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Development of Strategies for Monitoring and Managing Sandscape Vegetation, With an Assessment of Declining Vegetation in the Apostle Islands National Lakeshore

Natural Resource Report NPS/APIS/NRR—2022/2373



ON THE COVER
A rainbow over Lake Superior and the Apostle Islands.
Photo by Sarah Johnson.

Development of Strategies for Monitoring and Managing Sandscape Vegetation, With an Assessment of Declining Vegetation in the Apostle Islands National Lakeshore

Natural Resource Report NPS/APIS/NRR—2022/2373

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Executive Summary

Coastal dune habitats such as those of the Apostle Islands National Lakeshore (APIS) are regionally rare habitats of global and state-wide concern. Their dynamic, sandy landforms provide habitat for unique species specifically adapted to frequent disturbance, drought, and other stresses. Despite having disturbance-driven life histories, these species are at risk due to increased visitor use of sandscape habitats and environmental change. Resource managers at APIS have long understood the values of these sandscapes and threats presented by recreational trampling, but more recently they have recognized the precarious position that these coastal habitats are in due to their proximity to the lake and exposure to weather-related phenomena linked with long-term climate change. In recognition of emerging threats and the need to track impacts of these threats, park managers initiated a revision of their methods for monitoring sandscape vegetation. We applied these methods to 15 sandscape locations within the national lakeshore in 2014. Here, we outline what these revisions to the methods were, assess the current status of sandscape structure and composition, assess the utility of data collected with these methods, provide suggestions for further revisions of the sampling method, outline a two-tiered sampling approach for future monitoring, and we provide management recommendations. In a second section of the report, we provide a focused assessment of the size and health of *Juniperus communis* (common juniper), a target species of concern in these sandscape communities after it was observed by park managers to be dying or stressed on Michigan Island. Our assessments include the status of *J. communis* across all sandscapes monitored in 2014, and an analysis of change over time since 2012 in the health of *J. communis* on Michigan, Outer, and Stockton Islands. We provide evidence of impacts by rodents on foliar dieback, primarily on Michigan Island, and we discuss possible interactions with the non-native pale juniper web-worm (*Aethes rutilana*) and with climate change.

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Introduction

"Sandscapes" such as beaches and dunes are dynamic features of some coastlines in the Great Lakes region. These sandy landforms occur where high energy waves subside and deposit their sandy contents, usually in protected bays or on the leeward side of islands. Changes in Lake Superior water levels and storm activity drive erosion or aggradation of sediments, so sandscapes change in size and shape over time. The risks are high for species living in these harsh coastal ecosystems subject to the stresses of wind, sand burial, waves, and ice scouring (Maun 2009). Ecological communities on sandscapes have evolved with, and are even dependent upon, frequent natural disturbances. Both abiotic forces and certain dune stabilizing plant species can drive dune formation. The most common species in Great Lakes dune habitats, *Ammophila breviligulata* Fernald (American beachgrass or marram grass), is a primary colonizer and stabilizer of bare sand in dune systems (Cowles 1899, Olson 1958a, Maun 1998), granting it status of "ecosystem engineer" (Jones et al. 1997).

Vegetation and related sandscape morphology and dynamics are closely tied to climate and water levels (Zinnert et al. 2016, Robins et al. 2013, Máguas et al. 2011). The frequency, duration, and severity of these natural disturbances are shifting with global climate change. Lake Superior water levels experienced record low levels between 1997 and 2013 during a drought period, followed by a surge in lake levels 2014—present to above the long-term average due to increased precipitation amounts (Gronewold et al. 2015). The future of lake levels remains difficult to predict with current data availability (Gronewold et al. 2013). Accompanying these changes in water depths are shortened periods of ice cover, rising air and water temperatures, and greater wind speeds (Austin and Colman 2007, Desai et al. 2009). In addition to higher-force winds shifting more sand and creating drier microclimates, they are also expected to transport a greater percentage of airborne pollutants (Desai et al. 2009). A detailed discussion of these climate change vulnerabilities in the Apostle Islands is discussed in Handler et al. (2020). Nutrient-limited systems such as sandy coastal dunes are threatened by eutrophication (Jones et al. 2004) and the deposition of nitrogen via atmospheric and runoff delivery to Lake Superior have increased significantly since 1900 (McDonald et al. 2010). It is conceivable, therefore, that sandscape communities may be imperiled by the rapid shifts in Lake Superior's physical environment due to global climate change and changes in development and runoff into the Lake.

Despite their natural proclivity for frequent disturbance, the species adapted to coastal sandscape habitats are sensitive to frequent trampling by people (Vallés et al. 2011). Invasion by non-native species is also of concern for dune vegetation (Emery et al. 2012, Albert 2000, Leege and Murphy 2001). Interactions between these disturbances and climate change are another level of concern for coastal resource managers. For example, experimental research has concluded that the dune keystone species, *Ammophila breviligulata*, experiences stunted growth in warmer temperatures, which could influence important ecosystem processes such as dune structure, plant biomass, and soil organic content (Emery and Rudgers 2013).

Perched coastal dune systems are listed as globally vulnerable (G3) and in Wisconsin are listed as State Imperiled (S2). Coastal sandscape habitats are relatively rare in western Lake Superior, but

scattered throughout the Apostle Islands National Lakeshore are several premier examples of sandspits, cuspate forelands, a barrier island, and beaches. These sandscapes provide critical habitat for an assortment of specialized plant and animal species, with diversity of sandscape vegetation being the most significant contributor to overall island floristic diversity (Judziewicz and Koch 1993). State-listed rare plant species observed on the park's sandscapes include the state-endangered satiny willow (*Salix pellita*), the state Threatened northern gooseberry (*Ribes oxyacanthoides*), and the special concern marsh horsetail (*Equisetum palustre*). Many migratory birds depend on these coastal beaches as stopover and nesting areas. The federally endangered Piping Plover only nests on expansive sand beaches, including the national lakeshore's Long Island. These sandscapes are also an important resource for the local tourist economy, as the Lakeshore's sandy beaches attract many sea kayakers and motor boaters. Thus, monitoring status and changes in the health of these coastal features is a high priority for resource managers.

Here, we address three objectives in section one and one objective in section two of this report.

Section One Objectives:

- To establish a revised protocol for long-term monitoring of sandscape vegetation in the Apostle Islands National Lakeshore;
- To use the revised protocol to document the status of vegetation composition and structure across 14 of the park's sandscape features;
- To make recommendations for management of sandscape habitats. We will place particular emphasis on island-by-island assessments of restoration needs and suggest management approaches suited to APIS's larger management objectives.

Section Two Objective:

- To assess status and trends in the shrub *Juniperus communis* L. var. *depressa* Pursh (common juniper) on sandscapes throughout the Apostle Islands National Lakeshore. Park managers asked that we focus on this species after it was observed to be stressed and dying in areas of the Lakeshore in previous years, and because of its importance as a dune builder on several of the islands.

Section 1. Monitoring and Managing Sandscape Vegetation

1.1 A Revised Protocol for Long-term Monitoring of Sandscape Vegetation in the Apostle Islands National Lakeshore

Revision to Objectives for Sandscape Monitoring Program

Issue: Stating clear and measurable objectives is a critical first step in developing a monitoring program (Fancy and Bennetts 2012). As we reviewed the existing monitoring protocol for sandscape vegetation in the park, we sought out previously written objectives for this program. The following objectives for sandscape monitoring are listed in monitoring reports for the park:

Smith (1995) report:

1) Obtain baseline information on the current condition of all major sandscapes in the lakeshore.
2) Monitor sandscapes on a regular basis to detect human caused and natural changes to sandscapes through vegetation monitoring and trail mapping, including recovery from past disturbances.
3) Determine when unacceptable levels of visitor impact have occurred and management actions are necessary.

Burkman (2013) report:

1) Summarize sandscape monitoring data collected between 1988 and 2012,
2) Understand any changes in vegetation occurring over time,
3) Understand what, if any, threats are impacting the sandscapes or vegetation,
4) Determine which sandscapes are in most need of restoration work, and
5) Identify any research or management needs.

Revision: While these objectives are useful for understanding the overall goals for a monitoring program, they lack specific details that can be helpful in guiding management and in assessing the efficacy of the sampling design. Thus, we recommend that the revised monitoring program include more detailed objective statements that clarify specific variables that are of interest to park managers.

Example: The objectives for monitoring sandscapes in the Apostle Islands National Lakeshore are to document status and changes in the condition of these coastal dune habitats to identify management and research needs. Specifically, we aim to monitor the following parameters:

1) Percentage of vegetation cover (includes vascular plants, mosses, and lichens)
2) Percentage of non-vegetated areas of bare sand
3) Percentage of non-vegetated areas covered by plant litter
4) Plant composition measured as:
    a) Species richness

b) Alpha (island-level) and Beta (among-island) diversity
c) Relative abundances of native species and of plant functional groupings (e.g., plant habit, growth form)
d) Presence and relative abundance of non-native species

5) Relationship of these sandscape metrics with factors that may be driving any observed changes, such as:
   a) Presence, size, and frequency of trails
   b) Lake Superior lake levels
   c) Regional climate variables (e.g., precipitation, temperature, wind speeds)
   d) Abundance of non-native pests and pathogens including non-native flora and pale juniper web-worm
   e) Other variables that emerge as being potentially important over time (e.g., abundance of herbivores).

To further improve the management value of these data, we recommend that the park consider revising these objectives to be measurable by specifying levels of change that you wish to detect and at what level of certainty. For example, the Great Lakes Network (GLKN) has the specific goal in its forest vegetation program to have 80% power to detect a 20% change in various vegetation metrics while maintaining a 10% false-change error rate (type I error, α) (Sanders et al. 2008). Similarly, the Northeast Temperate I&M Network has the objective for their forest monitoring program to maintain 80% (or greater) power to detect a 40% change in surveyed metrics over a 12-year period. Their desired false-change error rate (Type I – alpha level) is 10% and undetected-change error rate (Type II – beta) is 20% (Miller and Mitchell 2014).

Revisions to Methods in Sandscape Monitoring Program

Issue 1: Sandscape monitoring methods developed in 1989 did not clearly standardize the number of sample points per acre among island sandscapes. This lack of standardization makes it difficult to adequately detect trends over time at a site and to compare these trends among sandscape sites. The original protocol did set forth the intention of sampling approximately 100 points/acre (Smith 1995), but this was not always clearly achieved with subsequent sample events. Further, it is unclear if this number of points/acre is adequate for meeting sampling objectives. A revised protocol should aim to better standardize the number of sampling points per acre and the sampling intensity should return an adequate amount of data to address objectives.

Revision 1: Ulf Gafvert, working for the NPS Great Lakes Inventory and Monitoring Network, used GIS to delineate sandscape boundaries to calculate total sandscape area. Using a grid system constrained to this sandscape area, he plotted potential sample points using an 8m transect spacing and 1m point spacing along transects. These maps showed transect orientation and location, and were used in the field to orient the crew as to where to place transects. This approach helped to standardize the number of points sampled per area of sandscape to 500 points/acre.

Issue 2: The 1989 monitoring protocol (Smith 1995) oriented transects parallel to Lake Superior, running lengthwise down beaches and curving around sandscape tips. While this approach may help constrain samples along transects to similar zones on the sandscape (i.e., foredune, dune, backdune, forested dune line), the longer and potentially more unwieldy transect form makes it more difficult to pinpoint areas on the sandscape that are deserving of more attention by managers. It is also possible that this method oversampled the younger dune with longer transects compared to the back-dune area. Ecological survey work is often conducted perpendicular to major influencing factors such as lakes, rivers, or roads (along what is referred to as a "gradsect") (Gillison and Brewer 1985).

Revision 2: The protocol was revised to use numerous short transects oriented perpendicular to the Lake. This adjustment was made by Ulf Gafvert using GIS to assign the orientation and direction of transects within each sandscape area. As best as was practically possible, the bearing was standardized for all transects at a given sandscape, which allows for better repeatability by future field crews. All future crews should take into the field with them maps showing the transect survey area for each sandscape, information on the compass bearing used for transects on each island, and any field notes describing transect set-up.

One positive aspect of the previous method that established transects parallel to the lake, is that this promoted data collection by "zones" that differed based on geomorphology and disturbance intensity (e.g., foredune, backdune, swale, forested dune). With the new method that places transects perpendicular to Lake Superior, the crew can record "zone type" for each point, allowing managers to cluster data by zone if they wish. Recording "zone" may be quite useful for some analyses, but it is also prone to observer subjectivity of where "to draw the line" between zones.

Issue 3: The "step-point" intercept method for vegetation sampling requires a critical review in how it is being used and the quality of data that the method returns (Leach 2006). The step-point method was originally chosen for use in these sandscape habitats due to dunes often being grass-dominated and consisting of relatively short-statured vegetation with minimal overlapping of foliage layers. This method has been used by some managers and researchers in grassland systems due to being able to efficiently collect data while covering more ground than what could be surveyed using an area-based method (Evans and Love 1957). However, there are numerous iterations of the step-point method, point-frequency method and area-based methods used by managers and researchers in grassland systems.

Point intercept methods may vary based on what data are recorded at each point. Some managers are interested in "basal cover," which is the percentage of vegetation rooted in the ground. Others might instead be interested in "foliar cover," which aims to measure the percentage of the ground that is covered by any foliage (illustrated in Figure 1). Foliar cover differs from "canopy cover" which is essentially measured by an imagined polygon delineating a plant's canopy, including spaces between branches. As with any method, there are perceived pros and cons for using basal, foliar, or canopy cover. Basal cover has been used by the Apostle Islands NL in their monitoring program up until now. Basal cover is measured by recording the number of direct "hits" touching the base of the plant where it emerges from the soil. In the Figure 1 scenario, the coverage of the grass species is 55.6% and coverage of bare ground is 44.4%. By constraining the number of "hits" to points where the

pointer is directly touching the base of the plant where it enters the ground (basal cover), the coverage of this grass species in the Figure 1 scenario would be 0% and bare ground would be 100% (or, if you count the 7th point a direct "hit," then the grass cover is 11.1% and bare ground is 88.9%). In many grassland habitats where basal cover is determined using a point-intercept method, vegetation is very dense and more diverse (e.g., a prairie) than a dune habitat. While basal cover data can and does provide useful information on changes to vegetation density (essentially, relative numbers of rooted individuals), we believe that it overestimates the percentage of bare ground and underestimates vegetation cover in sparse dune systems. Based on the definition of basal cover (percentage of vegetation at root level), this underestimates erect plants with sparse canopies such as beachgrass and overestimates cushion-form species such as false heather and common juniper. Common juniper only roots in the center of the plant, but its foliage may extend horizontally for up to 20 meters. In the past, landing on juniper throughout its widespread, sprawling canopy was coded by park staff as a direct "hit," but landing on beachgrass leaves extending outward from the plant center would be coded as hitting bare ground or litter. This discrepancy in how the method was being applied among species with different growth forms is a concerning issue.

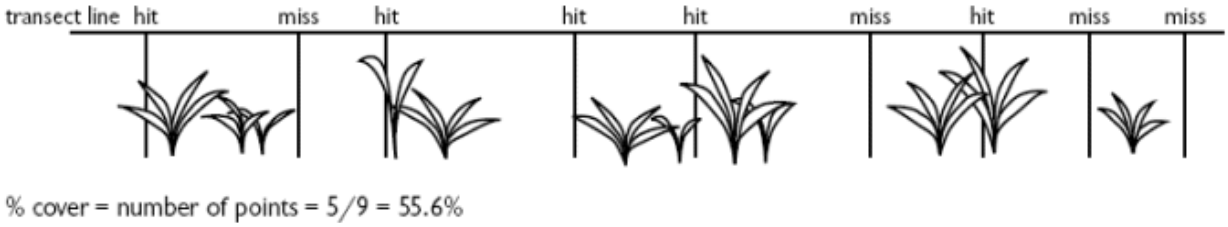


Figure 1. Example of the "hits" and "misses" for estimating foliar cover using a point intercept method such as the "step-point" method. Illustration from Elzinga et al. 1998.

Revision 3: We have modified the protocol to collect data on foliar cover instead of basal cover. Using the approach to measure foliar cover, a "hit" includes any time that the pointer is in direct contact with any type of foliage (leaves, stem, or base of plant; Figure 1). As with any method, the "foliar method" does not come without room for potential error. When sampling vegetation during windy conditions, wispy grass leaves can blow around and can potentially interfere with measures of direct foliar hits. However, National Park Service (NPS) crews do not usually work on extremely windy days due to boat travel limitations, limiting the number of sampling days during extreme wind events. Some sampling error is inevitable, so we recommend that crews familiarize themselves with the sampling schematic shown in Figure 1 and that they work together during the first few transects to standardize what is being perceived as a "hit". In cases of borderline hits, we recommend that these be counted as direct hits every other time to smooth out potential bias.

Issue 4: The original methods did not define a maximum distance from each sample point to the nearest plant in cases where there was an indirect foliar hit (e.g., when the pointer hit bare ground). Hence, the nearest plant could be 1 cm away from the point or it could be several meters away into a different habitat zone on the beach. This inherently limited the resource managers' ability to estimate plant density and to detect areas of non-vegetated bare ground.

Revision 4: We revised the method for dealing with non-direct vegetation hits in an efficient manner aimed at enriching the interpretation of data collected using this method. When a direct plant hit is not made at a sample point, the identity of the nearest plant is recorded if it is contained within a maximum distance of 0.5m and within a 180° arc in front of the sample point. If no neighboring plant is observed within this area, this is recorded as an "empty" point allowing managers to better document bare areas. Focusing on the areas in the 180° arc in front of the sample point is consistent with the protocol described by Evans and Love (1957) and by Owensby (1973) for use in more densely vegetated grasslands where bare areas are

1.2 Documentation of the Status of Vegetation Composition and Structure of Sandscapes in the Apostle Islands National Lakeshore

Methods

Study area

In summer 2014, we collected data on 14 sandscapes located throughout the Apostle Islands National Lakeshore situated on the south shore of western Lake Superior at the tip of the Bayfield Peninsula in Wisconsin (46°42′–47°05′N, 90°24′–91°03′W) (Figure 2). The Apostle Islands are a group of 22 islands underlain by Precambrian sandstone bedrock that is exposed along some shorelines, and is subject to erosive forces of high energy waves. Some of the islands have areas of relatively low energy where waves and nearshore currents deposit sand, most often on the southern end of islands and in bays (Engstrom 1974). "Sandscapes" in the Apostle Islands include cuspate forelands that are nearly equally as long as wide, sandspits that are longer than wide, beaches along bays, tombolos that are sand connections between two islands, and a barrier spit (Nuhfer and Dalles 1987). Sandscapes are very dynamic and experience frequent migrations and changes in length, width, and height (Engstrom 1974).

The foredune and interdune zones of these sandscapes are primarily vegetated by the important sand stabilizer *Ammophila breviligulata* Fernald (American beachgrass). Other vascular species that are associated with this community type include *Juniperus communis* L. var. *depressa* Pursh, *Lathyrus japonicas* Willd. (beach pea), *Prunus pumila* L. (sand cherry), *Artemesia campestris* L. subsp. *caudata* (Michx.) H.M.Hall & Clem. (beach wormwood), *Avenella flexuosa* (L.), Drejer (hair grass), *Hudsonia tomentosa* Nutt. var. *tomentosa* (false heather), among other less frequent species (Judziewicz and Koch1993). Lichens, especially of the genus *Clodonia* are present on relatively stable sand surfaces farther away from the Lake. On these more stabilized dune surfaces toward the tree line, it is also not uncommon to see a sparse coverage of red or white pine (*Pinus resinosa* Aiton and *P. strobus* L.), balsam fir (*Abies balsamea* L. Mill.), and early successional deciduous tree species such as paper birch (*Betula papyrifera* Marshall). At Stockton Island-Julian Bay and at the south end of Outer Island, there are prominent examples of pine savannas that occupy old dunes.

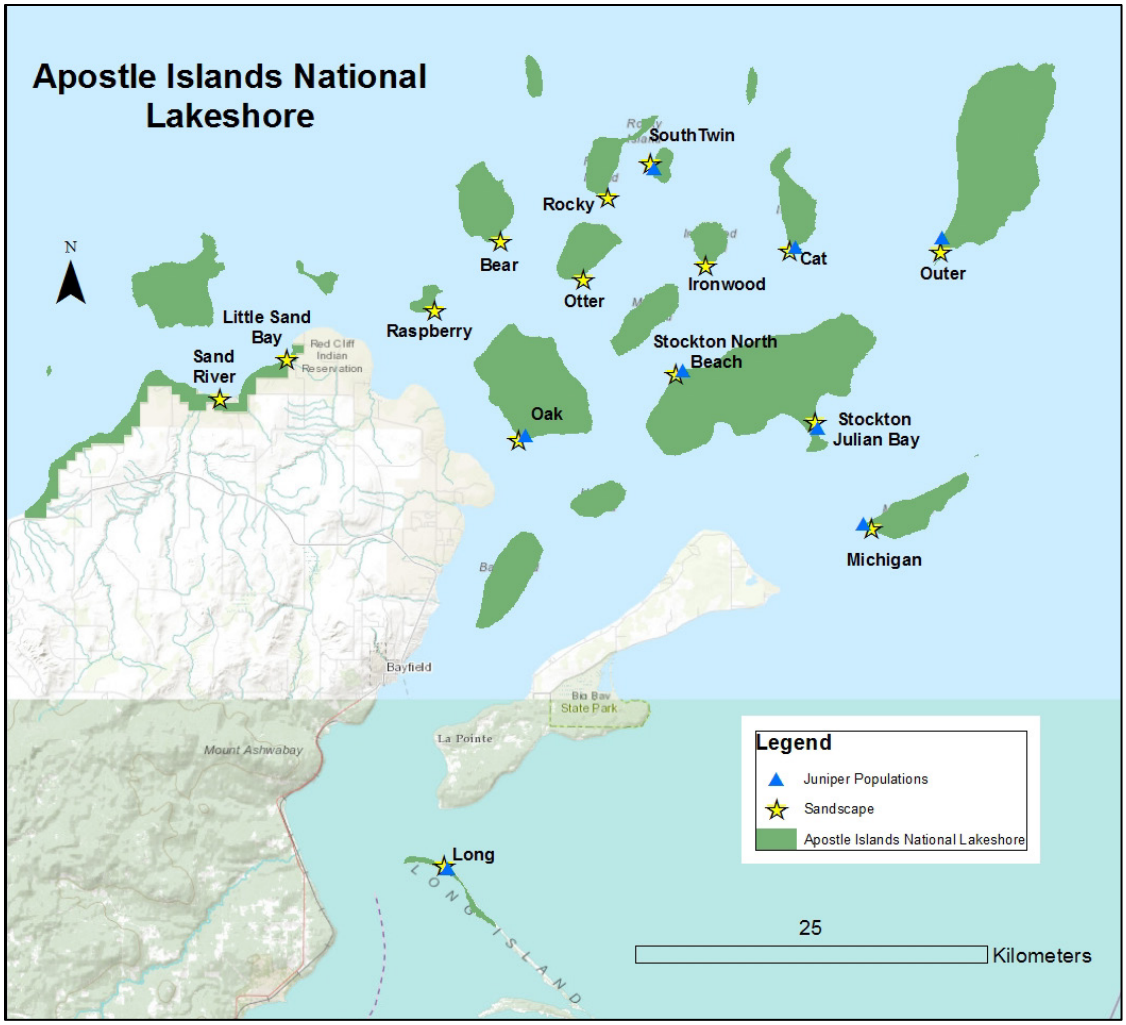


Figure 2. Overview of sandscapes and *Juniperus communis* populations sampled in the summer of 2014 at locations within the Apostle Islands National Lakeshore. Three juniper populations were also sampled in the summer of 2012 on Michigan, Stockton-Julian Bay, and Outer Islands

Field data collection

We established the start position for sandscape transects using GIS maps (with 2010 imagery) with a pre-delineated boundary of each sandscape and information on the approximate placement and bearing of transects. We established a semi-random start point by randomly tossing an item in an area constrained to within 10 m of the end of the sandscape, as delineated on the field maps. The park aims to limit permanent infrastructure placement in wilderness areas, so permanent plot markers were not installed. All transects began at the high-water line on the beach and followed the designated bearing perpendicular to Lake Superior and to the end of sandscape vegetation at the tree line (Table 1; Appendix A). While the high-water line will vary over time, this provides a means for standardizing transect start points during sample events. If we started sampling transects at the perennial vegetation zone, we would limit our perspective of the shape of the sandscapes and any blow-outs or large trampled areas that may occur. A baseline was established perpendicular to the first transect and flags were placed every eight meters along this line to mark the start points for all

other transects. Meter tapes were laid out for each transect and used for collecting point-intercept data spaced out every meter. These point intercept data were collected using a modified step-point sampler (Owensby 1973). The step-point sampler is made of PVC pipe or steel tubes and is held by a handle at waist height like a cane and set down on four legs. Attached to the front of the sampler is a downward pointing rod that points to the sample point location (see Owensby 1973 for diagram of sampler). At each start point, we recorded on the datasheet if we were starting sampling at the beach or forest end of the transect, allowing us to move efficiently in a zig-zag pattern to minimize trampling. To map out the beach and vegetation locations, we recorded the distance from the high water mark "splash zone" to dune vegetation (on both ends if applicable, such as towards the end of a sandspit). This is also the point on the beach where we started each transect. To collect data on the vegetation, we held the step-point sampler in one hand and set it down randomly—by not looking down at the pointer—at each meter point. If the downward pointing rod directly touched the living foliar surface of a plant or lichen (see Figure 1), we recorded this as a direct hit and recorded the species' identity. If more than one species of plant touched the rod, we recorded the identity of the plant rooted the closest to the rod. If the rod was not directly touching a plant or lichen, we recorded the identity of the closest plant within a maximum distance of 0.5 m and within a 180° arc in front of the sample point. In the case of non-direct hits, we recorded the surface below the rod as either bare ground or litter. Bare ground was defined as bare sand with no litter or vegetation. Leaf litter included any dead plant material such as leaves and woody material. For each point, we recorded the habitat "zone" using the following system:

Zone 1 = below debris line and swash zone on the beach

Zone 2 = foredune area above swash zone but below primary vegetated dune

Zone 3 = perennial dune vegetation, dune field

Zone 4 = trees present on the dune; generally backdune area or savanna

Zone 5 = low depression (swale) within the vegetated dune zone; wet or dry

Table 1. Sampling intensity by island and by topographic zones among Apostle Island sandscapes in 2014. Also included are the number of points targeted based on Ulf Gafvert's GIS grid surface created to approximate a 500 points/acre sample density. Gafvert's approximation of the number of non-vegetated points among beaches was limited by the resolution of the 2010 aerial photography he used, and the size of the sandscapes was likely different between 2010 and the 2014 survey dates. MD = mainland location.

Location	Sandscape Location	# of Transects	# of Points Sampled	# of Points Sampled above debris line	Number of Points Sampled above perennial vegetated dune line	Target # of Vegetated Points (based on Gafvert's maps)	Target # of non-Vegetated Points (based on Gafvert's maps)	Transect Bearing
BESS	Bear Is.	33	757	757	750	829	826	E–W
CASS	Cat Is.	34	578	578	545	537	1,045	E–W
IRSS	Ironwood Is.	23	556	556	543	768	613	N–S
LONG	Long Is.	18	507	507	394	382	0	N–S
MDLSBS	MD-Little Sand Bay	18	497	483	404	406	0	N–S
MDSR	MD-Sand River	16	280	272	260	152	0	N–S
MISS	Michigan Is.	98	4,749	4,681	4,041	3,597	2,951	N–S
OASS	Oak Is.	27	923	918	842	730	547	NE–SW
OTSS	Otter Is.	15	141	141	137	231	241	E–W
OUSS	Outer Is.	149	10,701	10,698	10,601	14,478	6,447	E–W
RASS	Raspberry Is.	24	695	679	608	587	821	N–S
ROSS	Rocky Is.	57	2,861	2,859	2,655	3,261	1,350	NW–SE
SOSS	South Twin Is.	26	1,469	1,462	1,419	1,669	501	E–W
STJB1	Stockton Is.-Julian Bay	95	5,634	5,519	5,173	–	–	E–W
STNBSS	Stockton Is.-N. Beach	31	736	727	678	1,436	989	NW–SE
TOTAL	**n/a**	**664**	**31,084**	**30,837**	**29,050**	**29,063**	**16,331**	**n/a**

Because some sandscapes are quite large in area (Table 1, "number of points sampled" is estimated based on a 500 points/acre density), we concluded halfway through the field season that establishing hundreds of transects using meter tapes was not an efficient method that the National Park Service would be able to continue using in future years if they survey sandscapes at a high intensity. Thus, we developed a markedly more efficient method of establishing transects. Using a crew of two people, one person would stand at the start point of the transect and use a compass to confirm that the second person was walking the correct bearing as they set out flags in a visible line. Once the second person reached the end of the transect, the person standing at the start point used a Laser Range Finder (TruPulse® 360) to measure the transect length by sighting off the person standing at the end of the transect. This team of two people was able to lay out multiple transects ahead of the vegetation sampling crew. Instead of following a meter tape, the person holding the step-point sampler would pace out meter points between flags. Our crew members standardized their metered-paces by first using meter tapes during the field season, thus our sampling error was probably minimal and insignificant compared to the time savings of not laying out and rolling up hundreds of meter tapes. As we sampled the vegetation, we retrieved each flag, minimizing the need to backtrack. The step-point method was originally designed to be used without meter tapes (Evans and Love 1957).

We surveyed 31,084 points among 664 transects in this study of 15 sandscapes (Appendix B). Our crew averaged 4–5 people. The survey work occurred on 25 days starting on 30 June and extending through August, but some of these were partial work days. Stockton Island-Julian Bay alone took four days to survey starting at the north edge of the pine barren and extending to the outlet of the lagoon (Appendix A Figure A14).

On Stockton Island at Julian Bay, the sandscape vegetation varies between the younger dunes dominated by *Ammophila breviligulata* and an older dune area characterized as a red pine savanna. Because the vegetation in the savanna is denser and contains more overlapping plants, we sampled the vegetation in this habitat using an area-based method instead of the point-intercept method. We estimated the percent cover by species and percent cover of bare ground within 1-m^2 quadrats spaced out every 5 m along transects spaced 50 m apart. We extended this quadrat method beyond the savanna to the more open dune community, but we also decided to take a paired sample approach to compare the quadrat method with the step-point intercept method at this location. Thus, we also applied the same step-point intercept method using the same sampling density as applied at other sandscapes.

Using a Trimble 5000 GPS, we delineated the locations and widths of formal and informal trails on each sandscape to show areas of human impacts. Any linear bare area that appeared to be made due to repeated trampling was considered a trail, regardless of width. We also established photo points at each sandscape (Appendix C).

Data analyses

Surface Structure of Sandscapes in 2014

Prior to analyzing the step-point data for surface structure, we standardized the data set by removing all points falling within "zone 1" between the high water mark and the debris line on the beach and

within "zone 2" above the debris line to the perennial vegetated dune line (see Table 1). Very few plant species grow in zone 1 in Lake Superior beach habitats and plant cover is sparse in zone 2. By removing zone 1 and 2 points, we removed most of the "empty" points that would be associated with the active beach zone. Using the resulting data set, we calculated the proportion of empty points and compared this with the number of vegetated points. Empty points represent points lacking any vegetation within 0.5 m and a 180° arc in front of each point. "Vegetation" here includes vascular plants, moss species, and lichen species.

We calculated the proportion of direct "hits" of three surface types—bare ground, litter, and vegetation—for each sandscape. We used restricted maximum likelihood mixed-model analysis (REML) to assess significant differences in the proportion of surface types and whether these differed by island. Sandscape location and surface type were included as fixed effects and transect nested in location was included a random variable. We also combined bare ground and litter hits to compare the proportion of non-foliar with foliar points. In this case, non-foliar hits are not the same as "empty" points, as a plant or lichen species may have been identified within the 0.5-m, 180° arc area by each point. We graphed these surface type proportions by island. To illustrate the spatial variability in the proportion of these surface types, we also calculated and graphed their proportions for each transect on all islands.

Status of Sandscape Vegetation in 2014 – Richness, Diversity, and Evenness

We computed the total number of species (species richness) on each sandscape using data on direct hits and indirect hits. Indirect hits occurred when the step-point sampler pointed to a non-foliar surface, but we recorded the nearest plant or lichen species found within 0.5 m in a 180° arc in front of the point. We also calculated the number of species observed per number of points sampled (species density) on each sandscape. These measures of diversity should be used with caution when comparing among sandscapes of different sample areas. To address the relationship of richness with sample area, rarefaction curves are a more accurate approach for making comparisons of diversity across sandscapes (and through time). Rarefaction curves are also useful for determining if one over- or under-samples an area to assess diversity. We applied EstimateS to the frequencies of species in each transect across all sandscapes to generate sample-based rarefaction curves and 95% confidence intervals (Colwell 2013). On these same graphs, we also plotted species diversity calculated as the exponential Shannon Diversity Index (Equation 1), a measure of true diversity that enumerates the number of equally abundant species observed with increasing samples of the community (Jost 2006).

Equation 1 $= exp(H')$

To compare the dominance structure of taxa across islands, we plotted rank-abundance curves consisting of log-transformed proportional abundances (y-axis) of taxa in rank order of abundance (x-axis).

Status of Sandscape Vegetation in 2014 – Species Composition

To identify the most frequently occurring taxa among sandscape communities, we compiled all taxa occurring in >1% of points. We plotted the proportional abundances of these "top tier" taxa by sandscape to evaluate if these top tier taxa were similar in abundance at each site.

We calculated the proportion of hits (direct + indirect) of native vs. exotic taxa and we plotted these values for each sandscape. We also calculated the percentage of native and exotic taxa comprising the flora of each sandscape. To assess differences in the composition of specialist vs. generalist taxa, we compiled for each vascular plant species their Coefficient of Conservatism score (C) assigned by expert botanists (Bernthal 2003). Ranging from 0 to 10, C values of 10 represent species very sensitive to habitat degradation and devoted to intact natural communities, while species with values of 0 are non-native, weedy species that show no alliance to specific habitats. We computed both the average Coefficient of Conservatism (Mean C) and a Floristic Quality Index (FQI; Equation 2) to compare floristic quality across sandscapes.

Equation 2 $$FQI = C_{mean} \times \sqrt{richness}$$

To assess the types of plants comprising the community, we grouped taxa by broad groups ("habit")––graminoids (grasses, sedges, and rushes), lichens, forbs, shrubs, tree seedlings, ferns, and mosses. We calculated and graphed the proportion of each of these plant habits in each sandscape community.

We also took a multivariate approach to evaluating the similarities and distinctions in the plant communities among sandscapes. Our data set of numerous taxa sampled on 15 sandscapes with numerous transects lends itself well to non-metric multidimensional scaling (NMDS) ordination analysis. Using PC-ORD 6 (McCune and Grace 2002), we input a primary data matrix containing proportional frequencies of taxa at each transect-sandscape location. To limit the number of zeroes in the data set, we removed all taxa with fewer than four occurrences and removed all locations with fewer than four occurrences of plants (or lichens). The NMDS was run using Sørensen distances and 20 random starting configurations and 200 iterations, achieving a final stress of 18.56.

Assessing the step-point sampling method

To evaluate the possibility of reducing the sampling intensity down to 50% or even 25% of the 2014 sample event, we sub-sampled the transects and created a series of graphs illustrating the proportion of each of the three surface types – bare ground, vegetation, and litter – across transects using the full data set and two reduced data sets. We evaluated these for any obvious patterns suggesting that the reduced sample intensity would be adequate or inadequate for evaluating sandscape surface structure. To determine if there were significant differences between two sub-samples of transects among sandscapes (odd and even transects), we applied a REML model with response variables being proportion of surface type (bare ground, litter, or direct foliar hit) and predictors including location as a fixed variable, transect as a random variable nested by location, and subsample as a fixed variable. If sub-samples were not significantly different, we could conclude that a 50% sub-sample would sufficiently represent surface structure among sandscapes.

At Stockton-Julian Bay, we had the opportunity to conduct a comparison between the fixed-area quadrat sampling method and the step-point sample method. We calculated the average proportion of bare ground, litter, and vegetation within the 1-m^2 quadrats and plotted these proportions across all transects surveyed for each sandscape. We compared this spatial display of these results with a similar graph of the proportions of these three surface types across transects surveyed using the step-

point sample method. We also compiled overall species richness and proportional abundances of taxa observed with each method.

With the intention of finding a useful way to display the step-point data for use by resource managers and to illustrate the utility of starting transects on the active beach zone, we plotted data for each point across each transect for all sandscapes. We overlaid onto these points data on their zone location, proportion of exotics, and surface type (Appendix B). JMP®12 (SAS Institute Inc., Cary, North Carolina) was used to create these figures.

Results

Surface structure of sandscapes in 2014

Among all islands, greater than 13% of the sampled points contained vegetation within 0.5 m and 180º from each point. Only five islands had >5% "empty" points containing no vegetation: Long, Michigan, Oak, Raspberry, and Stockton-Julian Bay (Figure 3). Only Stockton-Julian Bay had >10% empty points. Thus, there seems to be few large barren areas within the vegetated dune fields on most sandscapes.

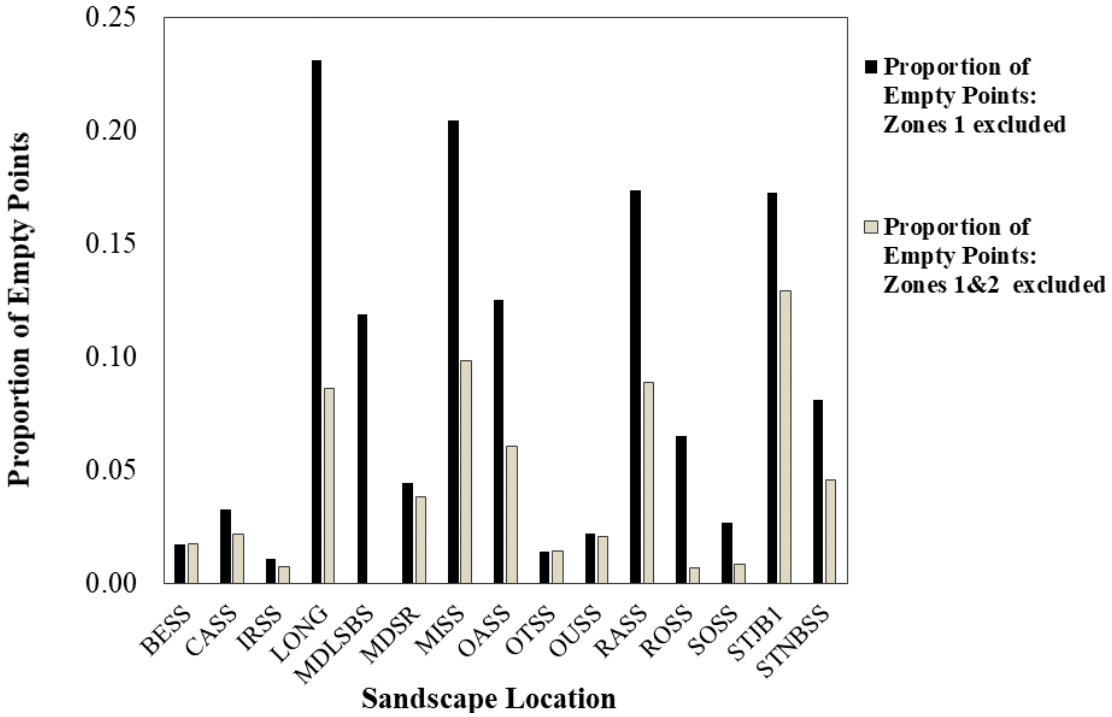


Figure 3. Proportion of empty points observed among sandscape locations using data restricted to areas above zone 1 (above the swash zone) and above zones 1 and 2 (perennial dune vegetation and above). The majority of empty points fall between the swash zone and the upper beach zone above the debris line. When we exclude these points below the perennial vegetated dune line this excludes a large percentage of bare ground areas associated with the active beach zone subject to wind and wave disturbance. Bare ground points observed in this dynamic area could also reflect trampling impacts, but the point-count approach cannot distinguish trampling from natural disturbance processes. Thus, to standardize the data across transects and sandscape locations, we excluded from all analyses the empty points falling in zones 1 and 2.

Another approach to assessing sandscape structure is through characterization of surface types identified at each point as "hits" using the step-point sampler. Consistent with the characterization of non-vegetated areas based on the number of "empty" points (Figure 3), Stockton-Julian Bay also had the highest proportion of bare ground "hits" (Figure 4). Other sandscapes with >20% bare ground hits included Cat, Michigan, Otter, Raspberry, and Stockton-North Beach. The proportion of hits on leaf litter were distinctly higher at Mainland-Little Sand Bay than on other sandscapes, and it was also twice as prevalent over other surface types at Little Sand Bay (Figure 4). Greater than 65% of hits were directly on vegetation on Long, Rocky, South Twin, and Otter Island sandscapes, and additionally Ironwood, Oak, and Outer Islands had >50% of direct vegetation hits (Figure 4). Across all sandscapes combined, foliar hits were approximately twice as common as bare ground hits and also significantly more common than hits on litter ($F_{2,1303}$ = 249.6, P<0.0001) (Figure 5).

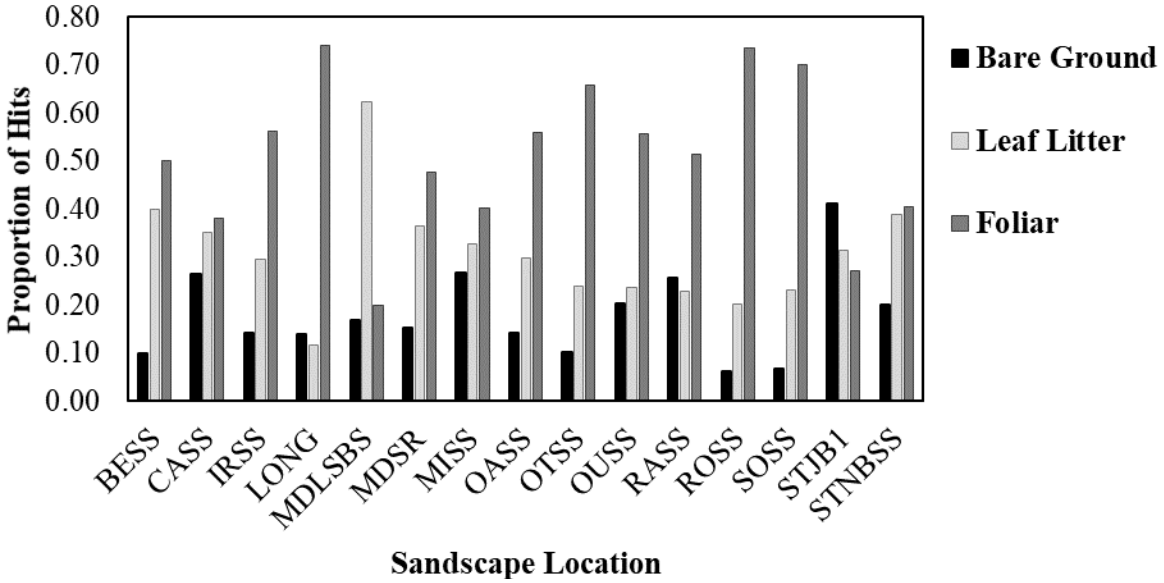


Figure 4. Proportion of sample points hitting the three surface types—bare ground, leaf litter, and direct hits of plant foliage—among sandscape locations in Apostle Islands National Lakeshore, summer 2014. The sampled area excludes all area on the beach below the perennial vegetation zone. The highest foliar cover was observed among Long (LONG), Rocky (ROSS), South Twin (SOSS), and Otter Island (OTSS) sandscapes. Leaf litter was distinctly higher at Mainland-Little Sand Bay (MDLSBS) than on other sandscapes, but it was also twice as prevalent over other surface types at Little Sand Bay. The highest proportion of bare ground was observed at Stockton Island-Julian Bay (STJB1).

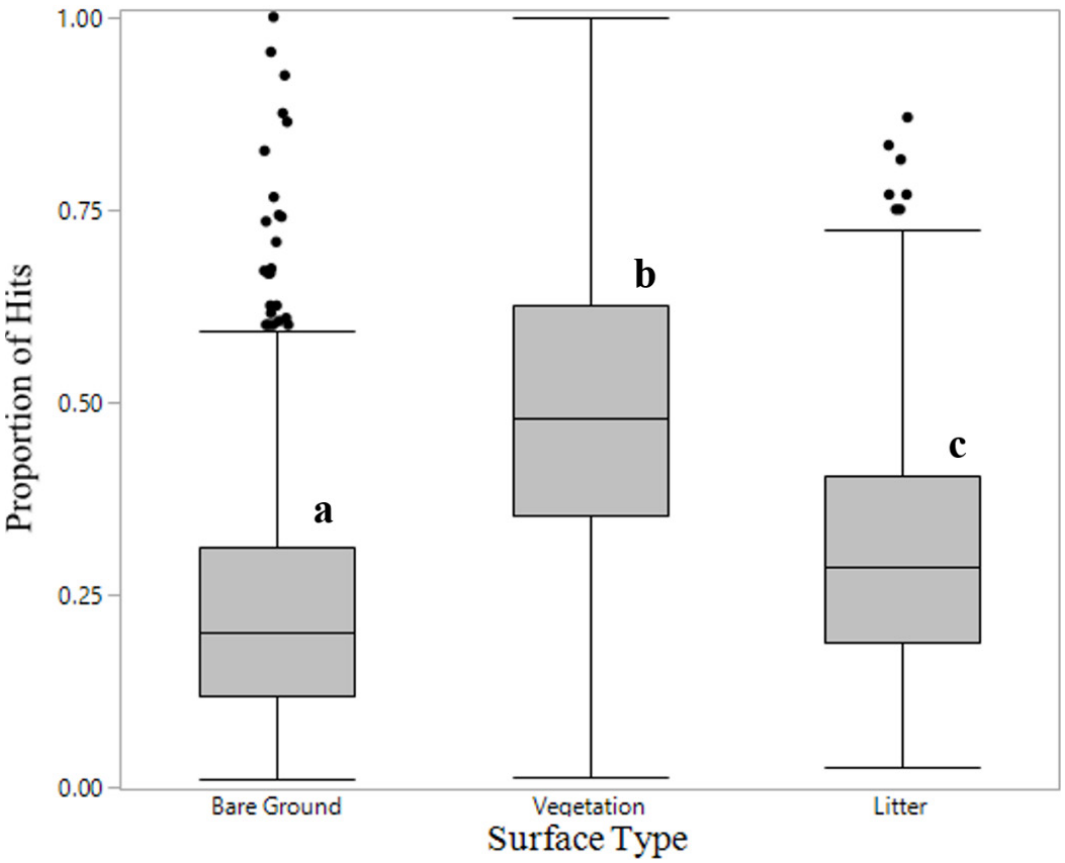


Figure 5. Boxplot of proportions of hits for each surface type compiled across all 15 sandscapes sampled in 2014 in Apostle Islands National Lakeshore. Letters indicate significant differences assessed using REML analysis ($F_{2,1303}$ = 249.6, P <00001). Vegetation was significantly more likely to be directly "hit" than other surface types, with bare ground hit the least often. The boxes represent the interquartile range (IQR; 25%, median, and 75%), whiskers represent 1.5x the IQR, and points indicate potential outliers.

When the two surface types "litter" and "bare ground" were combined and compared with the proportion of vegetated hits, sandscape locations with a greater proportion of non-foliar surface include Mainland-Little Sand Bay and Cat, Michigan, Stockton-Julian Bay, and Stockton-North Beach Islands (Figure 6). Notably, non-foliar cover was 62% more prevalent than foliar cover at Little Sand Bay and it was 47% more prevalent at Stockton-Julian Bay. The sparsity of vegetation picked up by the step-point sampling at Mainland-Little Sand Bay (Figure 6), coupled with no "empty" points (see Figure 3), indicates that vegetation density is relatively low but there are few large barren areas larger than 0.5 m in width in the areas we sampled there.

By graphing the proportion of hits for each of the three surface types across all transects, we show the spatial relationship of trends in these variables for each sandscape (Figures 7–22). Using Michigan Island as a demonstration of the utility of presenting the data in this way, we show that one of the areas with relatively fewer vegetated points and higher bare ground points coincides with transects 31–42 (Figure 7). These transects are at a location that shifts from a southwest to a southern aspect, so it is possible that this transitional area is also more highly disturbed by wind events and erosion. Also, an informal trail was observed bisecting this area (Appendix A, Figure A6). Thus,

NPS may wish to monitor this area in the near future for possible trampling disturbance that could be interacting with wind-driven disturbance. Managers can take a similar approach of interpreting these graphs for all sandscapes and in the future, trends over time in surface patterns can be assessed.

