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An abstract of
a thesis submitted to the Faculty of Emory College of Arts and Sciences
of Emory University in partial fulfillment
of the requirements of the degree of
Bachelor of Sciences with Honors

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Abstract

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In coastal environments, storm-washover fans represent transitional zones between marginal-marine and terrestrial environments that can undergo rapid ecological change. Because of their location and dynamism, trace assemblages of washover fans are quite varied and often reflect mixes of flora and fauna that ordinarily would not overlap. For example, on Georgia-coast washover fans, insects, fiddler crabs, mud snails, wading birds, shorebirds, deer, raccoons, feral hogs, and alligators regularly share these spaces. Additionally, on the Georgia barrier islands, habitual movements of raccoons (*Procyon lotor*) form trails, which are the most visually prominent traces crossing fans. These trails often branch and otherwise connect with one another, forming clear pathways that originate in the maritime forest and often trend north-south, following the shoreline. To better define these traces, I studied them on St. Catherines Island, Georgia, an undeveloped island with well-developed washover fans. I found that mapping trails with a handheld GPS unit and marking predation traces with waypoints was an effective method for documenting raccoon presence and behaviors on washover fans. Berm-to-marsh transects with quadrat sampling were used to document traces of raccoons and other animals. Deer, hog, alligator, fiddler crab, ghost crab, and multiple species of insect and bird traces were identified in the transects. Multiple trackways across washover fans frequently joined at one or two primary trails through dense regions of *Spartina alterniflora* and *Juncus roemerianus*. Trails crossing washover fans are often associated with food acquisition, especially predation on fiddler crabs (*Uca pugnax* and *U. pugilator*), which range from 1-45 burrows/m^2 in density. Data from field surveys were imported into ESRI's ArcGIS to create maps of trails and other traces. Some of the raccoon trails are also visible on Google Earth images, thus GIS mapping provided a way to "groundtruth" these macroscopic traces. For paleoichnologists, such mapping may provide a model for interpreting bedding-plane exposures of ancient storm-washover fans.

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Introduction

St. Catherines Island is part of the Georgia barrier-island chain, located between Ossabaw and Sapelo Islands (Figure 1). St. Catherines is a compound barrier island, consisting of a Pleistocene core with active Holocene beach ridges (Goldstein and Watkins 1998, Bishop et al. 2011). The island's 95 km^2 includes a variety of environments, ranging from densely vegetated forests of pine and live oak to tidal creeks and marshes composed largely of *Spartina alterniflora* and *Juncus roemarianus* (Goldstein and Watkins 1998). Beaches of fine- to medium-grained siliciclastic sediments dominate the ocean-facing side of the island. All of the Georgia barrier islands are in a low to moderate energy mesotidal environment; on average, tidal range is 2-3 meters, with non-storm wave amplitudes averaging about 0.25 meters (Goldstein and Watkins 1998; Frey and Howard 1988; Pilkey 2003, 248).

Figure 1. Study site location, St. Catherines Island

Barrier islands occur globally; in fact, studies have documented more than 1,500 barrier islands with occurrences on every inhabited continent (Stutz and Pilkey 2001; Pilkey and Fraser, 2005). Storm-washover fans are common features on the side of barrier islands facing the open ocean, forming transitional zones between marginal marine and inland terrestrial environments.

These fan deposits are formed when storm-driven waves breach coastal dunes, carrying medium- to fine-grain beach sediments beyond the dunes. These deposits normally display subplanar laminations and landward-dipping forest bedding (Howard & Scott 1983, Martin and Rindsberg, 2011). Washover fans are inherently dynamic coastal features; a single storm can create new fans, move pre-existing fans, and cover trackways with new sediment. Although washover fans have few endemic species, trace assemblages of fans on the Georgia coast frequently consist of an variety of traces made by mammals, birds, insects, and decapods whose habitats do not normally overlap (Figure 2).

Figure 2. Traces of an alligator (Alligator mississippiensis), raccoon (Procyon lotor), and sand fiddler crab (Uca pugilator) overlapping on the distal side of a storm washover fan in the study area.

For example, on Georgia-coast washover fans, vertebrate trace makers include white-tailed deer (*Odocoileus virginianus*), wild hogs (*Sus scrofa*), raccoons (*Procyon lotor*), American alligators (*Alligator mississippiensis*), loggerhead sea turtles (*Caretta caretta*), great blue herons *(Ardea herodias)*, American oystercatchers (*Haematopus palliates)*, gulls (*Larus sp.*), plovers (*Charadrius sp.*), and other bird species. Invertebrate species include rove beetles, ghost crabs (*Ocypode quadrata)*, mud and sand fiddler crabs (*Uca pugnax* and *U. pugilator*, respectively), and small gastropods (e.g. *Littorina irrorata.*). The tracks and traces of these organisms are generally well-expressed and easily spotted in the generally damp sands of washover fans, creating ample opportunities for ichnologists to study, especially with their promising potential for preservation in the fossil record. On St. Catherine's Island, raccoons are among the dominant vertebrate track makers across washover fans, often forming habitual trails that cut through surface vegetation. Additionally, raccoons are among the dominant consumers in these ecosystems, with omnivorous diets that include berries of saw palmetto (*Serenoa repens)*, decapods (*Uca sp., Ocypode quadrata)*, and eggs of shorebirds and sea turtles.

A number of conservation-oriented studies have extensively examined raccoon predation impacts on the nests of shorebirds, such as those of the threatened American oystercatcher (*Haematopus palliatus)* and endangered loggerhead turtle (*Caretta caretta)* (Stancyk *et al.* 1980; Loegering and Fraser 1995; Sabine *et al.* 2006). These researchers and others have explored options for tracking vertebrate populations and controlling raccoon populations to reduce nest predation. However, many of the proposed methods are expensive and often involve killing raccoons, which could potentially affect local ecosystem balance (Guynn and Yarrow 1995; Ratnaswamy *et al.* 1997; Ritchie and Johnson 2009). Several studies have tested non-lethal methods (e.g. chemically based taste aversion), but no known methods make use of extensive mapping to effectively target raccoons along their most commonly used trails (Stancyk *et al.* 1980; Conover 1990; Fletcher *et al.* 1990; Semel and Nicolaus, 1992; Olson *et al.*, 2000; Engeman *et al.* 2003).

