our cutoff width of 6.68 mm, above which a print was judged not to be from a beach mouse; differences in cutoff values between studies is negligible, as we recorded widths from the center of the two outer toe prints, whereas Stolen et al. (2014) measured them from the outside of each toe pad print, which probably accounts for the differences. For beach mice, we believe our upper cutoff is sufficiently accurate because only 7 of 215 classified individuals (classified using individuals as having unknown species identification) identified as beach mice were actually cotton mice (Table 2). Of bigger concern is misidentification of house mouse tracks as beach mouse tracks. Stolen et al. (2014) did not sample house mouse tracks, but we found 18.6% (40 of 215 classified individuals) of unknown tracks classified as beach mice were actually from house mice (Table 2). This rate of false detections could have significant adverse impacts upon estimates of occupancy by beach mice (Miller et al. 2011). Fortunately, house mice seldom occur in natural dune habitat far from human dwellings, and, even when they do occur, they may not compete well with beach mice (Greene et al. 2017). As such, nearly all our estimates of accuracy, with known or unknown identification, are biased down, as our analyses considered all species known to co-occur with beach mice in the coastal areas, which is seldom true. Nevertheless, when sympatric species have similar cutoff values for their footprint widths and managers suspect co-occurrence, it would be prudent to livetrap to confirm species identification to reduce false-positive detections (Miller et al. 2011).

The accuracy of species identification using tracks depends upon having a footprint that is typical or representative of the species. Providing sufficient ink without overwetting the pad can help preclude faint or smeared tracks (Figure S1, Supplemental Material) that might lead to inaccurate identifications. Another problem is that a track tube can receive too many tracks, which makes it difficult to distinguish and measure a single, symmetrical footprint. Researchers can reduce the number of tracks by limiting the time that a track tube is in place before the track card is replaced. Minimizing the amount of bait in a track tube can also reduce the number of visits to the tube and thus the number of tracks made. Duration of deployment does not appear to be an issue, as we found measurable tracks even in tubes whose papers had been in place for 2 mo, if the ink pad was sufficiently wet and minimal bait had been used.

Occurrences of faint and overlapping prints are not uncommon, especially when researchers deploy track cards for multiple days. Even when tracks are abundant, overlapping, and toe prints are faint or missing (Figure S1, Supplemental Material), observers can still differentiate them. Russell et al.’s (2009) automated method includes an algorithm that uses a user-defined number of templates of known species to automatically generate templates of possible combinations to account for missing toes, while reflecting the variance within the species characteristics (e.g., age and sex). Similarly, their method allows multiple footprints to share toe prints when prints are overlapping by searching for the best possible match. This approach, however, seemed too subjective for our track cards. We found the size of toe prints was not always consistent within a footprint, either due to variable pressure or the amount of ink on the toe pads. Occasionally, we could not visually assign toe prints to a specific footprint, or when it was identifiable, it sometimes appeared to be a better fit (by symmetry) to an adjacent, overlapping footprint. These uncertainties are important; good prints can confirm a species identification, but not every print can be identified accurately, and when two or more species have similar footprint characteristics (e.g., footprint width), faint, incomplete, or asymmetrical prints can result in a misidentification. Excluding such footprints may be necessary to achieve a desired accuracy in identification in a project.

Although our method uses only front footprints for classification, others (Palma and Gurgel-Gonçalves 2007) have found that hind footprints worked better for distinguishing rodent species. A main limitation in our study was the difficulty in obtaining symmetrical hind footprints; our sample contained 2.5 times as many symmetrical front footprints as symmetrical hind footprints, and as many as 12 track cards were sometimes necessary to obtain five symmetrical hind footprints for measurements. Because tracking surveys are likely to use one card per tracking station and cannot control the number of tracks that animals will lay before the card is collected, we recommend identifying species using front footprints when deploying tracking stations in the field.