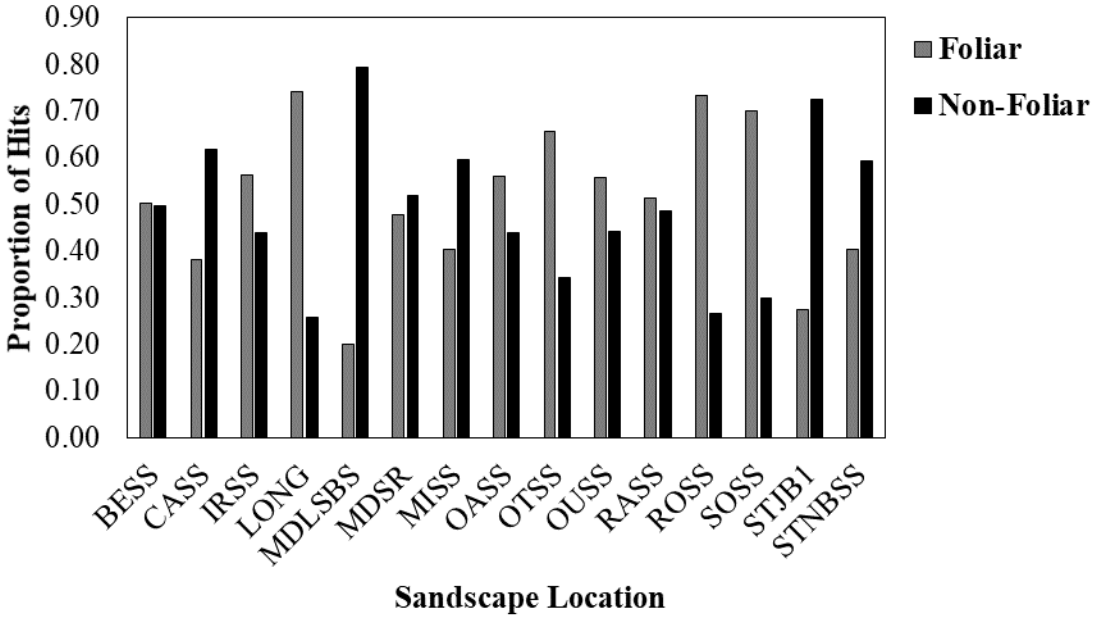


Figure 6. Proportion of sample points hitting non-foliar surfaces (bare ground + litter) or directly hitting plant foliage on sandscapes in Apostle Islands National Lakeshore in summer 2014. The sampled area excludes all area on the beach below the perennial vegetation zone. Sandscape locations with a greater proportion of non-foliar surface include Mainland-Little Sand Bay (MDLSBS) and Cat (CASS), Michigan (MISS), Stockton-Julian Bay (STJB1), and Stockton-North Beach (STNBSS) Islands. Notably, non-foliar cover was 62% more prevalent than foliar cover at Mainland-Little Sand Bay and it was 47% more prevalent at Stockton-Julian Bay.

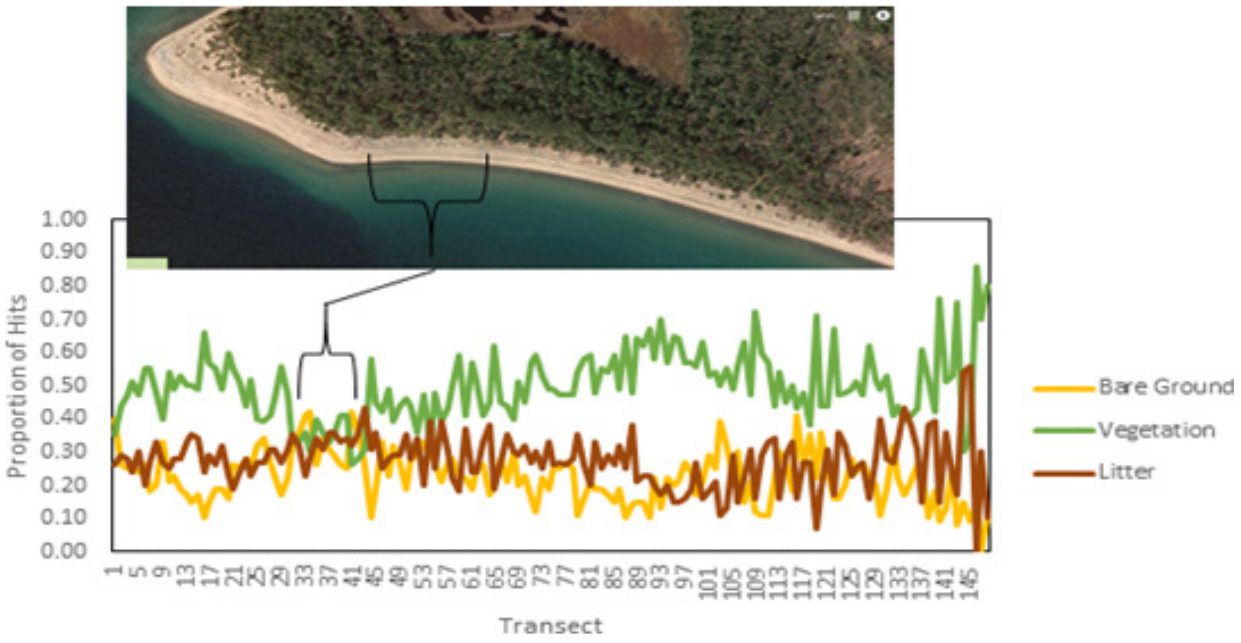


Figure 7. Proportion of point-count "hits" of bare ground, vegetation, and organic litter observed among transects sampled on Michigan Island in summer 2014. Transects 31–42 (indicated by brackets on aerial photo and graph) had the lowest proportion of direct hits on vegetation. This location shifts from a southwest to a southern aspect, so it is possible that this transitional area is also more highly disturbed by wind events and erosion. We recommend that NPS monitor this area in the near future for possible trampling disturbance that could be interacting with wind-driven disturbance. An informal trail was observed bisecting this area (Appendix Figure A6). The scatter observed in these data from transect to transect is probably a function of alternating crew members scoring "hits" differently (despite careful training to reduce this type of error), but the overall trends appear to be robust to this sample error.

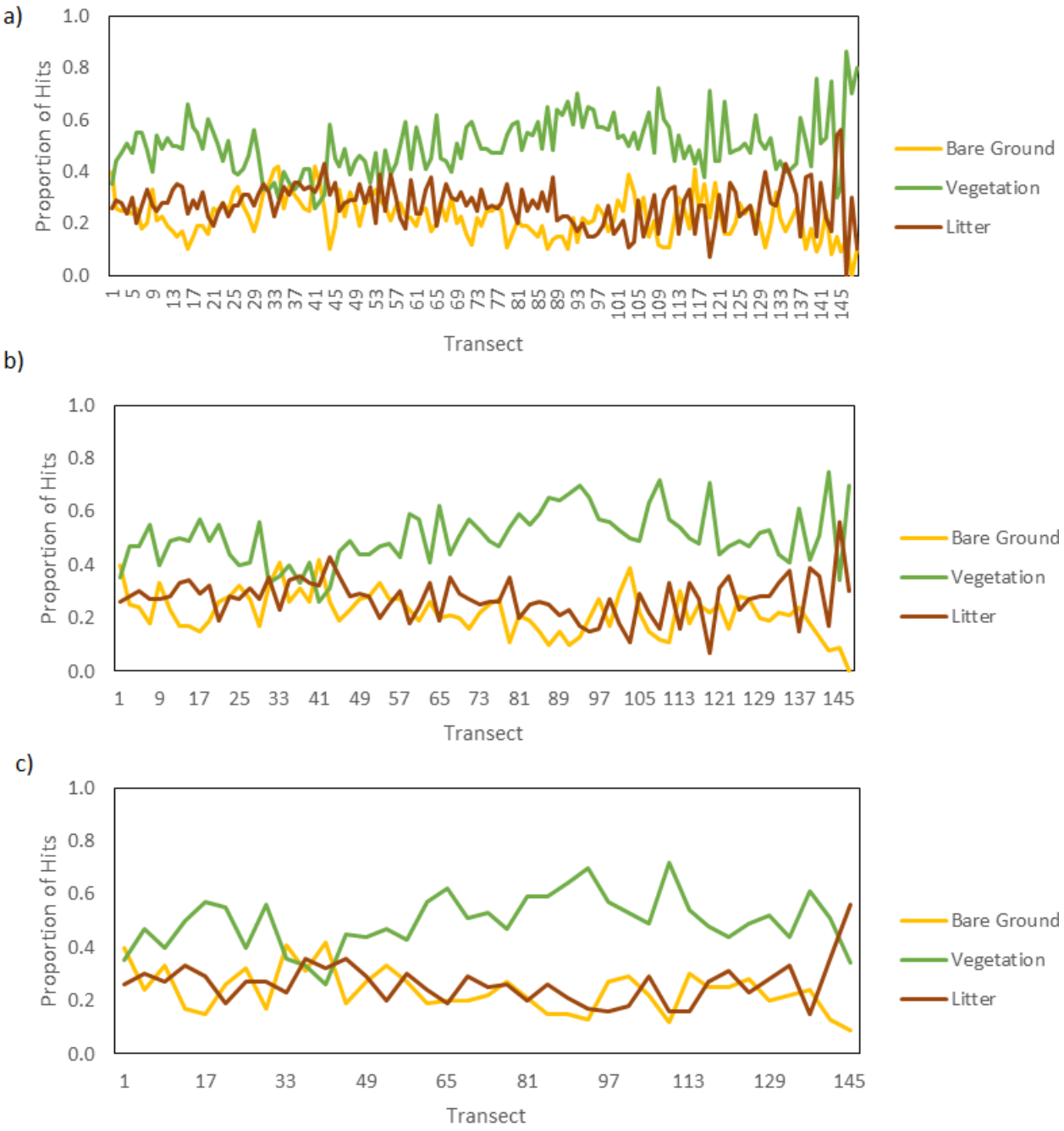


Figure 8. Comparison of proportion of hit types among three sample intensities using Michigan Island data: a) 100% sample (transect spacing every 8 m), b) 50% of sample (transect spacing every 16 m), and c) 25% of sample (transect spacing every 32 m). This demonstrates that reduced sample intensity is adequate for obtaining similar patterns in surface types across this sandscape.

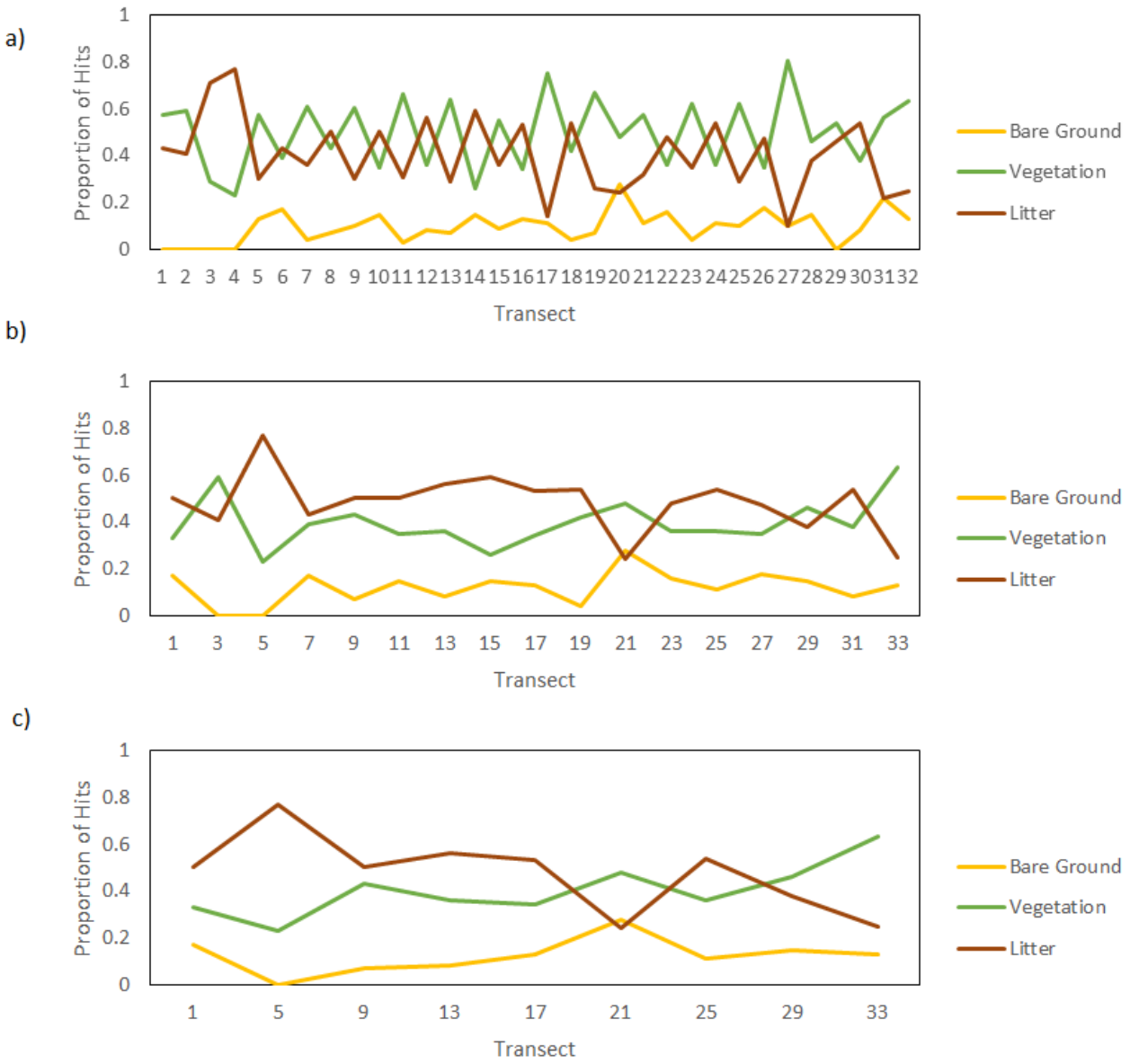


Figure 9. Comparison of proportion of hit types among three sample intensities using Bear Island data: a) 100% sample (transect spacing every 8 m), b) 50% of sample (transect spacing every 16 m), and c) 25% of sample (transect spacing every 32 m). This demonstrates that reduced sample intensity is adequate for obtaining similar patterns in surface types across this sandscape. This also shows that the proportion of litter and vegetation are more easily prone to sample error than bare ground. The scatter between even and odd transects in graph *a* are due to different crew members sampling alternating transects, thus there appears to be a discrepancy between what crew members are calling litter vs. vegetation.

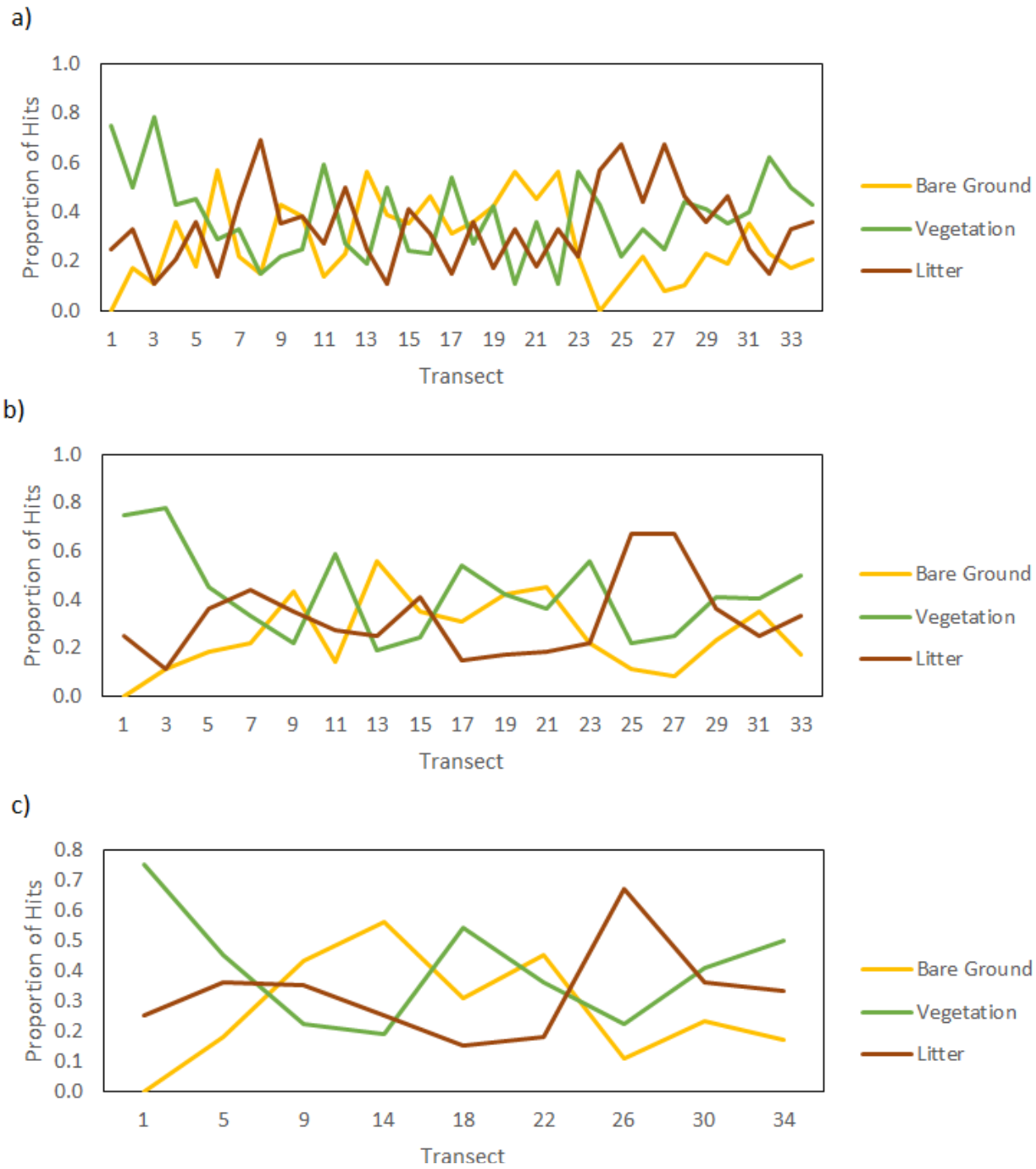


Figure 10. Comparison of proportion of hit types among three sample intensities using Cat Island data: a) 100% sample (transect spacing every 8 m), b) 50% of sample (transect spacing every 16 m), and c) 25% of sample (transect spacing every 32 m). This demonstrates that reduced sample intensity down to 50% could be adequate for characterizing the surface structure across the sandscape, but a 25% sampling intensity does not appear to be an adequate representation.

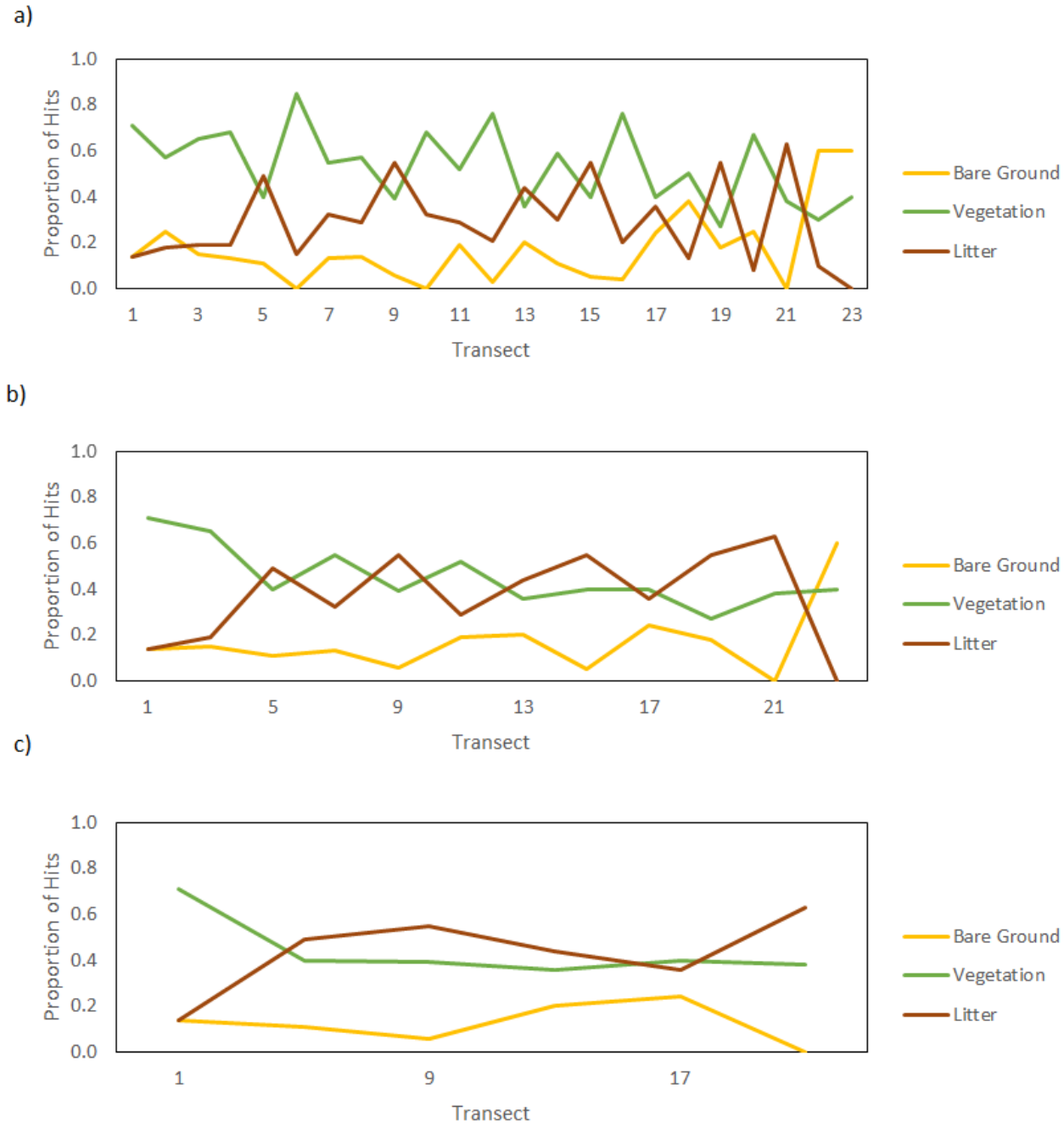


Figure 11. Comparison of proportion of hit types among three sample intensities using Ironwood Island data: a) 100% sample (transect spacing every 8 m), b) 50% of sample (transect spacing every 16 m), and c) 25% of sample (transect spacing every 32 m). We lose some of the resolution in the data at the 25% intensity level, but the 50% intensity sampling maintains most of the information that we see in the full sample (graph *a*). Graph *c* shows less scatter because this reduces the sampling error associated with crew members alternating transects sampled across the sandscape.

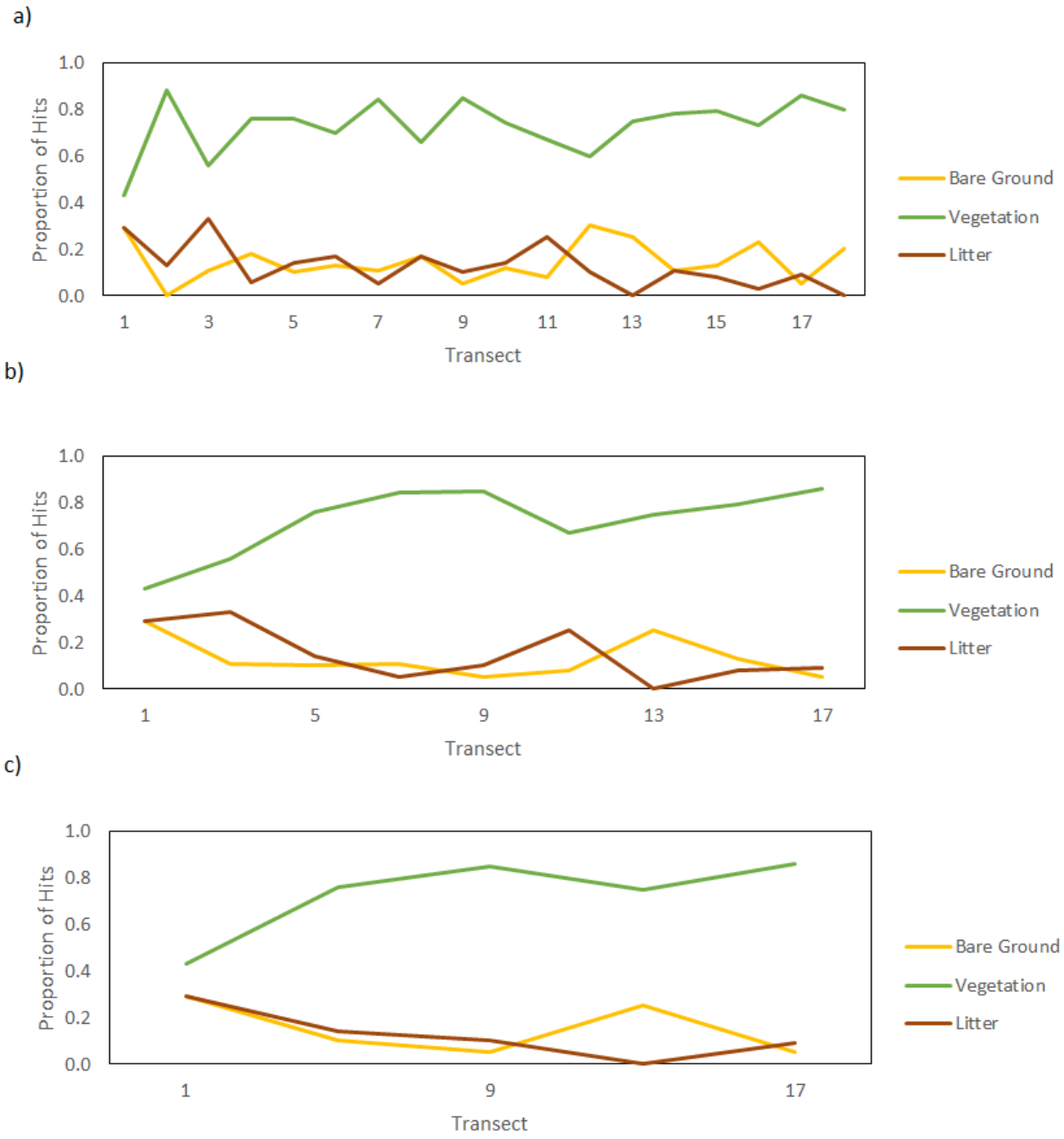


Figure 12. Comparison of proportion of hit types among three sample intensities using Long Island data: a) 100% sample (transect spacing every 8 m), b) 50% of sample (transect spacing every 16 m), and c) 25% of sample (transect spacing every 32 m). The reduced sampling intensities (graphs *b* and *c*) appear to be good approximations of the full dataset (graph *a*).

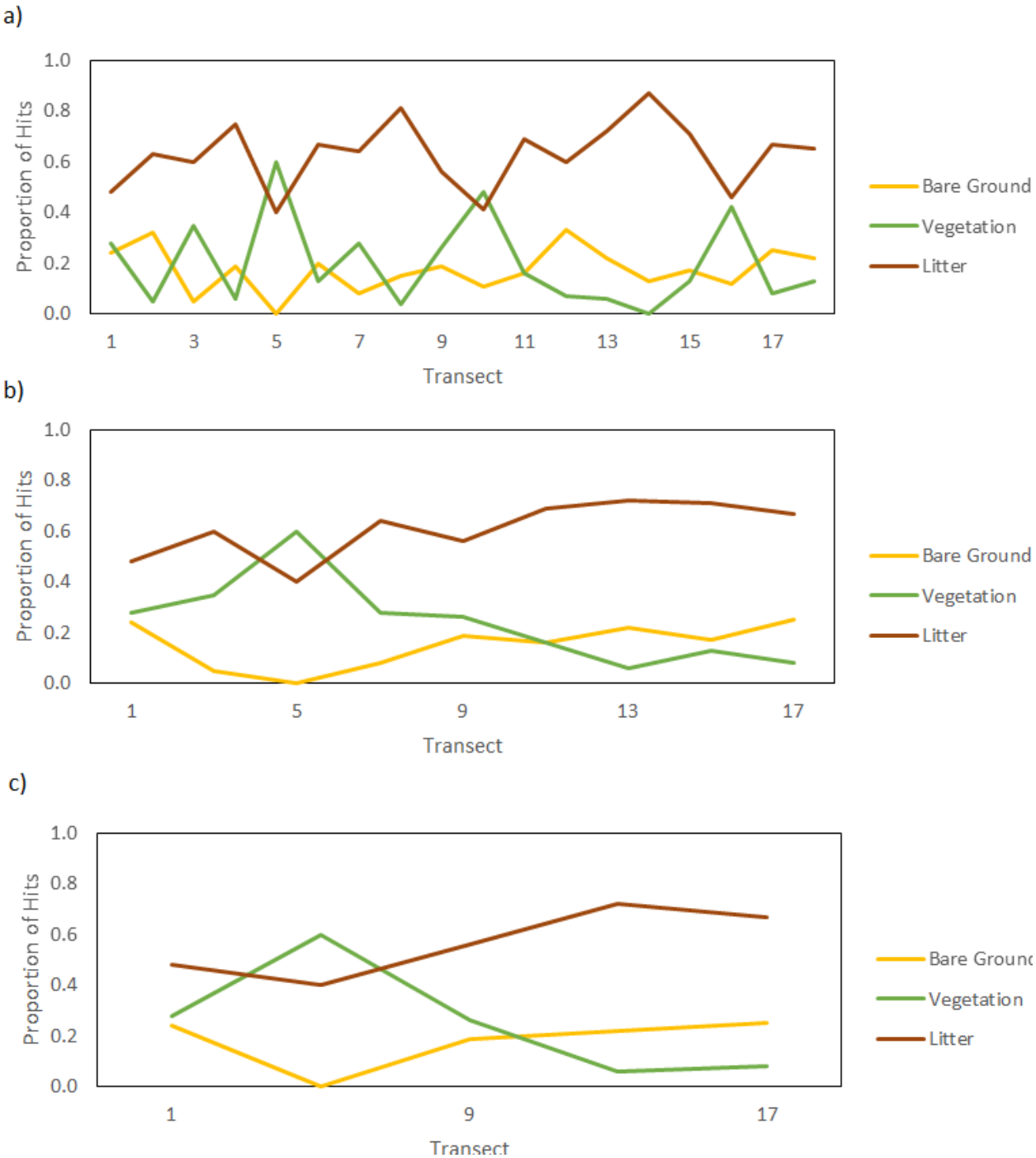


Figure 13. Comparison of proportion of hit types among three sample intensities using Mainland-Little Sand Bay data: a) 100% sample (transect spacing every 8 m), b) 50% of sample (transect spacing every 16 m), and c) 25% of sample (transect spacing every 32 m). The reduced sampling intensities (graphs *b* and *c*) appear to be good approximations of the full dataset (graph *a*).

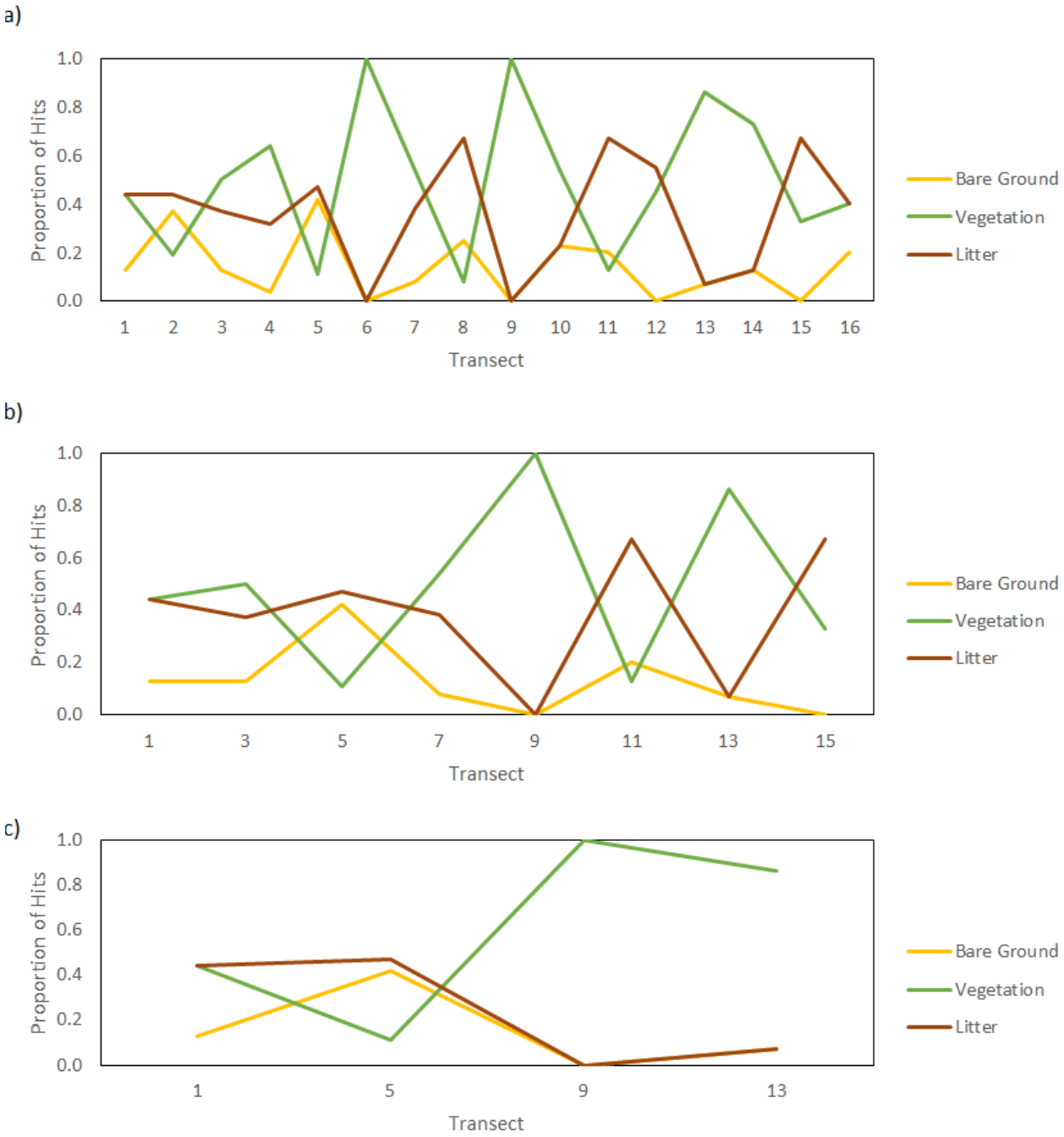


Figure 14. Comparison of proportion of hit types among three sample intensities using Mainland-Sand River data: a) 100% sample (transect spacing every 8 m), b) 50% of sample (transect spacing every 16 m), and c) 25% of sample (transect spacing every 32 m). The 50% sampling intensity (graph *b*) appears to be a good approximation of the full sample (graph *a*), but the 25% reduced sample masks some of the overall variability (graph *c*).

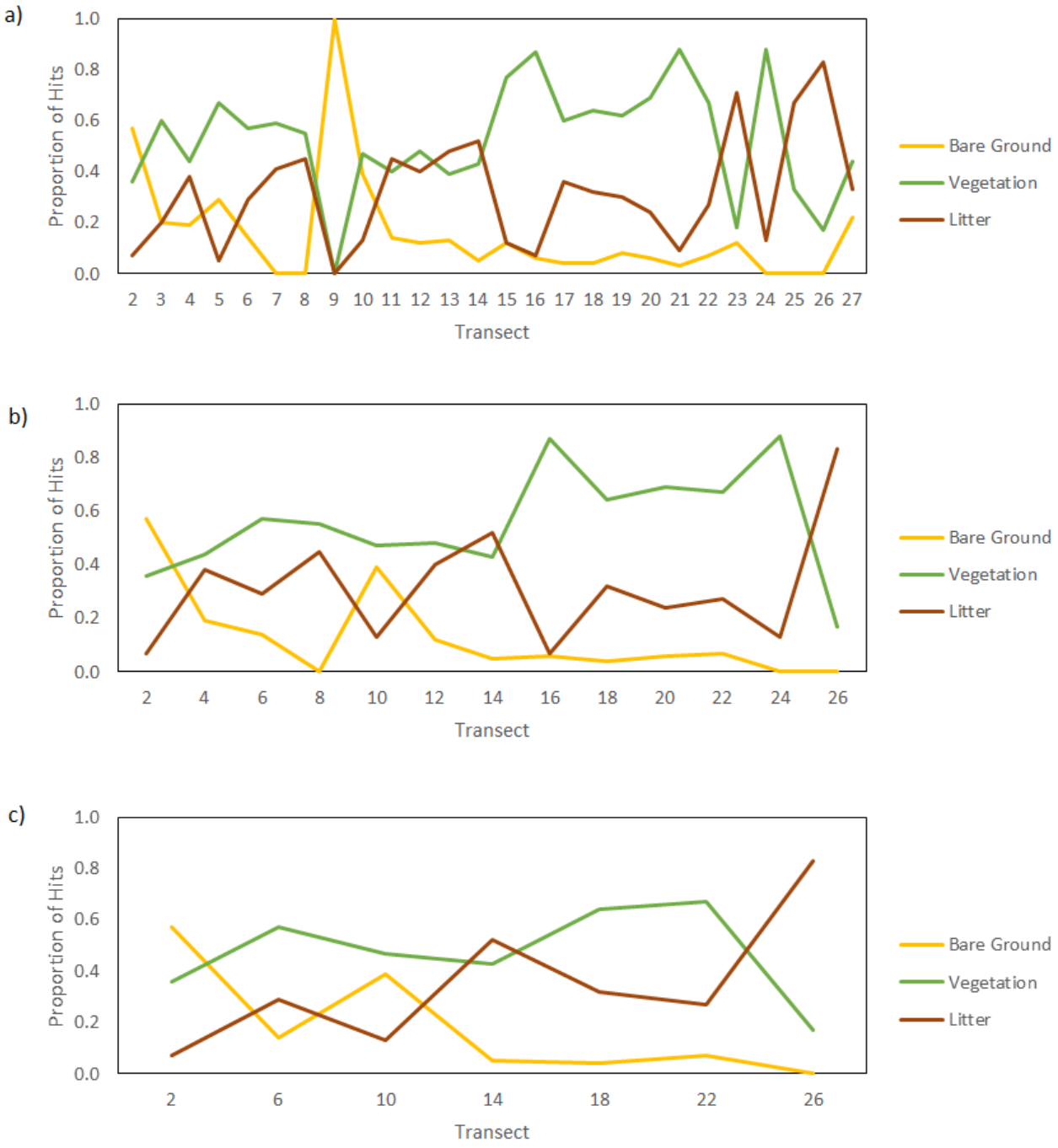


Figure 15. Comparison of proportion of hit types among three sample intensities using Oak Island data: a) 100% sample (transect spacing every 8 m), b) 50% of sample (transect spacing every 16 m), and c) 25% of sample (transect spacing every 32 m). The reduced sampling intensities (graphs *b* and *c*) appear to be good approximations of the full dataset (graph *a*).

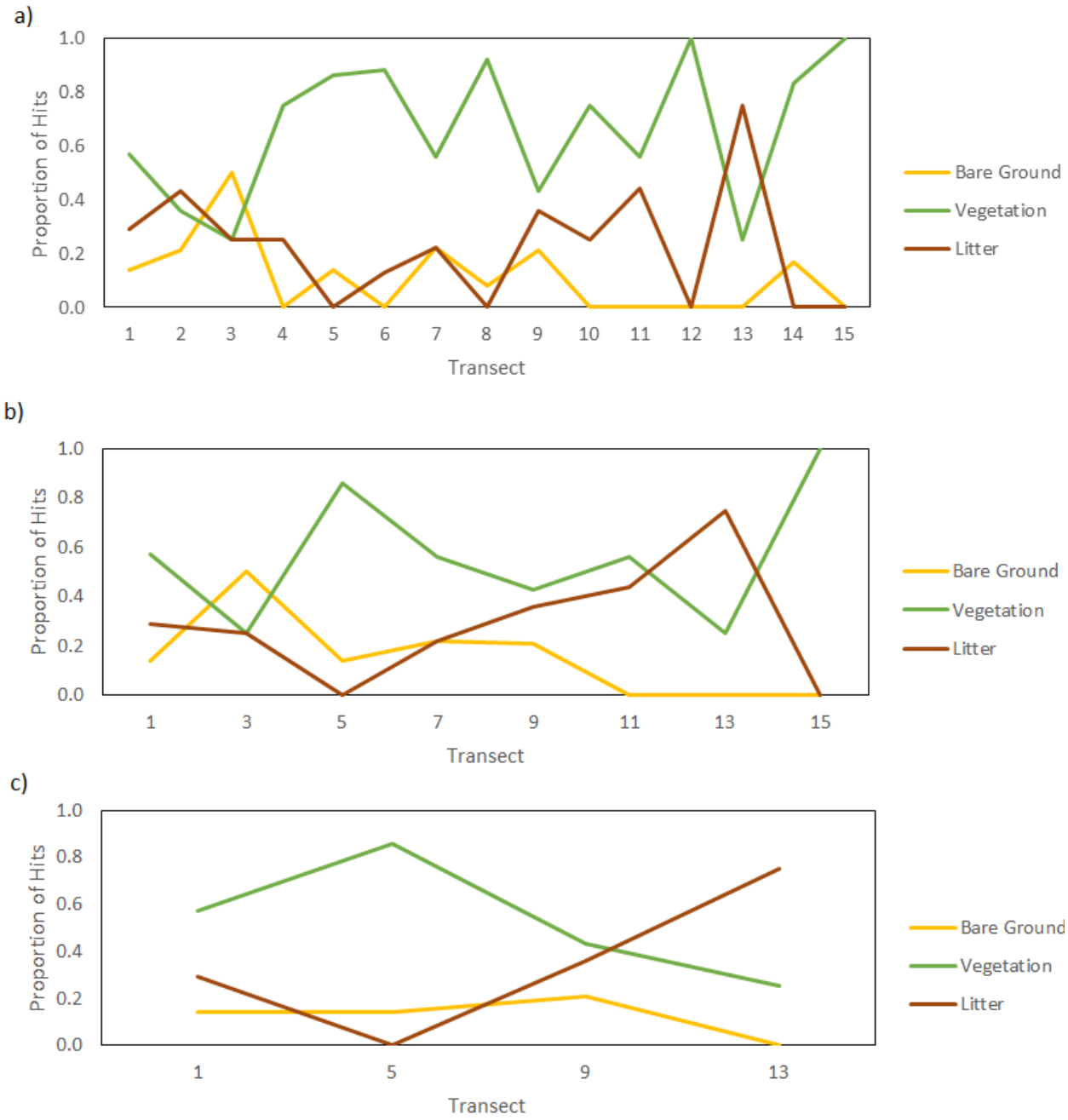


Figure 16. Comparison of proportion of hit types among three sample intensities using Otter Island data: a) 100% sample (transect spacing every 8 m), b) 50% of sample (transect spacing every 16 m), and c) 25% of sample (transect spacing every 32 m). The reduced sampling intensities (graphs *b* and *c*) appear to be good approximations of the full dataset (graph *a*).

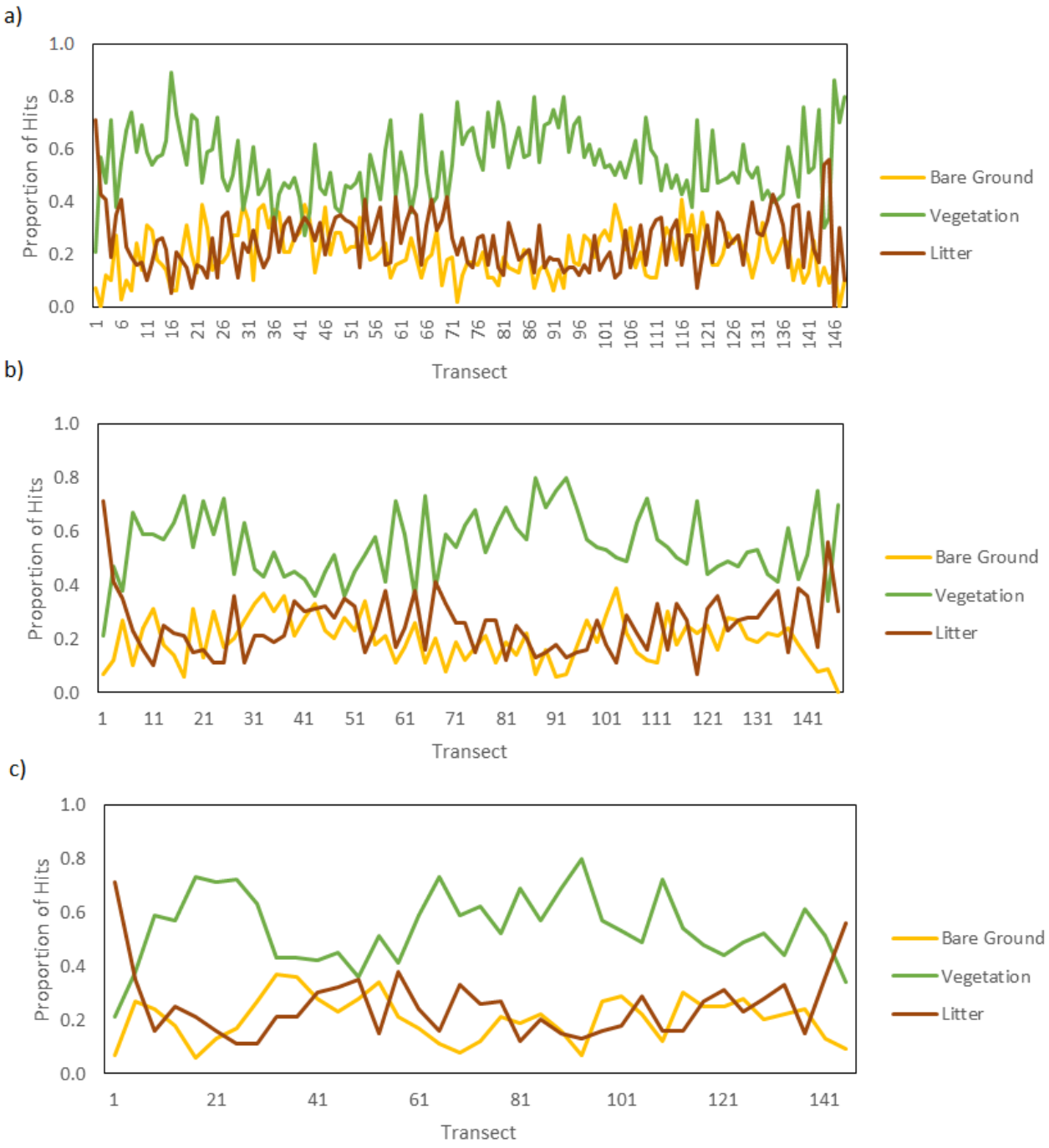


Figure 17. Comparison of proportion of hit types among three sample intensities using Outer Island data: a) 100% sample (transect spacing every 8 m), b) 50% of sample (transect spacing every 16 m), and c) 25% of sample (transect spacing every 32 m). The reduced sampling intensities (graphs *b* and *c*) appear to be good approximations of the full dataset (graph *a*).

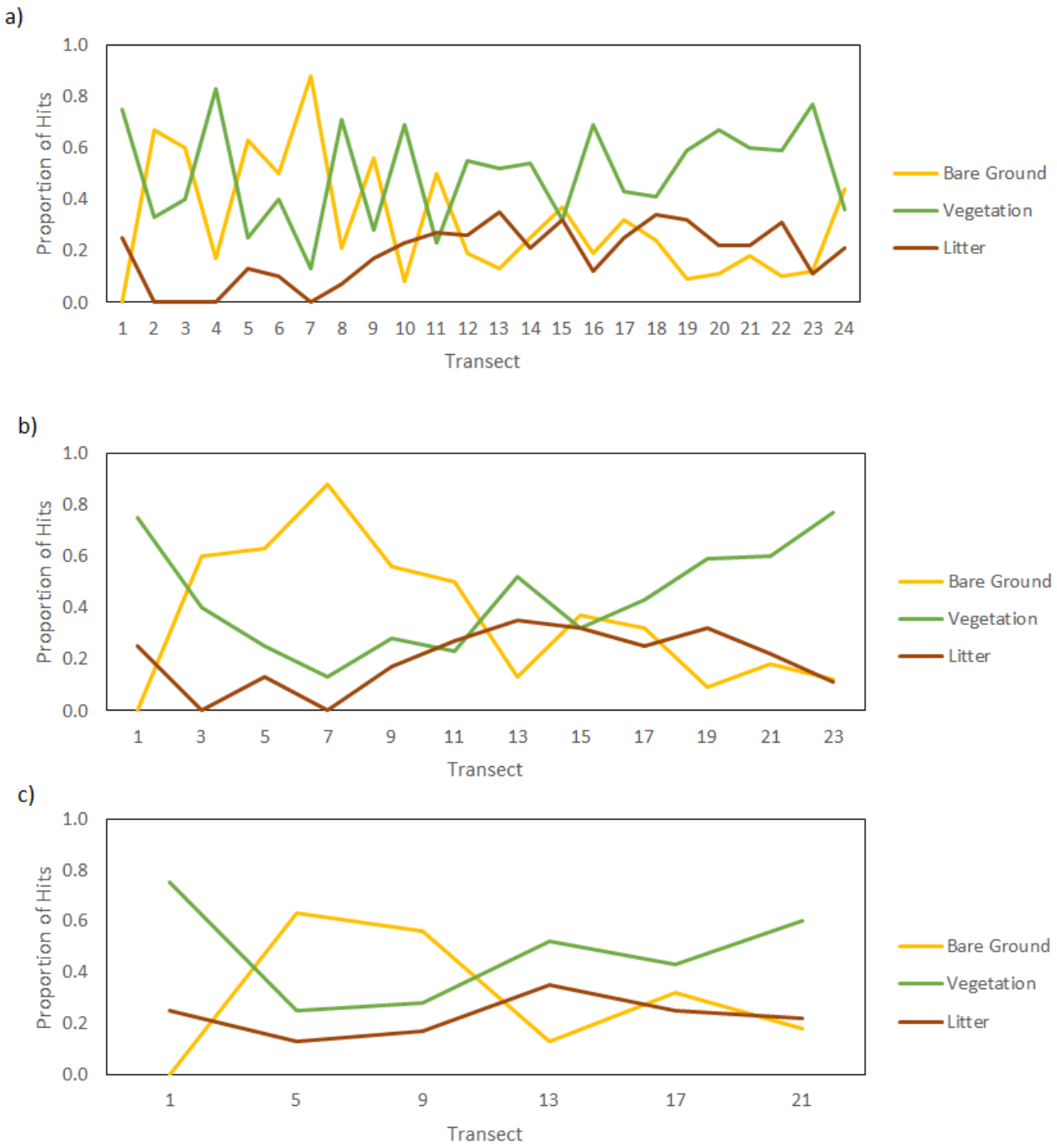


Figure 18. Comparison of proportion of hit types among three sample intensities using Raspberry Island data: a) 100% sample (transect spacing every 8 m), b) 50% of sample (transect spacing every 16 m), and c) 25% of sample (transect spacing every 32 m). The reduced sampling intensities (graphs *b* and *c*) appear to be good approximations of the full dataset (graph *a*).