As a result, this research proposes a systematic method for mapping of raccoons and their predation patterns through the use of a geographic information system (GIS). Thorough documentation of trails and movement patterns allows for more precision in targeting raccoons in both lethal and non-lethal control methods. Additionally, GIS is an effective tool for displaying spatial trends and establishing a geodatabase that can be edited and expanded over time as more data are collected.

Applications for Paleoichnology

Although documentation of the trace assemblages on modern washover fans is relevant for conservation biology, it also relates to the field of paleoichnology. The basic sedimentological processes by which washover fans are formed have existed on earth nearly as long as coastal processes. Therefore, the sedimentology of modern washover fans and the taphonomy of modern traces is an effective method for developing search images to assist paleoichnologists in both recognizing ancient washover fans and evaluating trace fossils found in those fans (Van Der Lingen 1969; Schwarz 1982; Barwis and Hayes 1985; Duncan 1986; Sedgwick and Davis 2003; Buynevich 2011; Buynevich *et al.* 2011). Additionally, studying modern organisms and their associated traces provides information about how behaviors are preserved in the tracks (McKeever 1991; Sarjeant 2008).

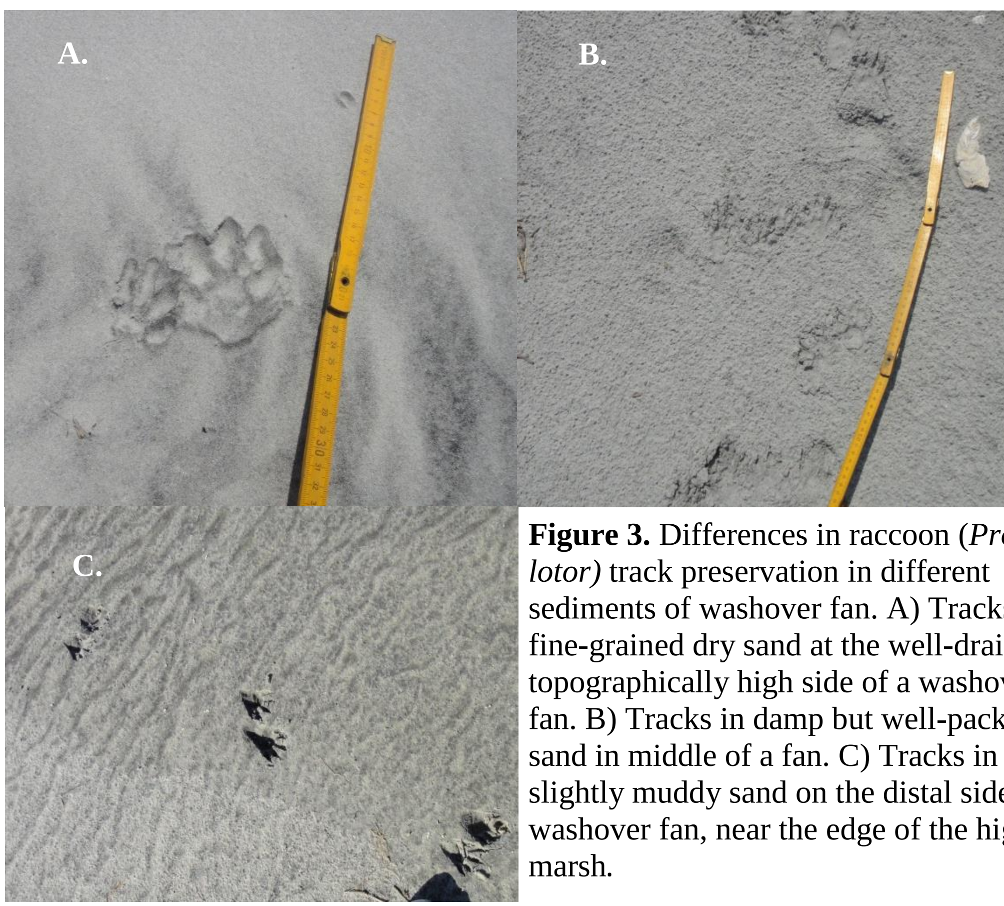


Figure 3. Differences in raccoon (*Procyon lotor)* track preservation in different sediments of washover fan. A) Tracks in fine-grained dry sand at the well-drained, topographically high side of a washover fan. B) Tracks in damp but well-packed sand in middle of a fan. C) Tracks in wet, slightly muddy sand on the distal side of washover fan, near the edge of the high marsh.

One of the ways to achieve this is through GIS mapping of trackways and associated traces, which allows for better visualization and analysis of spatial trends in behavior. The use of line transect sampling is well documented in the literature (Turnock 1991; D'eon 2001; Silveira *et al*, 2003; Franco *et al*. 2007). However, this paper proposes and demonstrates methods by which GIS mapping and line transect sampling can be combined to document the presence and behaviors of vertebrates, invertebrates, and associated traces across washover fans. Additionally, this study may help to develop a model for interpreting exposed trace fossils in bedding planes of ancient washover-fans.

Methods

Study Site

This study was conducted in an area in the northeastern portion of St. Catherines Island immediately south of Yellow Banks Bluff, a coastal outcrop of the Pleistocene Silver Bluff Formation (Martin and Rindsberg, 2011). The beach here directly faces the open Atlantic Ocean and only has small proto-dunes, providing ideal conditions for producing storm-washover fans. Additionally, this area is easily accessible by researchers, and incorporates most environments that might occur on the island, such as maritime forest, beach, washover fans, and high and low salt marshes. The study site also includes two isolated small hammocks with loblolly pines (*Pinus taeda*) toward its southern end. The study site and many of the trails crossing it are visible on Google Earth™, which allows for temporal comparison and "ground-truthing" of trails apparent in satellite images. Additionally, the area has been mapped previously using LiDAR (light detection and ranging) remote sensing technology, thus providing precise pre-existing base maps which are useful for ecological studies (Lefsky *et al.* 2002).

Materials Used

A Garmin GPSMap 60C Sx handheld unit was used for collecting all GPS field data. For downloading data from the GPS and then into ESRI's ArcGIS, I used an open-access application, DNR Garmin, which is produced by the Minnesota Department of Natural Resources. Other materials required for this sampling method were relatively simple and inexpensive, including a 1 m^2 quadrat, a Silva compass, and basic measuring equipment (e.g., tape measure and calipers). Photos were taken with a Sony Cybershot DSC-TX5 10.2 megapixel digital camera.