We found no evidence of sexual dimorphism in footprints, and, for most species, an individual’s weight was not strongly correlated with the width of its footprint. These findings suggest that the classification tree used to identify individuals to species in this study is
effective across sexes and ages within species. We did not capture enough Florida mice and golden mice to compare them with the other species. These species typically inhabit forested and scrub habitats inland from coastal sites and are seldom sympatric with beach mice (Wilkinson et al. 2012; Stolen et al. 2014). Regardless, additional measurements of their footprint characteristics would expand the classification tree and help in detecting these species in coastal communities when they do occur.

Our classification by footprint width offers a means of identifying coastal dune rodents using their tracks and wildlife managers could apply it to other small-mammal communities in which species have similar tracks. In widely distributed species, footprint characteristics may vary geographically, so we recommend collecting footprints from local populations and communities before developing a classification tree for track identification. If observers cannot easily differentiate sympatric species by footprint width, they might use other characteristics, such as footprint length (Ratz 1997) or automated methods that use complex metrics such as angles between each toe and its neighbors and to the central pad (Palma and Gurgel-Gonçalves 2007; Russell et al. 2009).

Regardless of technique, the ability to monitor fluctuations in the distributions of populations across time and space affords access to valuable information that managers can use to describe species–habitat relationships and evaluate management practices. Moreover, for imperiled taxa such as beach mice, accurate survey techniques can help managers assess population impacts of severe weather events such as tropical cyclones and monitor the success of translocations. Monitoring and identification of species through footprint characteristics may also allow managers to determine whether they need to reintroduce populations and to rapidly implement conservation actions, such as bringing animals into captivity when the vulnerability to extinction is high for wild populations (e.g., Greene et al. 2017).

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Supplemental Material

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**Table S1.** Data file of species, sex, weight, and front and hind footprint widths of rodent tracks collected during a study to passively identify rodent individuals to species within or near coastal dune communities in Florida and Alabama, 2009–2012.

Found at DOI: [https://doi.org/10.3996/062018-JFWM-055.S1](https://doi.org/10.3996/062018-JFWM-055.S1) (42 KB XLSX).

**Table S2.** Model results comparing front footprint measurements between the sexes for eight rodent species within or near coastal dunes in Florida and Alabama, 2009–2012.

Found at DOI: [https://doi.org/10.3996/062018-JFWM-055.S2](https://doi.org/10.3996/062018-JFWM-055.S2) (14 KB DOCX).

**Table S2.** Results of a model that regressed rodent weight on front footprint width collected in track tubes within or near coastal dune communities in Florida and Alabama, 2009–2012.

Found at DOI: [https://doi.org/10.3996/062018-JFWM-055.S3](https://doi.org/10.3996/062018-JFWM-055.S3) (14 KB DOCX).

**Figure S1.** Images of track cards with footprints used in a study conducted to passively identify rodent individuals to species that occur in the coastal dune communities in Florida and Alabama, 2009–2012. Example footprints (circled) are not typical, or representative of the species. These footprints are unmeasurable, or if measured, may lead to inaccurate species identification.

Found at DOI: [https://doi.org/10.3996/062018-JFWM-055.S4](https://doi.org/10.3996/062018-JFWM-055.S4) (330 KB PDF).

**Figure S2.** Histogram of front footprint widths of tracks from three subspecies of beach mouse *Peromyscus polionotus* subspp. collected during a study conducted to passively identify rodent individuals to species that occur in the coastal dune communities in Florida and Alabama, 2009–2012.

Found at DOI: [https://doi.org/10.3996/062018-JFWM-055.S5](https://doi.org/10.3996/062018-JFWM-055.S5) (2.4 MB TIF).

**Figure S3.** Histogram of front footprint widths of rodent tracks collected during a study to passively identify rodent individuals to species within or near coastal dune communities in Florida and Alabama, 2009–2012.

Found at DOI: [https://doi.org/10.3996/062018-JFWM-055.S6](https://doi.org/10.3996/062018-JFWM-055.S6) (2.15 MB TIF).

**Figure S4.** Weight (g) regressed on front footprint width (mm) for each rodent species or subspecies within or near coastal dune communities in Florida and Alabama, 2009–2012.

Found at DOI: [https://doi.org/10.3996/062018-JFWM-055.S7](https://doi.org/10.3996/062018-JFWM-055.S7) (2.39 MB TIF).

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