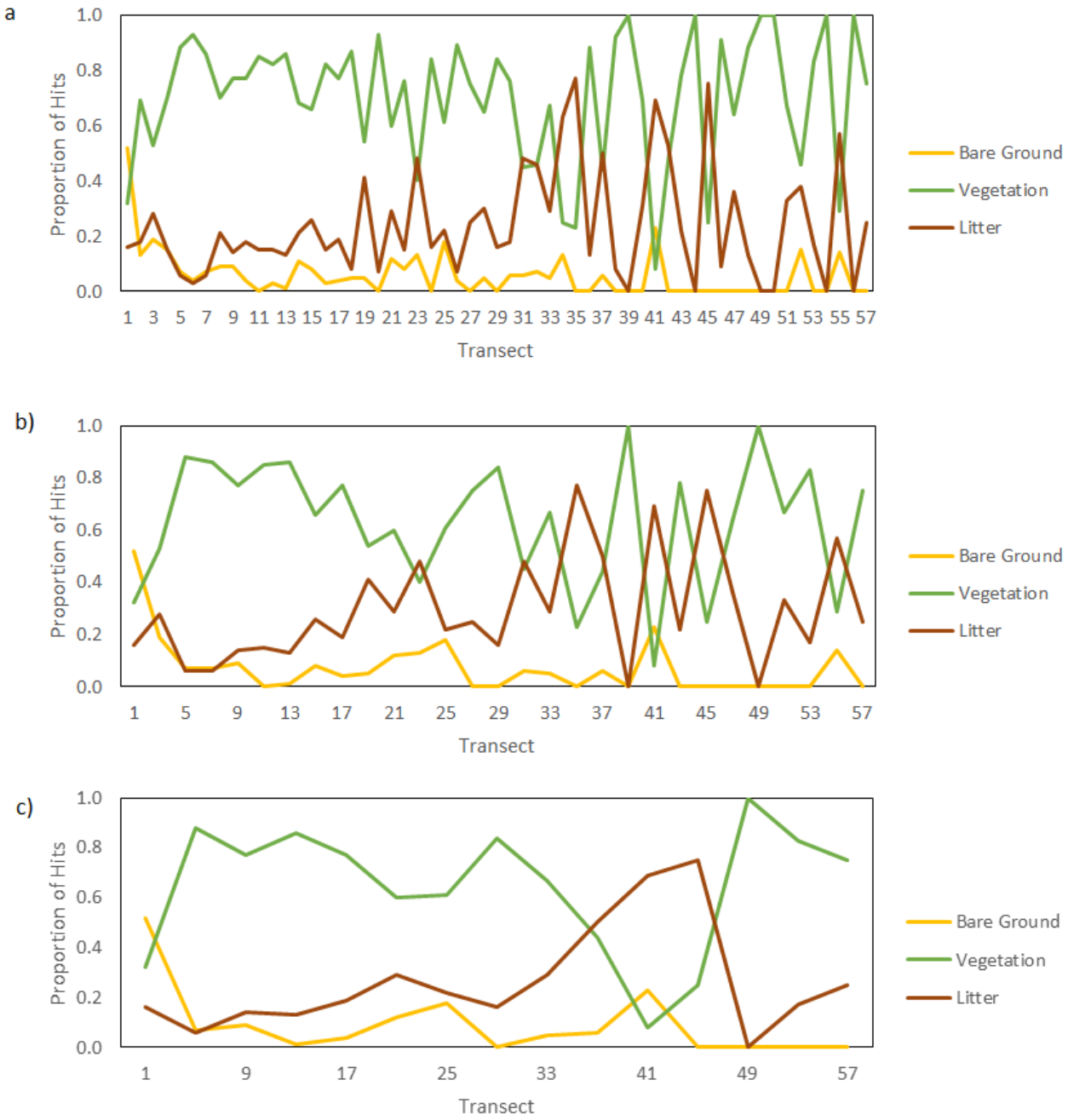


Figure 19. Comparison of proportion of hit types among three sample intensities using Rocky Island data: a) 100% sample (transect spacing every 8 m), b) 50% of sample (transect spacing every 16 m), and c) 25% of sample (transect spacing every 32 m). The reduced sampling intensities (graphs *b* and *c*) appear to be good approximations of the full dataset (graph *a*), but much of the variability is smoothed out.

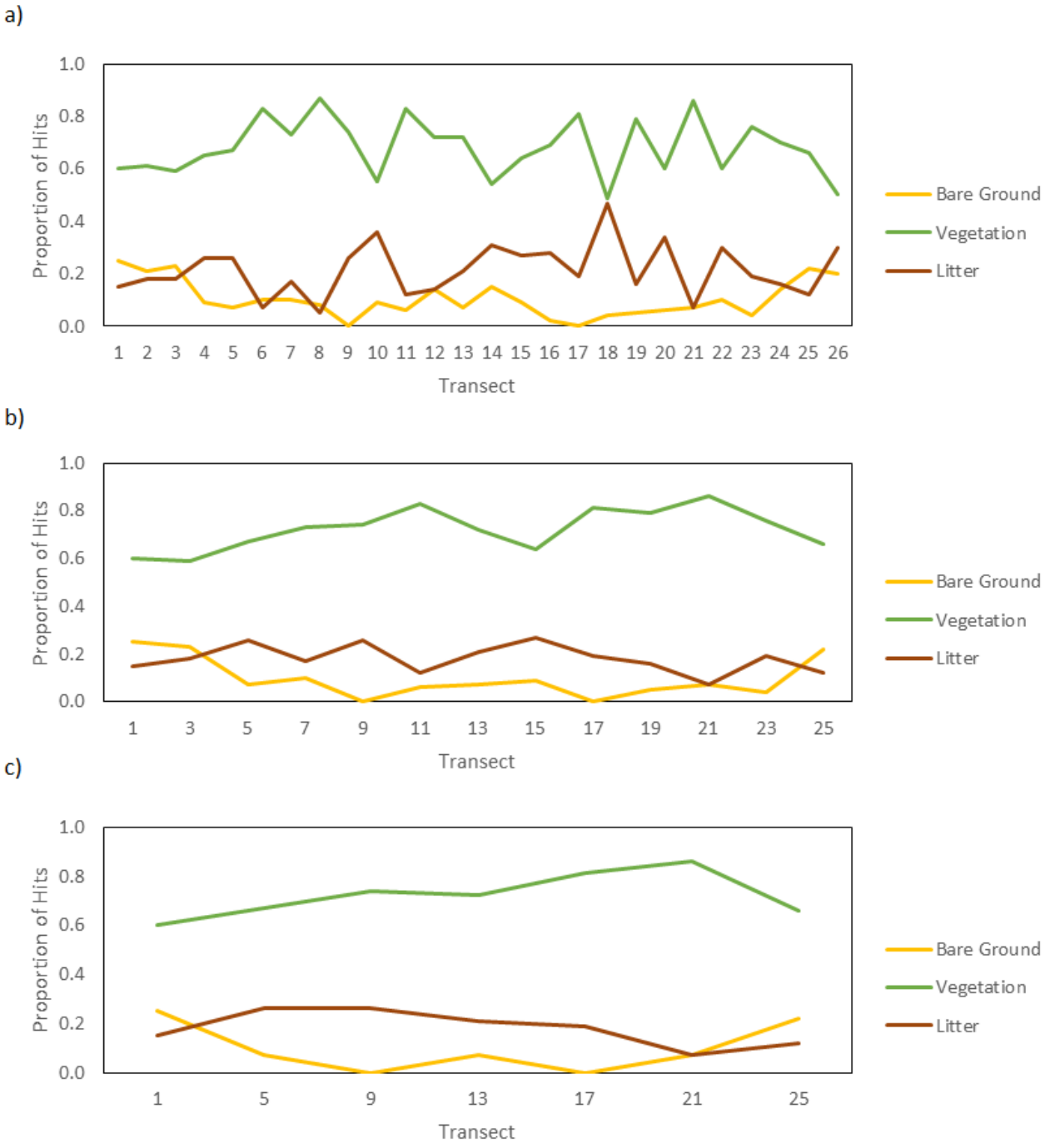


Figure 20. Comparison of proportion of hit types among three sample intensities using South Twin Island data: a) 100% sample (transect spacing every 8 m), b) 50% of sample (transect spacing every 16 m), and c) 25% of sample (transect spacing every 32 m). The reduced sampling intensities (graphs *b* and *c*) appear to be good approximations of the full dataset (graph *a*).

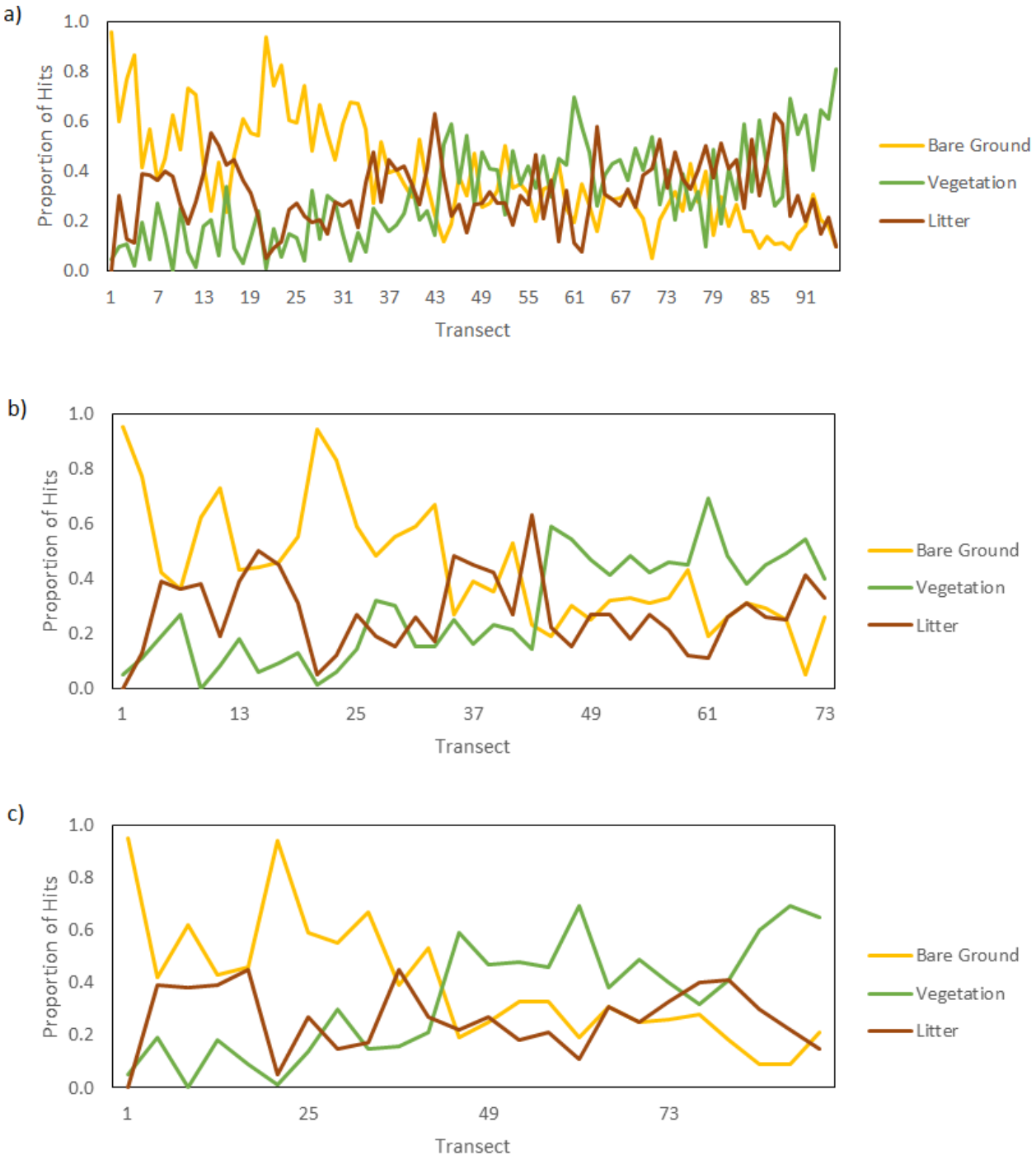


Figure 21. Comparison of proportion of hit types among three sample intensities using Stockton Island-Julian Bay data: a) 100% sample (transect spacing every 8 m), b) 50% of sample (transect spacing every 16 m), and c) 25% of sample (transect spacing every 32 m). The reduced sampling intensities (graphs *b* and *c*) appear to be good approximations of the full dataset (graph *a*).

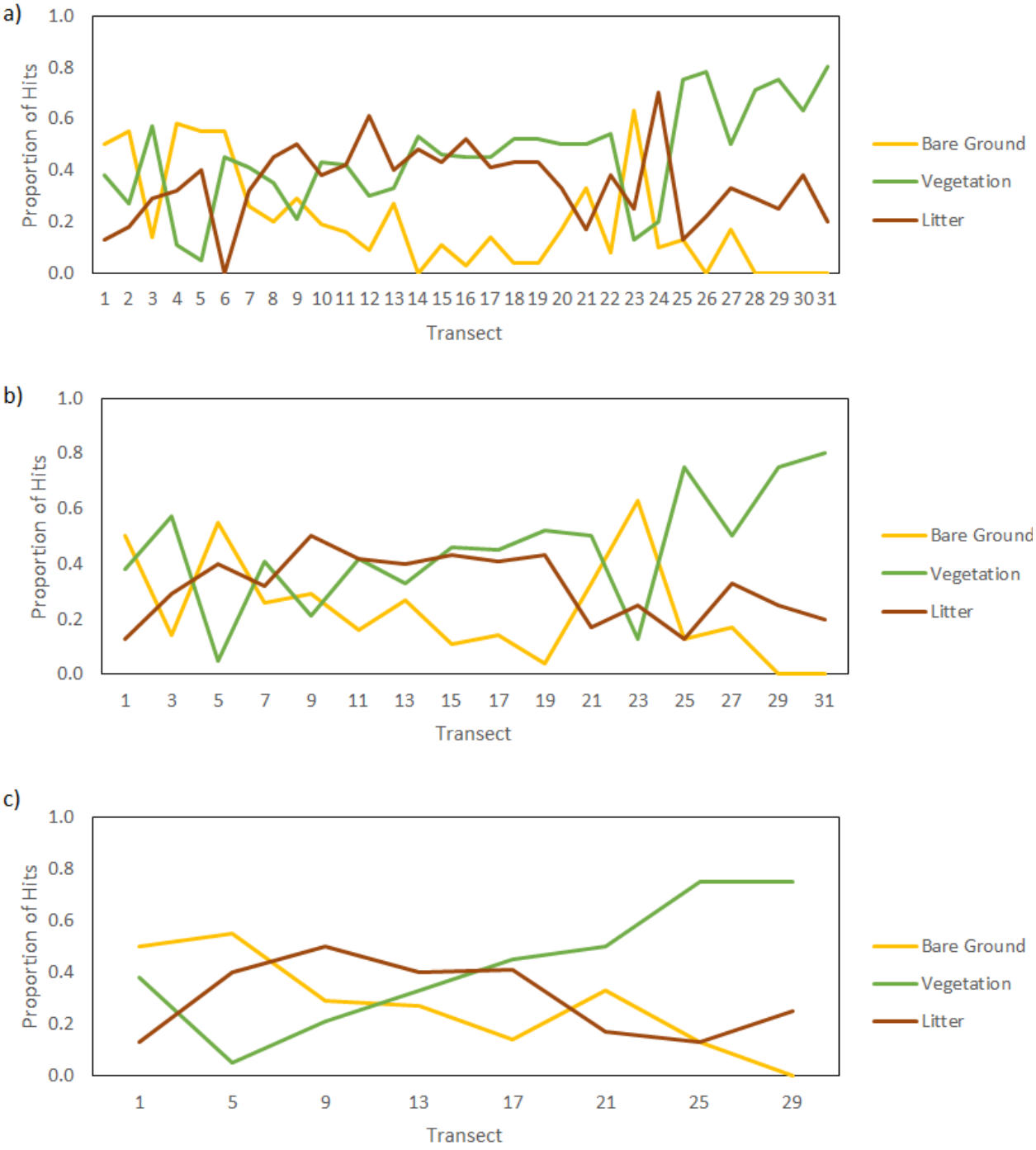


Figure 22. Comparison of proportion of hit types among three sample intensities using Stockton Island-North Beach data: a) 100% sample (transect spacing every 8 m), b) 50% of sample (transect spacing every 16 m), and c) 25% of sample (transect spacing every 32 m). The reduced sampling intensities (graphs *b* and *c*) appear to be good approximations of the full dataset (graph *a*).

Status of sandscape vegetation in 2014 – Richness, diversity, and evenness

The number of species (species richness) observed among sandscapes ranged from 14 at both Little Sand Bay and Sand River sandscapes on the mainland to 48 species on Outer Island (Figure 23).

Species richness is influenced by the size of the area surveyed, or in our case the number of survey points, so caution must be taken in comparing species richness among sandscapes. Within a sandscape, species richness of direct hits was only slightly higher than when indirect species counts were included in the overall species count. To account for differences in the number of points sampled among islands, we standardized measures of richness by calculating species density (richness divided by the number of sample points; Figure 24). On average across all sandscapes, we observed 0.04 (± 0.03) taxa per sample point. The highest species density (0.15) was observed on Otter Island sandscape where we sampled the fewest number of points. Likewise, we observed the lowest species density on the three largest sandscapes, Michigan, Outer, and Stockton-Julian Bay (<0.02 taxa per point sampled).

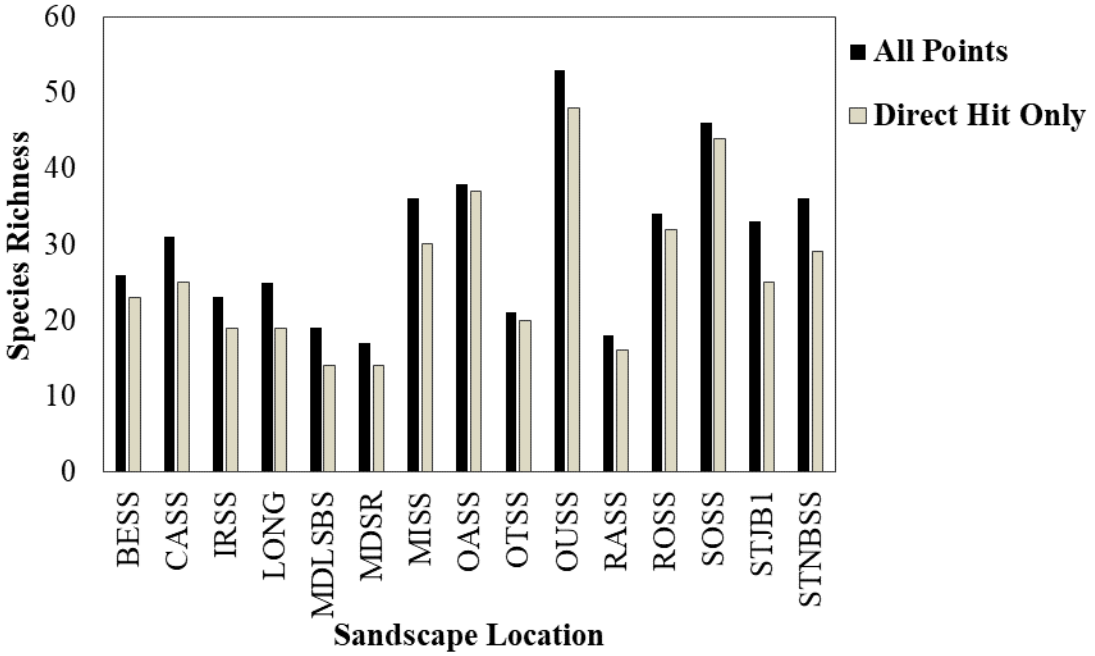


Figure 23. Species richness (number of total species) observed at each sandscape location in summer 2014. The total number of points and size of sandscapes varies among sandscape locations, so avoid comparing richness across islands. Instead, compare direct and indirect measures of species richness within each island. The primary conclusion from this graph is that most species observed at a location were captured through direct foliar hits, with a few additional species captured through indirect hits.

Because of this influence of sample size on both species richness and species density, to compare diversity among sandscapes and to evaluate if we were sampling too few or too many points, we proceeded with rarefaction techniques to illustrate species diversity as a function of increasing sample area (Figure 25a–c). The rate of observing new taxa at a sandscape was highest within the first few transects at most sandscapes (i.e., Michigan and Outer Islands) (Figure 25b). More taxa continued to be observed with additional points along additional transects on all sandscapes, but the rate at which additional taxa were added varied among islands. Oak and Cat Islands, for example, had a steeper rate of increase in richness with increasing sample effort (Figures 25a–b). Outer Island had the highest observed species richness (approximately 50), with 60% of the taxa observed within

the first 13% of sample points and the remaining 18 taxa added at a 10-fold slower rate across the remaining 8,850 points (Figure 25b).

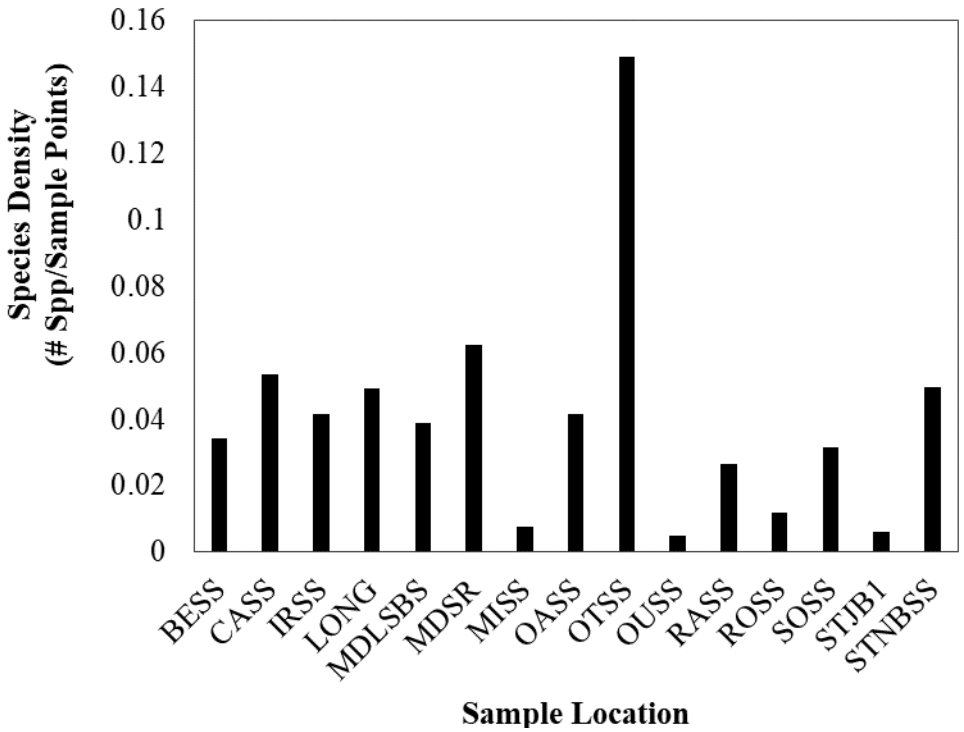


Figure 24. Species density (number of species proportional to the number of sample points) observed among Apostle Island sandscape locations in summer 2014. Note that Otter Island (OTSS) had the fewest number of sample points (n = 141) and the highest species density, which could indicate that we are oversampling other sandscape locations. Species density was lowest among the largest islands: Outer (OUSS), Stockton-Julian Bay (STJB1), and Michigan (MISS).

Species diversity (exp(H')), defined here as the number of equally abundant species within a community, was relatively low across all sandscapes and leveled out at five or fewer taxa across most sandscapes (Figures 25a–c). Thus, most taxa are uncommon and sparsely distributed across sandscapes. This diversity peaked within the first three sampled transects at most sites, but did see steeper increases at Long Island (Figure 25a), Oak Island and Otter Island (Figure 25b), suggesting a slightly more equitable distribution among some taxa.

Among all islands, the top-ranking species were proportionally much more abundant than species in declining rank order (steep rate of decline in log abundance curves) (Figure 26). Outer Island had the most species, followed by South Twin Island and Oak Island (longer tails in Figure 26). Evenness of species was lowest at Stockton-Julian Bay, as indicated by the steepest drop in proportional abundance among taxa there.

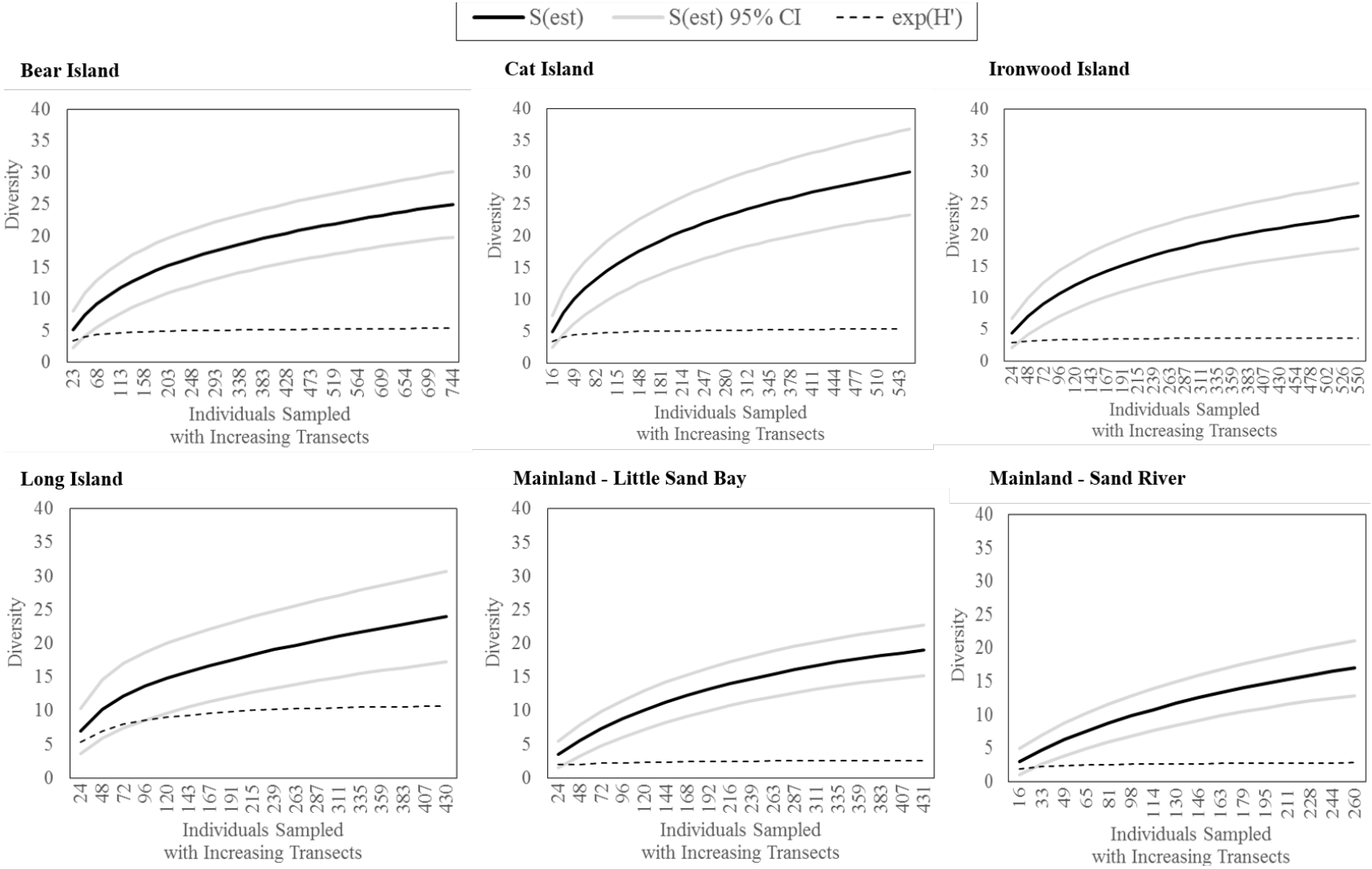


Figure 25a. Rarefaction curves generated for each sandscape location, plotting estimated species diversity with a 95% confidence interval and the Hill-Jost transformed Shannon Entropy (exp(*H*')) that quantifies the number of equally distributed species in the community of increasing sample sizes. We ran each simulation 500 times using EstimateS, which conducts iterative sampling of transect units without replacement until all samples are accumulated.

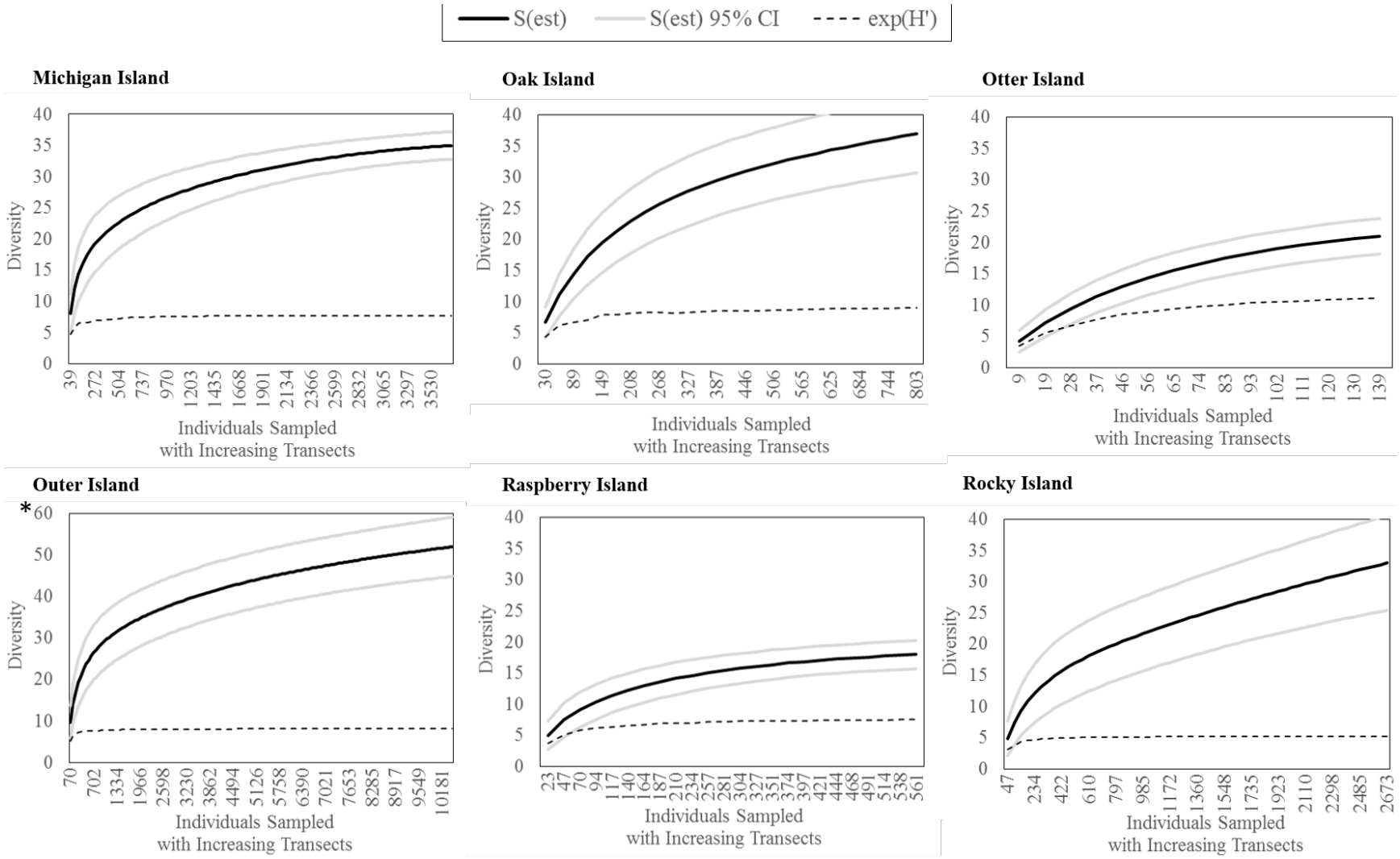


Figure 25b. Rarefaction curves generated for each sandscape location, plotting estimated species diversity with a 95% confidence interval and the Hill-Jost transformed Shannon Entropy (exp(*H'*)) that quantifies the number of equally distributed species in the community of increasing sample sizes. We ran each simulation 500 times using EstimateS, which conducts iterative sampling of transect units without replacement until all samples are accumulated.

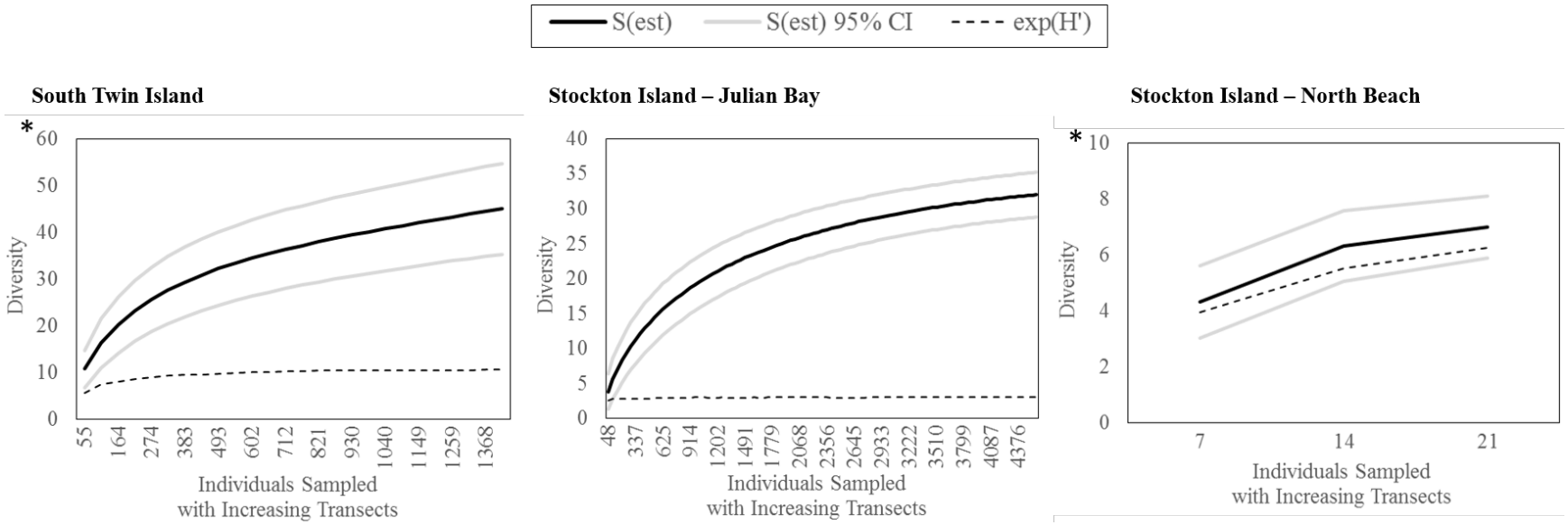


Figure 25c. Rarefaction curves generated for each sandscape location, plotting estimated species diversity with a 95% confidence interval and the Hill-Jost transformed Shannon Entropy (exp(*H'*)) that quantifies the number of equally distributed species in the community of increasing sample sizes. We ran each simulation 500 times using EstimateS, which conducts iterative sampling of transect units without replacement until all samples are accumulated.

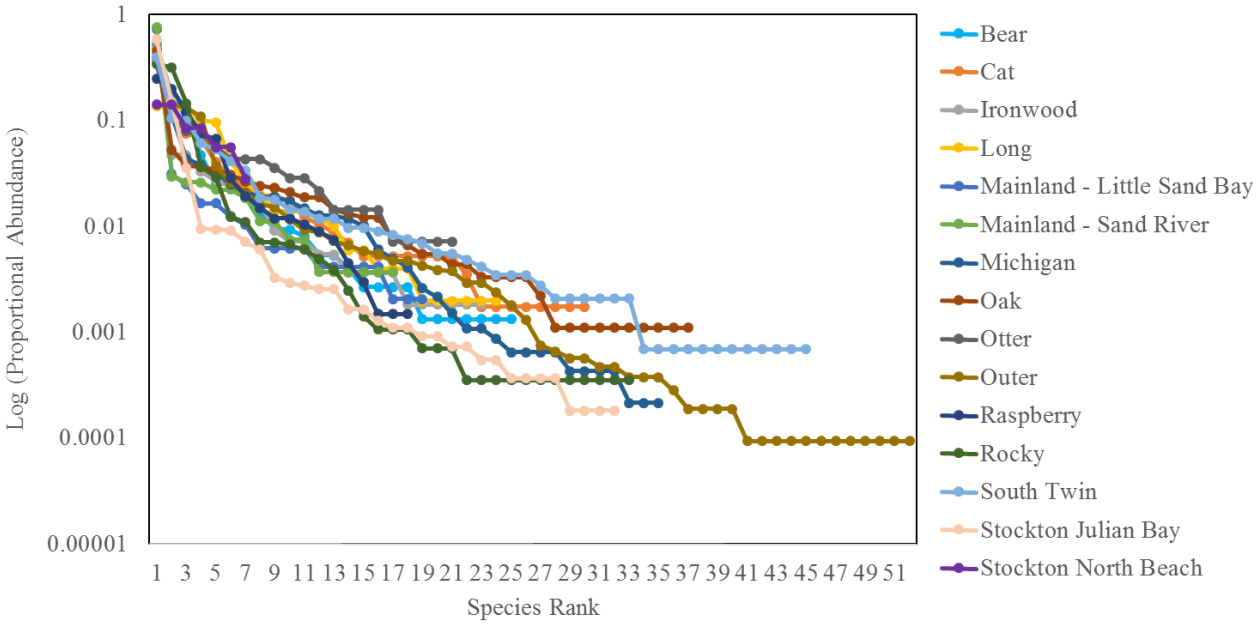


Figure 26. Rank abundance curves observed among sandscape locations in Apostle Islands National Lakeshore in summer 2016. Outer Island had the most species, followed by South Twin Island, then Oak Island. Evenness of species was lowest at Stockton-Julian Bay, as indicated by the steepest drop in proportional abundance among its species. Otter, Oak, and South Twin Islands had a more even representation of species than Outer Island. Among all islands, the top-ranking species were proportionally much more abundant than species in declining rank order. Among these islands, Stockton North Beach exhibited the least amount of species dominance.

Status of sandscape vegetation in 2014 – Species composition

Ten taxa were present in >1% of all sampled points across sandscapes (Figure 27a–b). Only *Ammophila breviligulata* (beachgrass) was among these top tier taxa at all sandscapes. If it was not the most abundant taxa, then it was a co-dominant. Only Outer and Long Islands had greater than three top tier taxa. Hence, taxa on most islands were uncommon.

Native taxa predominate on all islands (Figure 28). We observed the highest number of exotic taxa occurrences ("hits") on Otter Island (21%), Oak Island (19%), South Twin (15%), and Ironwood Island (10%), reflecting heavier historic disturbances such as fishing cabins on South Twin, sand mining on Oak, and a log landing on Ironwood Island (J. Van Stappen, personal communication). The locations of these exotic occurrences are included in sandscape profile graphs (Appendix B). Among the other sandscapes, the density of exotic taxa was lowest on Outer Island (0.4%), Long Island (0.5%), and Raspberry Island (0.05%) (Figure 28). The only sandscape with no exotic taxa recorded in our survey was Stockton Island-Julian Bay (Figure 29). Greater than 20% of the taxa (not hits) are exotic on Otter Island, Ironwood Island, and Mainland-Little Sand Bay, and >15% of taxa are exotic on Cat Island, South Twin Island, and Oak Island. Michigan and Stockton-North Beach are approaching 15% exotic taxa (Figure 29).

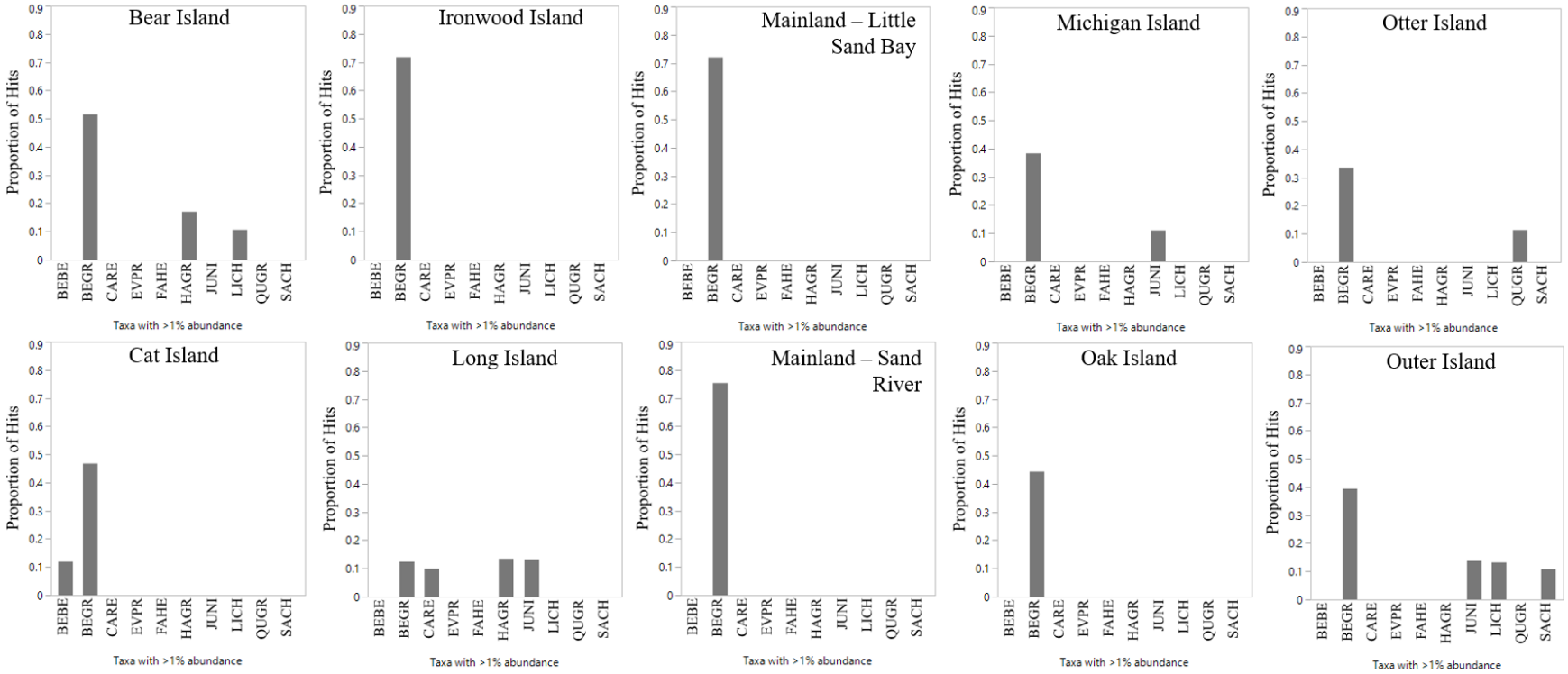


Figure 27a. Proportion of hits observed among the ten top tier taxa (present >1% of points) across all sandscapes and broken out by sandscape location. Only beachgrass was consistently a top tier taxa observed at all sandscape locations. Beachgrass was usually the most frequent species, but at some locations it was a co-dominant. BEBE = *Arctostaphylos uva-ursi*, BEGR = *Ammophila breviligulata*, EVPR = *Oenothera oakesiana*, FAHE = *Hudsonia tomentosa*, HAGR = *Deschampsia flexuosa*, JUNI = *Juniperus communis*, LICH = Lichen spp., QUGR = *Agropyron repens*, SACH = *Prunus pumila*.

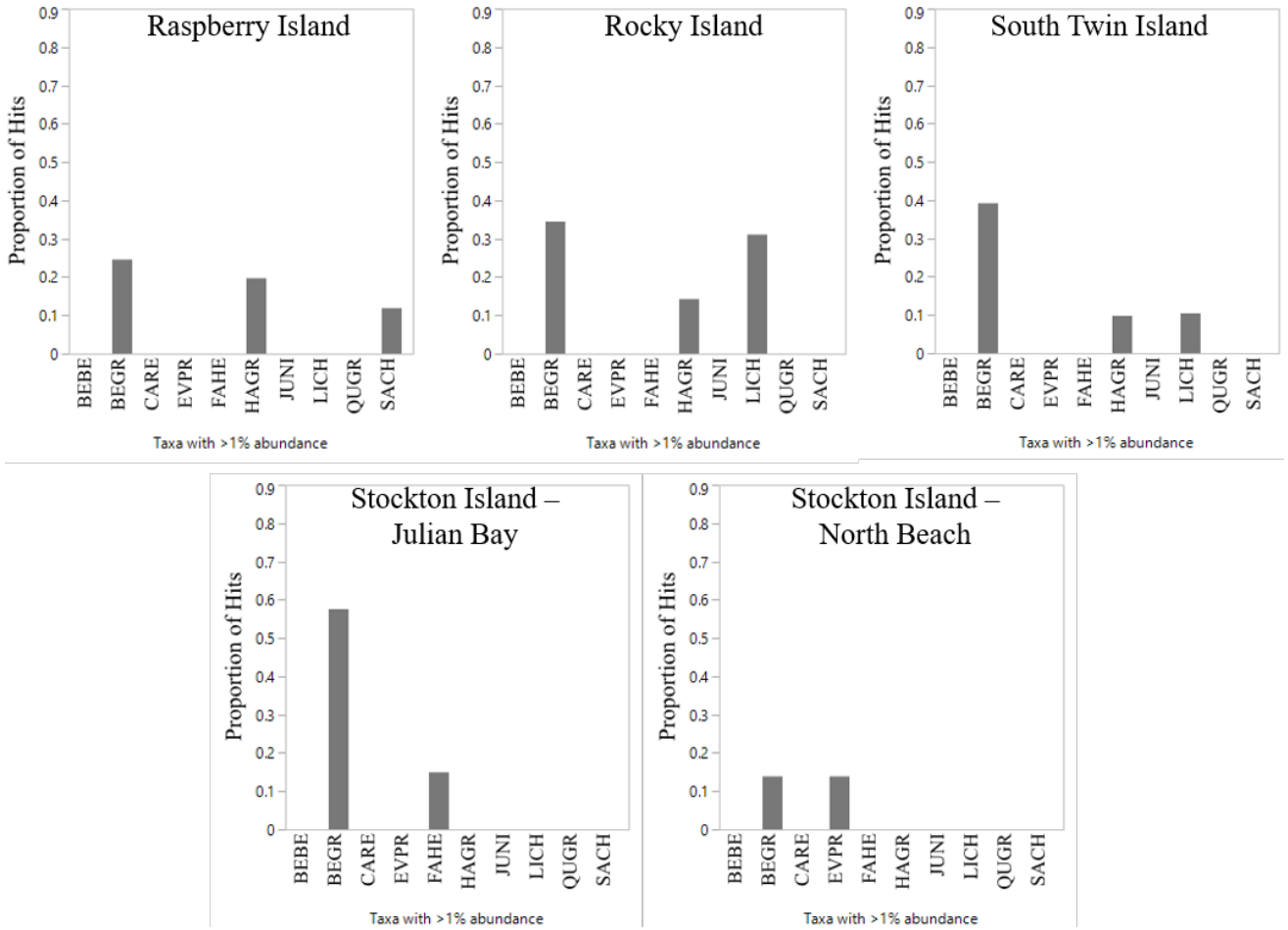


Figure 27b. Proportion of hits observed among the ten top tier taxa (present >1% of points) across all sandscapes and broken out by sandscape location. Only beachgrass was consistently a top tier taxa observed at all sandscape locations. Beachgrass was usually the most frequent species, but at some locations it was a co-dominant. BEBE = *Arctostaphylos uva-ursi*, BEGR = *Ammophila breviligulata*, EVPR = *Oenothera oakesiana*, FAHE = *Hudsonia tomentosa*, HAGR = *Deschampsia flexuosa*, JUNI = *Juniperus communis*, LICH = Lichen spp., QUGR = *Agropyron repens*, SACH = *Prunus pumila*.