Transect Sampling

A census-line transect sampling method was used to acquire a representative sample of traces on the washover fans. Using the 1 m^2 quadrat, samples were taken at 5 meter intervals along each transect. In order to increase sampling efficiency, 5 meters was estimated as equivalent to 3 strides based on the measurement of the author's strides, where 1 stride (left-left or right-right) = 1.6 m. Each new transect line started 20 m south of the previous transect. The east-west transects began at the wrack line on the proximal (eastern) side of the washover fans, with the high marsh serving as the distal (western) boundary. A compass was used to ensure consistent 270° heading. Each sampled quadrat was photographed, and any tracks or other traces in the quadrat were measured, documented, and photographed. In cases where fiddler-crab burrows were present, the number of burrow apertures was counted and recorded, which was used to estimate burrow density. Trackway directions were also measured by compass and documented.

Trail Mapping

In addition to these transects, raccoon trails were identified, walked, and mapped using the Garmin handheld GPS. Trails were defined as a clearly visible pathway free of vegetation (Figure 4). Additionally, to be mapped as a definitive raccoon trail, raccoon tracks or traces had to be present along the trail. Waypoints were taken at each end of trails, at any intersections with other trails, and at any other visible traces by raccoons, such as tracks or scat. Although transects were conducted exclusively within washover fans, raccoon trails were followed along their full length across washover fans, through vegetation, into the marsh, and onto the hammocks as far as the trail was distinguishable and traversable. Measurements, directionality, and photographs were taken to document each trail.

Figure 4. Raccoon (Procyon lotor) trail cutting through *Spartina alterniflora* in salt marsh, St. Catherines Island.

GIS Processes

Using ESRI's ArcGIS, I created a geodatabase of interactive digital maps. In addition to mapping the waypoints taken at each sample along the transects, photos of each transect have been matched by timestamps with corresponding waypoints within a digital map in ArcMap. The same process was applied to the waypoints and photographs marking habitual raccoon trails. Information about observed species' traces was entered into an Excel spreadsheet with a binary presence or absence system. This information was then entered into fields in the attribute tables of the shapefiles containing the waypoints in ArcMap. This resulted in a geodatabase within which users can select to only display sampling quadrats containing the tracks of a specific species. When relevant, vegetation data, such as identified species of plants, were also added to the waypoint attribute tables.

Results

Overall, 13 species of animals and 3 species of plants were represented in the transects. Table 1 includes a comprehensive list of these species and their frequency within the sampling quadrats. Each species was only counted once within a quadrat. For example, if both ghost-crab tracks and a ghost-crab burrow appeared within one quadrat, these two traces were counted as coming from one species. Similarly, if ghost-crab tracks were present but a burrow was not present, this was also counted as one species. Raccoons, hogs, ghost crabs, and fiddler crabs exhibited the highest frequencies.

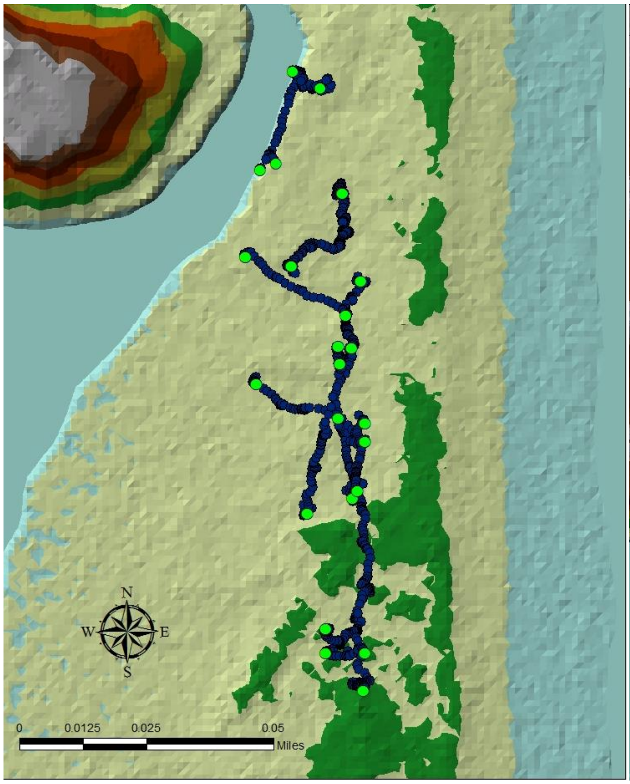
Table 1.. Frequency of species appearance in sampled quadrats.

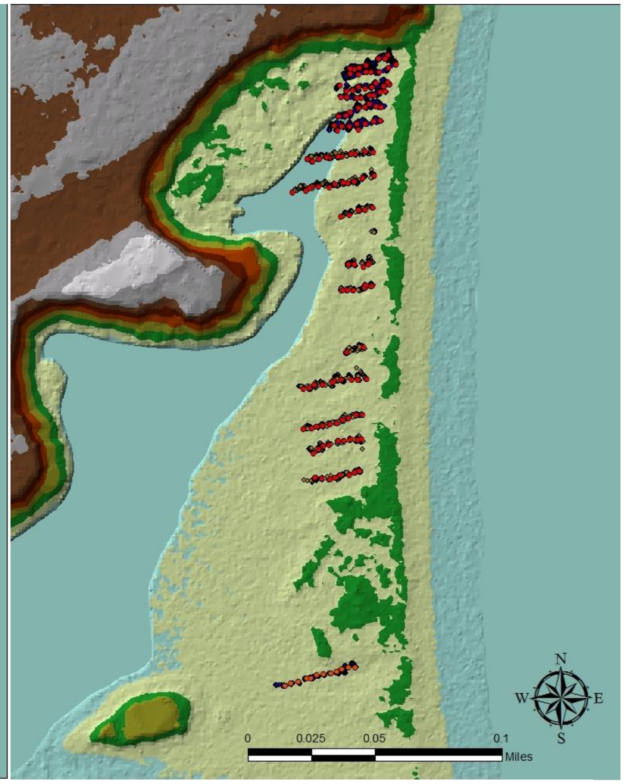
Species	Frequency (n=125)	Percentage of total quadrats
Mammals and Large Vertebrates		
Raccoon, *Procyon Lotor*	32	27.12%
Feral hog, *Sus scrofa*	30	25.42%
White tailed deer, *Odocoileus virginianus*	19	16.10%

Unidentified hoofed animal (either deer or hog)	11	9.32%
Alligator, *Alligator mississippiensis*	7	5.93%
Invertebrates		
Fiddler crabs, *Uca* sp.	42	35.59%
Ghost crabs, *Ocypode quadrata*	24	20.34%
Ants (Formicidae)	3	2.54%
Rove beetles (Staphylinidae)	1	0.85%
Unknown small gastropod	8	6.78%
Birds		
Plover, *Charadrius* sp.	1	0.85%
Grackle, *Quiscalus major*	1	0.85%
Willet, *Tringa semipalmata*	1	0.85%
Unknown Bird	2	1.69%
Vegetation		
Juncus roemarianus	1	0.85%
Panicum amarum	1	0.85%
Spartina alterniflora	1	0.85%

Maps

Trails	**Transects**

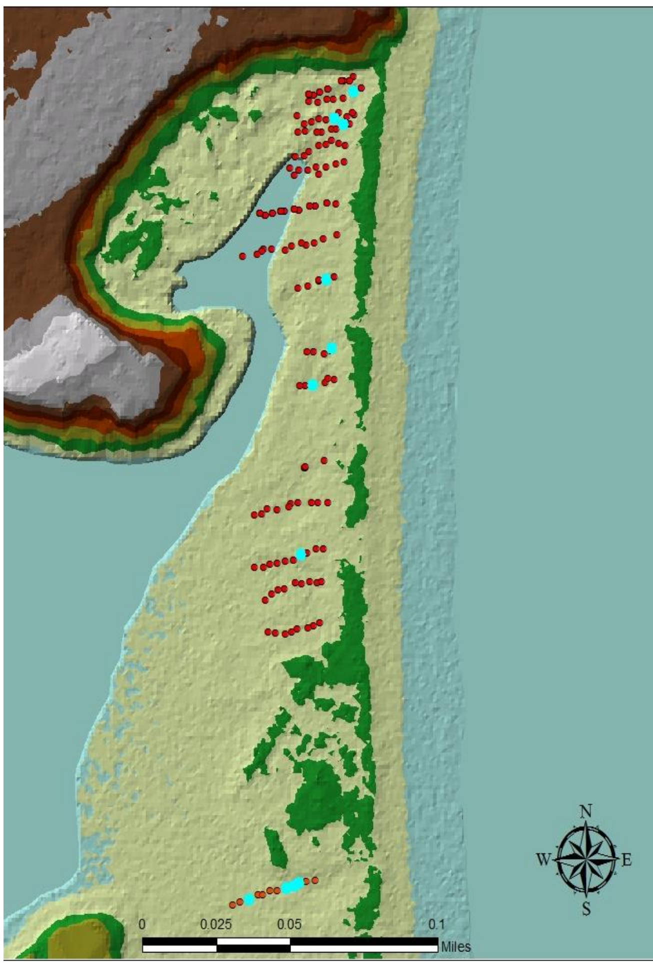




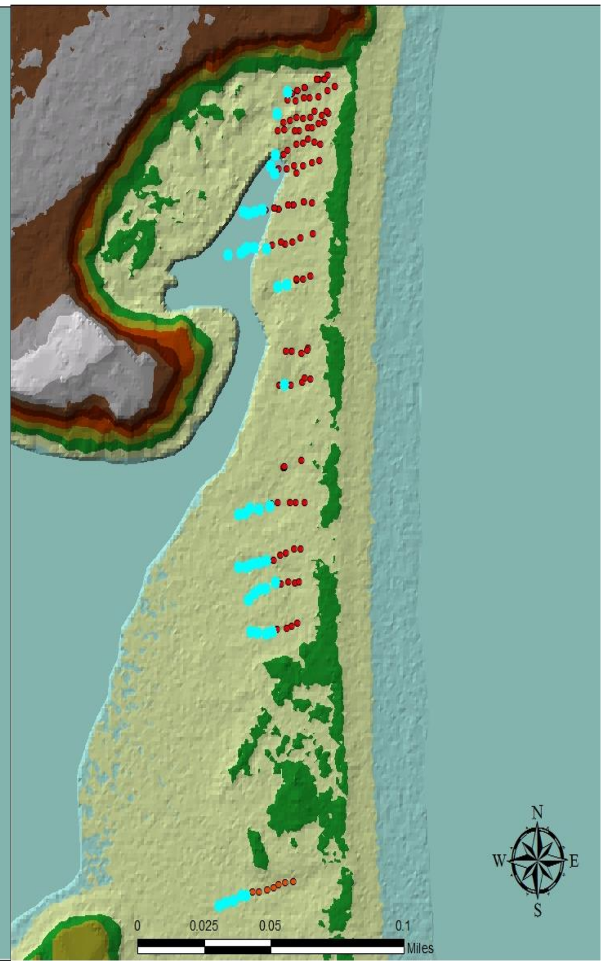
Figures 5 and 6. Left map displays habitual trails formed by raccoons and mapped with GPS. Right map shows 125 waypoints from the 17 transects sampled during the study.

Figure 5 displays habitual raccoon trails, which were documented using a handheld GPS unit. Trails were mapped using waypoints that marked the start and end points of trails, as well as for tracks, scat, or other traces along the trail. Short trails originated in the high marsh near the maritime forest, connecting with longer, north-south oriented trails. In areas of dense *Spartina alterniflora* or *Juncus roemarianus,* multiple trails merged into a single trail through this vegetation. When looking at trails, it is important to know their trends, which give a sense of where raccoons and other animals are moving. This map thus also shows the direction of movement along the trails. Figure 6 displays the 125 waypoints marking each sampled quadrat taken along transects. Within ArcGIS, each waypoint was associated with corresponding photos of the trail or a quadrat associated with that waypoint by matching timestamps between the GPS unit and the digital camera.

Heavy Wrack



Fiddler Crab Zone



Figures 7 and 8. Three primary zones evident in washover fans: proximal zone (ghost crabs, wrack, insects), medial “dead zone” (few tracks, traces, or insects), and distal zone (intensely bioturbated by fiddler crabs). Figure 7 shows quadrats with wrack. Figure 8 shows those with fiddler crabs. Blue waypoints indicate selected criteria.