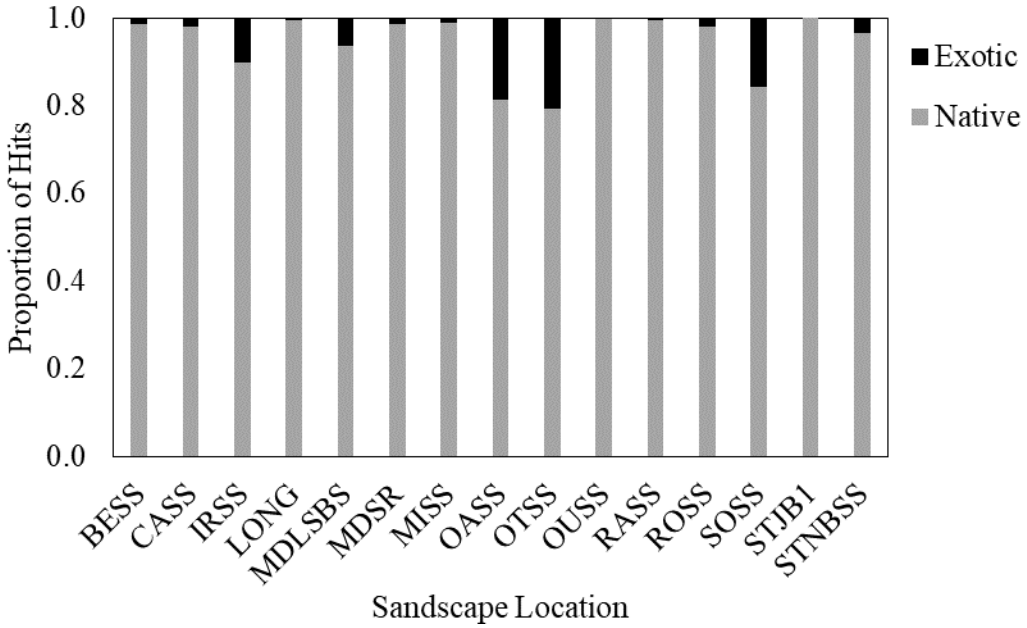


Figure 28. Proportion of native and exotic taxa (#exotic or native hits / #points sampled) observed among sandscape location points in Apostle Islands National Lakeshore in summer 2014. These data exclude "empty" points. The vegetation among all sandscape locations is primarily comprised of native species.

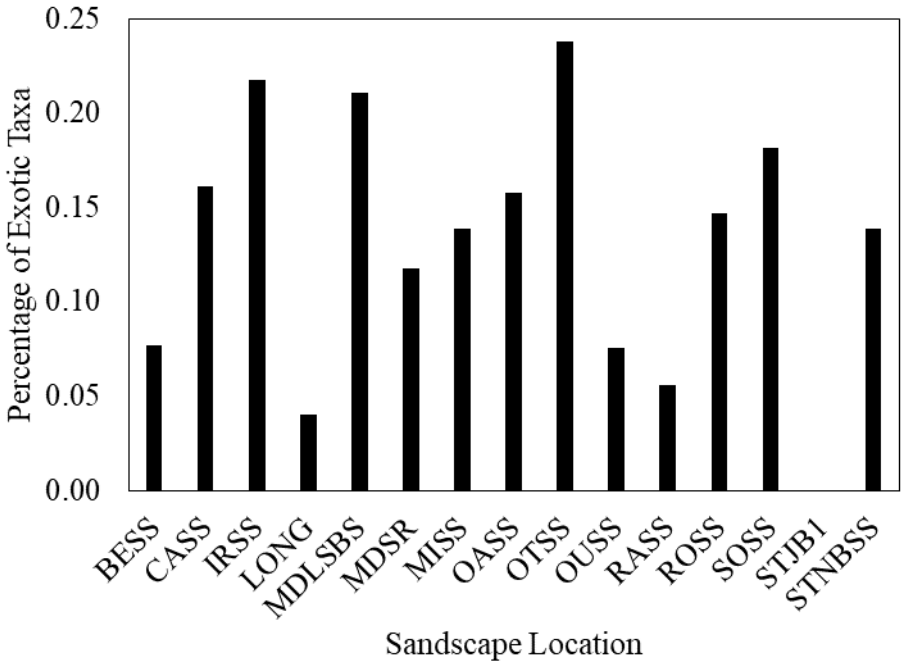


Figure 29. Percentage of exotic taxa (# exotic taxa / # total taxa) observed among sandscape locations in Apostle Islands National Lakeshore in summer 2014. Greater than 20% of the taxa (not hits) are exotic on Otter Island, Ironwood Island, and Mainland-Little Sand Bay, and >15% of taxa are exotic on Cat Island, South Twin Island, and Oak Island. Michigan and Stockton-North Beach are approaching 15% of exotic taxa.

Stockton Island-Julian Bay, followed by Raspberry and Outer Islands, had the highest number of specialist species devoted to relatively intact natural areas, as measured by the mean Coefficient of Conservatism (Mean C) and a Floristic Quality Index (FQI; Table 2). The higher Mean C and FQI for Stockton Island-Julian Bay is primarily due to the presence of specialist bog species that were picked up in some of the wetland swales found amid the dune field. Sandscapes with the lowest scores—Ironwood, Otter, and South Twin Islands—had relatively more exotic taxa, weighting those scores lower (C of C values = 0 for non-native taxa).

Table 2. Summary of species richness, species density, Mean C (average of Coefficient of Conservatism scores), and Floristic Quality Index (FQI; see Equation 2). Caution must be taken when interpreting FQI alone, as sample size will strongly influence species richness. Higher Mean C and FQI scores indicate that the plant community is comprised of more specialist species; lower scores indicate more generalist species with no strong affinity for a particular habitat type. The higher Mean C and FQI for Stockton-Julian Bay is being driven mostly by a few specialist bog species that were picked up in wetland swales that bisected the dune field. Islands with the lowest scores—Ironwood, Otter, and South Twin—have relatively more exotic species, whose C of C scores are "0".

Location	Richness	Species Density (# species / # sample points)	Mean C	FQI
BESS	26	0.034	4.71	24.01
CASS	32	0.055	4.30	24.32
IRSS	24	0.043	3.55	17.37
LONG	27	0.053	5.38	27.93
MDLSBS	19	0.038	4.17	18.16
MDSR	18	0.064	4.72	20.03
MISS	36	0.008	4.35	26.12
OASS	40	0.043	4.10	25.95
OTSS	22	0.156	3.50	16.42
OUSS	54	0.005	4.98	36.60
RASS	20	0.029	5.61	25.09
ROSS	35	0.012	4.41	26.07
SOSS	48	0.033	3.88	26.91
STJB1	34	0.006	6.10	35.36
STNBSS	36	0.049	4.52	27.09

Graminoids were by far the most frequent foliar type among most islands (primarily *Ammophila breviligulata*), but lichens were more frequent on Rocky Island (71% of hits) and Outer Island (40% of hits) (Figure 30). Lichens were nearly as frequent as graminoids on South Twin and Bear sandscapes. Shrub cover was greater than 15% on Raspberry Island, Stockton-Julian Bay, Outer

Island, and Michigan Island. Forb cover was less than 17% on all islands, with Otter, Oak, and Ironwood Islands having the highest frequency of forbs. Fewer than 1% of hits were of forbs on Stockton-Julian Bay. Ferns, mosses, and tree seedlings were scarce among sandscapes (Figure 30).

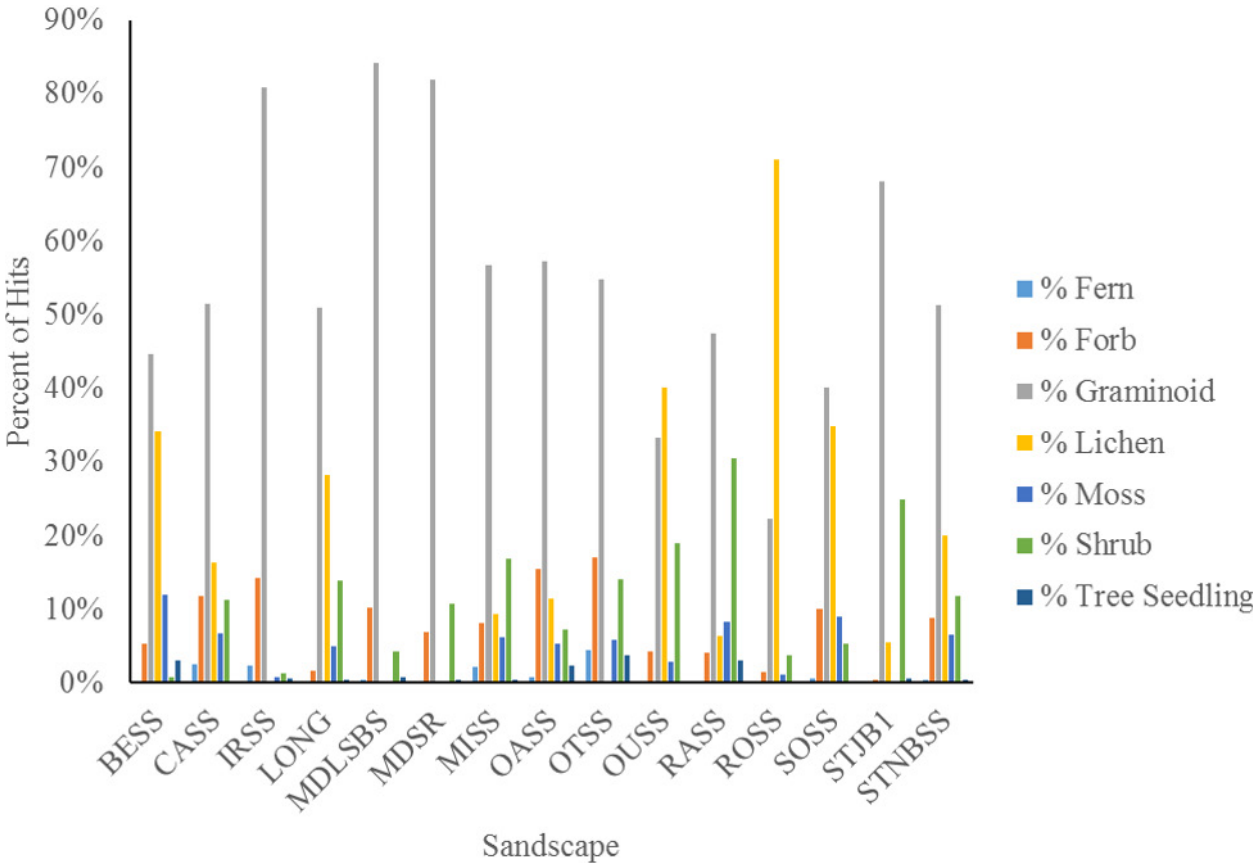


Figure 30. Percent of foliar hits broken out by type ("habit") among sandscapes. Graminoids were by far the most frequent among most islands (primarily *Ammophila breviligulata*), but lichens were more frequent on Rocky (71% of hits) and Outer Islands (40% of hits). Lichens were nearly as frequent as graminoids on South Twin and Bear sandscapes. Shrub cover was >15% on Raspberry Island, Stockton-Julian Bay, Outer Island, and Michigan Island. Forb cover was <17% on all islands, with Otter, Oak, and Ironwood Islands having the highest frequency of forbs. Fewer than 1% of hits were of forbs on Stockton-Julian Bay. Ferns, mosses, and tree seedlings were more scarce.

By applying NMDS ordination to this multivariate data set, we demonstrate the relationship in plant composition among all transects surveyed across all sandscapes (Figure 31). This two-dimensional solution explained 74.6% of the variation in these sandscape communities. The majority of transects overlapped, indicating similar composition (left-hand side of Figure 31), but some sandscapes' transects were more unique in their composition and thus their distribution in ordination space was more scattered (right-hand side of Figure 31). The prevalence of exotic taxa contributes to the distinctiveness among some sandscapes' transects (lower right-hand corner of Figure 31). Similarly, the relative abundance of each species contributes to the phytological relationships and distinctions among transects (Figure 32a–i). Based on our knowledge of species' natural history and the results of

these ordinations, we developed ecological interpretations of the primary factors contributing to the spread or clustering of transects along axes 1 and 2 (Figure 31). Species we consider to be specialists to dune habitats were more negatively associated with Axis 1 (Figures 31 and 32a–i), including *Ammophila breviligulata* (beachgrass), *Hudsonia tomentosa* (false heather), *Juniperus communis* (common juniper), *Lathyrus japonicus* (beach pea), *Deschampsia flexuosa* (hair grass), and *Prunus pumila* (sand cherry). Of these taxa, *A. breviligulata* is the earliest successional species in the western Lake Superior dune community, and this species predominated among transects negatively associated with Axis 2 (Figures 31 and 32a–i). Shrub species, lichens, and mosses became proportionally more frequent among transects positively associated with Axis 2 and negatively associated with Axis 1 (upper-left corner of Figures 31 and 32a–i). Sandscapes with the most similar transects (tighter cluster of transects) included Stockton-Julian Bay, the two mainland sandscapes, Stockton-North Beach, and Outer Island. Otter Island, South Twin Island, Cat Island, Long Island, and Raspberry Island, had sandscapes with a high level of distinctiveness in plant communities among transects, primarily driven by the occurrences of non-native taxa.

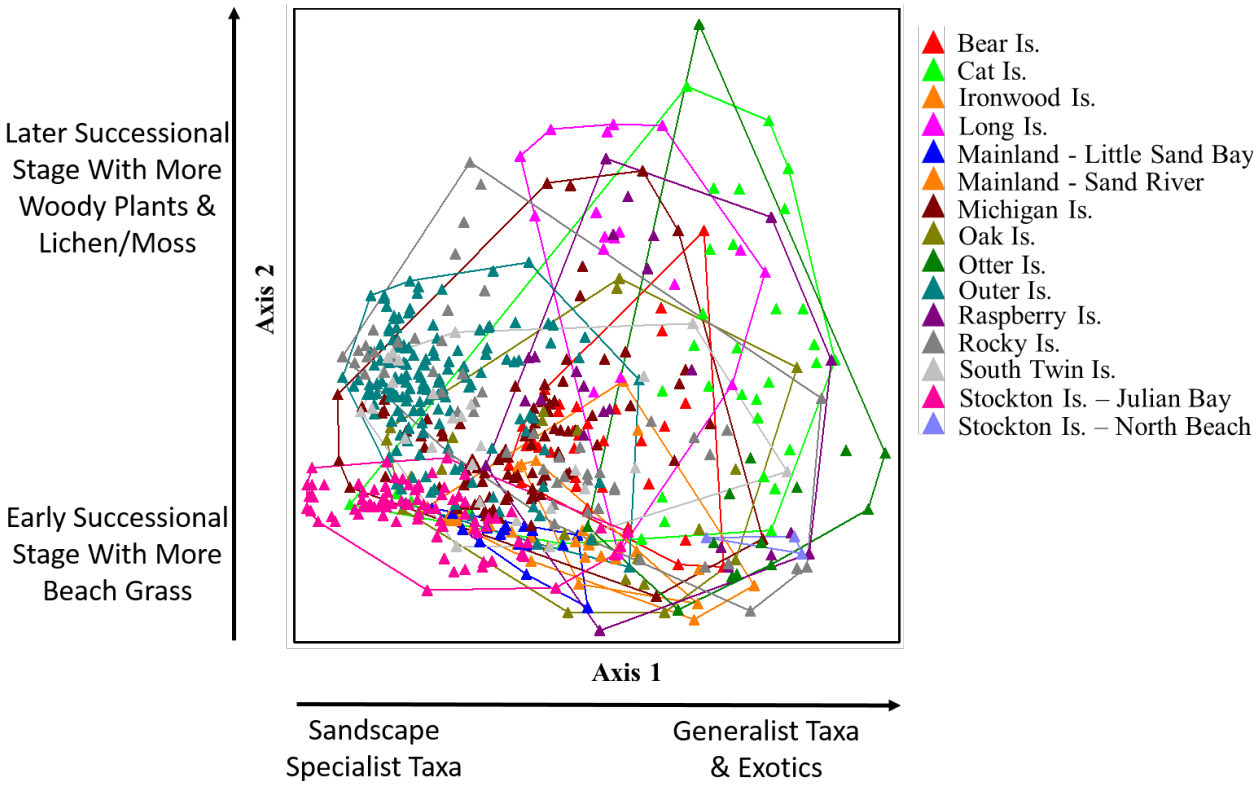


Figure 31. Non-metric multidimensional ordination (NMDS) graph showing two axes explaining 74.6% of the variation in taxa abundance among transects and among sandscape locations. Polygons connect the most distinct transects within a sandscape, thus smaller polygons represent more homogenous plant communities at those sandscapes. Triangles closest together in ordination space are the most similar in plant composition and those farthest apart have the most distinct composition. Based on overlays of species abundances at transect-sandscape locations, we have added our interpretations of the major factors distinguishing transect-sandscape communities across axes 1 and 2.

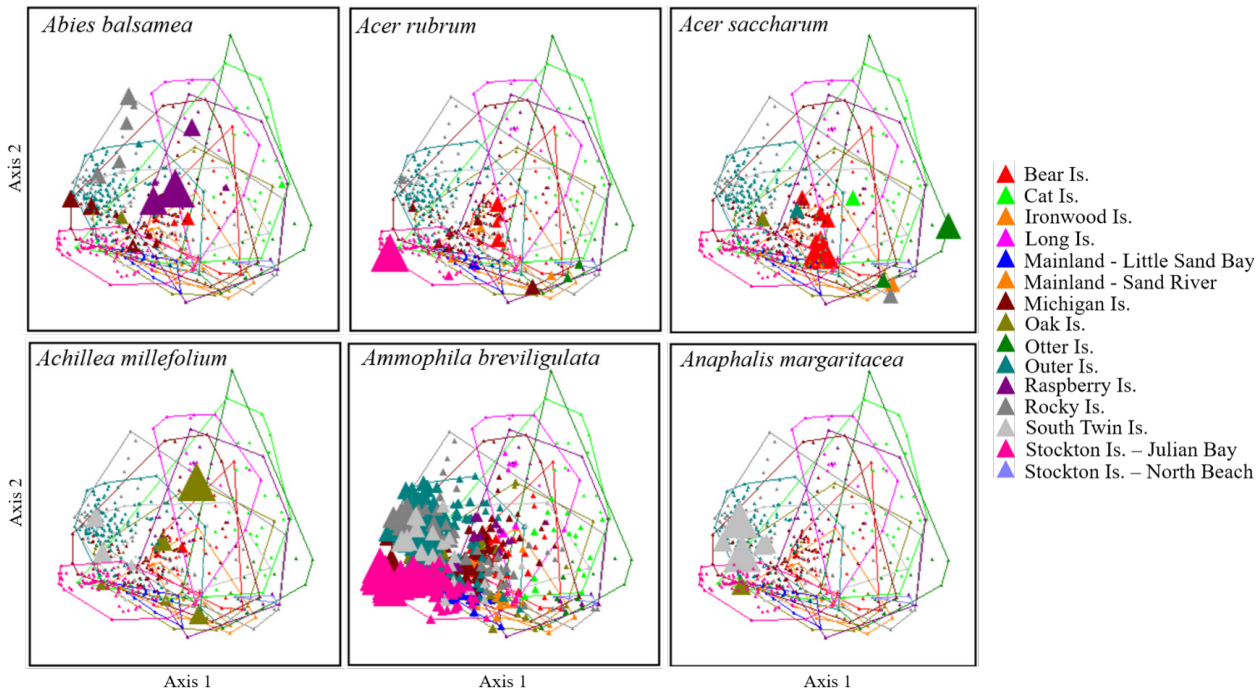


Figure 32a. Non-metric multidimensional ordination (NMDS) graph showing two axes explaining 74.6% of the variation in taxa abundance among transects and among sandscape locations. Triangles, representing transect-sandscape locations, are enlarged relative to an increasing abundance of each focal taxa.

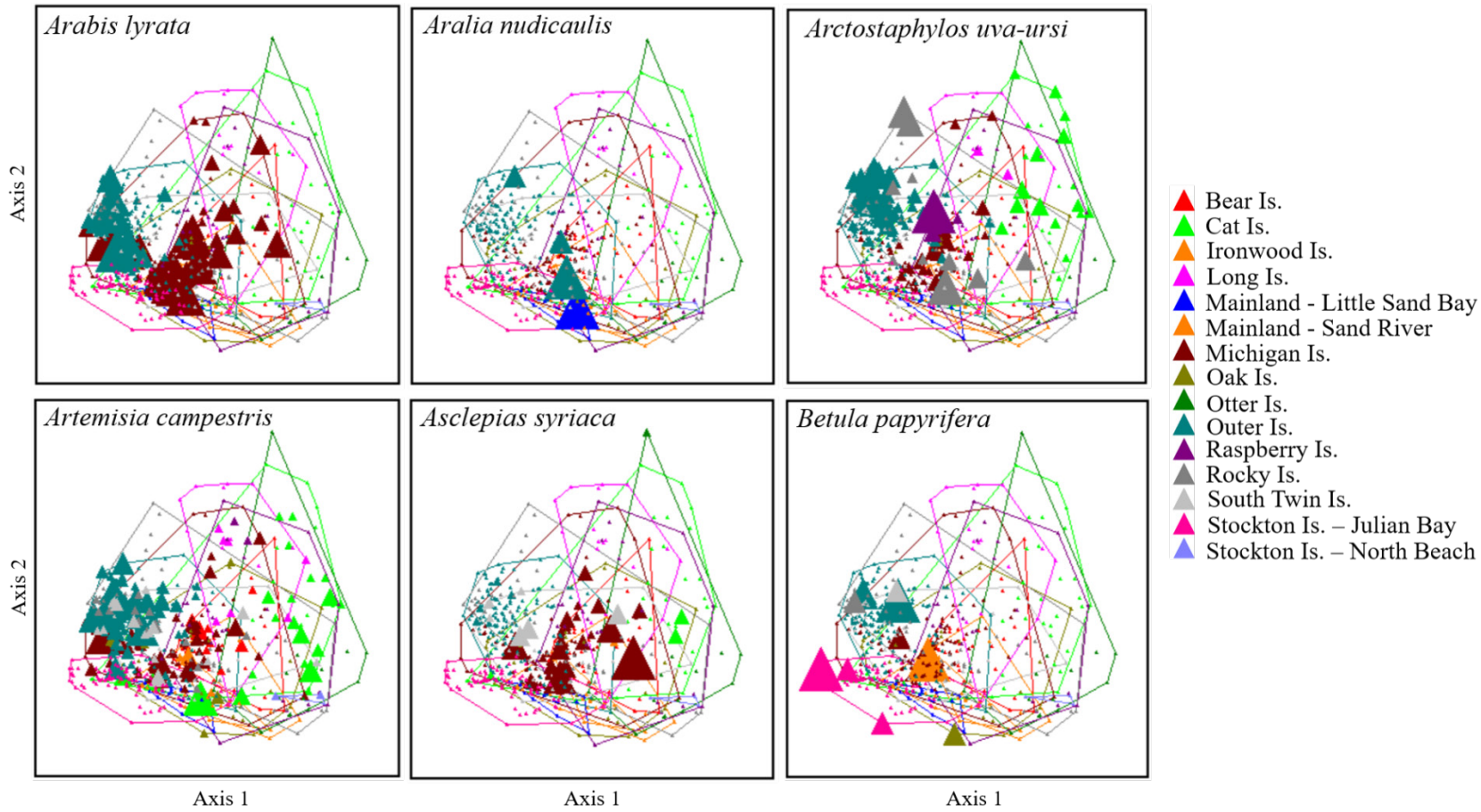


Figure 32b. Non-metric multidimensional ordination (NMDS) graph showing two axes explaining 74.6% of the variation in taxa abundance among transects and among sandscape locations. Triangles, representing transect-sandscape locations, are enlarged relative to an increasing abundance of each focal taxa.

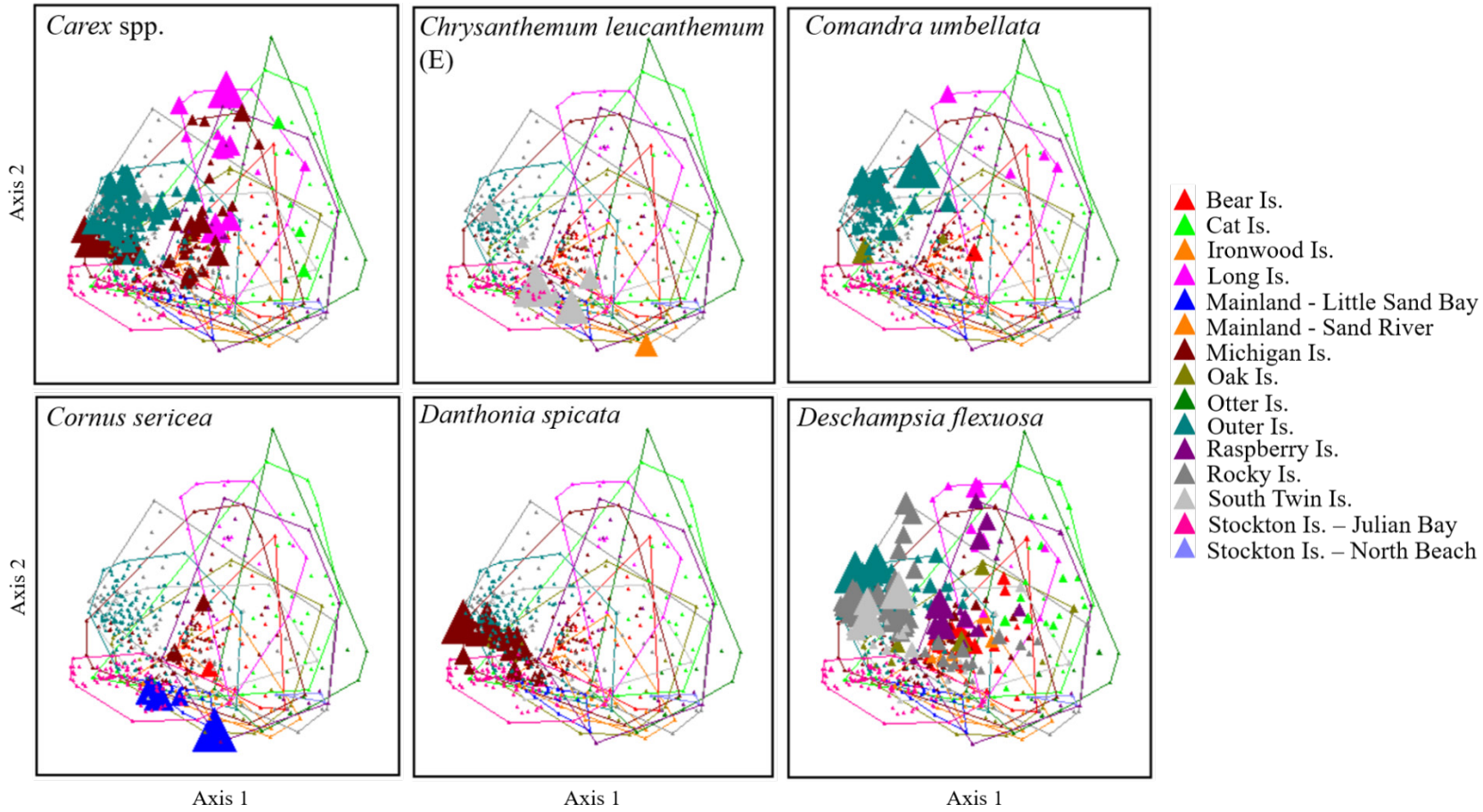


Figure 32c. Non-metric multidimensional ordination (NMDS) graph showing two axes explaining 74.6% of the variation in taxa abundance among transects and among sandscape locations. Triangles, representing transect-sandscape locations, are enlarged relative to an increasing abundance of each focal taxa.

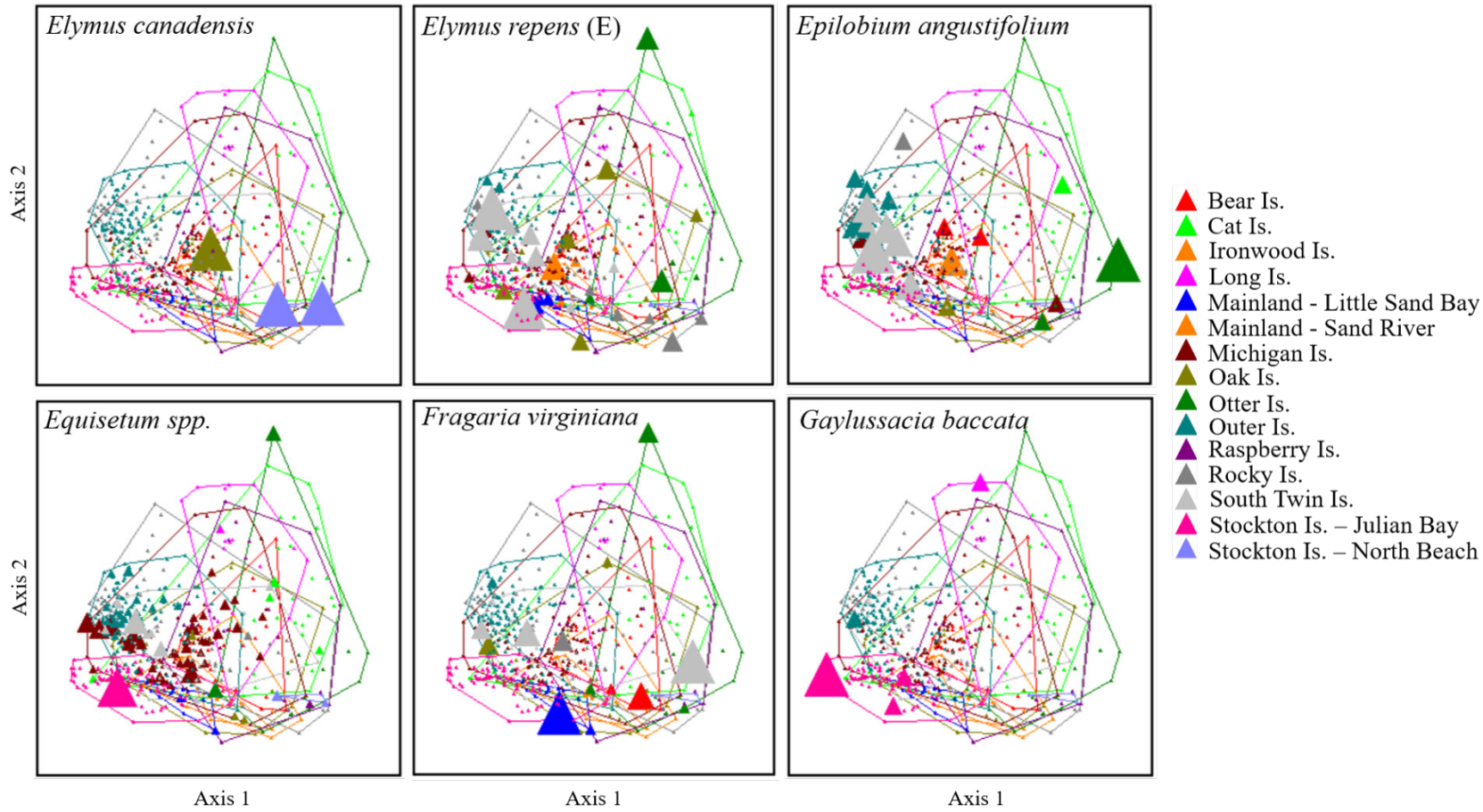


Figure 32d. Non-metric multidimensional ordination (NMDS) graph showing two axes explaining 74.6% of the variation in taxa abundance among transects and among sandscape locations. Triangles, representing transect-sandscape locations, are enlarged relative to an increasing abundance of each focal taxa.

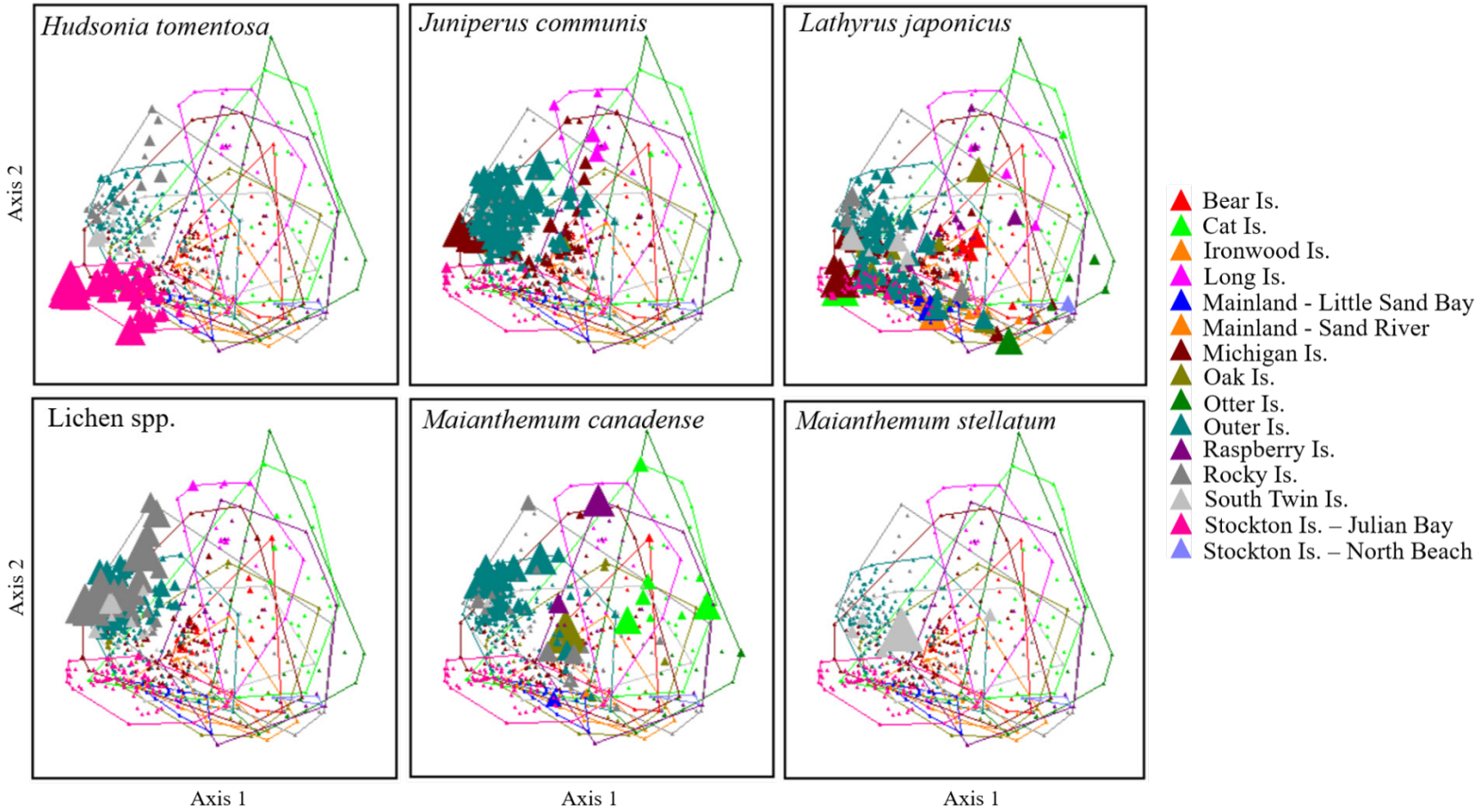


Figure 32e. Non-metric multidimensional ordination (NMDS) graph showing two axes explaining 74.6% of the variation in taxa abundance among transects and among sandscape locations. Triangles, representing transect-sandscape locations, are enlarged relative to an increasing abundance of each focal taxa.

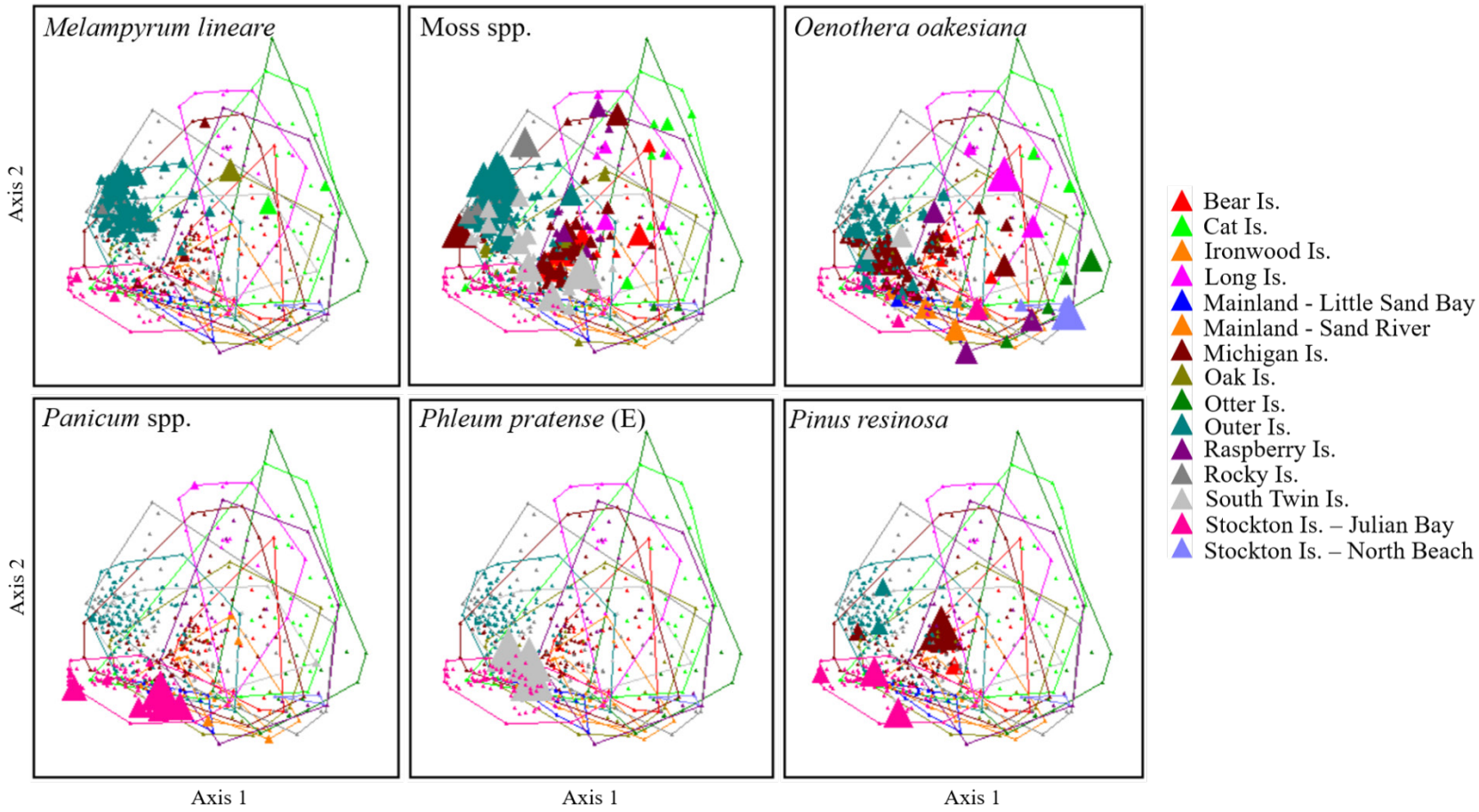


Figure 32f. Non-metric multidimensional ordination (NMDS) graph showing two axes explaining 74.6% of the variation in taxa abundance among transects and among sandscape locations. Triangles, representing transect-sandscape locations, are enlarged relative to an increasing abundance of each focal taxa.

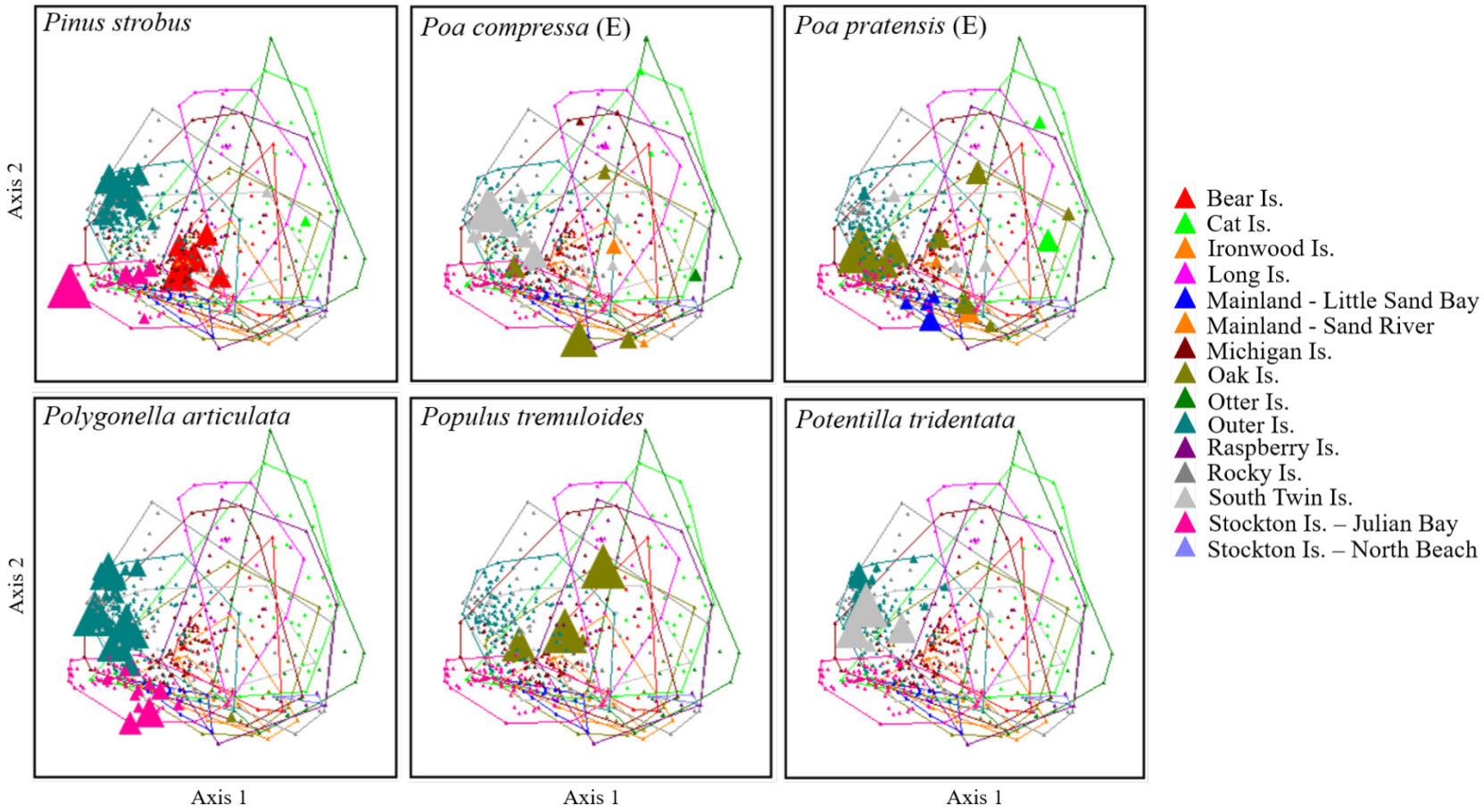


Figure 32g. Non-metric multidimensional ordination (NMDS) graph showing two axes explaining 74.6% of the variation in taxa abundance among transects and among sandscape locations. Triangles, representing transect-sandscape locations, are enlarged relative to an increasing abundance of each focal taxa.

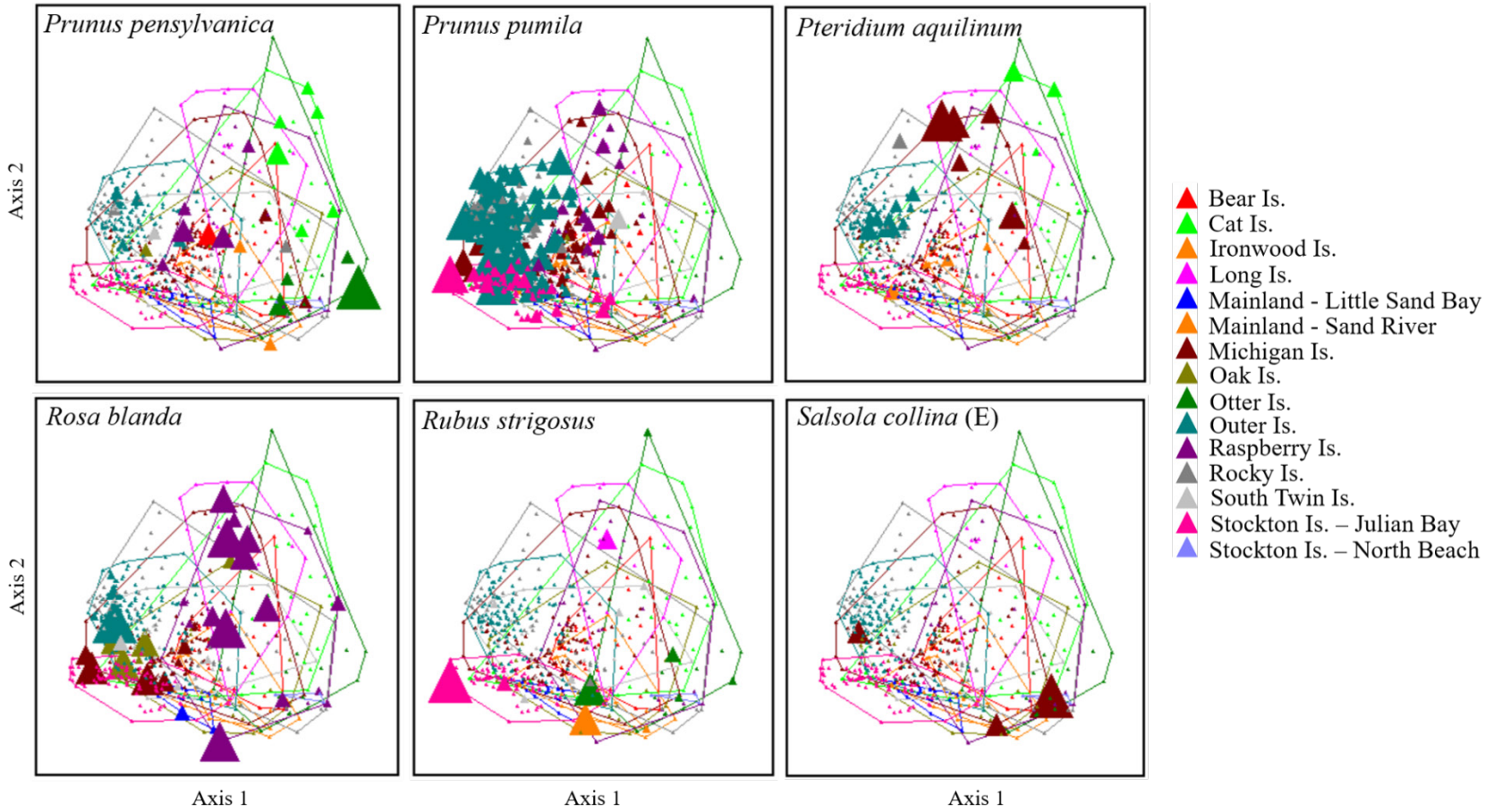


Figure 32h. Non-metric multidimensional ordination (NMDS) graph showing two axes explaining 74.6% of the variation in taxa abundance among transects and among sandscape locations. Triangles, representing transect-sandscape locations, are enlarged relative to an increasing abundance of each focal taxa.

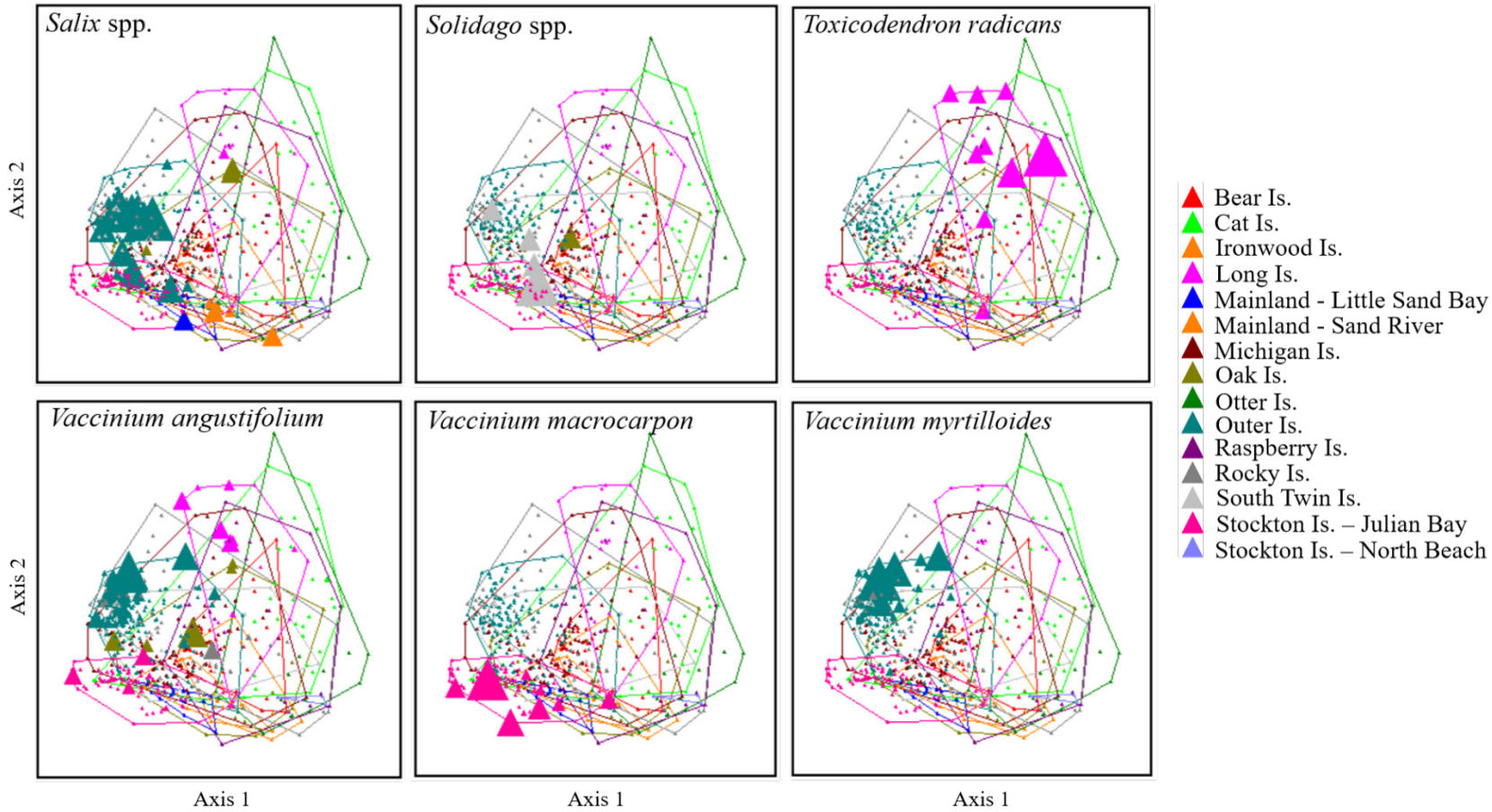


Figure 32i. Non-metric multidimensional ordination (NMDS) graph showing two axes explaining 74.6% of the variation in taxa abundance among transects and among sandscape locations. Triangles, representing transect-sandscape locations, are enlarged relative to an increasing abundance of each focal taxa.