Overall, the fans appeared to have three basic zones: (1) the proximal zone, which contained evidence of ghost crabs, insects, and was often filled with wrack (Figure 7); (2) the medial zone, which showed little evidence of bioturbation or vegetation: and (3) the distal zone, which was dominated by fiddler crab traces (Figure 8). These zones are generalized, but seem consistent across fans. The relatively dry sediments of the proximal zone consist of fine- to medium-grained sand. Medial zone sediments had a higher moisture content than the proximal zone, but were more firmly packed and minimally bioturbated. In contrast, the distal zone is the moistest of the three, and intensely bioturbated by fiddler crabs. Sediment in the distal zone is also increasingly muddy towards the high marsh bordering it. Based on my analysis, fiddler-crab burrow density can serve as a marker for delineating the transition between the medial zone and the distal zone. Burrow densities ranged from 1-45 burrows per m^2; a total of 379 burrows were counted.

Table 2. Descriptive statistics of fiddler crab burrow density. Column 1 includes quadrats which did not contain fiddler crab burrows. Column 2 includes only those quadrats containing burrows.

	All quadrats (Burrows/m^2)	Only containing fiddler crabs (Burrows/m^2)
Mean	3	9
Mode	0	3
Standard Deviation	6.4	8.29

One of the original goals of this study was to examine interspecies relationships from a spatial perspective, so correlation statistics were calculated by testing overlap of traces of potential predators and prey. Table 2 displays the Pearson's correlation coefficients and two-tailed p-values (n=125). None of the overlap relationships tested were statistically significant ($p < .05$). The relationships to be tested were chosen based on predation preferences documented in the literature.

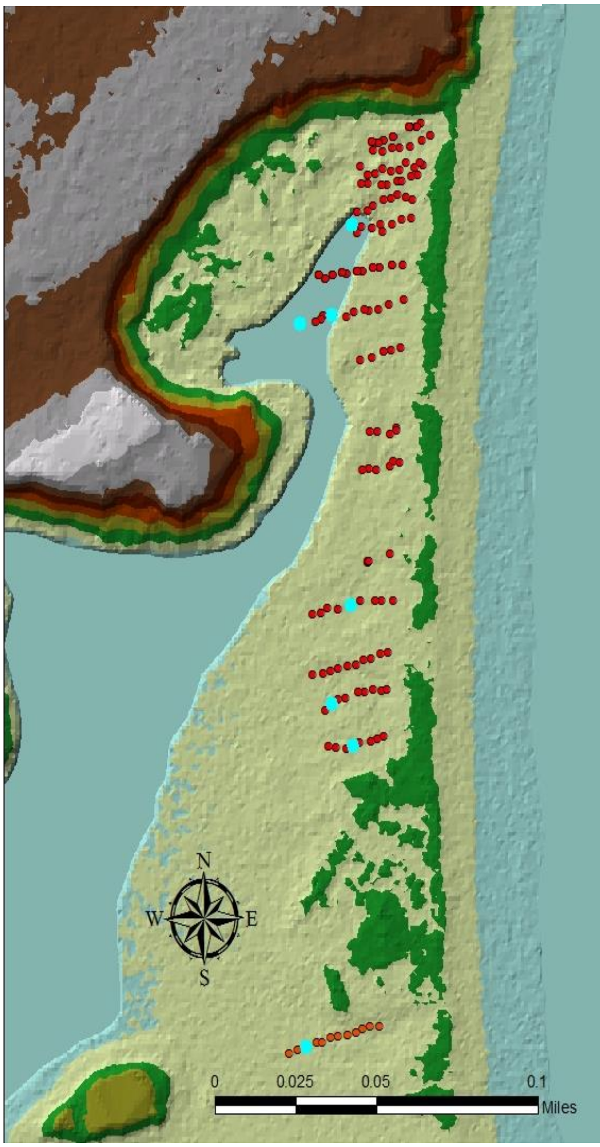
Table 3. Pearson's correlation coefficients and two-tailed p values

Relationship	r value	p value
Raccoon and Fiddler crab	-0.13397	0.136354
Hog and Fiddler Crab	0.094475	0.294614
Raccoon and ghost crab	-0.09181	0.308532
Hog and ghost crab	-0.09968	0.268719

Fiddler Crabs

For raccoons hunting on washover fans, fiddler crabs are the most abundant and accessible food items. Figure 9 shows the spatial relationship between raccoon tracks and fiddler crab burrows. Fiddler crabs are also documented prey items for feral hogs inhabiting washover fans (Wood and Roark, 1980). Figure 10 shows the overlap between hog trackways and fiddler crab burrows. Feral hogs potentially compete with raccoons for this food resource.

Raccoon and Fiddler Crab Overlap



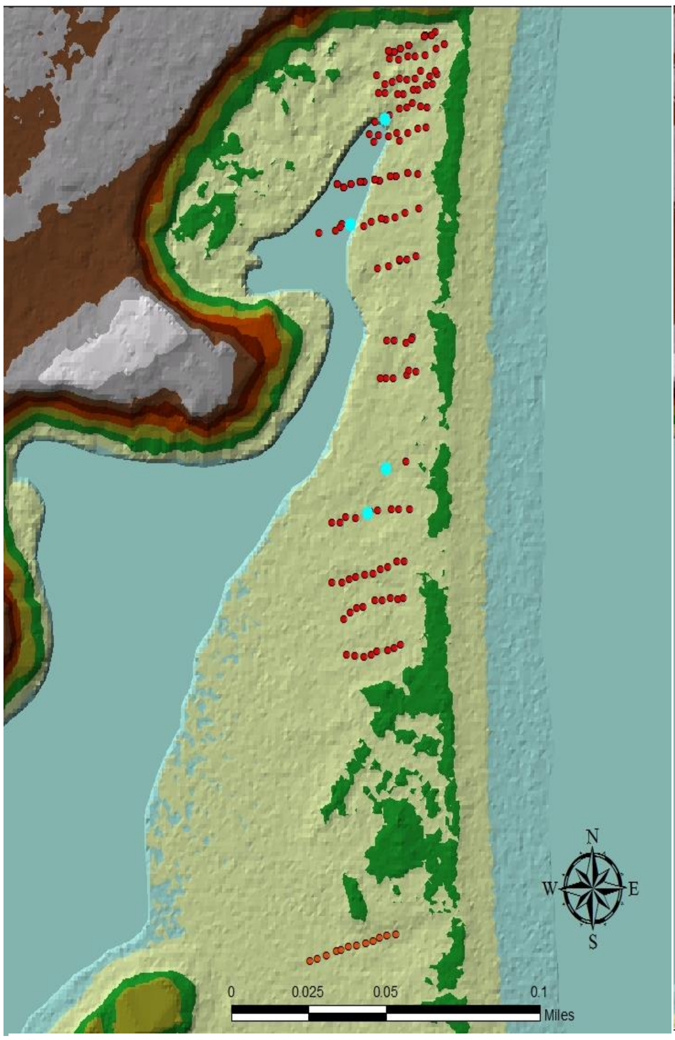
Hog and Fiddler Crab Overlap

Figures 9 and 10. Map on left displays quadrats containing both fiddler-crab burrows and raccoon traces. Map on right displays waypoints containing both fiddler-crab burrows and hog tracks.

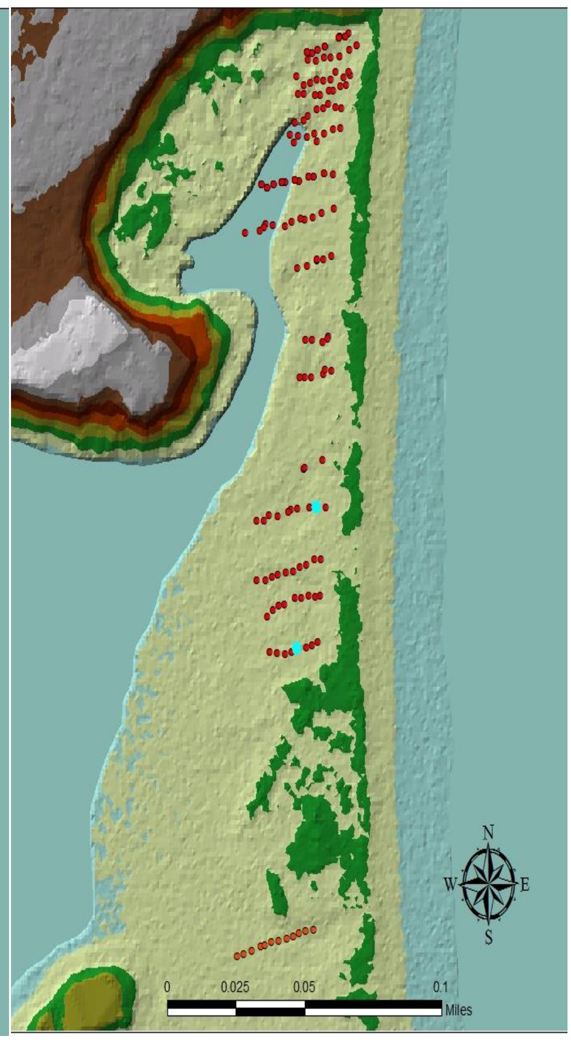
Although ghost-crab traces were not as common as those of fiddler crabs, these were still numerous on washover fans, particularly on the proximal edge. Ghost crabs also make up a portion of the raccoon's diet (Barton and Roth, 2008) Additionally, ghost crabs compete with raccoons for predation of sea turtle nests during the summer months (Harman and Stains, 1979;

Anderson, 1981; Barton and Roth, 2008;). Figure 11 shows the overlap between raccoon presence and ghost crab presence in the transects. Feral hog predation on ghost crabs has not been documented in the literature, but multiple studies have documented pigs feeding on fiddler crabs and land crabs (Wood and Roarke 1980, Pitman, 2006). As mentioned previously with fiddler crabs, feral hogs may be competing with raccoons for ghost crabs. Hence Figure 12 displays overlap in the movements of wild hog and ghost crabs.

Raccoon and Ghost Crab Overlap



Hog and Ghost Crab Overlap



Figures 11 and 12. Left map displays waypoints of quadrats containing both ghost-crab traces (tracks or burrows) and raccoon tracks.Right map displays waypoints of quadrats containing both feral hog tracks and ghost crab burrows or tracks, St. Catherines Island.

Bird Presence

Bird tracks were commonly observed on the beach but seemed less common on washover fans. Raccoon traces and bird tracks were never in the same quadrat; however, shorebirds are certainly competitors for raccoon food supplies, particularly fiddler crabs and ghost crabs (Bildstein *et al.*, 1989; Full and Weinstein, 1992). In every quadrat where bird tracks were present, crabs were also there. Figure 13 shows sampling plots where bird tracks and crab traces co-occurred.