Sandscape disturbance – Presence, size, and frequency of trails

Two of the largest sandscapes—Stockton Island-Julian Bay and Outer Island—had the highest total length of trails (Table 3; Appendix A Figures A14 and A9). Both Outer and Mainland-Little Sand Bay had the highest number of trail segments, but given the smaller size of Little Sand Bay, 11 trail segments have resulted in a significant trail network there (Appendix A Figure A4). Except for on Mainland-Sand River and Long Island, the maximum trail width was <1m (Table 3). No trails were observed on Bear Island (Appendix A Figure A1), indicating low visitor usage and impacts. A large bare area due to trampling was delineated on the popular Oak Island (Appendix A Figure A7).

Table 3. Summary of the number and size of trails delineated with GPS at each sandscape location. Using a meter tape in the field, we recorded maximum trail width while taking photo-points of trails. We did not collect maximum width data of the trails on South Twin Island.

Island	Total Trail Length (m)	# Trails	Max Width (m)
Bear	0.0	0	0.00
Cat	119.6	3	0.46
Ironwood	60.2	2	0.30
Long	73.2	1	1.07
Michigan	181.7	3	0.46
Oak	197.4	3	0.30
Otter	165.4	7	0.30
Outer	1001.6	14	0.30
Raspberry	359.3	5	0.91
Rocky	408.5	4	0.30
Sand River	148.1	1	1.22
Stockton Julian Bay	1026.7	6	0.76
Stockton North Beach	85.4	1	0.46
South Twin	268.5	3	–
Little Sand Bay	442.2	12	0.91

Assessing the step-point sampling method

By reducing the sampling intensity from an 8 m transect spacing to a 16 m (50% intensity) or 32 m (25% intensity) spacing, the overall patterns and interpretations of sandscape surface structures are upheld in the data for most of the sandscapes (see Figures 7–21). Some of the resolution is lost with the 25% sampling intensity, especially on the smaller sandscapes (e.g., see Figure 13). Scatter in the proportion of surface hits occurs the most in the full data set, indicating what is likely to be sampling error associated with crew members leap-frogging to sample alternating transects. By removing

alternating transects to create the 50% reduced data set, much of this variability is removed (e.g., see Figure 8). Despite this sampling error, the differences among surface types was greater than the *within*-surface type variability among transects (e.g., see Figure 16), suggesting that the step-point method's data are somewhat robust to slight differences in how crew members code "hits". There was no significant difference between even and odd transects ($F_{1,1476}$ = 0.005; P =0.96), further supporting a 16 m spacing of transects instead of 8 m.

These results, along with the rarefaction results for species diversity (see Figures 25a–c) indicate that a reduced sample size should return adequate data on sandscape structure and the diversity and abundance of the most frequent species among sandscapes. However, the reduced sampling effort could result in lower statistical power to detect changes in the abundance of the rarer components of these sandscapes.

By comparing the step-point method with a quadrat sampling approach at Stockton-Julian Bay, we observed that the two methods closely approximate each other with data on the relative abundance of bare ground, vegetation, and litter (Figures 33–34). Both methods picked up the large blow out area starting 450 m north of the start of the pine barren. However, there was a discrepancy in that at approximately 800 m north, the quadrat method picked up a higher percentage of bare ground than the step-point method. Thirty-two taxa were observed among the 5,174 points and 95 transects of the step-point method, compared with 20 taxa recorded among 305 1-m^2 quadrats on 23 transects (Table 4). Among the top ten most frequent taxa observed with each method, six were shared (Table 4) and most of the remaining taxa were sparsely abundant. A key difference between the two methods was that the step-point method took four days and the quadrat method only took one day with a similar size crew.

In determining where the start point should be for each transect (zone 1 or start of zone 3), we present data in support of starting all transect sampling on the active beach zone (Figures 34–35). In our summer 2014 protocol, we established the start points at the top of the splash zone on the beach (wet sand). Of course, wave height will vary over time, but in most cases during our surveys, we were consistent in placing the start points at mid-beach or within the upper ⅓ of the active beach zone. Transects were established by two of the same people working together, and they were careful in keeping start points consistent across a given sandscape. Hence, with this method we can document areas of possible concern to managers (Figures 34–35; Appendix B Figures B1–B15).

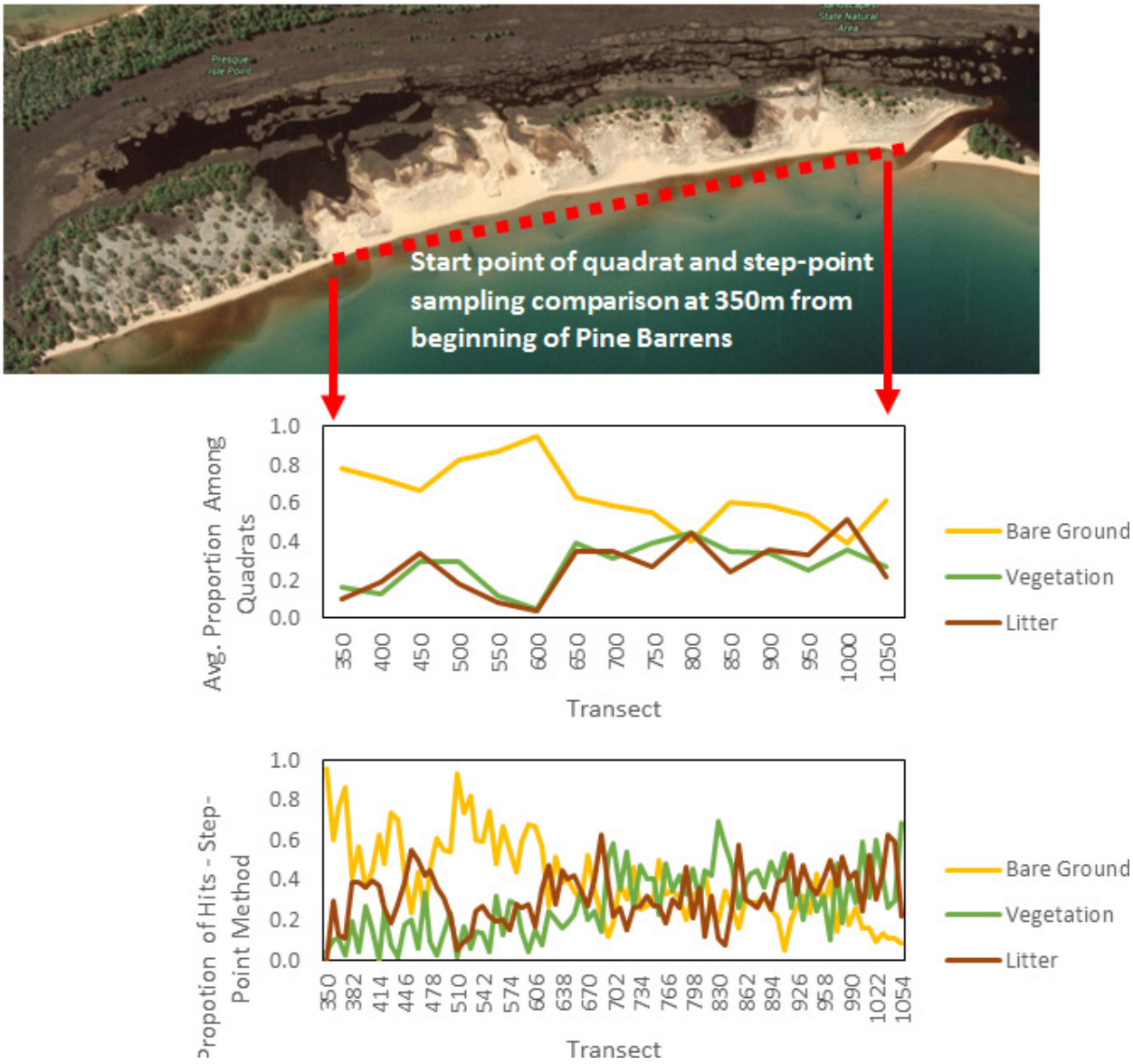


Figure 33. Comparison of the surface type profile of data collected with 1-m^2 quadrats (spaced every 5 m along 23 transects spaced every 50 m) and from data collected using the step-point sample method (points spaced every meter along 89 transects spaced every 8 m). The line on the aerial images indicates the start and end transect points in the area sampled. The two methods appear to closely approximate each other, except the step-point method estimates lower bare ground along transects 798+ compared to these same transects sampled using the quadrat method.

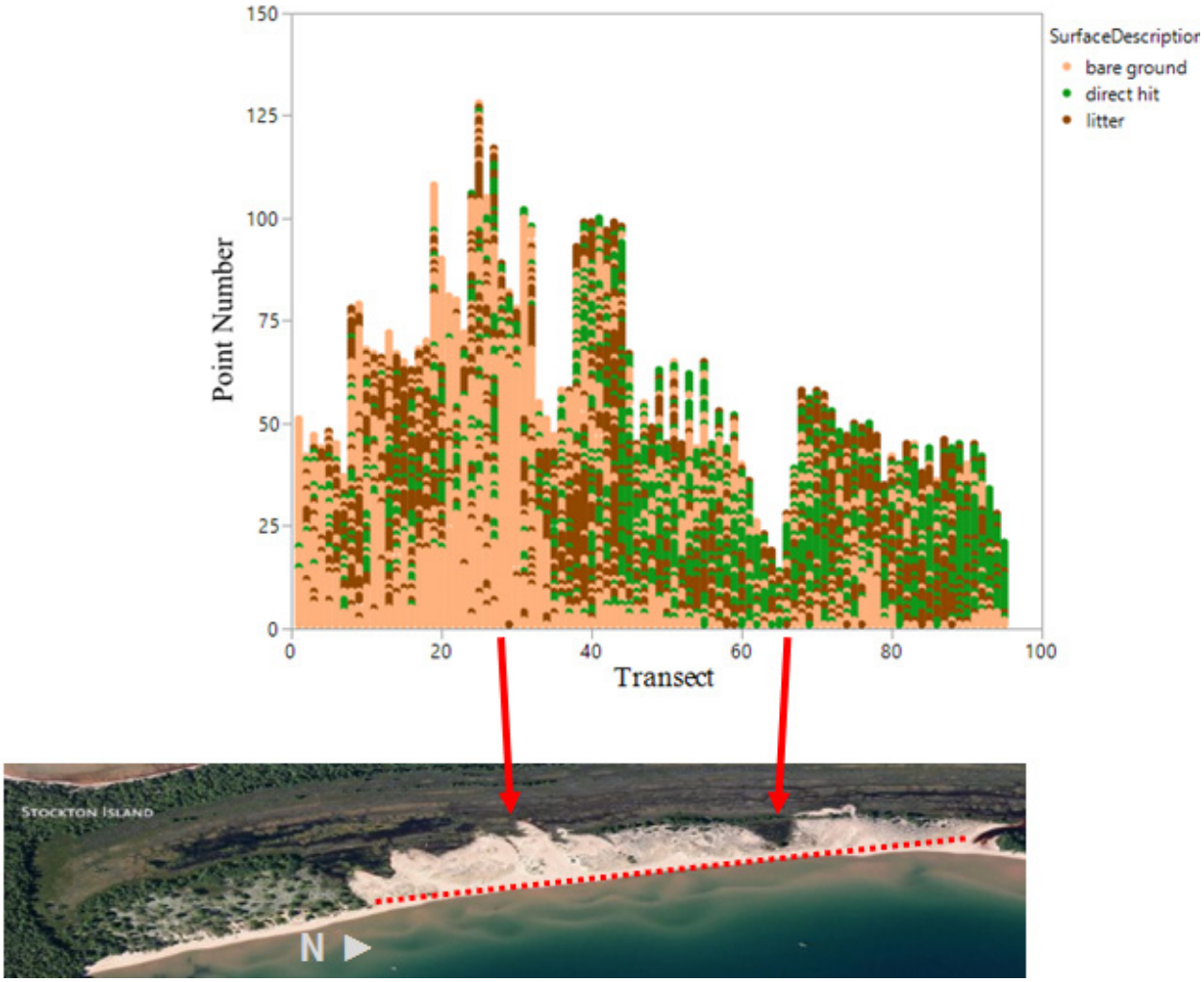


Figure 34. Sandscape profile graph illustrating step-point surface hit types at **Stockton Island-Julian Bay**, starting north of the pine barren. The largest number of points where bare ground was observed was in the first 1/3 of sampled transects. By starting all transects at a similar point on the beach, we are able to map the profile of the dune vegetation and areas of dune blow-outs and possible trampling effects closer to the beach. When vegetation starts abruptly at point 1, this can indicate eroded beaches with very little open sand. Additional beach profile graphs for other sandscapes are included in Appendix 3.

Table 4. Taxa and their proportional abundance observed by two sampling methods—step-point and quadrat—applied to the dune community at Stockton-Julian Bay. The step-point sampling method was more intensive in that 5,174 points were sampled one-meter apart along transects spaced every 8 m. The quadrat method recorded all taxa within a 1 m^2 area in 305 quadrats spaced every 5 m along transects spaced every 50 m. "n.d." = not detected.

Scientific Name	Step-Point Method–Proportion of Hits (n = 5,174 points)	Quadrat Method–Relative Freq (# quads/ 305 quads)
Acer rubrum	0.0016	0.0066
Acer saccharum	n.d.	0.0033
Ammophila breviligulata	0.6916	0.5049
Andromeda polifolia	0.0002	0.0033
Arabis lyrata	0.0002	n.d.
Betula papyrifera	0.0009	n.d.
Carex pensylvanica	n.d.	0.0066
Carex spp.	0.0013	n.d.
Chamaedaphne calyculata	0.0031	0.0230
Deschampsia flexuosa	0.0013	0.0066
Equisetum spp.	0.0020	n.d.
Gaylussacia baccata	0.0011	0.0066
Hudsonia tomentosa	0.1826	0.1344
Juniperus communis	0.0040	n.d.
Kalmia polifolia	0.0004	n.d.
Lathyrus japonicus	0.0004	n.d.
Lichen spp.	0.0120	0.0098
Melampyrum lineare	0.0004	n.d.
Moss spp.	0.0007	0.0066
Myrica gale	0.0004	0.0066
Oenothera oakesiana	0.0007	0.0098
Panicum spp.	0.0087	0.0098
Pinus resinosa	0.0011	n.d.
Pinus strobus	0.0031	n.d.
Polygonella articulata	0.0036	n.d.
Potentilla tridentata	0.0002	0.0033

Table 4 (continued). Taxa and their proportional abundance observed by two sampling methods—step-point and quadrat—applied to the dune community at Stockton-Julian Bay. The step-point sampling method was more intensive in that 5,174 points were sampled one-meter apart along transects spaced every 8 m. The quadrat method recorded all taxa within a 1 m^2 area in 305 quadrats spaced every 5 m along transects spaced every 50 m. “n.d.” = not detected.

Scientific Name	Step-Point Method–Proportion of Hits (n = 5,174 points)	Quadrat Method–Relative Freq (# quads/ 305 quads)
Prunus pensylvanica	n.d.	0.0033
Prunus pumila	0.0426	0.0754
Rosa blanda	n.d.	0.0033
Rubus spp.	0.0009	n.d.
Rubus strigosus	0.0020	n.d.
Salix spp.	0.0002	n.d.
Spiraea alba	0.0073	0.0131
Vaccinium angustifolium	0.0033	n.d.
Vaccinium macrocarpon	0.0111	0.0131

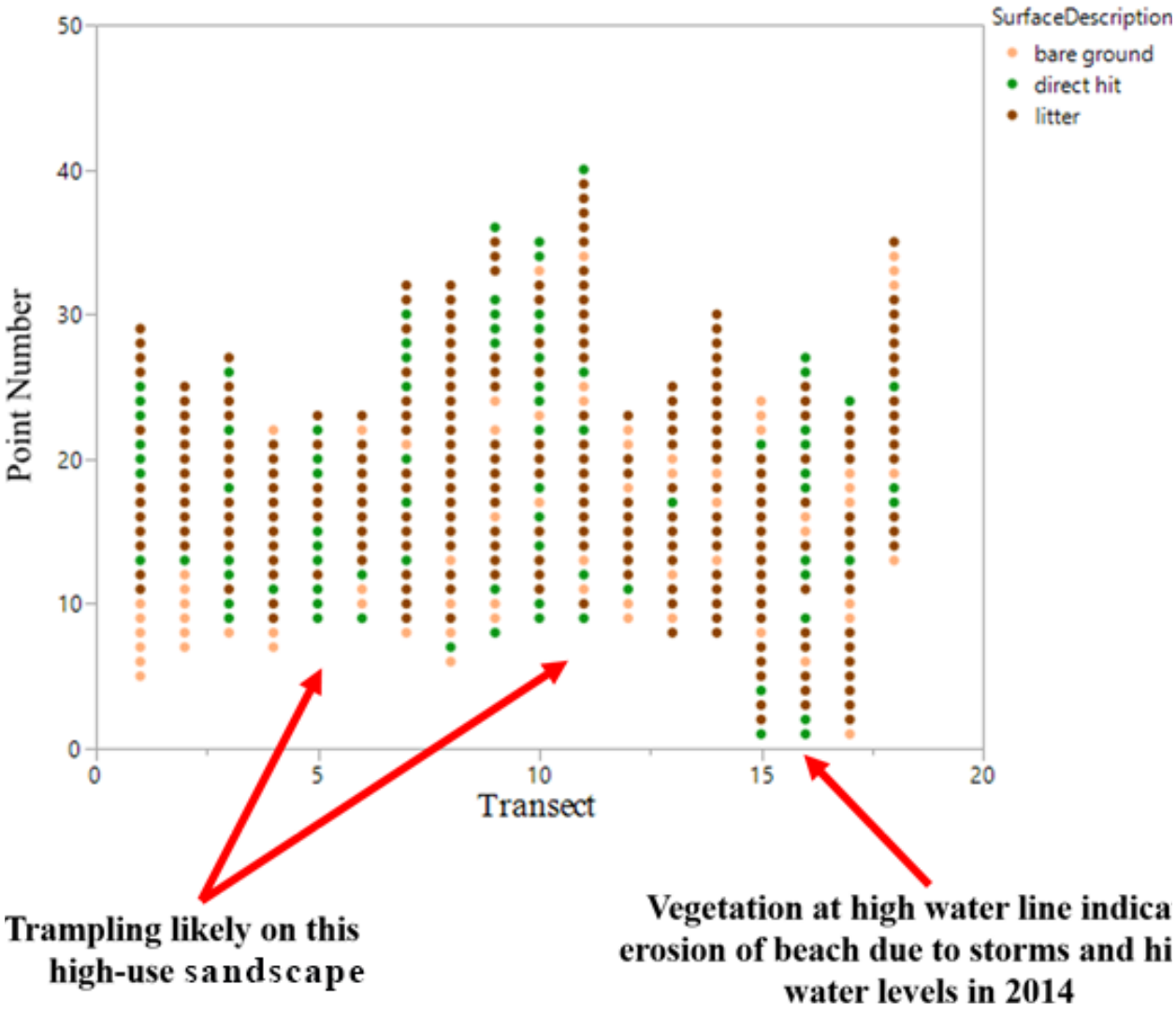


Figure 35. Example of the usefulness of starting transect sample points in the active beach zone and approaches managers can use to interpret plots such as these. In this case, we graph surface type data for Mainland-Little Sand Bay and exclude zones 1 and 2 with points lacking any vegetation ("empty" points).

Discussion

These 15 sandscapes contain a range of microhabitats from young, active dunes to older and more stable dunes. This gradient of habitats can be seen both within and among the sandscapes, but is most noticeable on the larger sandscapes. Patterns such as these have been of interest to ecologists studying dune systems since the late 1800s (e.g., Cowles 1899, Olson 1958b, Rosenthal et al. 2005). These, and other studies of succession in dune vegetation, have documented higher species richness on older dunes due in part to soil stability, higher soil moisture, greater nutrient availability, differences in soil texture, and less wind exposure. More recently, Emery et al. (2015) detailed a positive relationship between the abundance of arbuscular mycorrhizal fungi and dune species richness. Thus, there is clear evidence for both abiotic and biotic controls of species composition in dune systems. Species composition is further controlled by colonization events, which are more

restricted in an island system such as the Apostle Islands. Because species are adapted in different ways to their microhabitats in dune systems, having an array of successional states available both within and among sandscape sites is desirable (Marshall 2014). Thus, maintaining relatively simple sandscapes dominated by *Ammophila breviligulata* should be as much of an interest to managers, as is the more diverse backdune areas that support later successional taxa such as shrubs, lichens, and mosses.

Among the 15 sandscapes at APIS, *Ammophila breviligulata* is the most frequent species encountered. It shares dominance status with other taxa on only Long Island and Stockton Island-North Beach. *Ammophila breviligulata*, in addition to other grass and sedge species comprising the graminoids, contributes to an open and grassland-like community in these coastal habitats. Where sands have become more stable with sufficient moisture and nutrient levels, lichens are commonly encountered. Further into the dune field and towards the backdunes abutting the treeline, a variety of shrubs appear, representing later successional habitat better protected from wind and waves.

Impacts to these patterns in these sandscape communities provide certain signatures that we can look for to detect changes linked with natural and human-caused disturbance. Uncoupling the causes of disturbance can be difficult, but should become better understood over time with the use of multiple response variables and a more standardized sampling protocol that maps the sandscape shape and size. We have compiled a set of hypothesized changes and multiple interpretations of these changes for a large set of response variables (Table 5). Interpreting changes over time requires a firm understanding of the sampling methods and limitations of the data. For example, increases in the proportion of bare ground coupled with declines in foliar cover—as observed in previous years using the original monitoring methods (Burkman 2013)—can be interpreted to be due to dieback in the dominant grass species *Ammophila breviligulata* due to trampling, declines in sand burial, climate change-related variables, or other unknown reasons. Changes in bare ground and foliar cover could also be a function of increased sand deposition and a higher proportion of early successional, active beach and nascent dunes not previously included in the total sample area. Sandscape size has increased since the 1950s (Johnson and Mead 2013) and much of this expansion likely occurred during the late 1990s and 2000s due to lower average lake-wide levels in Lake Superior (Figure 36). More recently, beach areas have declined due to higher water levels and storm events in 2014 to present (Figure 36), and in some cases nascent dunes now have cut-banks (S. Johnson, personal observation). These shoreline patterns of change and sandscape contraction and expansion are important aspects for continued monitoring, as their status and changes can contribute to how we interpret the status and change in sandscape vegetation using the step-point method.

Table 5. Hypothesized drivers and feasible interpretations of change in response variables collected with the sandscape monitoring methods. Because there can be multiple interpretations of change, it is important to evaluate multiple response variables and to include graphical and spatial displays of data. It is also important to minimize sampling error with the revised sampling methods.

	Hypotheses/Interpretations	
Response Variables	**Increases in response variable**	**Decreases in response variable**
Trail Length, Density, Size	Sandscapes are being directly impacted by high visitor use	Visitor usage is declining or restoration attempts have been successful
Empty Points (no vegetation within 0.5 m, 180° arc in front of sample points)	Trampling impacts have increased with visitor usage	Visitor usage is declining or restoration attempts have been successful
	Blow-out areas and wind-scoured surfaces have increased with storm activity	Succession has occurred in active dune areas
	Dieback of a dominant plant species or multiple species has occurred	Species invasion has occurred
Proportion of vegetated hits	Loss of active dunes with storm erosion, thus sample area is constrained to higher density back dunes	Increased deposition of sand and expansion of active dune area with lower density vegetation
	Foliar cover has increased with succession of active dune areas	Dieback of a dominant plant species or multiple species has occurred
	Visitor usage is declining and/or restoration attempts have been successful	Increased visitor usage and trampling
	Species invasion has occurred	Blow-out areas and wind-scoured surfaces have increased with storm activity (especially when linked with increases in empty points)
Proportion of bare ground hits	Increased deposition of sand and expansion of active dune area with lower density vegetation	Loss of active dunes with storm erosion, thus sample area is constrained to higher density back dunes
	Blow-out areas and wind-scoured surfaces have increased with storm activity (especially when linked with increases in empty points)	Foliar and/or litter cover has increased with succession of active dune areas

Table 5 (continued). Hypothesized drivers and feasible interpretations of change in response variables collected with the sandscape monitoring methods. Because there can be multiple interpretations of change, it is important to evaluate multiple response variables and to include graphical and spatial displays of data. It is also important to minimize sampling error with the revised sampling methods.

	Hypotheses/Interpretations	
Response Variables	**Increases in response variable**	**Decreases in response variable**
Proportion of bare ground hits (continued)	Increased visitor usage and trampling	Visitor usage is declining and/or restoration attempts have been successful
	Dieback of a dominant plant species or multiple species has occurred	Species invasion has occurred
Proportion of litter hits	Loss of younger active dunes with storm erosion, thus sample area is constrained to later successional back dunes with higher litter inputs	Blow-out areas and wind-scoured surfaces have increased with storm activity
	Dieback of a dominant plant species or multiple species has occurred, contributing to litter biomass	Restoration activities have been successful in revegetating areas, thus increasing contributions to litter biomass
	Storm and wind events have deposited more litter onto sandscapes (e.g., Michigan Island woody debris deposits that increased between 2012 and 2014)	Rates of dieback in a dominant species or set of species has slowed due to being out of a drought period, declines in pests or pathogens, etc.
	Decomposition rates decrease due to drought	Wind speeds have declined, resulting in less wind scouring
	—	Decomposition rates increase due to increased nutrient availability (e.g., atmospheric deposition of N) and/or soil moisture
Proportion of exotic species hits	Visitor impacts have increased	Increased deposition of sand and expansion of active dune area dominated currently by native taxa specialized to early successional habitats (except for taxa such as exotic pigweed), thus the relative proportion of exotic taxa could show declines in the total survey area
	Native vegetation has declined in relative abundance	Restoration activities have been successful
	Exotic taxa abundances on the mainland or on Madeline Island have increased, improving the probability of colonizations	Native vegetation has increased in relative abundance in the invaded areas

Table 5 (continued). Hypothesized drivers and feasible interpretations of change in response variables collected with the sandscape monitoring methods. Because there can be multiple interpretations of change, it is important to evaluate multiple response variables and to include graphical and spatial displays of data. It is also important to minimize sampling error with the revised sampling methods.

	Hypotheses/Interpretations	
Response Variables	**Increases in response variable**	**Decreases in response variable**
Proportion of exotic species hits (continued)	Climate change has promoted more successful establishment of some taxa	Exotic taxa abundances have declined in relative abundance (possibly due to pests or pathogens)
Proportion of direct+indirect lichen hits	Loss of active dunes with storm erosion, thus sample area is constrained to later successional back dunes	Increased deposition of sand and expansion of active dune area where lichens do not predominate
	Lichen cover has increased with succession of active dune areas	Blow-out areas and wind-scoured surfaces have increased with storm activity
	Prevailing winds influencing sandscapes have declined and/or soil moisture levels have increased	Increased die-back of lichens due to atmospheric deposition of pollutants
	Reduced visitor impacts and/or successful restoration	Increased visitor usage and trampling
Proportion of direct+indirect shrub hits	Loss of active dunes with storm erosion, thus sample area is constrained to later successional back dunes	Increased deposition of sand and expansion of active dune area where shrubs do not predominate
	Shrub cover has increased with succession of active dune areas	Dieback of a dominant plant species or multiple species has occurred
	Other plant types have declined in relative abundance	Other plant types have increased in relative abundance (e.g., species invasion)
Diversity - rarefaction curves	Loss of active dunes with storm erosion, thus sample area is constrained to higher diversity back dunes	Declines in open backdune areas included in survey area due to increases in tree density
	Richness increases with succession of active dune areas	Declines in open backdune areas + declines in the younger, active dune areas due to erosion with heavy storm events
	Increased species colonization - both native and exotic	Dieback of plant species due to pests, pathogens, climate change
	—	Expansion of common dominants, outcompeting rarer taxa

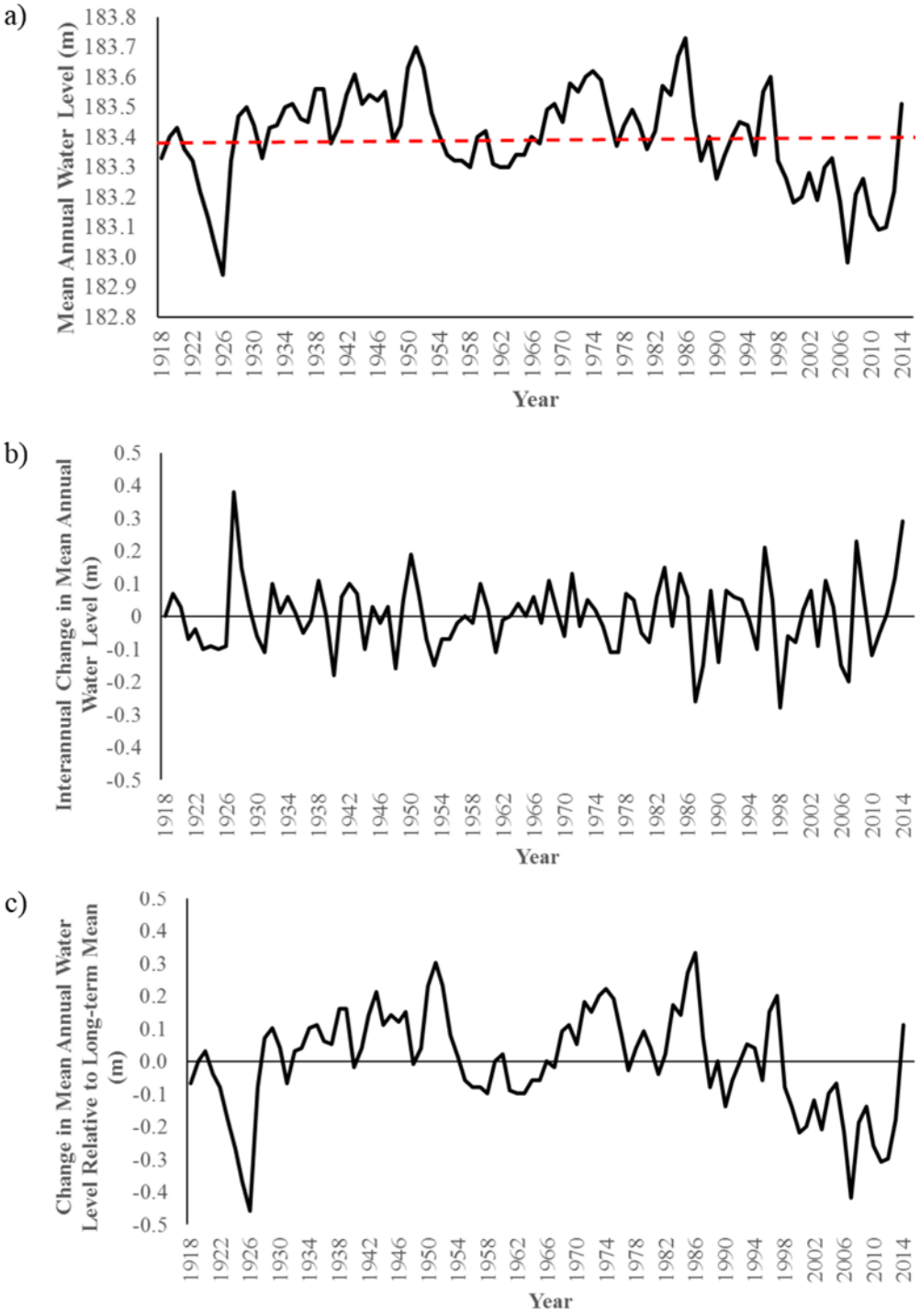


Figure 36. Mean annual water levels (m) of Lake Superior 1918–2014, a) in relation to the long-term water level (red dashed line), b) change in mean annual water levels over this period relative to the year prior, and c) change in mean annual water levels over this period relative to the long-term annual mean. Our survey of sandscapes in Apostle Island National Lakeshore occurred in 2014 when water levels rose significantly compared with the preceding 15 years. These data represent lake-wide annual averages obtained from NOAA – Great Lakes Environmental Research Laboratory.

1.3 Recommendations for Management of Sandscape Habitats

Monitoring Protocol

- The revised method used in 2014 returned useful data for evaluating the surface structure, diversity, and composition of sandscapes on the Apostle Islands.
- To be more efficient and to reduce trampling impacts, we recommend reducing the sample intensity to transects spaced every 16 m. Spacing transects every 32 m would still supply adequate data for most sandscapes for monitoring current status, but to improve the power to track changes over time, we recommend that the NPS proceed with using the 16-m spacing.
- To improve repeatability, we encourage the park staff to calibrate their metered paces with measuring tapes. We also recommend crew members working together on the first few transects so that they calibrate what constitutes as a direct hit, where to establish start points for transects, and how to identify the dune species.
- Future crews should use a GPS to relocate the start point that we established in 2014. Aim to establish the resurveys within this same proximity. Take the field maps into the field and always orient transects in the same direction as we did in 2014. The start point of each transect is unfortunately subject to much variability with each sample event due to the non-permanent nature of transects and the dynamics of the beach zone. We recommend establishing the start points of all transects at the upper edge of the splash zone on the beach. Assuming that crews will not travel to islands on especially windy days, wave height will usually be at average height (which was our experience in 2014). The first set of points will be bare ground, but it is easy to quickly pace these out. By starting in this lower zone on the beach, the resulting surveyed transects provide a more useful map of the foredune shape and areas of blow-outs and trampling occurring near the beach (Appendix B figures). We recommend that the park consider if it could be possible to monument a permanent stake or set of witness trees in the forested back dune area that can be used to relocated the start point of transects on each sandscape.
- We recommend taking into the field copies of the photopoint sheets for each sandscape. While out in the field, are there noticeable features that are the same or different? Comment on these features in the field notes and take new photos at the same points.
- We recommend a two-tiered approach to monitoring sandscapes:
    - **Tier 1 sampling**: At all sandscapes, delineate and measure trails and take photographs at photo-points to track change over time in direct visitor impacts. Look for new exotic invasive species such as *Salsola collina*. Locate and delineate the four bare areas on Outer Island that we established photo-points for in 2014. Frequency: every 2–3 years on a rotating basis. A crew of 1–2 people can complete this task. Pair this fieldwork with aerial photograph interpretation to look for major changes in trails, erosion, or patterns in the vegetation (e.g., woody plant, invasive species encroachment, or increased bare ground).

- **Tier 2 sampling**:
  - *Option 1:* Step-point sampling of all sandscapes in the same year. Frequency: every 5–6 years. We recommend that a crew of 4–5 people be used so that two people lay out transects and 2–3 people follow behind to conduct the step-point sampling. There are at least two benefits to concentrating the survey work in a single year: 1) There will be more statistical power in the data set to track systematic shifts in the vegetation due to factors such as climate change and lake level, and 2) The accumulation of long-term sampling error associated with different crews each year will be reduced, further improving the ability to detect true changes over time. There also could be logistical advantages for the natural resources management staff to plan for one major sampling event every 5–6 years instead of organizing sampling events every year. If managers are concerned about long-term changes in the diversity and abundance of uncommon taxa (the majority of taxa), then we recommend that a timed-meander approach be taken to record all taxa present within each sandscape zone. Spatially restricted survey areas can be developed for each sandscapes. At the end of timed segments of the meander survey (e.g., 30 minutes), the recorder can record percent cover for each taxa observed. Timed-meander methods are used for natural areas assessments in Wisconsin and Minnesota by their Departments of Natural Resources. If the NPS chooses to include timed meander surveys, we can help develop specific protocols that are based on existing protocols used elsewhere. Tracking changes in the abundance of uncommon individuals is not likely with either the full or reduced sampling intensity using the step-point method (Johnson et al. 2008). Thus, the reduced sampling intensity using the step-point method and the addition of a timed-meander survey should provide the NPS with the information it seeks to efficiently address objectives related to diversity.
  - *Option 2:* Split up the sandscape monitoring so that sandscape cohorts are surveyed together in the same year (Table 6). This is less ideal for statistical reasons (see paragraph above), but is more ideal for logistical purposes in allowing park managers to better balance time on multiple resource needs.

Table 6. Proposed rotation schedule for the “tier 2” component of sampling vegetation on sandscapes in Apostle Islands National Lakeshore. This rotation schedule is suggested as “option 2” in the report. The rotation could be repeated consecutively, or up to a 6-year repetition with a two-year hiatus in between repetitions. Option 1 would be to sample all sandscapes in a single year and to space out survey work to every 5–6 years. We grouped sandscapes by their primary aspect to improve power for detecting systematic changes in the sandscapes most likely subjected to more similar wind and wave action. An “x” indicates that sampling will take place during that year, and a en dash (–) indicates that sampling would not take place during that year.

Sandscape Location	Primary Aspect	Sandcape Rotation Schedule		
		Year 1	Year 2	Year 3
Bear Island	W	–	–	x
Cat Island	SW	–	–	x
Ironwood Island	S	–	x	–
Long Island	N	x	–	–
Mainland Little Sand Bay	N	x	–	–
Mainland Sand River	N	x	–	–
Michigan Island	S	–	x	–
Oak Island	S	–	x	–
Otter Island	S	–	x	–
Outer Island	SW	–	–	x
Raspberry Island	S	–	x	–
Rocky Island	S	–	x	
South Twin Island	W	–	–	x
Stockton Island - Julian Bay	E	x	–	–
Stockton Island - North Beach	N	x	–	–

Management Recommendations Based on 2014 Survey Work

Some of the sandscapes have large bare areas and informal trails created by visitor trampling. These areas of concern would be good locations for future restoration plots, specifically plots with *Ammophila breviligulata* (American beachgrass) and *Deschampsia flexuosa* (Hairgrass), as these are two species that have been successfully reintroduced to sandscapes in the Apostle Islands previously. Prior research has also shown that dune restoration sites that have focused on planting only *Ammophila breviligulata* have over time developed a species composition similar to neighboring natural dune communities (Emery and Rudgers 2010). Because barren areas contain smaller abundances of arbuscular mycorrhizal fungi that provide positive benefits to growth and biomass of *Ammophila breviligulata*, Emery and Rudgers (2010) recommend adding native mycorrhizal fungi to

plantings. We also recommend that NPS consider experimenting with seeding with a more diverse native seed mix in some target areas such as in the older and later successional dune areas where beachgrass may not be as appropriate. In the Emery and Rudgers (2010) study, *Artemesia campestris* was the only species associated with the natural dune communities but that was not found in the restoration sites. Hence, this species may be more dispersal limited, especially in an island landscape, or it could require more specific habitat features not associated with human-disturbed sites. It could be a worthwhile attempt to incorporate this species into restoration plots in the future, either by transplants or by seed. Our taxa-level ordination graphs (Figures 30–32) should be useful for considering the types of species most suitable for each sandscape.

While native species are most common among these sandscapes, the percentage of exotic taxa hits is at or approaching 10% or more on Otter, Oak, South Twin, and Ironwood Islands. Most exotic taxa were observed in the older, more stable dune areas and adjacent to the treeline (Appendix B Figures 1–15), but an emerging early successional exotic taxa (*Salsola collina* Pall.) has been observed in the active beach area on Michigan Island. We recommend that the invasive species intern look for and remove this species if found and that they aim to control larger patches of other exotic species (e.g., areas of denser "exotic" points in Appendix B Figures B1–B15). I also recommend that park managers consult with invasive species experts to develop a control plan.

Active restoration of sandscape vegetation has occurred on Apostle Island sandscapes with a history of frequent visitor use. Sandscape management activities have included adding floating boardwalks over sand dunes to constrain foot traffic, installing signs to request that visitors stay on the trails, and planting barren areas that have resulted from over-use by park visitors. Based on an Excel file shared with us by P. Burkman, we summarize here what has been learned from restoration efforts thus far in the Apostle Islands National Lakeshore:

- Sandscape restoration efforts have taken place on Cat, Ironwood, Long, Oak, Raspberry, South Twin, and Stockton Island's Julian Bay and Stockton Island's Quarry Bay sandscapes. Restoration efforts involved the replanting of 52,680 plants and 29 different species across sandscapes. Restoration success was assessed by monitoring restoration sites using 1 m^2 plots, which were revisited every few years, as well as by establishing photo-points that were compared yearly.
- In 2009, hairgrass plots were planted on Cat Island. In 2011, when these plots were revisited, 119 of the plants survived, showing an increase in overall percent vegetated cover to 478%.
- In 2001, sedge species, wild rose, *Equisetum*, wild strawberry, common juniper, blueberry, Canada wild rye, and pearly everlasting were planted on Oak Island. A monitoring visit to this restoration site in 2008 found the sedge, wild rose, and *Equisetum* doing very well, while none of the pearly everlasting had survived.
- In 2005, sand cherry, hairgrass, raspberry, speckled alder, and wild rose were replanted in plots on Raspberry Island. By 2008, 67 sand cherry and 31 hairgrass plants were observed, while none of the raspberry, speckled alder, or wild rose survived.

- In 2005, three-toothed cinquefoil, hairgrass, beachgrass, pearly everlasting, wormwood, common goldenrod, common juniper, common milkweed, wild beach-rose, scouring rush, beach pea, evening primrose, blueberry, fireweed, pin cherry, raspberry, and red-top were planted on South Twin Island. None of the blueberry, fireweed, pin cherry, raspberry, or red-top plants had survived when the plots were revisited in 2009. However, the cinquefoil, hairgrass, beachgrass, wormwood, common goldenrod, common juniper, common milkweed, and wild beach-rose all exhibited 100% survival rate and in some cases had increased in abundance.
- The second restoration monitoring approach taken by the National Park Service was the planting of plots and establishment of photo-points used to visually identify changes in vegetation. Change was determined by using a photo-point ranking scale in which
  - −3 represented bare ground and a complete loss of plants,
  - −2 represented an area in which plants decreased in size and vigor,
  - −1 symbolized an area in which plants decreased in vigor,
  - 0 indicated that there was no change from the year that the previous photo was taken,
  - 1 represented an area in which the plants grew bigger, yet the amount of bare ground did not change,
  - 2 symbolized an area with robust plants and decreasing bare ground due to plant and litter increases, and
  - 3 indicated areas in which plants significantly increased and bare ground greatly decreased.
- On Cat Island, multiple species were planted in four separate plots on the sandscape. In 2010, when these plots were revisited, each of the plots were given a 1 on the photo-point scale, indicating that the plants had grown, yet the amount of bare ground did not change. In 2011, plots 1, 3, and 4 showed an increase in vegetation and a decrease of bare ground and were each given a 2 on the photo-point scale. However, in 2011 plot 2 did not show any change from 2010. In 2013, plots 2 and 4 showed improvement, while plot 3 remained unchanged. Due to photo problems, the progress of plot 1 could not be evaluated in 2013 or 2015. In 2015, plot 2 showed additional improvement, and plot 3 and 4 showed little change from their previous state. In general, from 2010 until 2015, each of the plots showed successful reestablishment of native species.
- On Ironwood Island, three plots were established on the sandscape. In 2013, each of the plots received a 2 on the photo-point scale, and when revisited in both 2014 and 2015, the plots showed improvement, as the number of plants significantly increased and the amount of bare ground decreased greatly.
- On Long Island, four species-specific plots were established in 2009. Hairgrass was planted in plot 1, and the plants showed steady improvement from 2009 to 2010, receiving a 2 on the photo-point scale. In 2011 and 2015, the plot continued to show improvement. Beachgrass and wormwood were planted in the second plot, and while the plants were larger in 2010, both species decreased in vigor in 2011. In 2015, the site eroded away, and the plants were lost. Two additional beachgrass plots were also planted on Long Island, which followed a similar trend as

plot 2. Both plots 3 and 4 showed initial improvement, as the plants grew larger, yet in 2011, the plants decreased in vigor. In 2015, when the plots were last visited, there was still little change.

- On Raspberry Island, several beachgrass and hairgrass plots were planted in 2009. In 2010, plots 1, 4, and 10 had larger plants but showed little change in bare ground. Plots 5, 8, and 9 each had robust plants with less bare ground due to plant and litter increases. In 2011, each of the plots illustrated successful reintroduction of beachgrass and hairgrass, receiving either a 2 or 3 on the photo-point scale.
- On South Twin Island, several beachgrass and hairgrass plots were planted and revisited in 2010 and 2013. Plots 3, 4, 6, and 7 showed increases in vegetative cover and decreases in bare ground, while plots 5 and 8 each had robust plants with some decrease in bare ground. This trend continued into 2013, illustrating successful introduction of hairgrass and beachgrass in these plots.

Based on our observations in 2014, we provide the following recommendations for potential management among sandscapes:

Oak Island

There is a 235.4 m^2 bare area near the base of the campsite trail on Oak Island. This seems to be a high traffic area in which visitors leave their kayaks and gear while camping on the island. The size of this bare area could be decreased if American beachgrass is planted here. A designated boat landing area could also be considered here.

Mainland-Little Sand Bay

A similar bare area as observed on Oak Island also exists near the beach access point on the Little Sand Bay sandscape. Due to high traffic and extensive beach use, there is a large area with very little vegetation. If this area increases over time, it may be beneficial to establish a boardwalk leading to the beach and to revegetate some of the areas near the trails.

Outer Island

There are notable bare areas of variable sizes on Outer Island's sandspit. Within these bare areas, we noticed remains of the bases of beachgrass plants, suggesting a die-off event. We systematically chose four areas near the center of the Outer Island sandspit to GPS in 2014 (Appendix A figures and Appendix C photo-points). It is unclear what is causing these patches, but it could be a combination of wind exposure, trampling, grazing by birds and mammals, nematodes, successional processes, etc. These GPSed bare areas can be relocated and delineated using a GPS to assess whether or not they are increasing in size, and if so, restoration plots may be appropriate to help reestablish plant populations.

Otter Island

On Otter Island, there are numerous small, informal trails created by foot traffic between campsite, the dock and the picnic area. Along these high traffic paths, there are some exotic species, including Quack Grass, that could use attention. A new boardwalk may encourage people to stay on a set path rather than trampling vegetation and spreading non-natives around the sandscape.

Stockton Island Julian Bay – Open dune area

On the Stockton Julian Bay sandscape, additional restoration may be beneficial on dunes where there are large blowouts. Visitors seem to use these blowout areas, further limited vegetation establishment. Restoration plots, especially beachgrass plots, could potentially help dissuade foot traffic in these areas.

South Twin Island

South Twin Island does not have obvious bare areas, however management of exotic species on the island east of the boardwalk near the picnic area may be helpful. Hawkweed (*Hieracium auruntiacum* L.) and oxeye daisy (*Leucanthemum vulgare*) Lam. were two frequent species there.

Raspberry Island

Raspberry Island has several informal trails near the forested edge of the sandscape, along with bare areas near the outhouse. Establishing formal boardwalk trails to the outhouse and replanting hairgrass and beachgrass in these large bare areas may limit further trampling of vegetation on the sandscape.

Long Island

Long Island has a unique sandscape with steep, undercut banks. Some of these banks are stabilized by dune vegetation. However, in blowout areas, *Juniperus communis* may be a useful dune stabilizing species to plant. Additionally, due to recent construction near the old lighthouse in 2014, there is a lot of debris from cut vegetation and bare areas due to trampling. This was a focus area of restoration in May 2015.

Section 2. Assessing Status and Trends in Common Juniper Among Sandscape Habitats Where It Occurs in Apostle Islands National Lakeshore

Introduction

Juniperus communis var. *depressa* (common juniper) is an important dune-stabilizing shrub found on sandscapes in Apostle Islands National Lakeshore. There have been no peer-reviewed publications that we are aware of on declines of *J. communis* var. *depressa* in North America. However, research in Europe has focused on alarming declines of the tree-form variety of *J. communis* (var. *communis*). Declines in Europe are largely due to habitat loss and fragmentation, but research on extant populations has documented senescent populations with reduced regeneration success. Implicated in these declines are climate warming (Gruwez et al. 2015), nitrogen deposition (Verheyen et al. 2009), grazing, and browsing (Clifton et al. 1997). Therefore, observations of dead and dying junipers at Apostle Islands National Lakeshore warrant concern about the status and future of *J. communis* and its sandscape habitat in the Great Lakes region.