Bird Presence

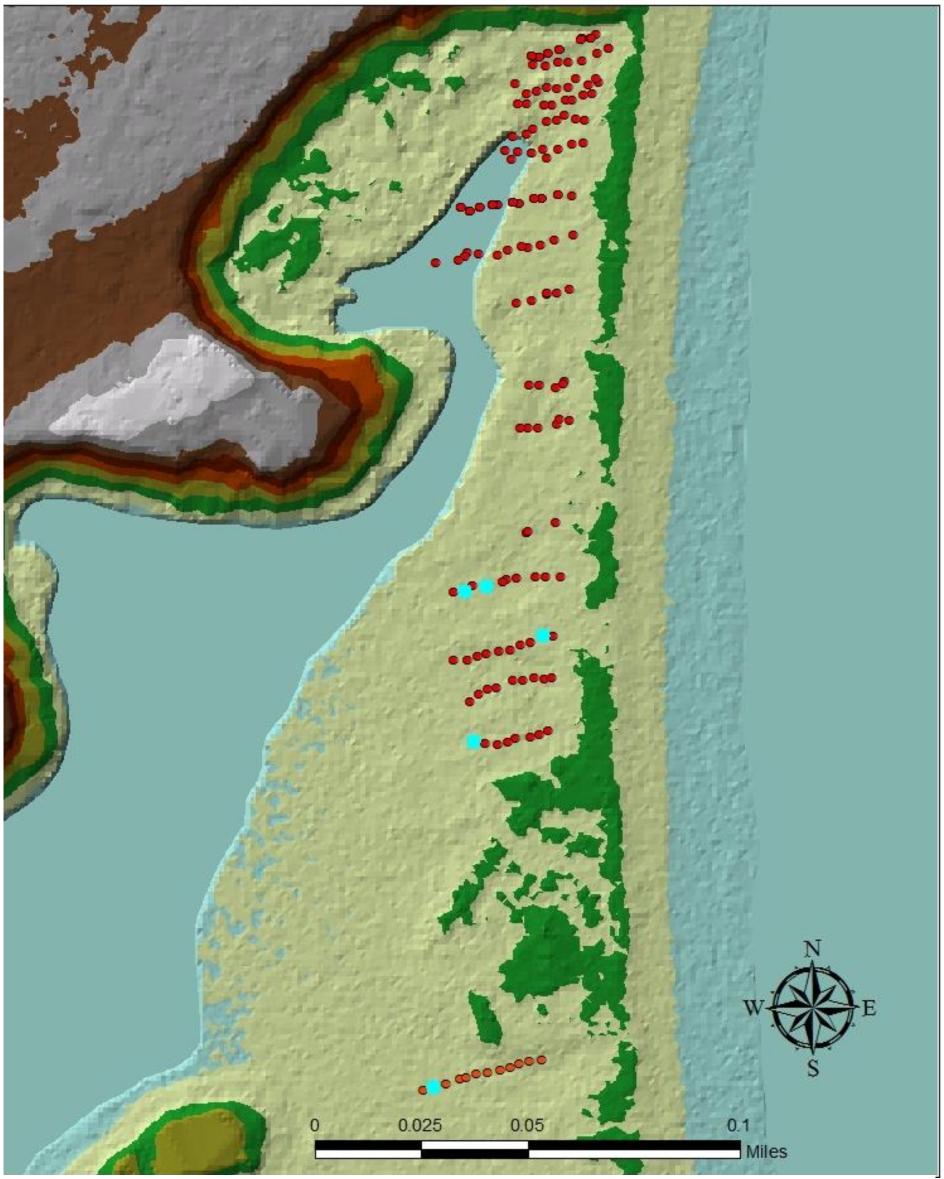


Figure 13 Quadrats containing bird tracks and crab burrows, St. Catherines Island

Alligator Presence

Predation between raccoons and alligators has been documented, both in terms of alligators eating raccoons and raccoons predating alligator nests (Ogden 1978; Wolfe and Bradshaw, 1987; Shoop and Ruckdeschel, 1990). Alligator tracks only appeared in the far northern portion of the fan, where an alligator is known to have a den. Co-occurrence between alligators and raccoons was limited, but they had some overlap Figure 14 displays alligator presence.

Alligator Presence

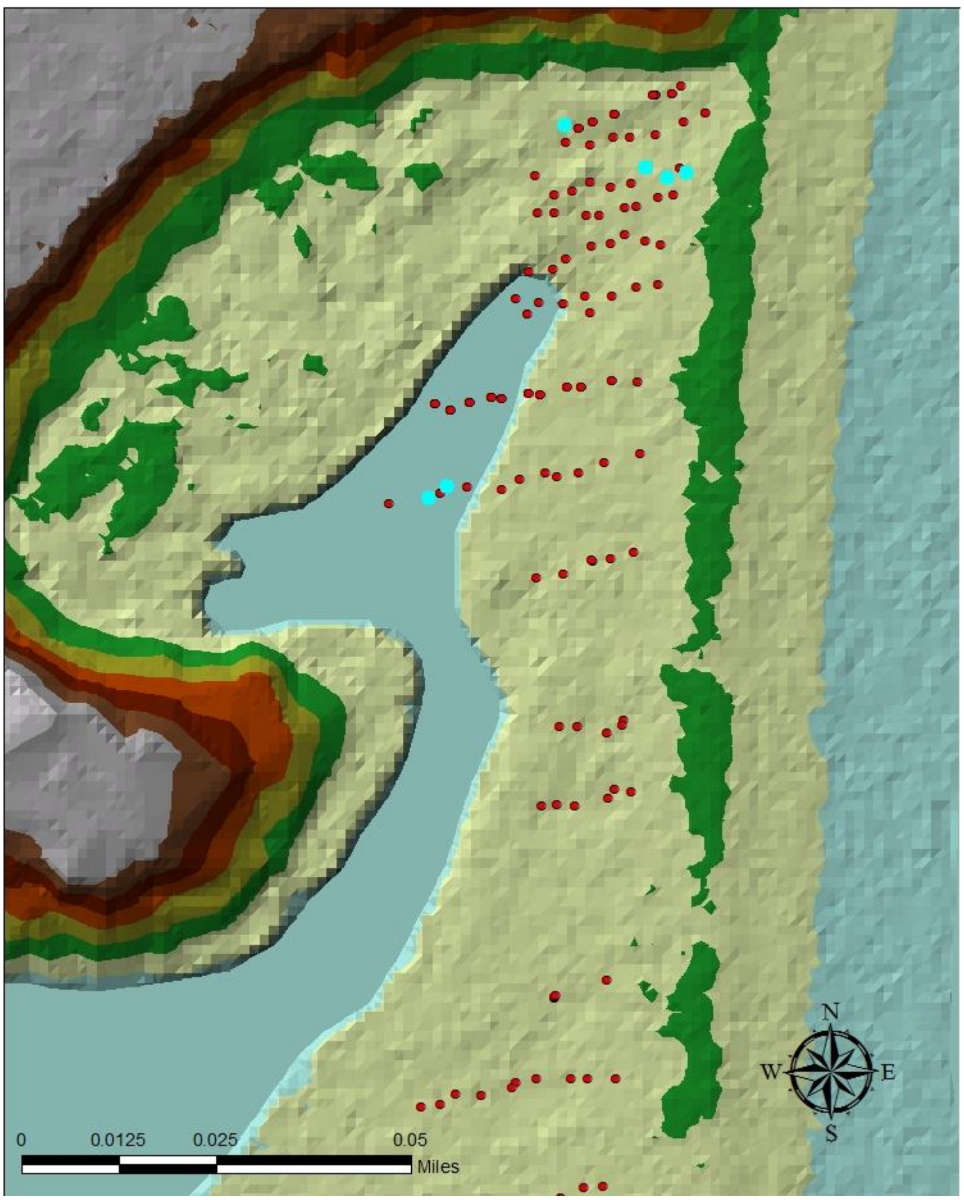


Figure 14 Quadrats containing alligator tracks, St. Catherine's Island

Using Google Earth

On a Google Earth™ image of the southern portion of my study area, trails through marsh vegetation are readily apparent. The area visible in this image includes the two hammocks near the top left and center of the image and an access point from an old road in the bottom right corner. Map 15 shows what my “ground-truthed” trails (in red) look like overlain on the satellite images. Map 16 displays both my documented trails and highlights (in green) some of the most visible trails on the Google Earth^{TM} imagery.

Figures 15 and 16. Map on left displays trails recorded with the handheld GPS. Map on right displays recorded trails, and trails visible in Google Earth^{TM} have been drawn in green to increase visibility.

Discussion

The main goal of this study was to map and document tracks and traces across storm-washover fans by combining transect sampling and GIS mapping. Overall, the methods used in this study for documenting and sampling the biodiversity of washover fans seemed effective. In just 17 transects, many of the common species on the island were represented, although shorebirds seemed underrepresented. GPS waypoints were helpful for mapping transects and recording waypoints, which could be displayed visually with GIS.

However, GPS-derived field data proved to be extremely useful in tracking habitual trails of raccoons. Through the use of GPS, clear directional trends became evident, such as showing how raccoons moved from maritime forests into salt marshes by several access points, one of which is an old road formerly used for beach access. In the dense vegetation of the salt marsh, trails were few and well-worn, expanding into multiple trails in the open spaces of the washover fans. Trails across washover fans trended north-south, connecting with two hammocks at the western end of the research area. When patches of dense *Juncus* intersected the north-south routes, trails once again merged into several main routes through the vegetation. Although these spatial trends could be observed and documented in the field without the help of GPS, its use sped up this process and increased the accuracy of the data. The resulting GIS maps provided clear visualizations of field observations, which are helpful for effectively communicating results.

Multiple studies have evaluated the efficacy of various methods of population survey and tracking methods, including radio telemetry, trail counts, transects, and camera trapping (Mayle *et al.*, 2000; D'eon, 2001; Silveira *et al.*, 2003; Franco *et al.*, 2007). Silveira *et al.* (2003)

criticized the use of line transects for being less effective than camera trapping for establishing species presence and density. However, their study was conducted over a large area with transects conducted from a truck. Franco *et al.* (2007) studied a smaller area using transects and radio telemetry to observe kestrels (*Falco naumanni*). They found that transect sampling returned almost as many significant results and caused no animal disturbance, while also requiring fewer people, fewer days, and less funding.

My study required only one researcher with relatively few pieces of equipment, i.e., field notebook, camera, tape measure, quadrat, and handheld GPS unit. This provided a distinct advantage over more expensive and complicated methods and equipment, such as radio collars and trail cameras. However, there were limitations to this methodology. Large study areas with difficult terrain, sediments with poor track preservation, or a combination of these factors could make transects time consuming, unfeasible, and ineffective for data collection.

As a result of unexpected difficulties in accessing the island for subsequent data collection, the amount of information gathered in this study was more limited than originally expected. This challenge made it difficult to evaluate interspecies spatial correlations (overlap) with meaningful statistical rigor. Correlations were weak and not statistically significant for all tested relationships. However, a larger sample size would probably affect statistical outcomes. This study conducted a broad survey of all species, but more specifically targeting just a few species, such as raccoons and fiddler crabs, might speed up data collection and yield more samples within the same amount of time. For example, a researcher looking specifically at raccoons and fiddler crabs would not have to take extra time to carefully examine the quadrats for less obvious bird tracks or gastropod trails. This sort of focused research could be an especially useful method for researchers examining variations in temporal movement patterns.

In terms of more follow-up to the described research, Harman and Stains (1979) examined seasonal variations in raccoon diets based on relative abundance of crabs and vegetation. Given more time, I would have liked to have conducted this study across several seasons to see if dietary variations can be tied to changes in movement patterns on washover fans. Additionally, future conservation research could consider seasonal movement patterns in terms of opportunistic predation by raccoons, on nests of threatened species, such as loggerhead turtles *(Caretta caretta)*.

Zonations of traces across the washover fans are also relevant to the field of paleoichnology. Although bones and other body fossils might have been transported far away from where an organism originally lived and died, trace fossils are normally in the same place they were formed. For this reason, evaluating the density of fossil crab burrows can provide information about depositional environments, such as proximity to shore (Martin and Rindsberg, 2011). Other than the study by Martin and Rindsberg (2011), which was also on St. Catherines, previous paleoichnological and geological research on washover fans has focused primarily on sedimentology (Schwartz, 1982; Barwis and Hayes, 1985; Sedgwick and Davis, 2003) and taphonomy of hoofprints in washover fans and beach facies (Van Der Lingen *et al.*, 1969; Loope, 1986; McKeever, 1991; Buyenevich *et al.*, 2011). Duncan (1986) also examined the angles of modern ghost crab burrows with relation to substrate slope and direction of shoreline, which provided a more thorough understanding of how to interpret fossil crab burrows in the context of their original ecosystems. Through studies that examine modern analogs, paleoichnologists will be able to establish better search images and models with which to interpret trace fossils. My research thus further contributes to this understanding of modern and ancient washover fans by providing a spatial overview of the locations and densities of traces and tracemakers.

Conclusions

As new technologies develop, it is important to evaluate whether research methods can be updated using these tools. Incorporating new digital methods into field techniques allow researchers to both analyze and present data in new ways. Digitized data can be easily archived, shared, and combined with other research to benefit from collective knowledge. For example, sea-turtle researchers could easily combine their data with mine to look for overlaps in raccoon trails and sea-turtle nesting areas. By using my data on raccoon movement patterns, researchers interested in targeting raccoons with non-lethal methods (e.g. trapping, chemical taste aversion) could focus their methods more effectively, especially in areas where raccoons and hogs may overlap (Stancyk *et al.*, 1980; Conover, 1990; Fletcher *et al.*, 1990; Semel and Nicolaus, 1992; Ratnaswamy *et al.*, 1997; Olson *et al.*, 2000).

Additionally, Google Earth™ effectively displayed many of the prominent raccoon trails across the washover fans. Although walking the trails with a handheld GPS is a more effective method of accurately mapping the trails and studying which species are using them, Google Earth™ may prove useful for locating potential sites for a similar future study, or for providing rough overviews of vertebrate movement patterns and presence, particularly when financial resources and time are limited. It is interesting to note that Google Earth™ now has a historical imagery feature; using this feature, I found that images prior to 2012 were not of high enough

Figure 17. Trails overlain on Google Earth™ image from 2010.

quality to see raccoon trails visible in the most recent images. Figure 17 displays my trails data on imagery from 2010. Compared to the more recent image used in Figures 15 and 16, this 2010 image is much less clear and trails are barely visible, if visible at all.

In the field of paleoichnology, this study should be most useful for establishing search images of the traces of storm washover fans, but GPS tracking and mapping is potentially applicable for documenting traces fossils in bedding-plane exposures with multiple, sizable trackways.

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