Surveys of *Juniperus communis* populations on Michigan, Stockton, and Outer Islands were conducted in 2012 (Johnson and Mead 2013) to explore patterns and possible mechanisms for foliar die-back. Dieback was the greatest among large, male shrubs on Michigan Island, and was significantly more likely to occur at relatively high elevations above Lake Superior and farther distances from the lake. Johnson and Mead (2013) concluded that these patterns of dieback could reflect successional processes and likely climate-induced stress due to long-term drought conditions related to lake level declines, precipitation declines, and increased evaporative demand associated with rising temperatures. During this study, Johnson and Mead (2013) also observed a significant presence of *Aethes rutilana* (pale juniper webworm) and fungal spores on dead foliage, suggesting possible multi-trophic scale interactions with climate change. Hence, they recommended that targeted monitoring of *J. communis* be conducted to determine if dieback among the shrubs continues, at what rate, and to gain further understanding of the possible drivers of change.

Here, our aim was to sub-sample the populations of *Juniperus communis* on Michigan, Stockton, and Outer Islands in 2014 to determine the degree to which dieback may have continued to occur. Park resource managers also asked us to expand our *J. communis* surveys to the other sandscapes in the Lakeshore, in order to investigate the scale at which the dieback has occurred among the Apostle Islands.

Methods

Juniperus communis var. *depressa* (Cupressaceae) is a prostrate, evergreen shrub with upturned branches (0.3–1.2 m tall) covered by whorls of three sharply pointed, narrow leaves. It occupies open habitats including stabilized dunes, rocky substrates, and sandy disturbed soils. There is no firm evidence of clonal growth and we did not observe it in the field, but adventitious rooting may be possible in this species (Bannan 1942). Its distribution covers all but south-central North America, and the closely related *J. communis* var. *communis* extends throughout Europe. It is a dieocious

gymnosperm, with male plants producing small, erect catkins and females annually producing fleshy, berry-like cones that ripen over a three-year period (Jack 1893). Living up to 150 years, older individuals usually have larger crown sizes (Marion and Houle 1996) that may extend outward up to 10 m in diameter (Houle and Duchesne 1999).

Study Sites

In summer 2014, we observed and collected data on *Juniperus communis* at eight of 14 sandscapes studied in Apostle Islands National Lakeshore—Cat, Long Michigan, Oak, Outer, South Twin, Stockton-Julian Bay, and Stockton-North Beach. We sub-sampled *J. communis* shrubs on Michigan, Stockton, and Outer Islands, where the populations were larger and where we had baseline data from 2012 to assess change over a two-year period.

These three sites surveyed in both 2012 and 2014 vary in their exposure to winds, waves, and nearshore currents, with the wave energy ranked highest on Outer Island (Engstrom 1974). The *Juniperus communis* populations we studied on Michigan Island were primarily oriented along the south-facing foreland of the progradational shoreline, but some of the shrubs were located at the southwest-facing tip. This tip has grown at an average rate of two meters per year since 1938 (Figure 37), extending out to 91 m by 1978 (Middleton 1983) and to 150 m by 2010, based on our measurements in aerial imagery. On Outer Island, our focus was on *Juniperus communis* growing on the rolling beach ridges found on the west-northwest-facing progradational foreland, which has migrated west by approximately 75 m since 1938 (Figure 38). At Stockton Island, the population of *J. communis* is somewhat protected by Julian Bay except from winds out of the East. Here, the *J. communis* shrubs populate a wide, rolling foreland that ends abruptly with a vertical scarp abutting the active beach zone. Air photos illustrate that the vegetated foredune community has narrowed by 20–25 m and the active beach has widened landward since 1938 (Figure 39).

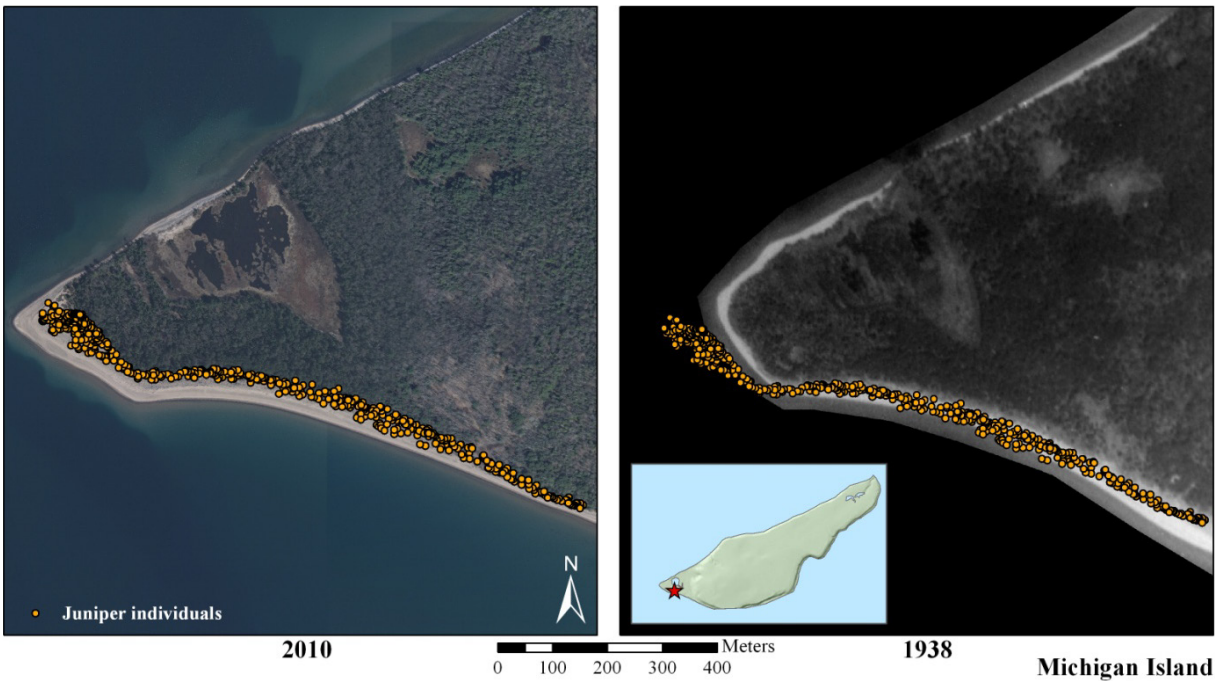


Figure 37. Points on map indicate all individuals of *Juniperus communis* included in sampling efforts on Michigan Island cuspate foreland in August 2012, overlaid onto 2010 aerial imagery (*left*) and 1938 aerial imagery (*right*).

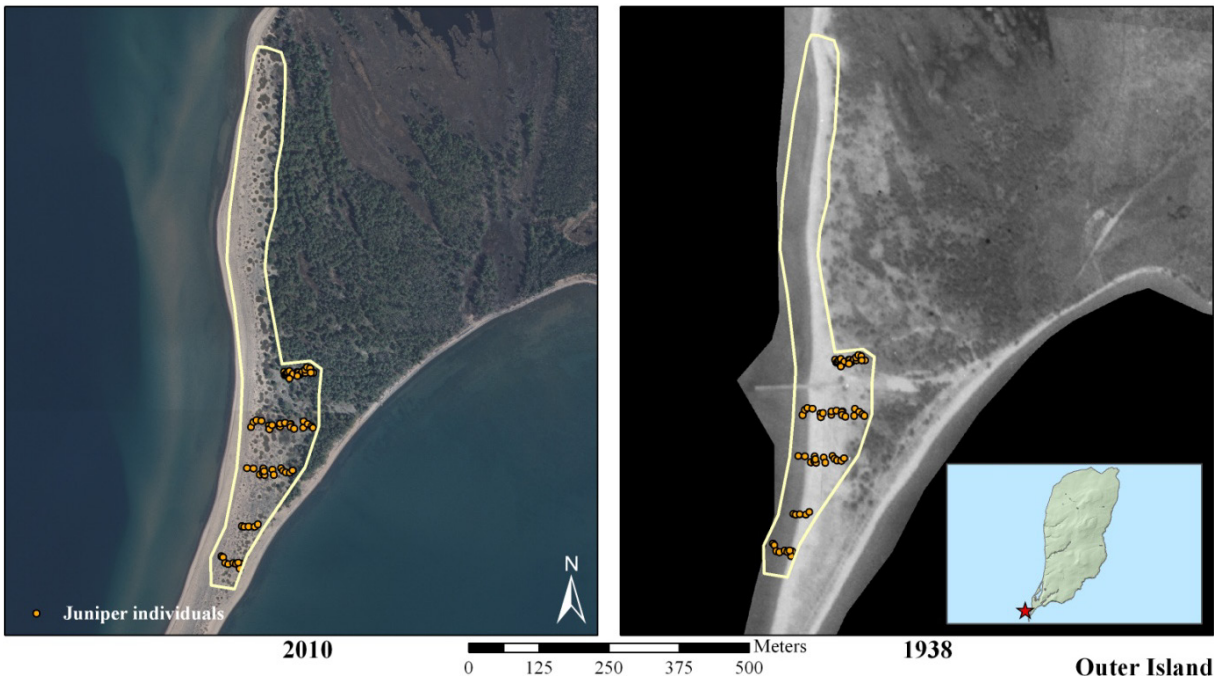


Figure 38. Points on map indicate individuals of *Juniperus communis* included in sampling efforts on Outer Island sandspit in August 2012, overlaid onto 2010 aerial imagery (*left*) and 1938 aerial imagery (*right*). Due to a malfunctioning GPS unit, locations of all junipers sampled are not shown, but the polygon area delineates the area where we sampled.

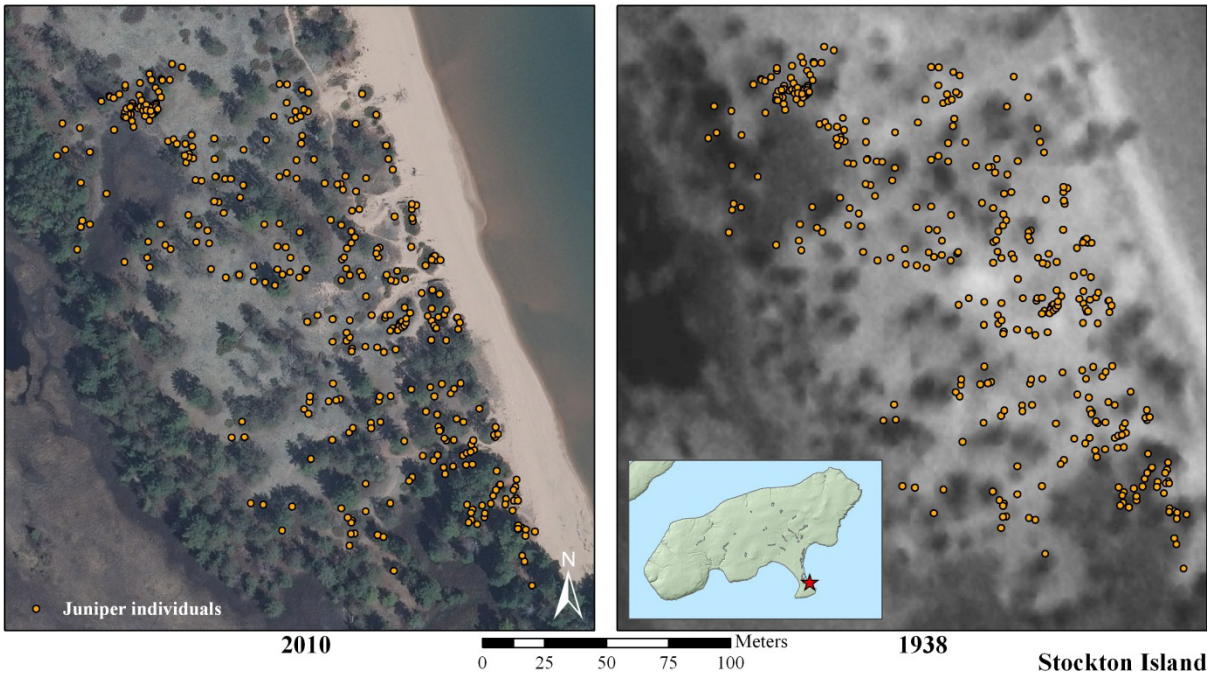


Figure 39. Points on map indicate all individuals of *Juniperus communis* sampled within belt transects on Stockton Island's tombolo near Julian Bay in August 2012, overlaid onto 2010 aerial imagery (*left*) and 1938 aerial imagery (*right*).

Field Surveys of Juniperus communis *Populations in 2012*

Juniperus communis individuals generally form a radial pattern, so we delineated individual shrubs by tracing branches to roots. We measured the maximum diameter (m) and maximum height (cm) of all individuals and recorded the sex if known. The proportion of dead foliage was estimated solely by the lead author to reduce sampling bias.

We used the Trimble Juno SB equipped with Terrasync v3.2 software to mark locations of all individuals we could access during surveys on Michigan and Stockton Islands (within approximately 5 ha and 4 ha, respectively). We averaged 10 or more coordinates at each shrub to increase accuracy and minimize error. The average maximum PDOP (Positional Dilution of Perception) for the *Juniperus communis* shrubs sampled using this method is 1.54 for Stockton Island and 1.64 for Michigan Island. Using ArcMap, we delineated the sandscape-lake edge for each sandscape based on infrared imagery from 2010, and we used Spatial Analyst to calculate the nearest distance of each shrub to Lake Superior (m).

We applied standard survey techniques using a laser level (Topcon RL-60B) to obtain relative elevations of the centers of all *Juniperus communis* shrubs and the relative elevation of Lake Superior adjacent to each study site. The relative elevation readings for Lake Superior were taken at the water's edge when the lake was calm.

The extensive population of *Juniperus communis* on Outer Island's large sandspit, coupled with logistical limitations to conducting fieldwork there, dictated that we subsample the population (covering approximately 15 ha) using belt transects. Our start point for the first transect was

randomly located south of the Outer Island lagoon, constrained to within 50 m of the western edge of the Outer Island lagoon (where sandscape community met shrub-carr wetland species). Transects ran west to east, starting at the edge of Lake Superior and extending to the end of *J. communis* occurrences or 150 m, whichever occurred first. Transects were 15 m wide (7.5 m on each side of the center) and 100 m apart, for a total of 12 transects extending south toward the end of the spit. We sampled all *J. communis* with centers located within belt transects. If shrub centers straddled the outer line of the transect, we included every other individual in our survey. We sampled 266 *J. communis* with this method and collected the same suite of data described above for plant attributes and relative elevations. A faulty GPS unit resulted in the loss of GPS locations for all but 68 *J. communis* on Outer Island, restricting the available geospatial data.

Field Surveys of Juniperus communis *Populations in 2014*

Complete population censuses were conducted on all islands not previously surveyed in 2012—Cat, Long, Oak, and South Twin. Here, we applied the same sampling techniques as described for the 2012 field surveys. On Michigan, Stockton, and Outer Islands, we used belt-transect methods to sub-sample populations that we surveyed in 2012, enabling us to conduct change analyses of percent dead foliage over the two-year period.

Belt transects 15 m wide were spaced every 50 m along the three sandscapes. We surveyed 11 transects on Michigan Island and four transects on Outer and Stockton Islands. Using the Trimble Juno SB units, we relocated individuals surveyed in 2012 and re-evaluated plant diameter, plant height, and percent dead foliage. In addition to using the GPS loaded with aerial images and 2012 GPS locations for individuals, we also carried in the field printed copies of these maps and data shrub attribute data from 2012 (e.g., sex, diameter, height). The error associated with GPS points using the Trimble Juno SB is on average 4 m and this, along with the error compounded with two sample events, made it a challenge to always relocate exact individuals. On Outer Island, we used GPS locations where they existed from 2012, but along transects where 2012 GPS data were missing, we established new GPS points.

New for 2014, we included an evaluation of prevalence of the pale juniper webworm (*Aethes rutilana*) on plants. We assessed prevalence of 2–4 cm clusters of webbed needle clusters by calculating the percentage of clusters present out of 10 branches assessed (five branches on opposite sides of each plant). To confirm the identity of the webworm, we collected larvae from web casings and maintained these in the lab until they metamorphosed into moths (Figure 40). We sent photographs to the University of Wisconsin Insect Diagnostics Laboratory, where P. Liesch confirmed the identification as *Aethes rutilana*.

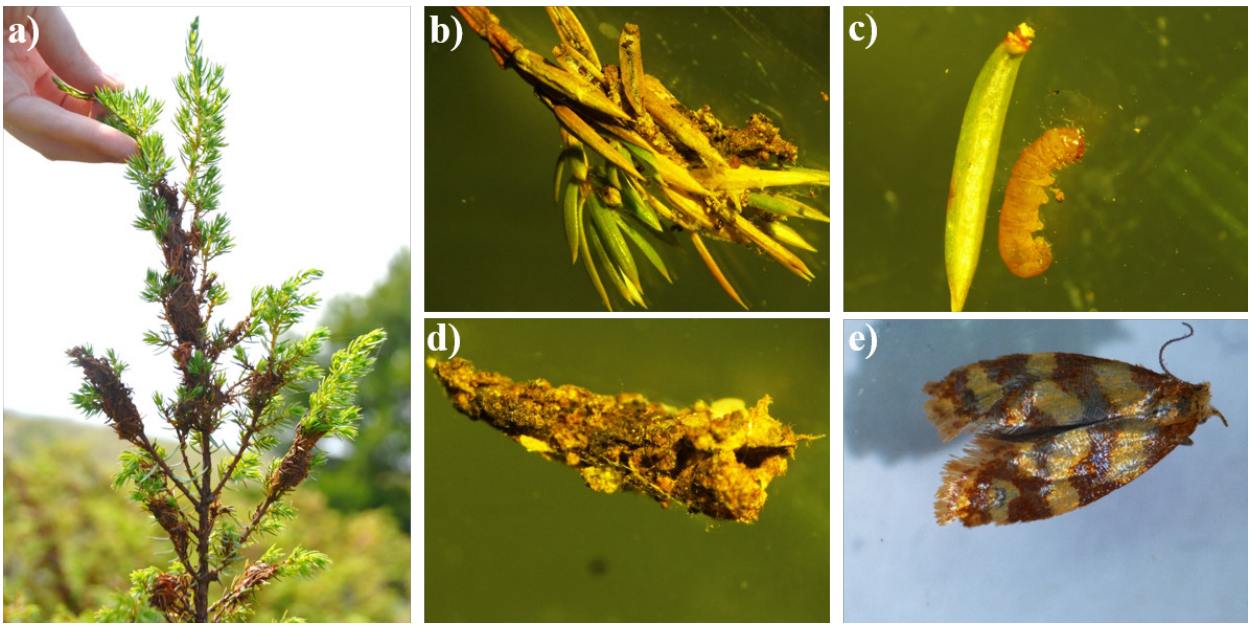


Figure 40. *Juniperus communis* branch (*a*) observed on Outer Island in Apostle Islands National Lakeshore in 2014 covered by clusters of webbed needles and frass (*b*) that contain larvae (*c*) and pupae (*d*) of the non-native pale juniper webworm (*Aethes rutilana*) moth (*e*).

Because we observed rodent activity among *Juniperus communis* plants on Michigan Island in early June 2014, we assessed the presence or absence of rodent herbivory on branches of *J. communis* individuals on Michigan, Outer, and Stockton Islands. This was usually in the form of bark "girdling", but we also observed tips clipped off of some plants (Figure 41).

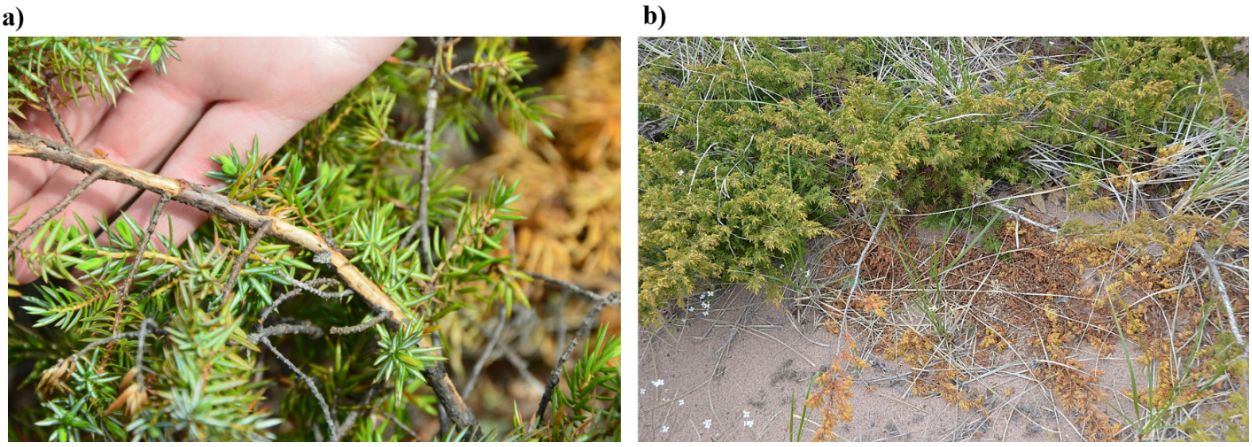


Figure 41. *Juniperus communis* branch girdled (*a*) and branch tips nipped off (as seen by brown tips on ground) (*b*) by herbivores during the winter months prior to summer 2014 on Michigan Island, Apostle Islands National Lakeshore.

Live-trapping Small Mammals in Juniperus communis *Habitat*

To determine the identity and density of rodents in the *Juniperus communis* habitat, we included a small mammal trapping component to our fieldwork on Michigan and Outer Islands in 2014. We set

out 50 9-inch Sherman live-traps along three traplines, with traps placed in microsites perceived to be most suitable for rodent activity (e.g., near holes, hollow logs, and shrub copses). These three traplines were systematically placed in four habitat areas: 1) open dunes with *J. communis*, 2) dune-forest edge within *J. communis*, 3) dune-forest edge outside of *J. communis*, and 4) open dunes and near logs away from *J. communis*. On mornings preceding trapping, we placed closed traps in different microsites along three trapline units. We marked traps temporarily using flagging. Using a pinch of oats, we set the traps at approximately 17:00 each evening for three nights on Outer and two evenings on Michigan Island (the third night was omitted due to poor weather). We checked the traps at approximately 08:00 each morning. If a rodent was captured, we transferred it to a plastic bag to take photos for identification and sex determination (by Dr. P. Anich, Northland College), and to collect a range of morphometric measurements including weight (g) using a Pesola scale (mass of animal in bag minus mass of empty bag), length of hind foot (mm), ear length (mm), body length (mm), and tail length (mm). We released all animals in the same location as captured.

Statistical Methods

Status of *Juniperus* across sandscapes in 2014

To evaluate the population status of *Juniperus communis* among sandscapes surveyed in 2014, we tabulated descriptive statistics for shrub diameter, height, percentage of dead foliage, shrub sex, and evidence of rodent herbivory and the non-native pale-juniper web-worm (*Aethes rutilana*). Using R, version 3.1.2, the logit function in R ("car" package) was used to transform the variable "percent dead foliage", and the log function in R was used to transform the variables "crown diameter" and "height".

Change in the status of *Juniperus communis* on Michigan, Outer, and Stockton Islands, 2012–2014

To evaluate change in plant size (diameter, height) and health (percentage of dead foliage), we used JMP®13 (SAS Institute Inc., Cary, North Carolina, 1989–2017) to conduct restricted maximum likelihood (REML) mixed-model analyses to assess significant differences in the percentage of dead foliage on shrub canopies by year, island, sex, and interactions in these grouping variables. "Shrub ID" was included in the analysis as a random variable. We ran similar models using other response metrics including plant diameter and shrub height. All response metrics were natural log transformed to meet statistical assumptions. We used REML (instead of Analysis of Variance) to accommodate an unbalanced number of *Juniperus communis* sampled within groups. Due to some inconsistencies in relocating the same shrubs in 2014 as we did in 2012, we used GIS to review GPS locations of sampled shrubs during both years, and we excluded data points from this analysis that had a low confidence level in relocation from 2012 to 2014. Finally, we used simple linear and indicator variable regressions ("lm" function in R software) to regress percentage of dead foliage in 2014 against dead foliage observed in 2012, and to evaluate the effect of the presence or absence of rodent herbivory on 2014 dead foliage.

Results

Status of Juniperus *Across Sandscapes in 2014*

We observed *Juniperus communis* on eight of 15 sandscapes surveyed in 2014 (Table 7). Average shrub diameter was largest on Outer Island (5.66 ± 2.76 m) and smallest on South Twin Island (1.02

± 0.44 m) (Table 7, Figure 42). Average shrub height among sandscapes was less variable than diameter, but shrubs were on average shorter on South Twin Island (Table 7, Figure 43). We assume that these small shrubs on South Twin Island were transplanted there during restoration work in 2005. Comparisons of shrub densities of *Juniperus communis* among the sandscapes should be evaluated with caution due to a combination of sub-sampling on larger sandscapes and exhaustive surveys on smaller sandscapes. Thus, we evaluated population structures at the individual sandscape scale. The population structures on both Stockton and Oak Island demonstrate a reverse-J curve reflective of an all-aged population that is both ageing and regenerating (Figure 44). On Michigan, Long, and Outer Islands, the hump-backed density-diameter distributions indicate an aging population with more moderately sized shrubs (Figure 44). There was a greater percentage of male *J. communis* shrubs on all islands (Figure 45), but the high percentage of shrubs with an unknown sex (most often due to immaturity of shrub or sometimes old age) on Oak and South Twin complicates sex ratio interpretation there. Among shrubs of known sex, all islands have a male:female ratio >1, indicative of male dominance (Table 8). Both Cat and Oak Islands demonstrate high male dominance in those two populations (50% and 37% more males than females, respectively) (Table 8).

Table 7. Descriptive statistics for size and percent dead foliage observed on individual *Juniperus communis* shrubs on sandscapes surveyed in 2014 in Apostle Islands National Lakeshore. The number sampled represents sub-samples of *J. communis* shrubs on Michigan, Outer, and Stockton-Julian Bay; whereas, on other sandscapes an exhaustive survey was conducted (with the Long Island survey constrained to the sandscape area by the dock and lighthouse).

Sandscape	# Sampled	Mean % Dead Foliage (±SE)	Mean Plant Diameter (m) (±SE)	Mean Plant Height (m) (±SE)
Cat	26	18.6 (±4.9)	3.00 (±0.6)	0.58 (±0.05)
Long	61	18.9 (±5.8)	3.41 (±0.3)	0.74 (±0.06)
Michigan	138	30.8 (±2.1)	3.79 (±0.3)	0.58 (±0.02)
Oak	38	10.0 (±5.5)	1.79 (±0.3)	0.49 (±0.06)
Outer	54	13.1 (±4.1)	5.66 (±0.8)	0.65 (±0.04)
South Twin	36	1.4 (±2.7)	1.02 (±0.2)	0.34 (±0.03)
Stockton-Julian	157	7.4 (±2.1)	2.45 (±0.2)	0.53 (±0.02)
Stockton-North Beach	27	12.2 (±4.0)	2.86 (±0.6)	0.54 (±0.04)

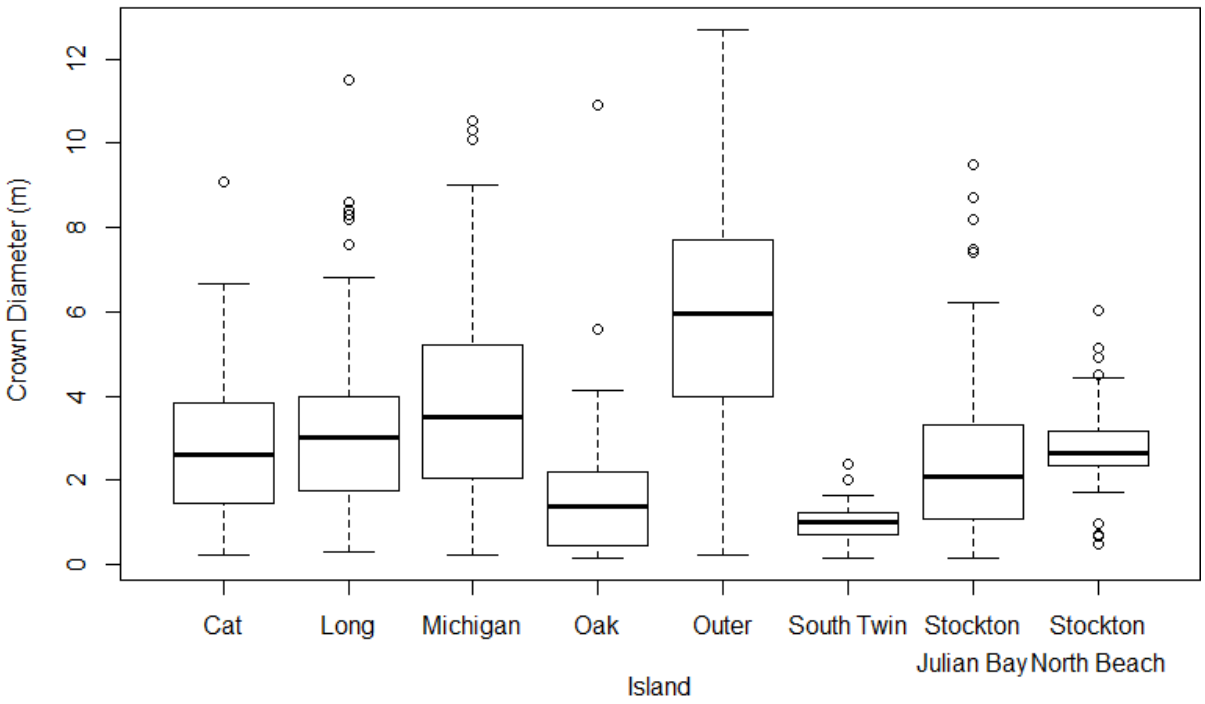


Figure 42. Box-plots of crown diameter (in meters) of *Juniperus communis* among sandscapes surveyed in 2014 in Apostle Islands National Lakeshore. The boxes represent the interquartile range (IQR; 25%, median, and 75%), whiskers represent 1.5x the IQR, and points indicate potential outliers.

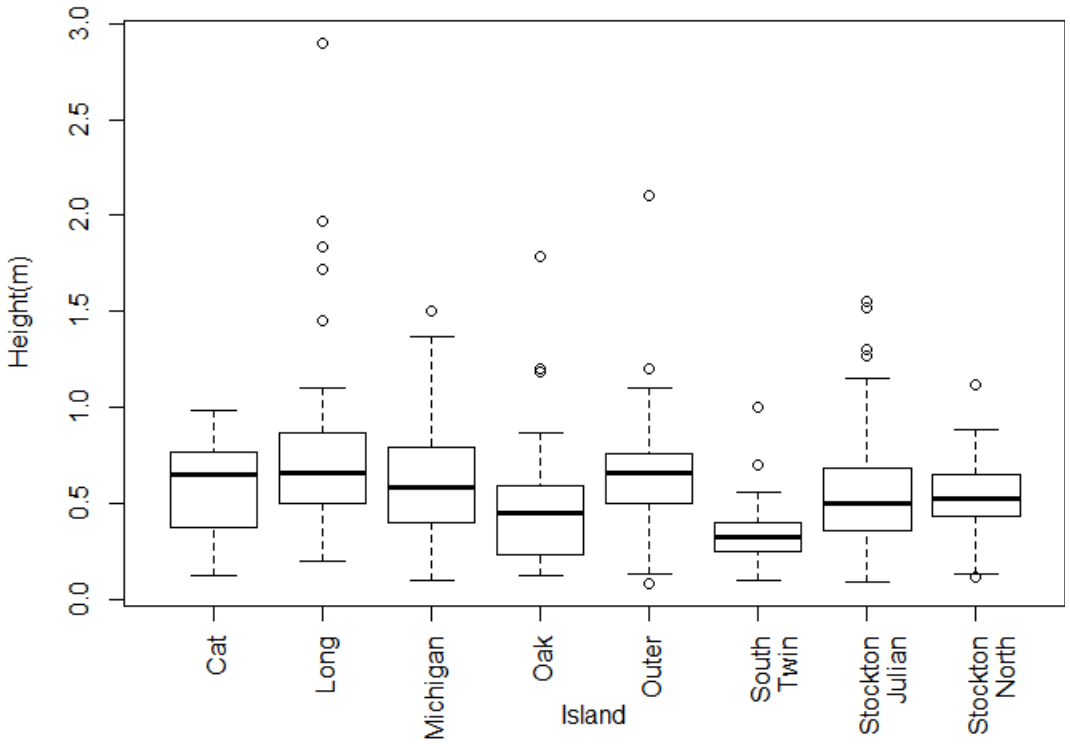


Figure 43. Height of *Juniperus communis* (in meters) among sandscapes surveyed in 2014 in Apostle Islands National Lakeshore. The boxes represent the interquartile range (IQR; 25%, median, and 75%), whiskers represent 1.5x the IQR, and points indicate potential outliers.

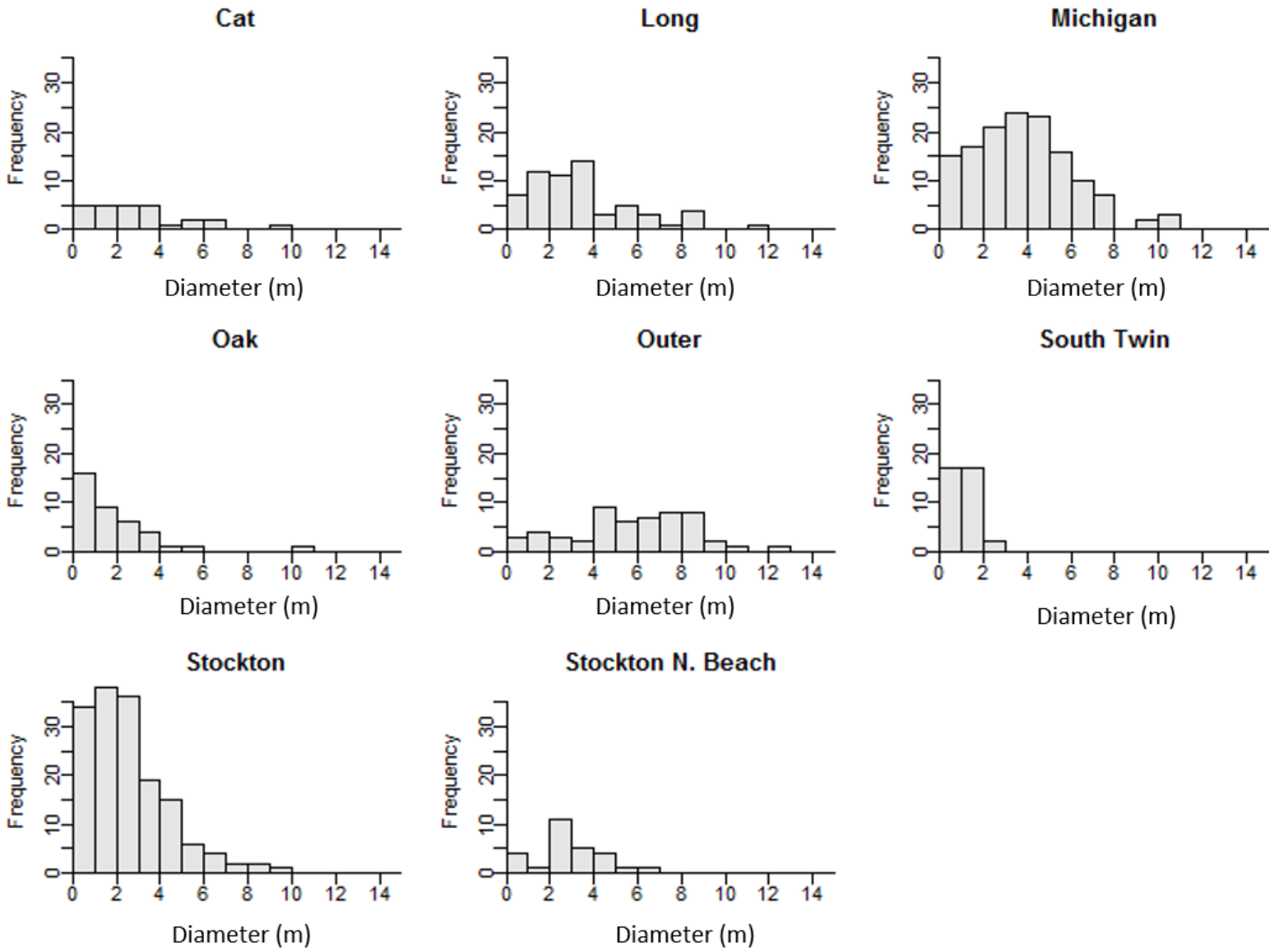


Figure 44. Shrub density-diameter plots showing the size distributions of *Juniperus communis* among sandscapes surveyed in 2014 in Apostle Islands National Lakeshore.

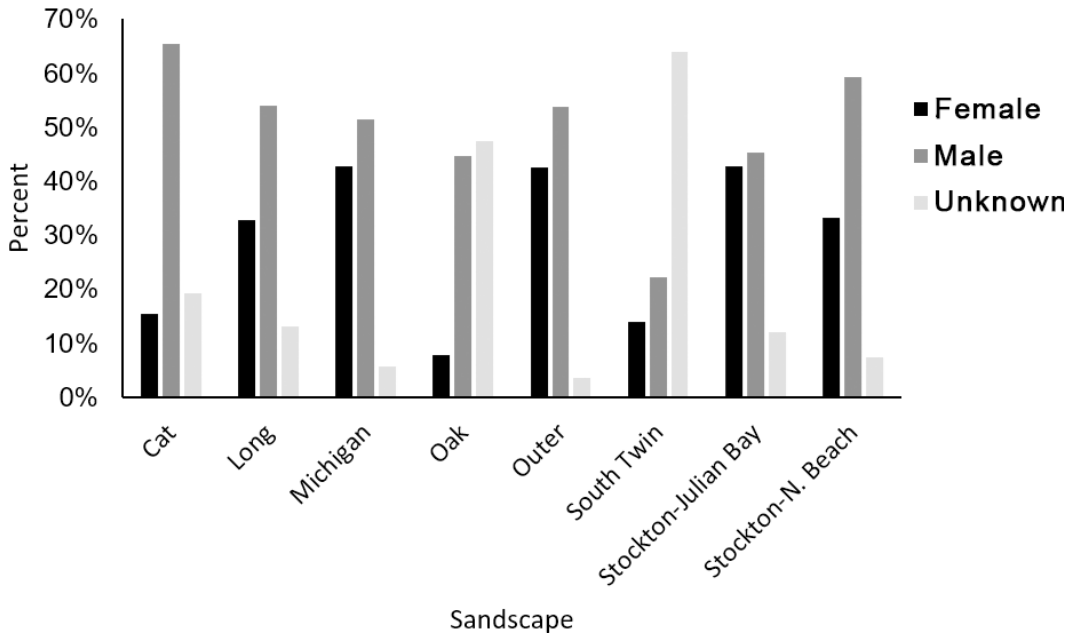


Figure 45. Percent of *Juniperus communis* shrubs identified as male, female, or unknown on sandscapes surveyed in Apostle Islands National Lakeshore in 2014.

Table 8. Sex structure of populations of *Juniperus communis* shrubs, the percent of shrubs with branch girdling by herbivores, and the percentage of shrubs with more than 10% of branch tips with web clusters of the pale juniper web-worm at Apostle Islands National Lakeshore, 2014.

Sandscape	# Female	# Male	# Unknown Sex	Male: Female Ratio	% Branch Girdling	>10% Tips with Web-worm Clusters
Cat	4	17	5	4.3	0.0	3.9
Long	20	33	8	1.7	0.0	0.0
Michigan	59	71	8	1.2	23.9	20.3
Oak	3	17	18	5.7	0.0	0.0
Outer	23	29	2	1.3	0.0	66.7
South Twin	5	8	23	1.6	0.0	0.0
Stockton-Julian	67	71	19	1.1	0.0	1.9
Stockton-North Beach	9	16	2	1.8	0.0	0.0

The average percentage of dead foliage on *Juniperus communis* was greater than 15% on Cat, Long, and Michigan Islands (Table 7). Shrubs on Michigan Island had greater percentages of dead foliage (31% of dead foliage on shrubs, on average) than shrubs observed elsewhere within the lakeshore (Table 7, Figures 46–47). Rodent herbivory that consisted of bark-stripped branches and clipped branch tips was only observed on Michigan Island (see Figure 41), with 24% of shrubs showing signs of herbivory (Table 8). Areas with a higher percentage of dead foliage on the Michigan Island

sandscape (Figure 47) correspond to areas with increased presence of stem girdling by rodents (Figure 48).

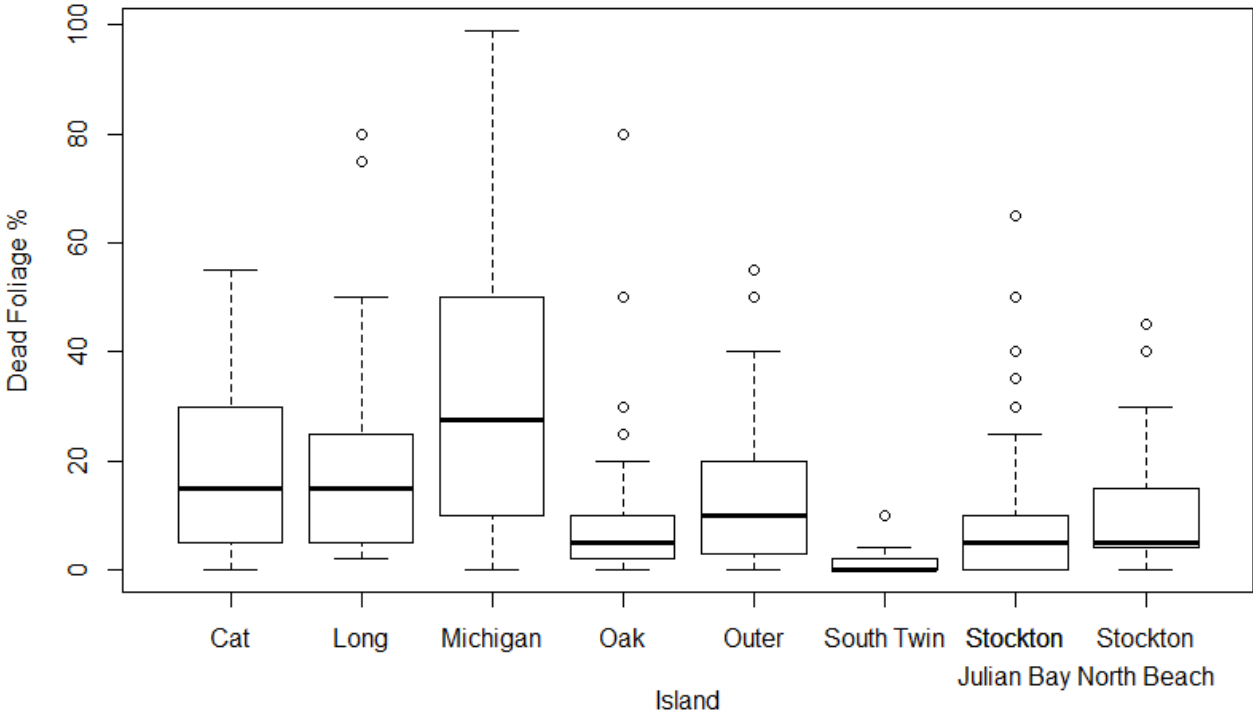


Figure 46. Percent dead foliage observed on *Juniperus communis* shrubs on sandscapes within Apostle Islands National Lakeshore in 2014.

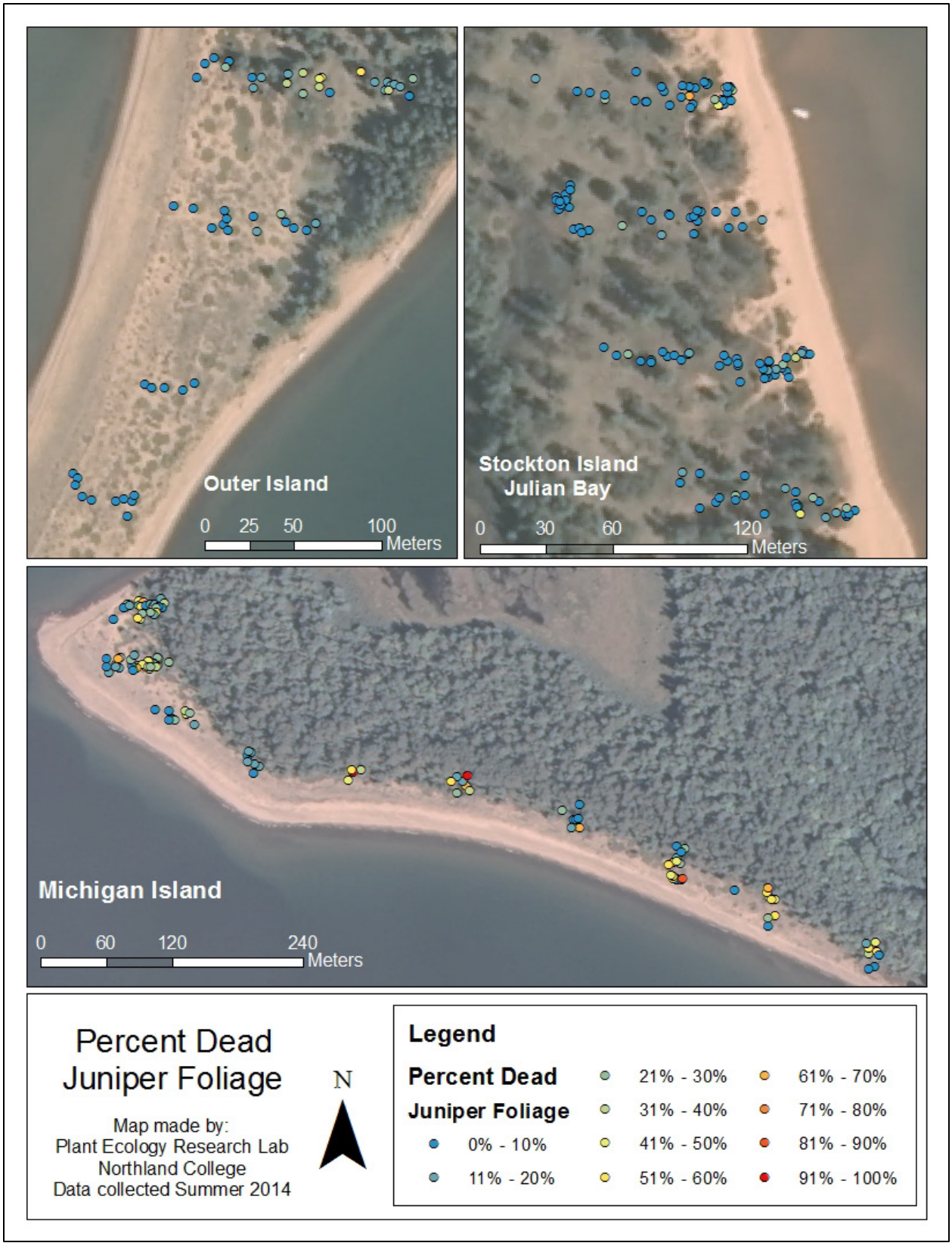


Figure 47. Percent dead foliage on shrub canopies of *Juniperus communis* surveyed on Michigan, Outer, and Stockton Islands. Apostle Islands National Lakeshore, 2014.

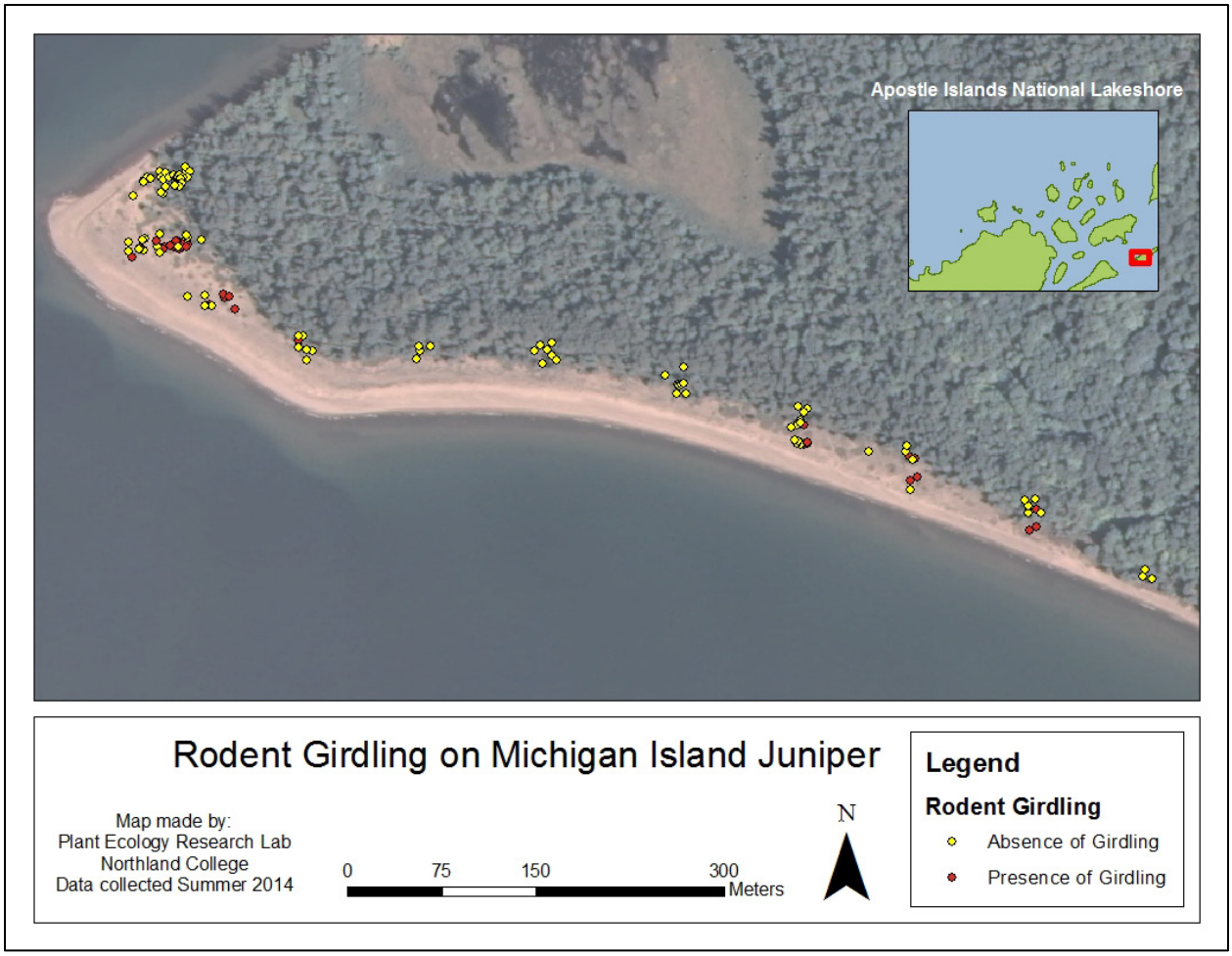


Figure 48. Presence (red) and absence (yellow) of herbivory in the form of bark girdling on branches of *Juniperus communis* on Michigan Island, Apostle Islands National Lakeshore, 2014.

Based on small mammal trapping on Michigan Island, the dominant small mammal occupying areas within or near *Junperis communis* habitat was *Myodes gapperi* (southern red-backed vole) (Table 9). We captured 25 rodent individuals there during two nights of trapping, 72% of which were *M. gapperi*. *Peromyscus* spp. (white-footed/deer mouse group) was the next most common (16% of the sample population), and one *Mus musculus* (house mouse) was captured (Table 9). Both *Peromyscus* spp. and *M. gapperi* were abundant on Outer Island during three nights of trapping, but *Peromyscus* spp. outnumbered *M. gapperi* there (Table 9). *Peromyscus* spp. were only ever observed in traps set within *J. communis* and were equally observed in *J. communis* shrubs at the forest edge and within *J. communis* shrubs on open sandscape habitats (Table 10). *Myodes gapperi* was most commonly captured in traps set within *J. communis* at the forest edge, but were also located away from *J. communis* at the forest edge and in *J. communis* shrubs on the open sandscapes (Table 10).

Table 9. Rodent species observed via small mammal trapping surveys on Michigan and Outer Islands in the Apostle Islands National Lakeshore in 2014. The unknown identifications refer to rodents that escaped the trap before we could observe it closely or take a photograph.

		Michigan Island		Outer Island	
Taxa	**Common Name**	**#**	**% of Sample Population**	**#**	**% of Sample Population**
Myodes gapperi	Southern red-backed vole	18	72.0	12	39.0
Peromyscus spp.	White-footed/Deer mouse group	4	16.0	18	58.0
Mus musculus	House Mouse	1	3.8	0	0
Unknown	–	2	8.0	1	3.0
Total Number of Trapped Individuals	–	**25**	n/a	**31**	n/a

Table 10. Number of individuals by species observed by habitat type during small mammal trapping surveys on Michigan and Outer Islands in Apostle Islands National Lakeshore in 2014.

Species	***Juniperus* - Forest Edge**	**No *Juniperus* - Forest Edge**	***Juniperus* - Open Sandscape**	**Dead Logs and Open Sandscape**
Mus musculus	0	0	0	1
Myodes gapperi	19	6	5	0
Peromyscus spp.	11	0	11	0
Unknown	1	0	1	1

The presence of non-native pale juniper webworm (*Aethus rutilana*) on *Juniperus communis* was obvious by branches either sparsely or densely covered by 2–4-cm clusters of needles wrapped with webbing (see Figure 40a–b). These webworm "casings" were noticed on four of the sandscapes, with 67% of shrubs on Outer Island and 20% of shrubs on Michigan Island showing signs of web-worm on >10% of branch tips (Table 7, Figure 49). The needle clusters wrapped by webbing usually contained frass, a web-worm larvae (see Figure 40c), and sometimes a pupal case (see Figure 40d).

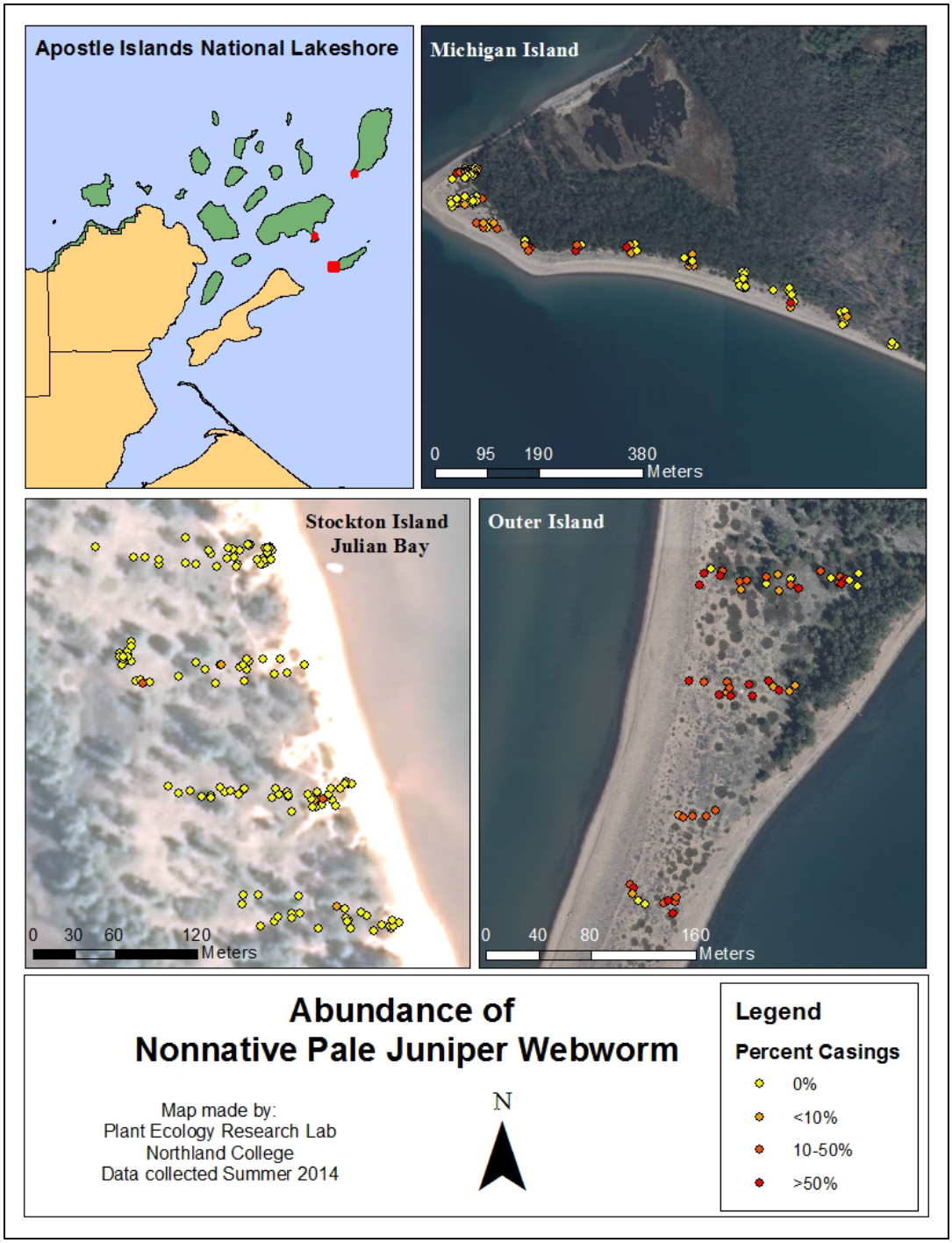


Figure 49. Percentage of *Juniperus communis* shrubs with >10% of branches containing pale juniper webworm casings (*Aethes rutilana*) on Michigan, Outer, and Stockton Islands, Apostle Islands National Lakeshore, 2014.

Change in the Status of Juniperus communis *on Michigan, Outer, and Stockton Islands, 2012–2014*

Despite trends of slight increases in shrub diameter from 2012 to 2014 on Michigan, Stockton-Julian Bay, and Outer Island, the increases were not statistically significant (P = 0.94, Island × Year interaction) (Figure 50). The differences in shrub diameter among these three islands continues to vary significantly (P <0.0001), with Stockton Island-Julian Bay having smaller shrub diameters than shrubs on Michigan and Outer Islands (Figure 50). *Juniperus communis* shrubs did grow taller over the two-year period by an average of 12 cm (P <0.0001) (Figure 51). Height of these shrubs does not vary by sandscape location (P = 0.08), nor was there a significant Island × Year interaction (P = 0.48).

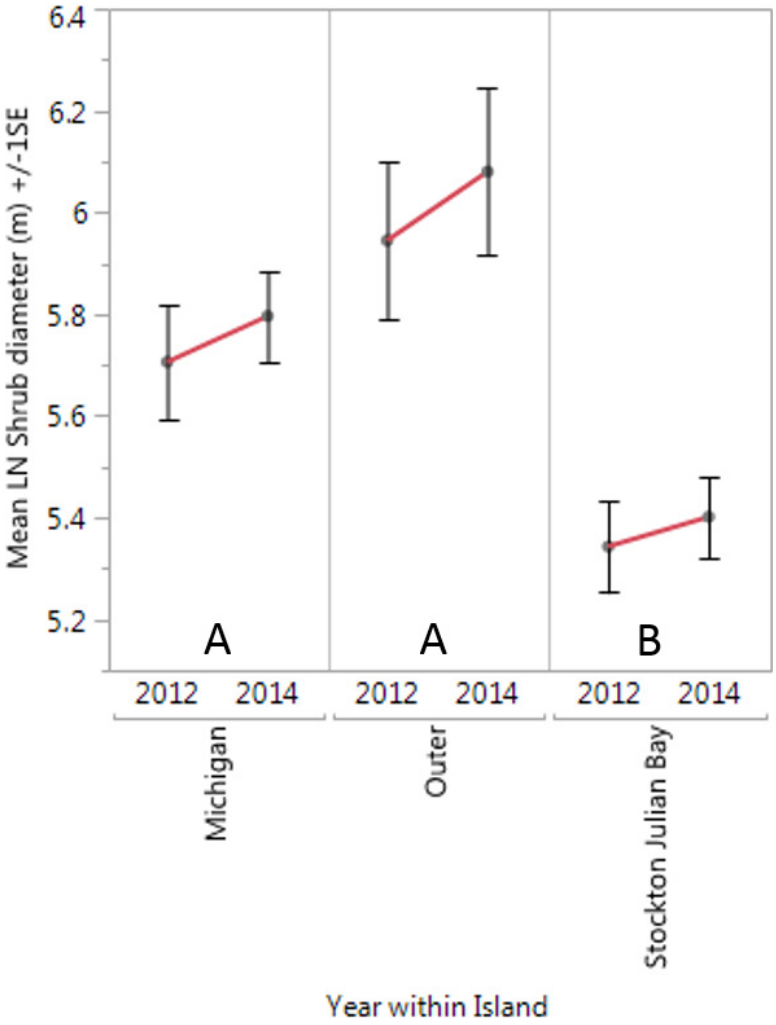


Figure 50. Change in the average crown diameter (m) of *Juniperus communis* shrubs (*ln* transformed) observed in 2012 and in 2014 on three sandscapes in Apostle Islands National Lakeshore. Different capitalized letters indicate significant differences among Islands. Differences among Islands were significant (*P* <0.0001) with post-hoc analyses indicating that Stockton Island-Julian Bay has smaller shrub diameters than shrubs on Michigan and Outer Islands. There were no significant differences in Islands × Year (*P* = 0.94).

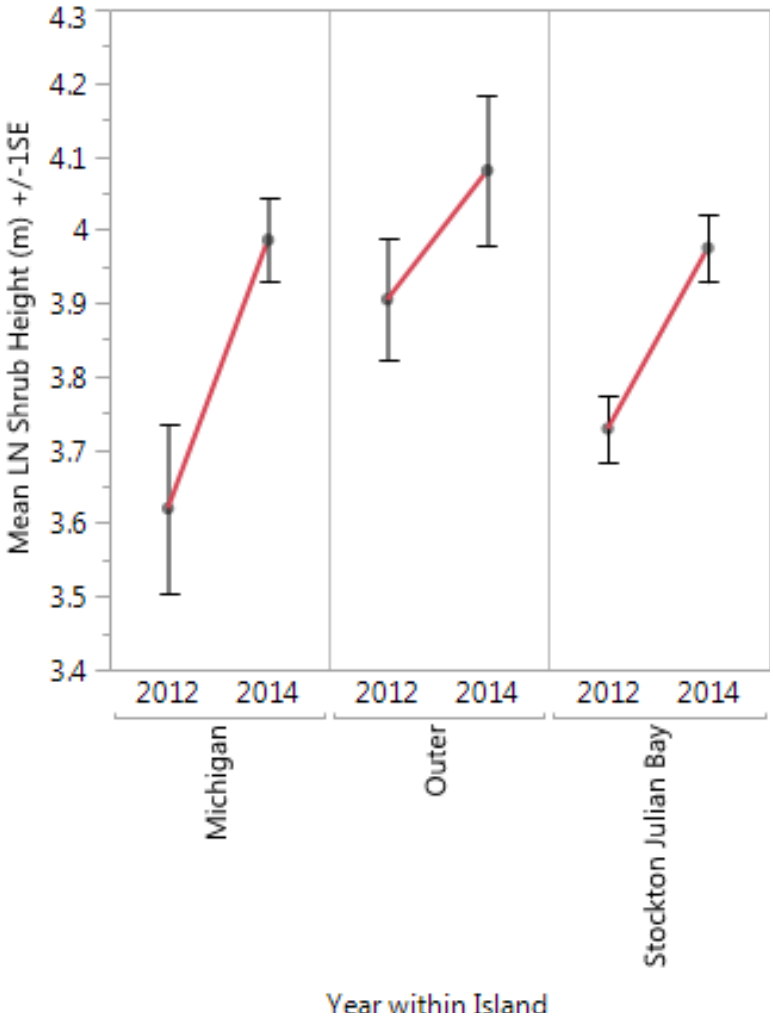


Figure 51. Change in the average crown diameter (m) of *Juniperus communis* shrubs (*ln* transformed) observed in 2012 and in 2014 on three sandscapes in Apostle Islands National Lakeshore. There was a significant difference in shrub height by Year (P <0.0001), but no significant differences by Island (P = 0.08) or Island × Year (P = 0.48). Mean height was, on average, 12 m larger in 2014 than in 2012 (untransformed heights).

The percentage of dead foliage on *Juniperus communis* shrubs did not significantly increase from 2012 to 2014 across all locations (P = 0.14, "Year" effect). Overall differences among islands was significant (P <0.0001), with Stockton Island-Julian Bay having significantly lower dead foliage and Michigan Island having significantly higher dead foliage than the other islands (Figure 52). The Island × Year interaction effect was marginally significant (P <0.1), but post-hoc analyses indicate that no island experienced a significant change in the percentage of dead foliage on shrubs from 2012–2014 (Figure 52). The percentage of dead foliage in 2012 was a good predictor of 2014 foliar die-back (R^2 = 0.69; $F_{1,142}$ = 309.2, P <0.0001) (Figure 53). When the presence or absence of rodent herbivory was included as a factor in the regression model, 71% of the variation in the percentage of dead foliage observed in 2014 was explained by foliar death in 2012 and rodent herbivory (overall model: $F_{3,140}$ = 122.5, P <0.0001; both factors significant at P <0.0001) (Figure 54).

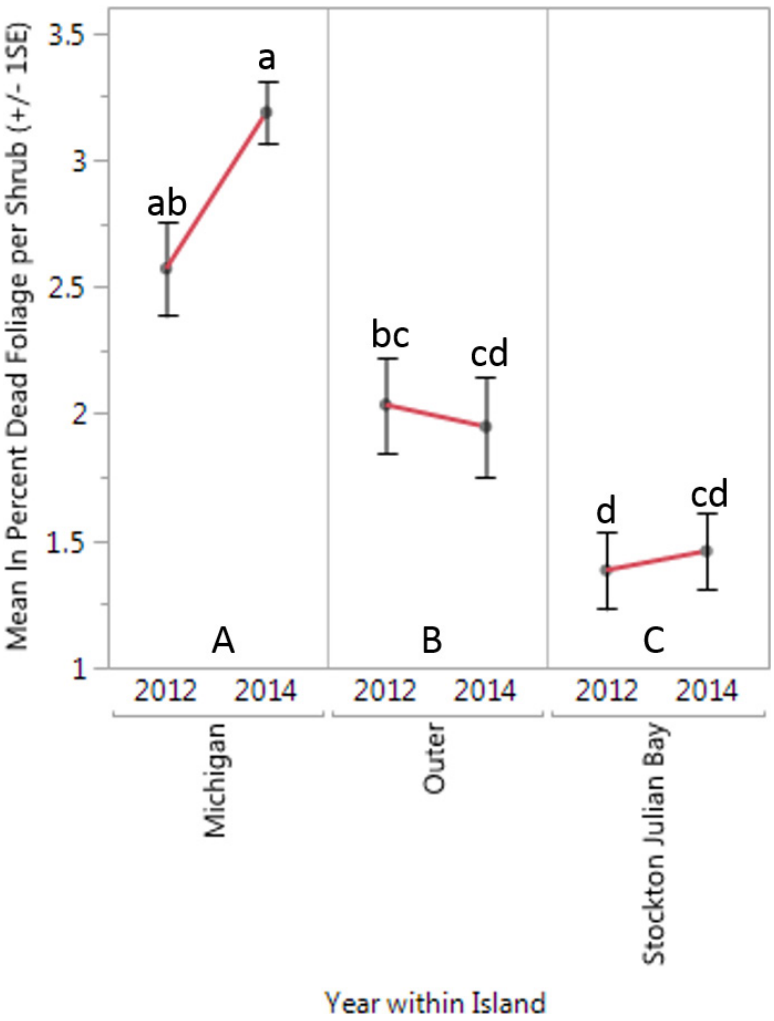


Figure 52. Mean percentage dead foliage per *Juniperus communis* shrub (*ln* transformed) observed in 2012 and in 2014 on three sandscapes in Apostle Islands National Lakeshore. Different capitalized letters indicate significant differences among Islands and lowercase letters indicate significant differences in Island × Year. Differences among Islands were significant (P <0.0001), with Stockton Island-Julian Bay having significantly lower dead foliage and Michigan Island having significantly higher dead foliage than the other islands. Differences in Island × Year were marginally significant (P <0.1). Post-hoc analyses indicate that no island experienced a significant change in the percentage of dead foliage on shrubs.

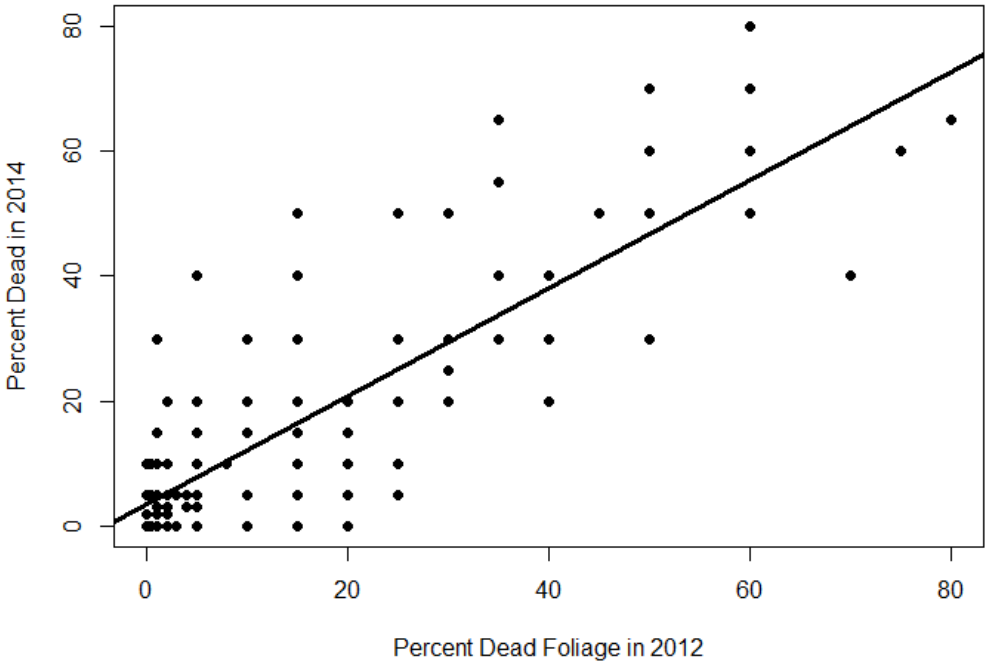


Figure 53. Simple linear regression of percent dead foliage observed on *Juniperus communis* shrubs in 2014 regressed against the percentage dead foliage in 2014 among three sandscapes in Apostle Islands National Lakeshore. The percentage of dead foliage in 2012 explained 69% of the variation in the percentage of dead foliage observed in 2014 ($F_{1,142} = 309.2$, $P < 0.0001$).

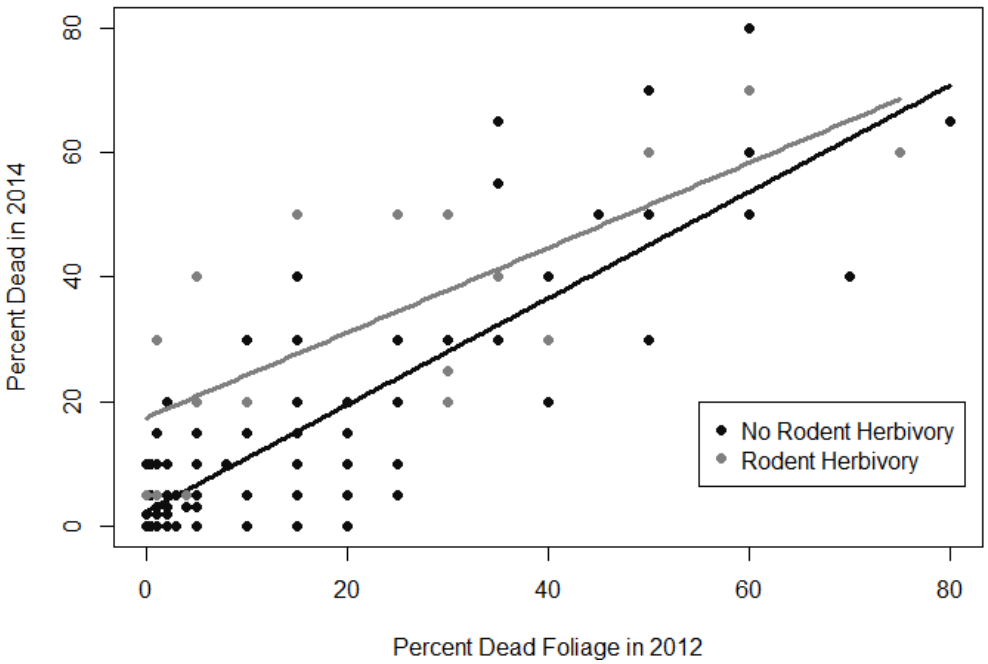


Figure 54. Multiple linear regression of percent dead foliage observed on *Juniperus communis* shrubs in 2014 regressed against the percentage of dead foliage and presence/absence of rodent herbivory in 2014 included as a factor. The percentage of dead foliage in 2012 and rodent herbivory in 2014 explained 71% of the variation in the percentage of dead foliage observed in 2014 (overall model: $F_{3,140} = 122.5$, $P<0.0001$; both factors significant at $P < 0.0001$).

Discussion

Juniperus communis is present on all but seven of the sandscapes found within Apostle Islands National Lakeshore. Overall, *J. communis* populations appear to be stable and even robust in most locations. Yet, the population on Michigan Island has experienced some stresses related to rodent herbivory. Although we did not detect the physical signs of herbivory in 2012, we feel certain that the dieback observed that year was due to branch herbivory. There are three factors that likely contributed to us not detecting branch herbivory in 2012. One, it is possible that the rodent activity among the *Juniperus communis* shrubs is restricted to winter and spring months when snow is present and when other food sources are scarce. We conducted the 2014 work in early summer when rodent-nipped branch tips and bark removal was fresh and evident (Figure 41). Note that nipped twig tips were on the ground beneath the shrub, but the diameter of the clipped twigs was too small to notice browsed tips on the shrub. The 2012 work occurred in August when wind could have blown nipped tips away. Also, areas where bark had been removed could have browned over by late summer, making it less obvious to our survey crew. We observed rodent scat, piles of seeds, and the occasional hole beneath shrubs in our early June 2014 survey, but we did not notice these in August 2012. Second, it is possible that the use of the *Juniperus communis* habitat by rodents increased during the notably cold, snowy, and long winter of 2013–2014, resulting in more evidence for our crew in early June 2014.

Southern red-backed voles (*Myodes gapperi*) are the dominant rodent occupying the *Juniperus communis* habitat on Michigan sandscape, and are present there in densities higher than usually observed on the mainland (P. Anich, personal communication). *Peromyscus* spp. are also somewhat common there (16% of the sample population), so we cannot be certain which taxa is responsible for the herbivory damage. It is unlikely that *Mus musculus* (house mouse, native to Europe) is responsible. Both *M. gapperi* and *Peromyscus* spp. are native to this ecoregion and their abundances may reflect temporally variable population densities of mammalian carnivores on the islands (Allen et al. 2016). We recommend additional small mammal trapping and camera trap studies in the *Juniperus communis* habitat, primarily on Michigan and Outer Island sandscapes. These relatively simple sandscape systems could serve as a "learning laboratory" for studying plant-animal interactions and possible trophic cascades involving predator dynamics. Further, scientists and managers could study temporal changes in these species interactions in the context of winter severity, drought, and other climate variables. Future studies could expand the focus of small mammal interactions to other plant species, too. For example, we noticed some girdled stems of *Prunus pumila* (sand cherry) and caches of cherry pits. We also noticed clipped beachgrass (*Ammophila breviligulata*) in some areas on the sandscapes.

Outer Island has the largest sandscape and the largest population of *Juniperus communis* in the lakeshore. Shrubs there are also, on average, the largest and there is only a moderate-to-low level of foliar dieback. It is notable, however, that the non-native pale juniper webworm (*Aethus rutilana*) is much more prevalent on *J. communis* shrubs on Outer Island than on the four other sandscapes where we located it. Over half of the *J. communis* shrubs had >10% of branches occupied by webbed clusters of the webworm. *Aethus rutilana* is a Lepidopteran moth species with a 9–11 mm wingspan that burrows into and feeds on the interior of leaves of *Juniperus communis* (Freeman 1967). Ovum

are placed in leaf axils of the *J. communis* in mid- to late summer and emergent larvae begin mining leaves in the fall. They eject a silky webbing and frass that tie needles together in the 2–4-cm noticeable clusters. They overwinter in a narrow tube and they again feed on leaves in the late spring and early summer months before they create pupal cocoons inside of the webbed leaves. Moths emerge in mid-summer (Bland et al. 2014). There is little documentation of *Aethus rutilana* in North America and this dense population on Outer Island may be unique (P. Liesch, personal communication). This species originates in southern England where low population numbers match declines in *J. communis* there (Bland et al. 2014). We recommend that APIS managers continue to observe and possibly monitor this *Aethus rutilana* population and its interactions with *J. communis*. Will the *Aethus rutilana* population continue to thrive and will there be lagging impacts on *J. communis*? Or will there be no noticeable negative impacts? Could the Apostle Islands National Lakeshore serve as a refuge site for a species considered at-risk in Europe?

Globally, die-offs in woody plants are widespread and researchers have implicated drought, warming temperatures, and pests and pathogens (Logan et al. 2003). Conifers, in particular, have experienced high rates of mortality due to drought and insect pests (Adams et al. 2009). Many researchers have implicated drought stress as a precursor to insect attack (e.g., Carnicer et al. 2011), but the mechanisms are little understood (Jamieson et al. 2012). One theory suggests that changes in foliar quality, such as increased available nitrogen, may promote more insect defoliation and propagation of insect populations during drought pulses. Sustained water stress, however, can negatively impact populations of phytophagous insects (Huberty and Denno 2004). Therefore, we suggest that managers at the Apostle Islands National Lakeshore continue to carefully monitor outbreaks of the pale juniper webworm and the overall health of *Juniperus communis* on these sandscapes.

Johnson and Mead (2013) detected some age-related senescence in populations on Michigan, Stockton-Julian Bay, and Outer Island. The density-size distributions that we observed among populations in 2014 indicate that Michigan, Long, and Outer Islands have fewer small shrubs than what we expect in actively regenerating populations. Some regeneration is occurring, though.

Dioecy in *Juniperus communis* holds potentially significant implications for overall population health and responsiveness to stressors. Perhaps due to decreased fitness, dioecy is relatively uncommon among plants. Divergences in the needs and responses of the sexes to climate change and other drivers of change potentially make dioecious plants more vulnerable to extinction (Vamosi and Vamosi 2005). Male-biased ratios are commonly cited for senescent populations of dioecious species and these patterns are often attributed to greater reproductive demands for resources by females (Bierzychudek and Eckhart 1988, Obeso 2002). No distinct relationships could be found between sex of plant and spatial patterns within populations of *Juniperus communis* studied in northern Québec (Marion and Houle 1996), but distinctions in growth patterns (Iszkuło and Boratyñski 2011) and biased sex ratios in senescent populations (Clifton et al. 1997, Ward 1982) have been observed in Europe. Johnson and Mead (2013) detected a female-biased sex ratio on Michigan and Stockton Islands in the 2012 exhaustive survey, but we observed a male-dominated sex ratio on these and other islands, using sub-sampling methods. Due to the non-random distribution of the sexes (Johnson and Mead 2013), it is possible that we biased the data towards males by our sub-sampling design.

However, we do recommend that resource managers at APIS continue to monitor sex ratios, as the male dominance that we observed in 2014 could portend future population declines.

Conclusions

Juniperus communis is an ecologically important member of sandscapes in Apostle Islands National Lakeshore. In addition to the dune-building services it provides, it appears to be serving as a nurse plant for other species and so is important for successional processes in the vegetation. It also serves as habitat and a food source for small mammals and likely birds. The use of *J. communis* by the non-native pale juniper webworm (*Aethus rutilana*) raises an intriguing research question regarding the use of and possible impacts to *J. communis*, and the possible role of this being a refuge habitat for the moth. We recommend that the NPS natural resource managers continue to monitor *Juniperus communis* on Michigan and Outer Island sandscapes every 5–6 years.

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Appendix A. Sandscape maps.

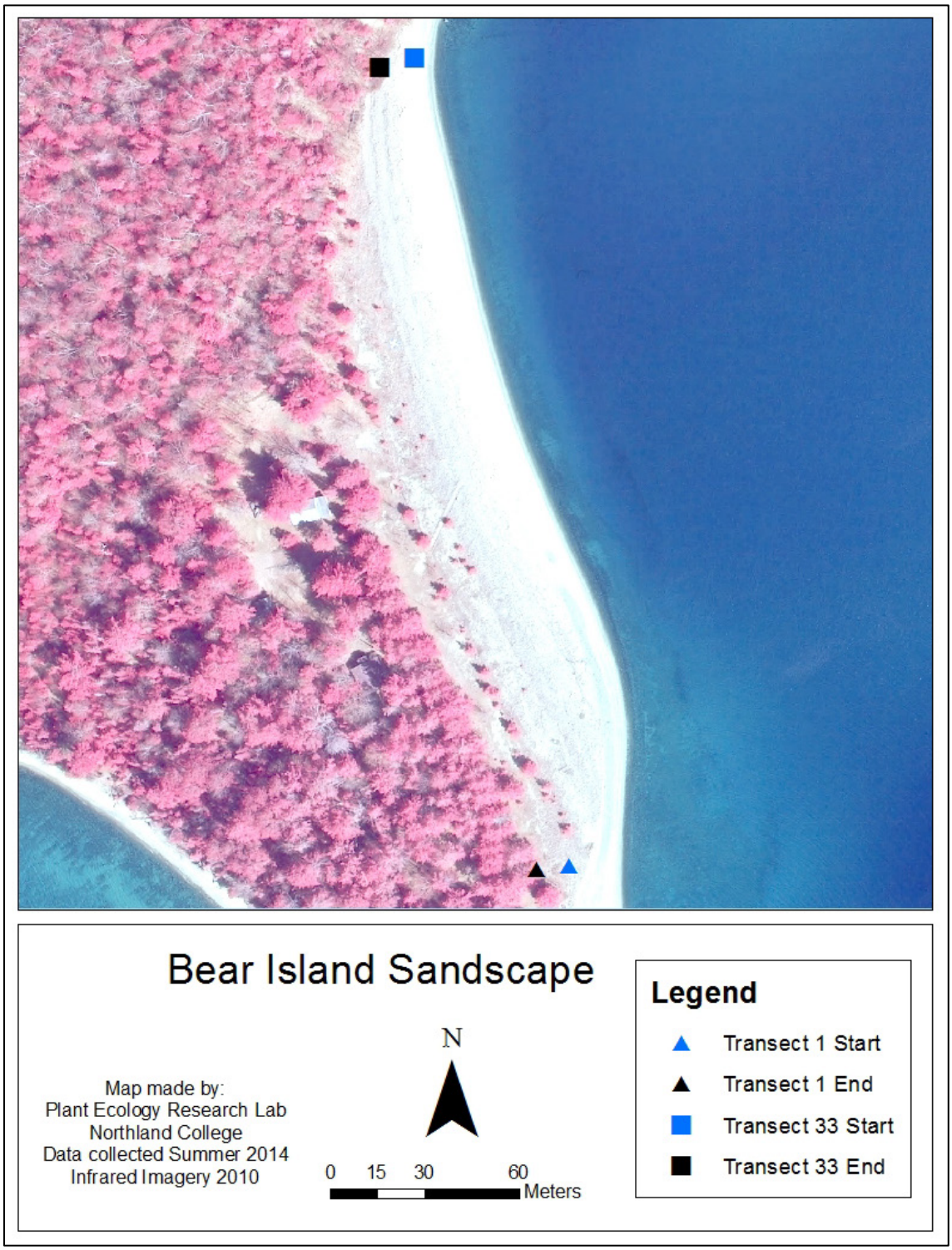


Figure A1. Sandscape imagery showing the start and end transect points used in 2014 by the Northland College field crew on Bear Island.



Figure A2. Sandscape imagery showing the location of trails delineated in 2014 by the Northland College field crew on Cat Island. Also shown are the start and end transect points.

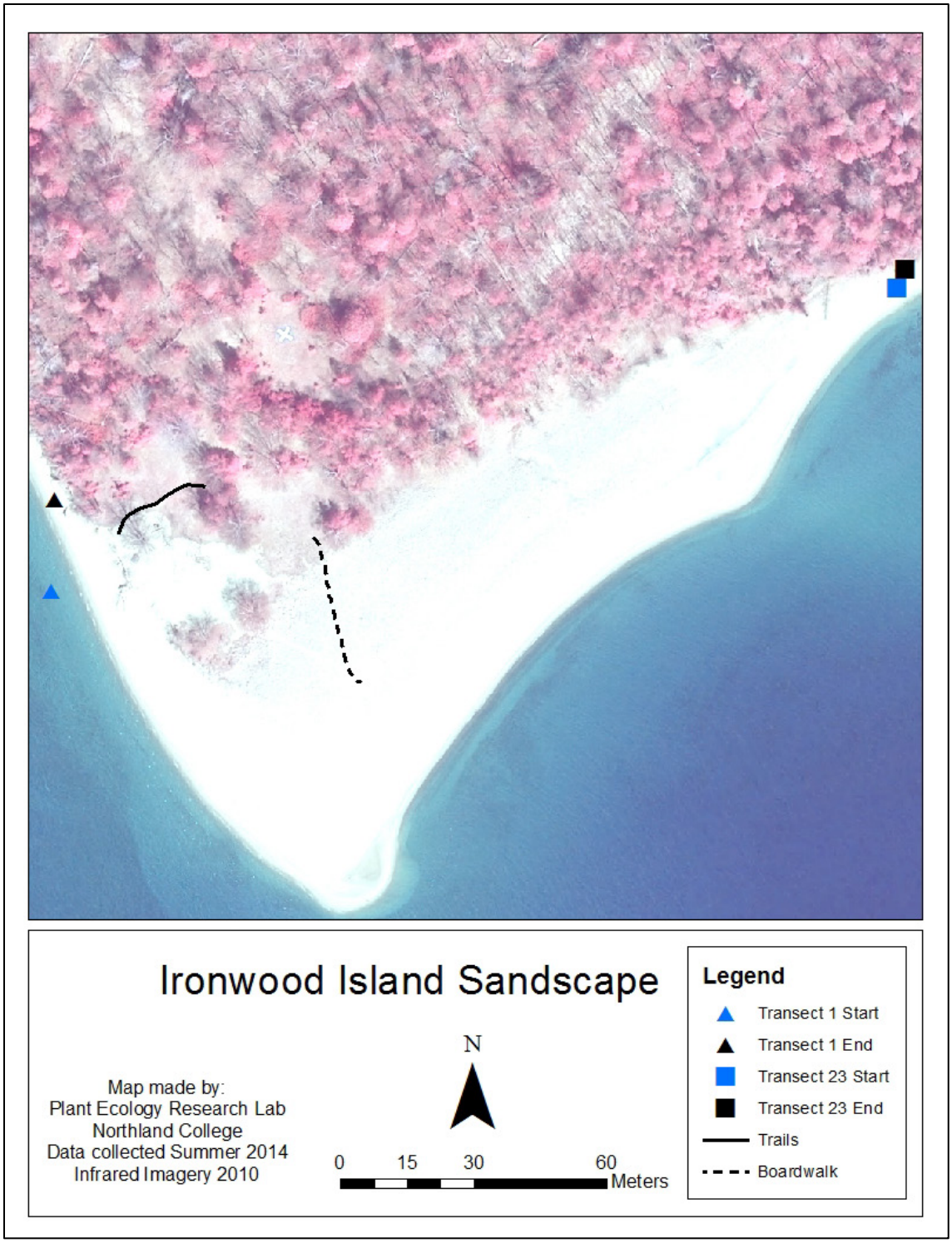


Figure A3. Sandscape imagery showing the location of trails delineated in 2014 by the Northland College field crew on Ironwood Island. Also shown are the start and end transect points.



Figure A4. Sandscape imagery showing the location of trails delineated in 2014 by the Northland College field crew on Mainland-Little Sand Bay. Also shown are the start and end transect points.

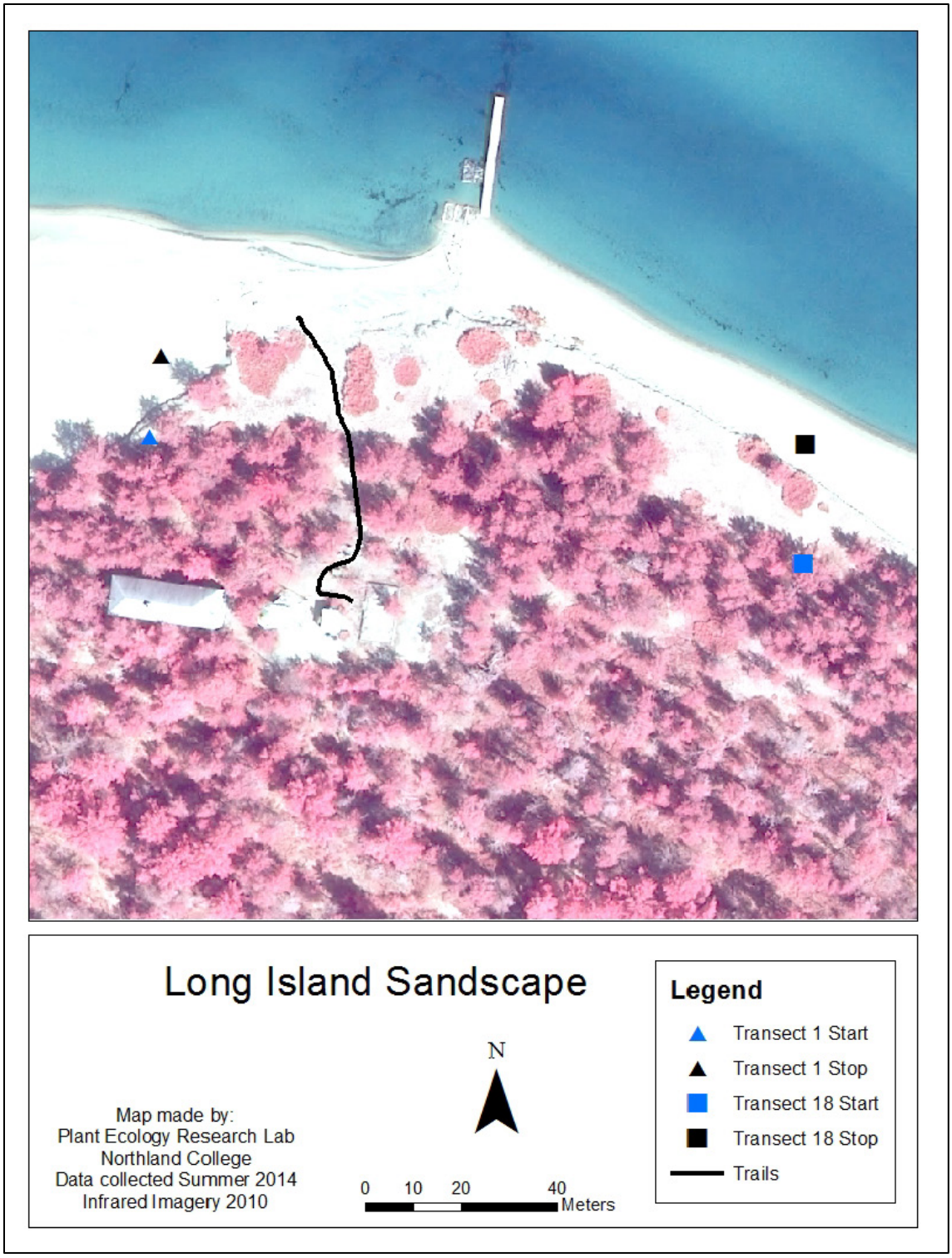


Figure A5. Sandscape imagery showing the location of trails delineated in 2014 by the Northland College field crew on Long Island. Also shown are the start and end transect points.

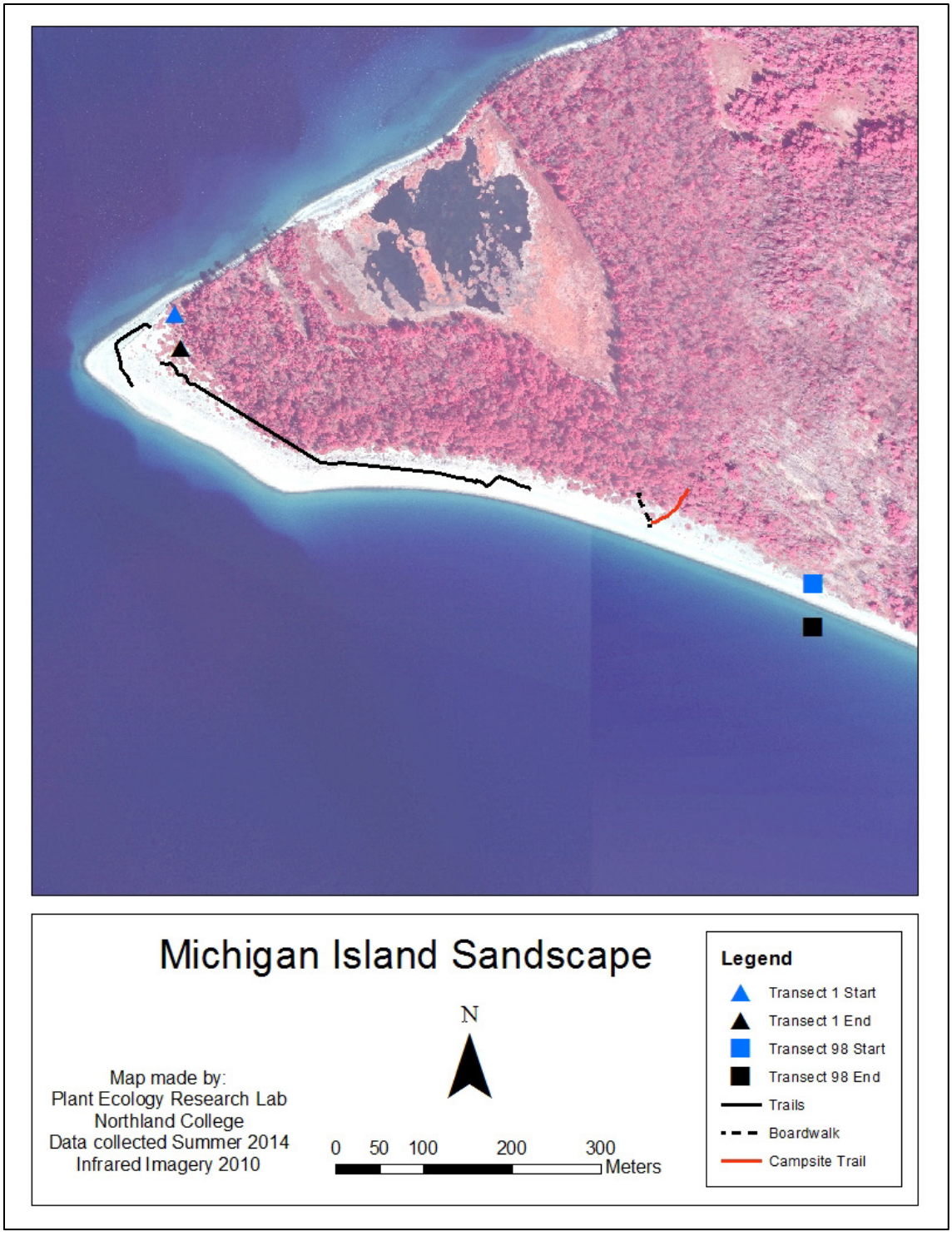


Figure A6. Sandscape imagery showing the location of trails delineated in 2014 by the Northland College field crew on Michigan Island. Also shown are the start and end transect points.

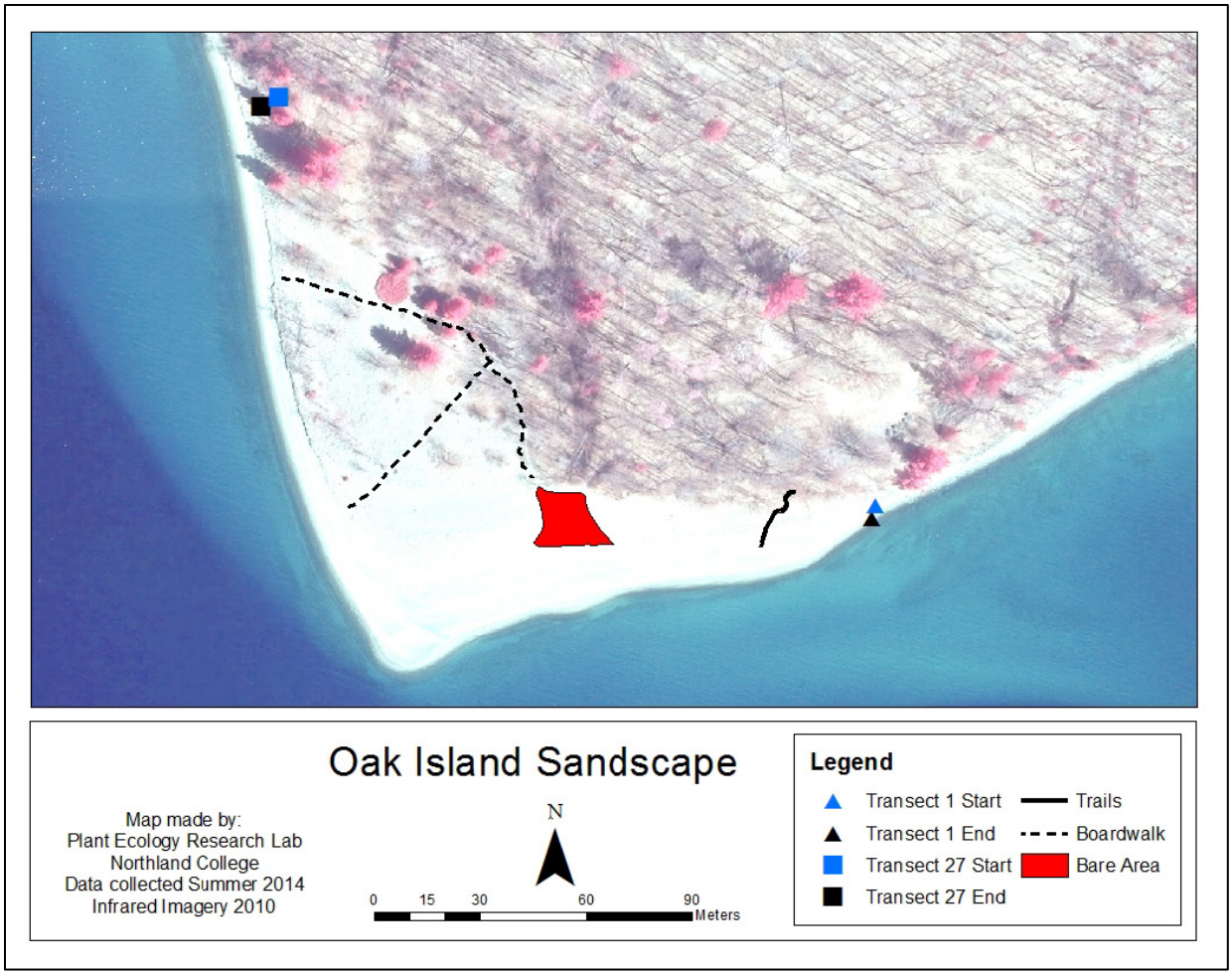


Figure A7. Sandscape imagery showing the location of trails delineated in 2014 by the Northland College field crew on Oak Island. Also shown are the start and end transect points.

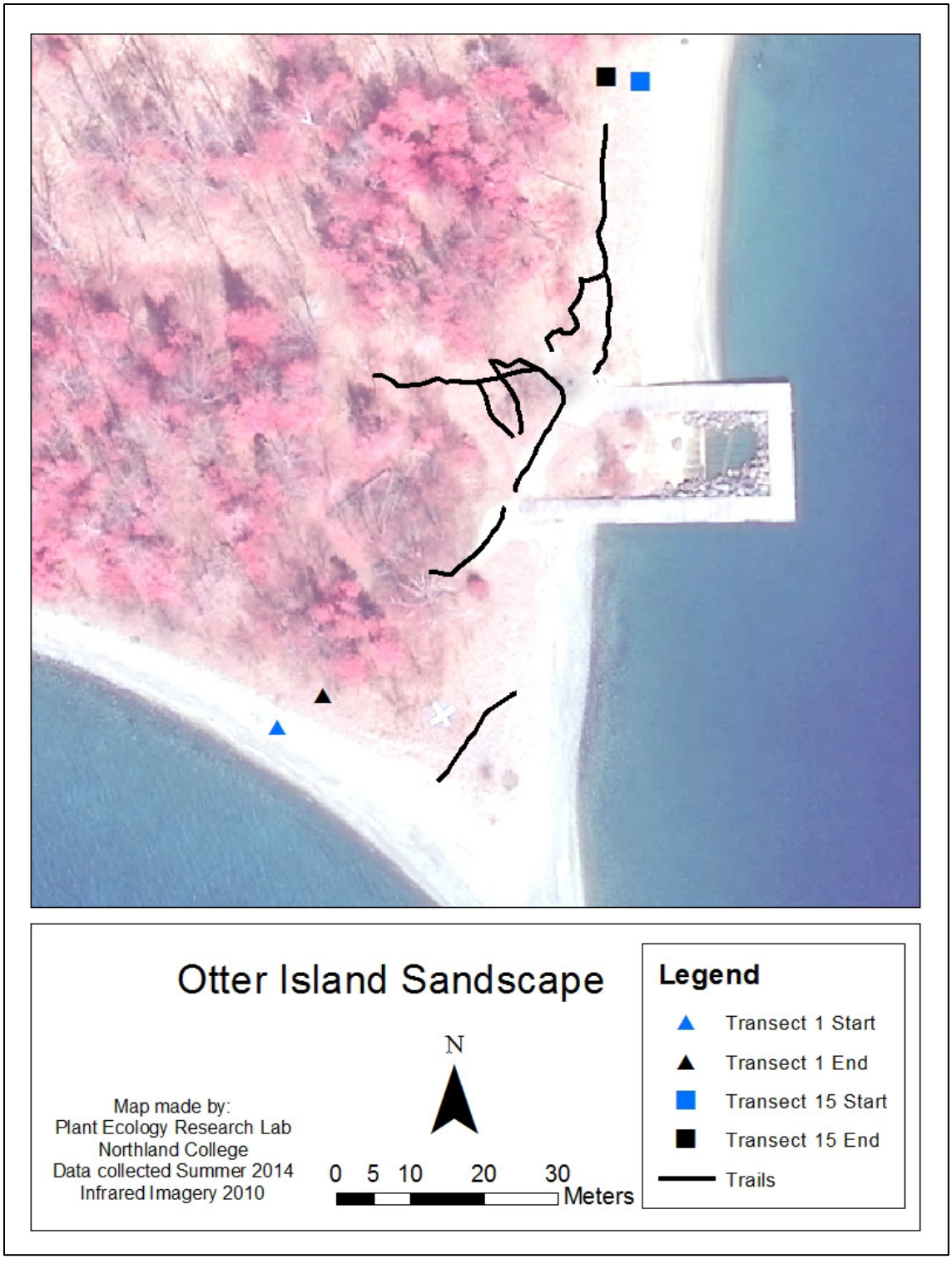


Figure A8. Sandscape imagery showing the location of trails delineated in 2014 by the Northland College field crew on Otter Island. Also shown are the start and end transect points.

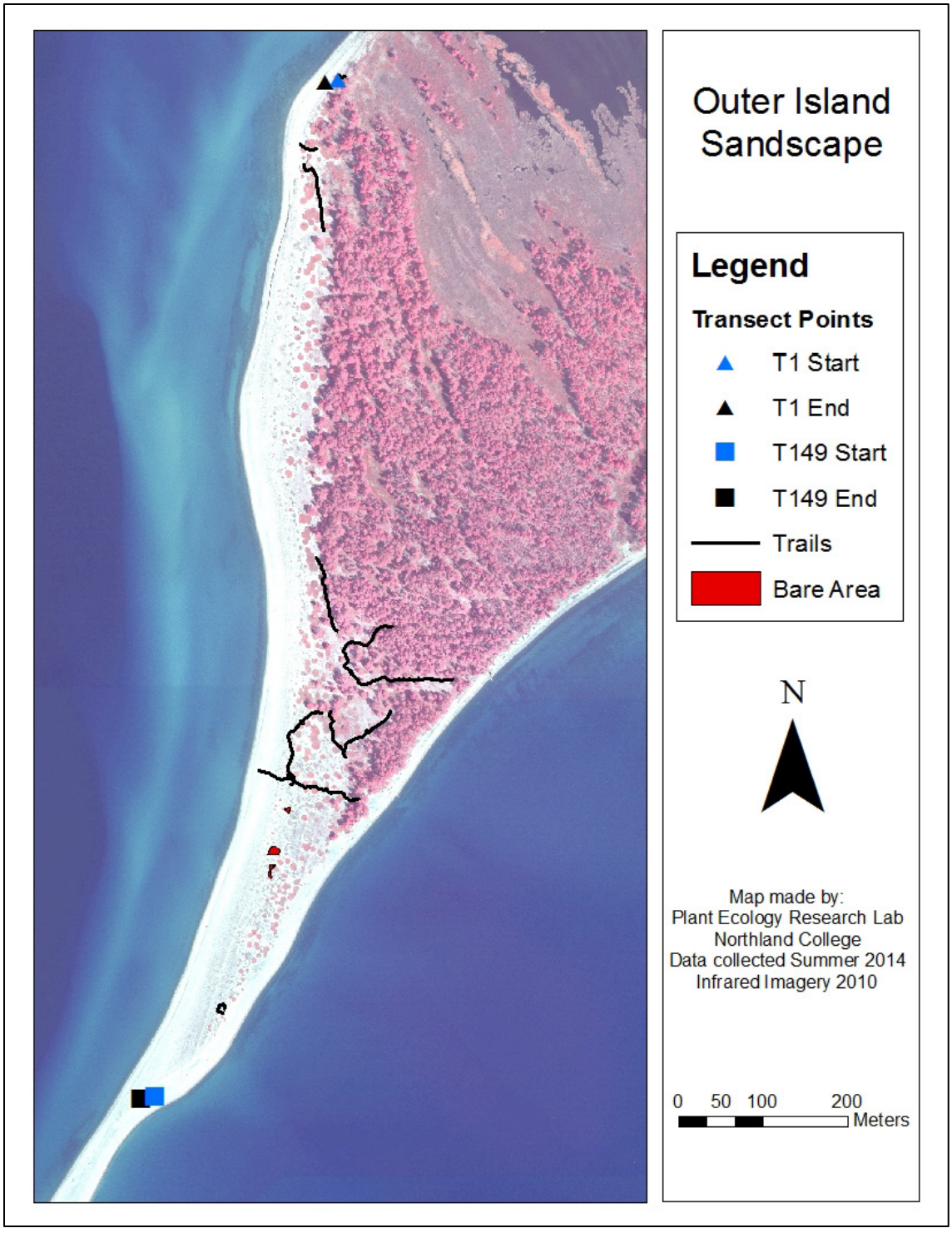


Figure A9. Sandscape imagery showing the location of trails delineated in 2014 by the Northland College field crew on Outer Island. Also shown are the start and end transect points.

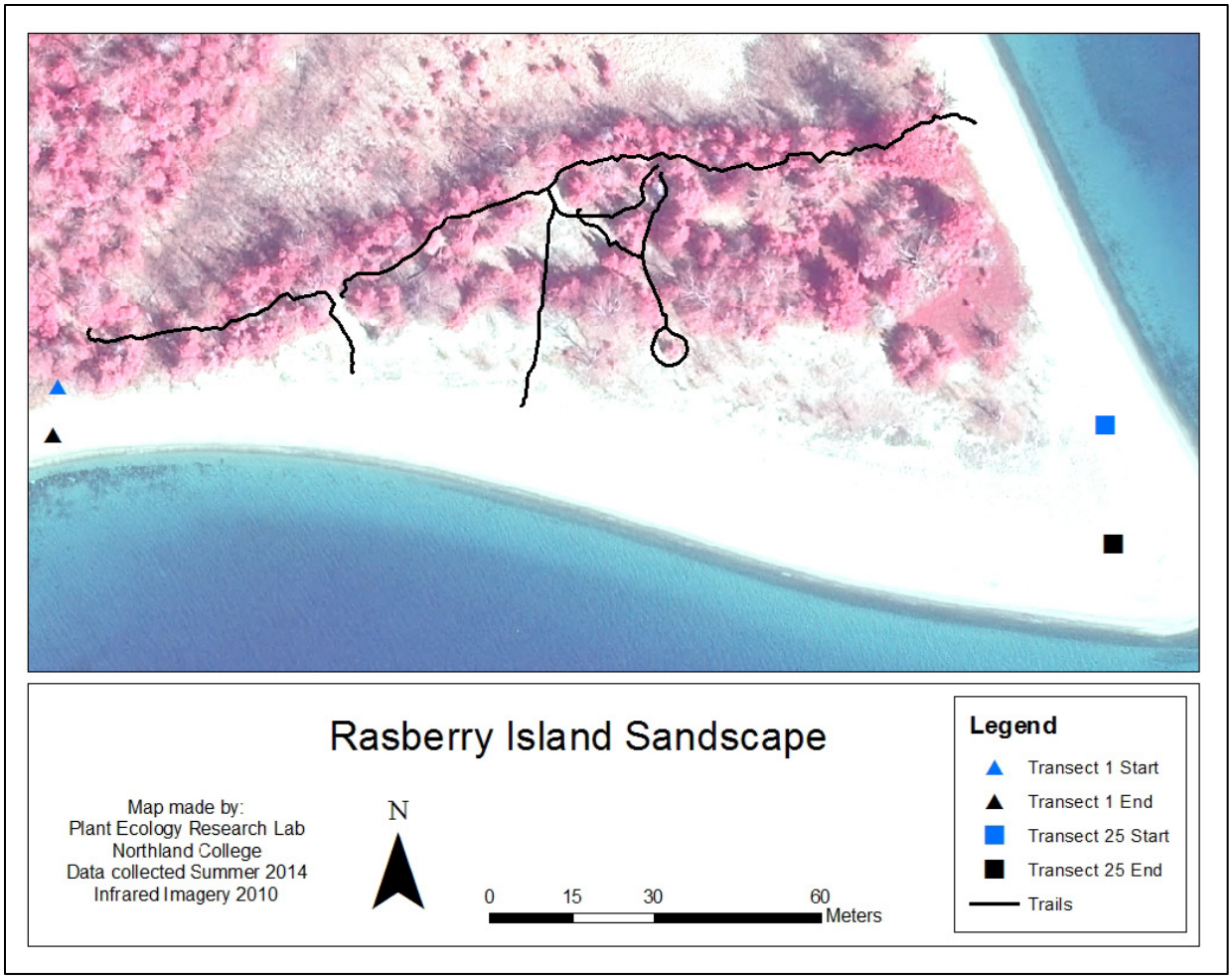


Figure A10. Sandscape imagery showing the location of trails delineated in 2014 by the Northland College field crew on Raspberry Island. Also shown are the start and end transect points.

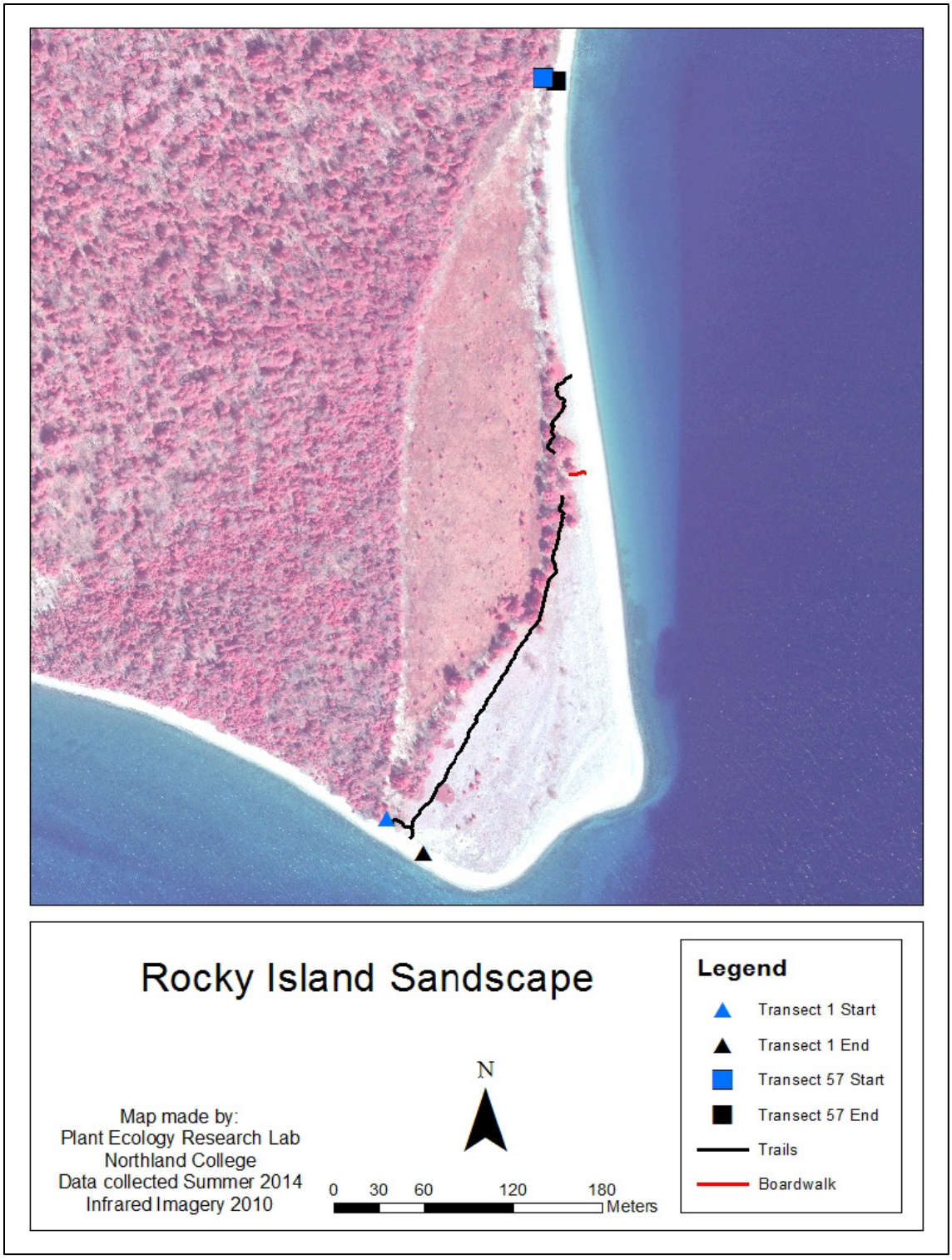


Figure A11. Sandscape imagery showing the location of trails delineated in 2014 by the Northland College field crew on Rocky Island. Also shown are the start and end transect points.

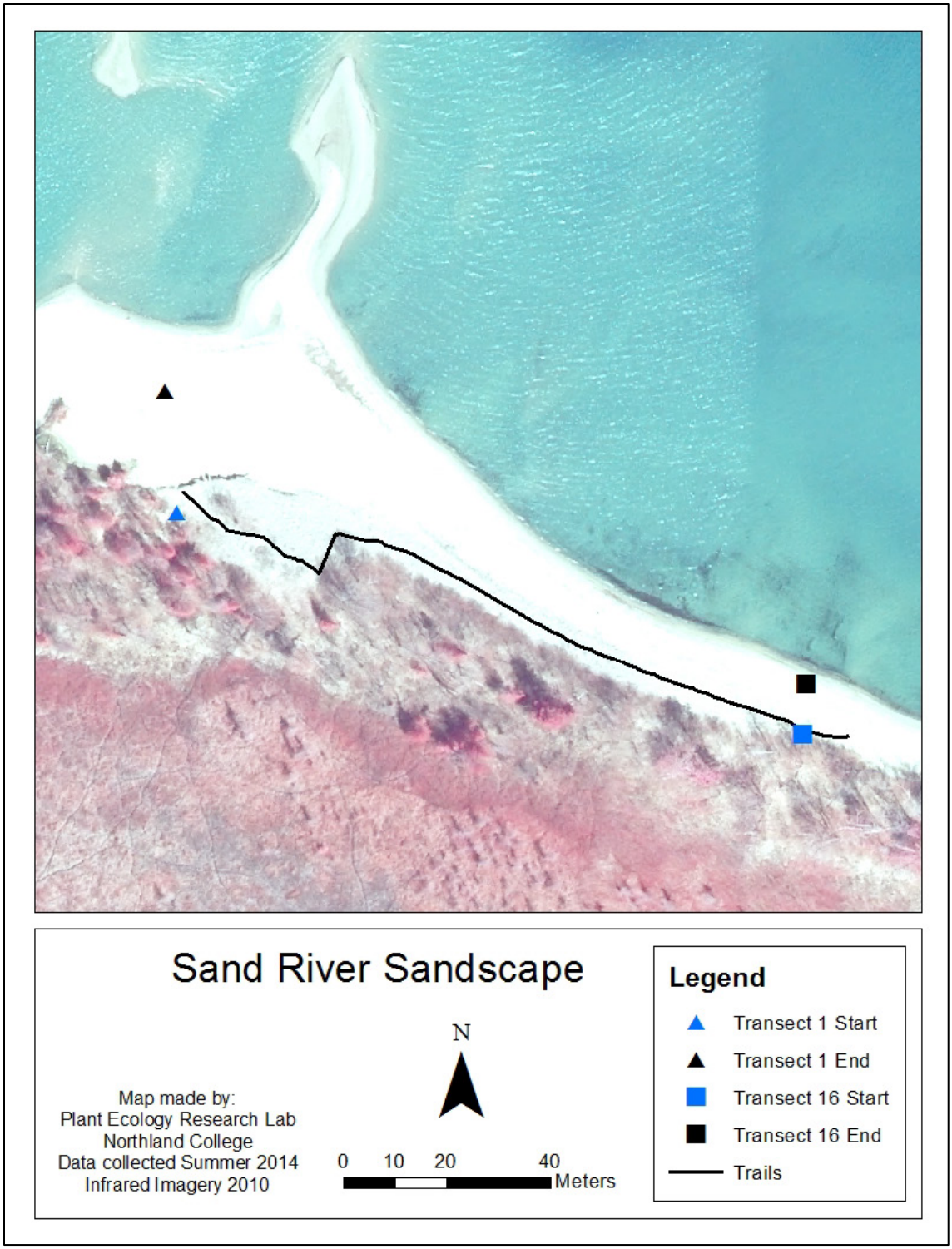


Figure A12. Sandscape imagery showing the location of trails delineated in 2014 by the Northland College field crew on Sand Island. Also shown are the start and end transect points.

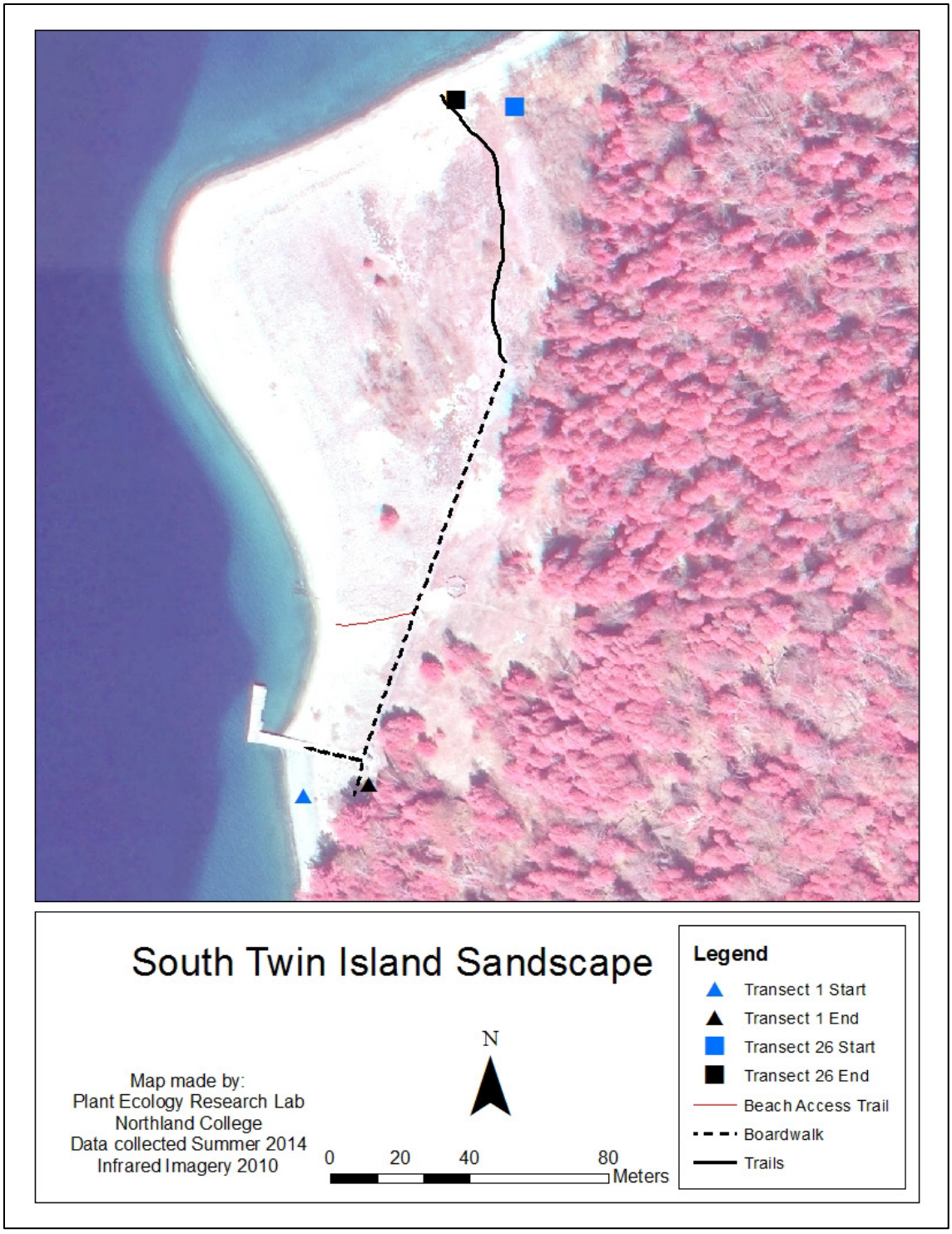


Figure A13. Sandscape imagery showing the location of trails delineated in 2014 by the Northland College field crew on South Twin Island. Also shown are the start and end transect points.

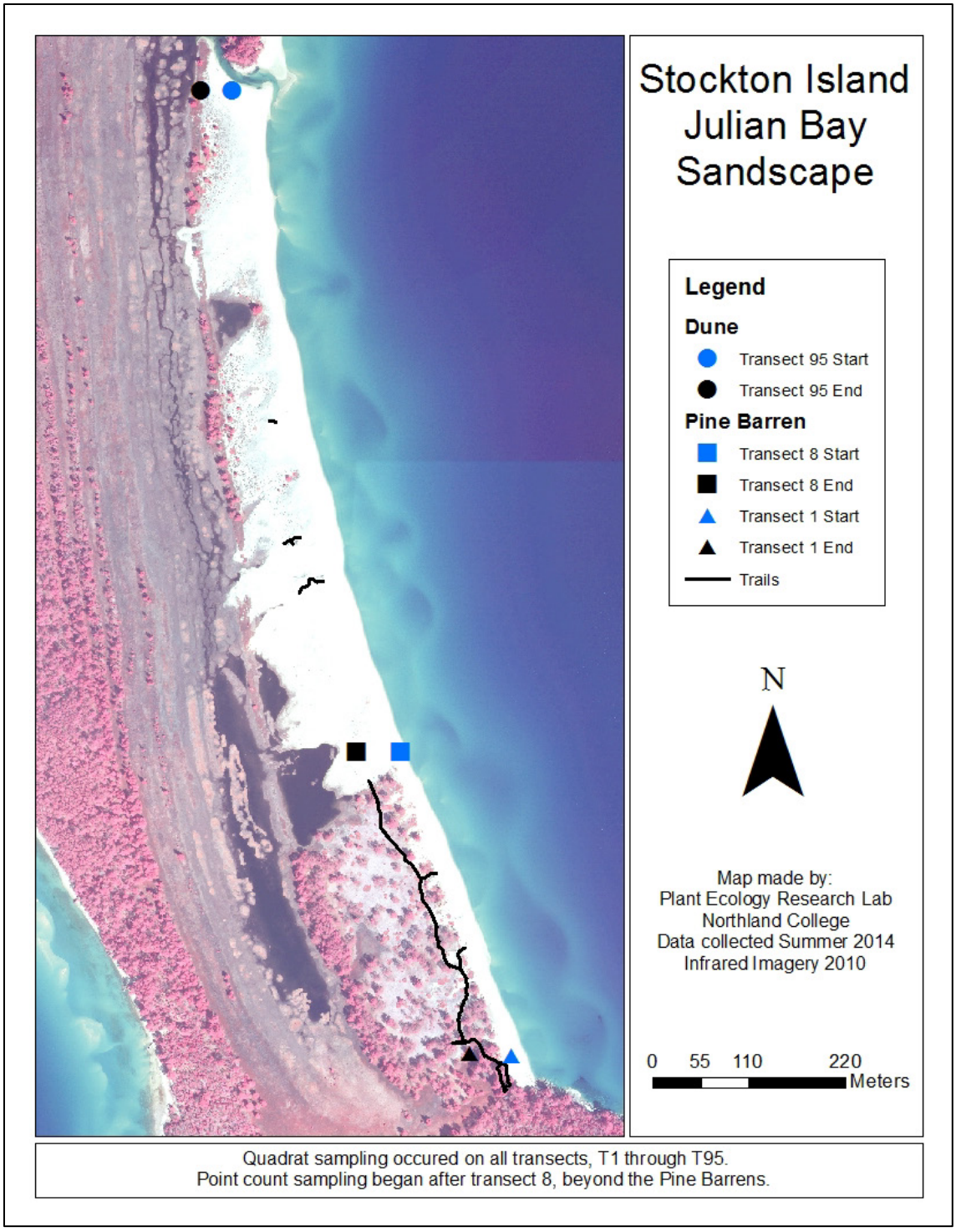


Figure A14. Sandscape imagery showing the location of trails delineated in 2014 by the Northland College field crew on Stockton-Julian Bay Island. Also shown are the start and end transect points.

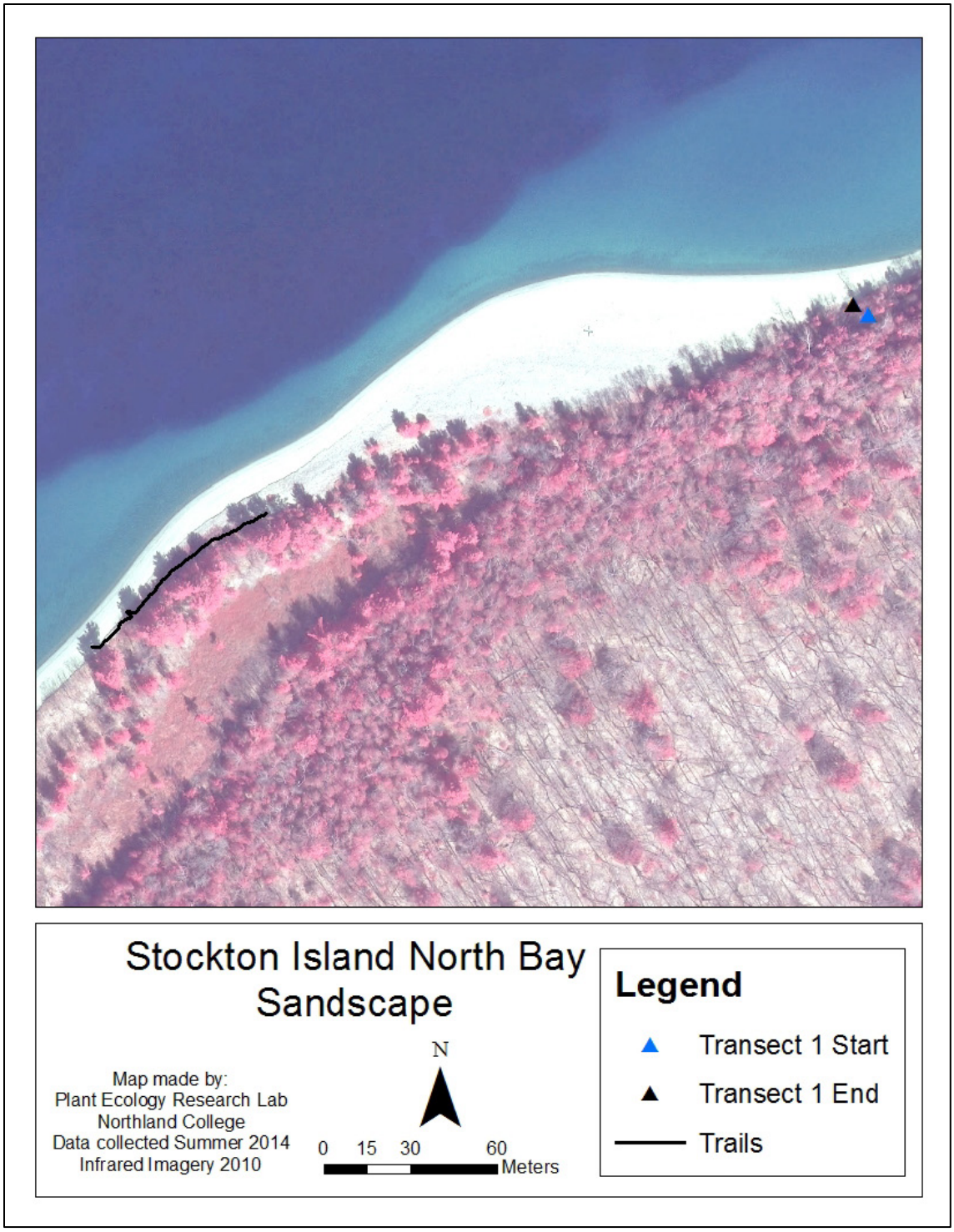


Figure A15. Sandscape imagery showing the location of trails delineated in 2014 by the Northland College field crew on Stockton Island-North Beach. Also shown are the start and end transect points.

Appendix B. Beach profile graphs.

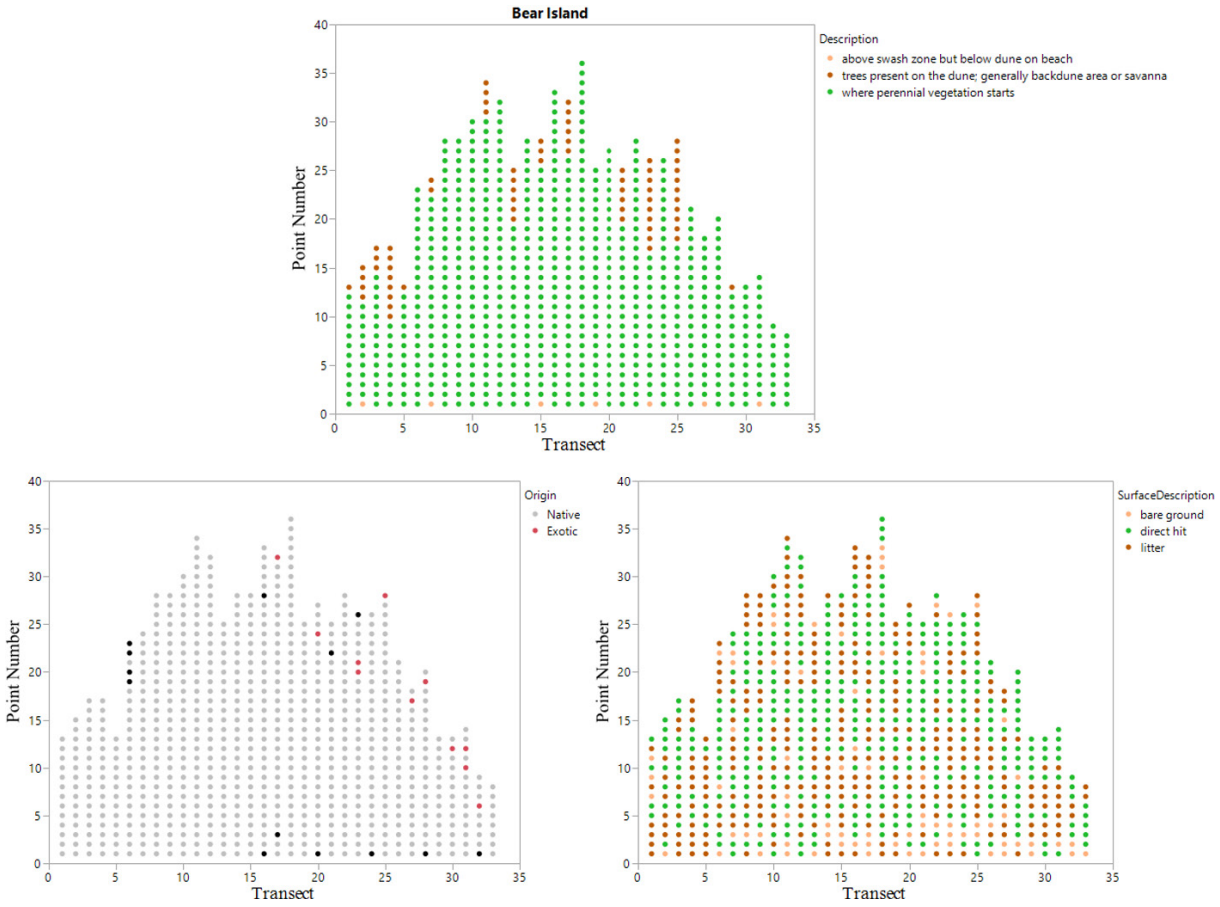


Figure B1. Sandscape profile graphs for Bear Island. All points are plotted, including any points in zones 1 and 2 below the perennial dune vegetation, to illustrate the profile of sandscape features with all transects starting at the high water line on the beach. Black dots on the Origin graph represent “empty” points with no vegetation.

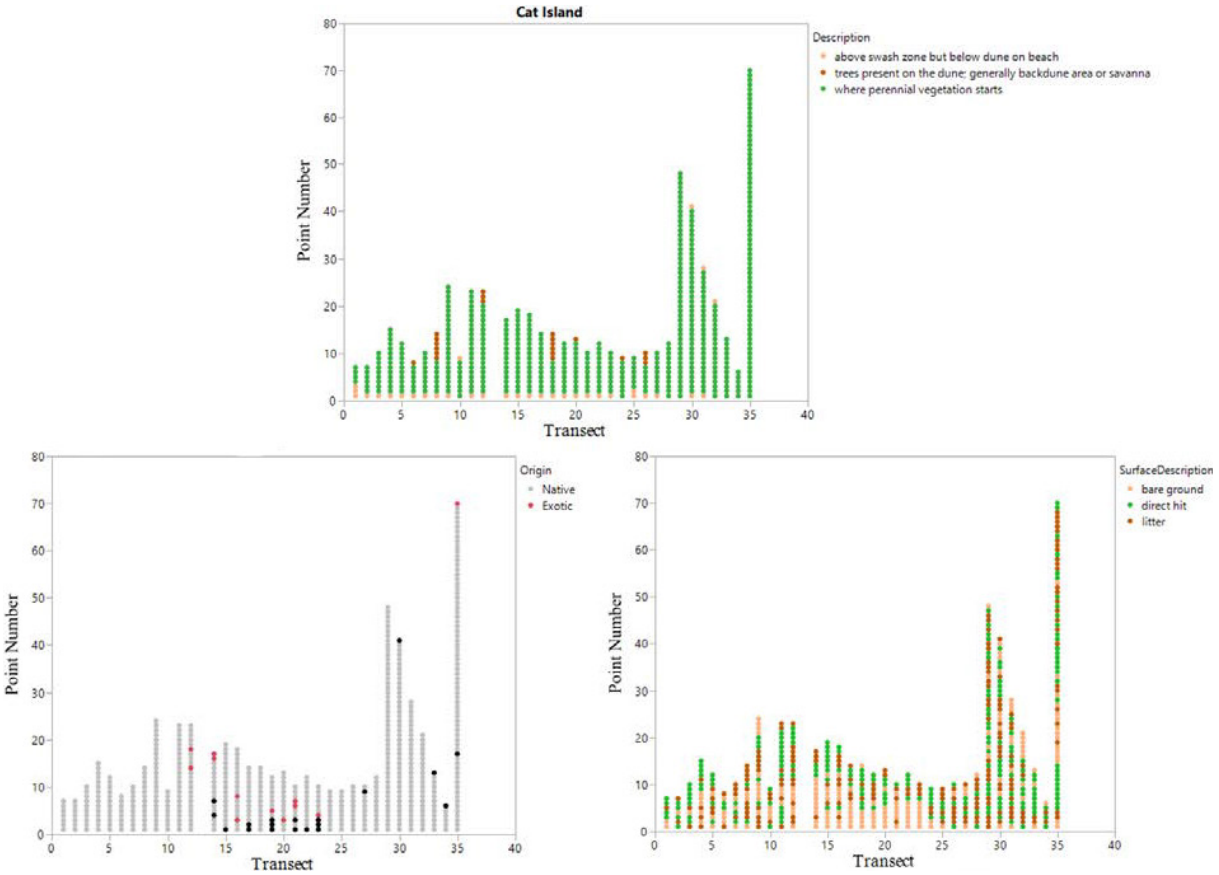


Figure B2. Sandscape profile graphs for Cat Island. All points are plotted, including any points in zones 1 and 2 below the perennial dune vegetation, to illustrate the profile of sandscape features with all transects starting at the high water line on the beach. Black dots on the Origin graph represent “empty” points with no vegetation.

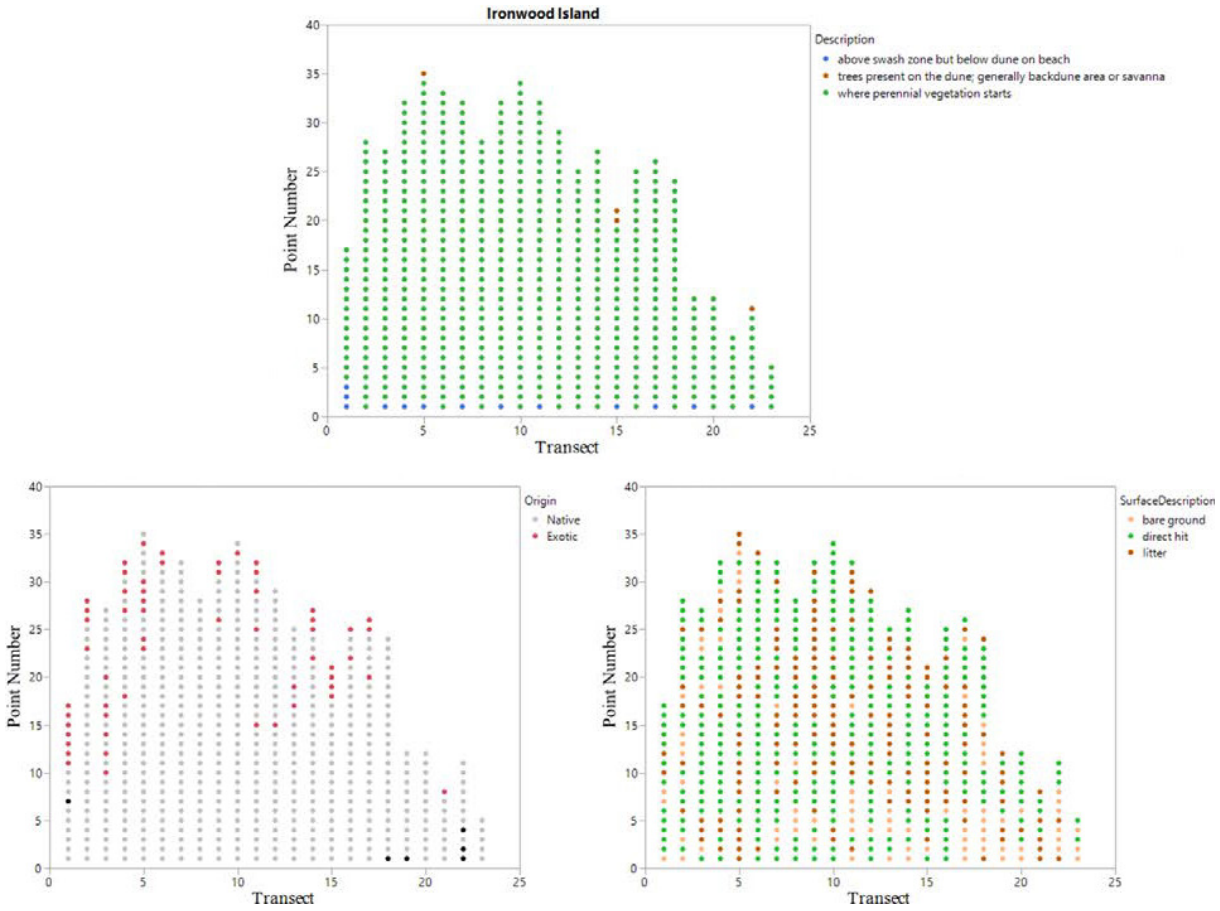


Figure B3. Sandscape profile graphs for Ironwood Island. All points are plotted, including any points in zones 1 and 2 below the perennial dune vegetation, to illustrate the profile of sandscape features with all transects starting at the high water line on the beach. Black dots on the Origin graph represent “empty” points with no vegetation.

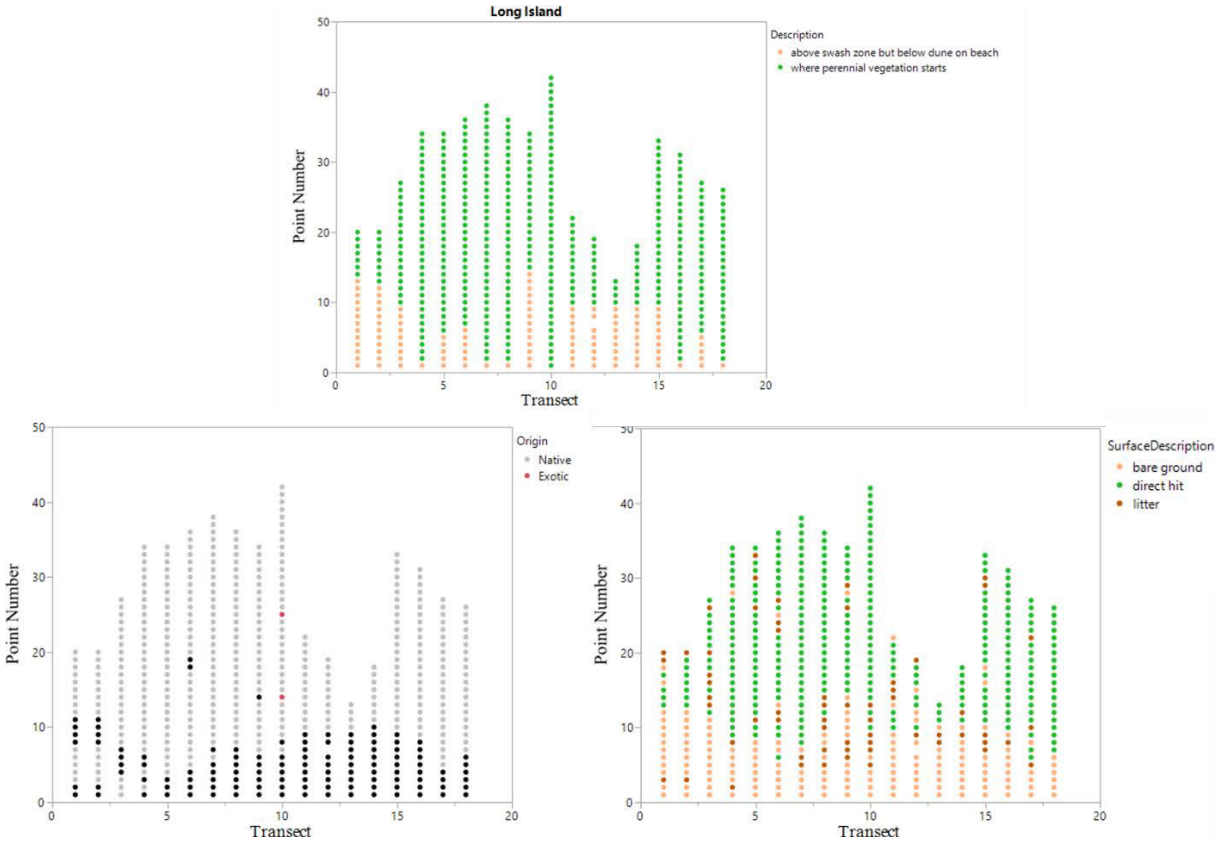


Figure B4. Sandscape profile graphs for Long Island. All points are plotted, including any points in zones 1 and 2 below the perennial dune vegetation, to illustrate the profile of sandscape features with all transects starting at the high water line on the beach. Black dots on the Origin graph represent “empty” points with no vegetation.

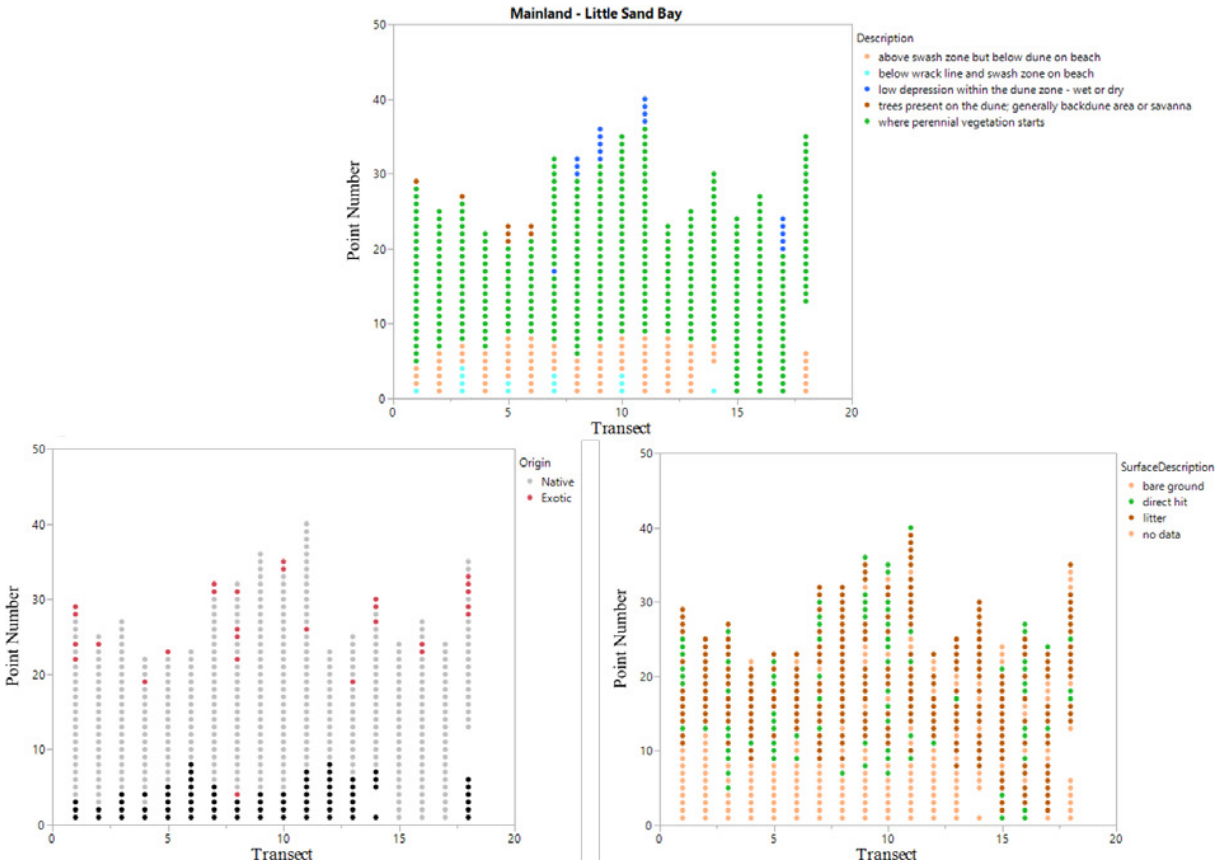


Figure B5. Sandscape profile graphs for Mainland-Little Sand Bay. All points are plotted, including any points in zones 1 and 2 below the perennial dune vegetation, to illustrate the profile of sandscape features with all transects starting at the high water line on the beach. Black dots on the Origin graph represent “empty” points with no vegetation.

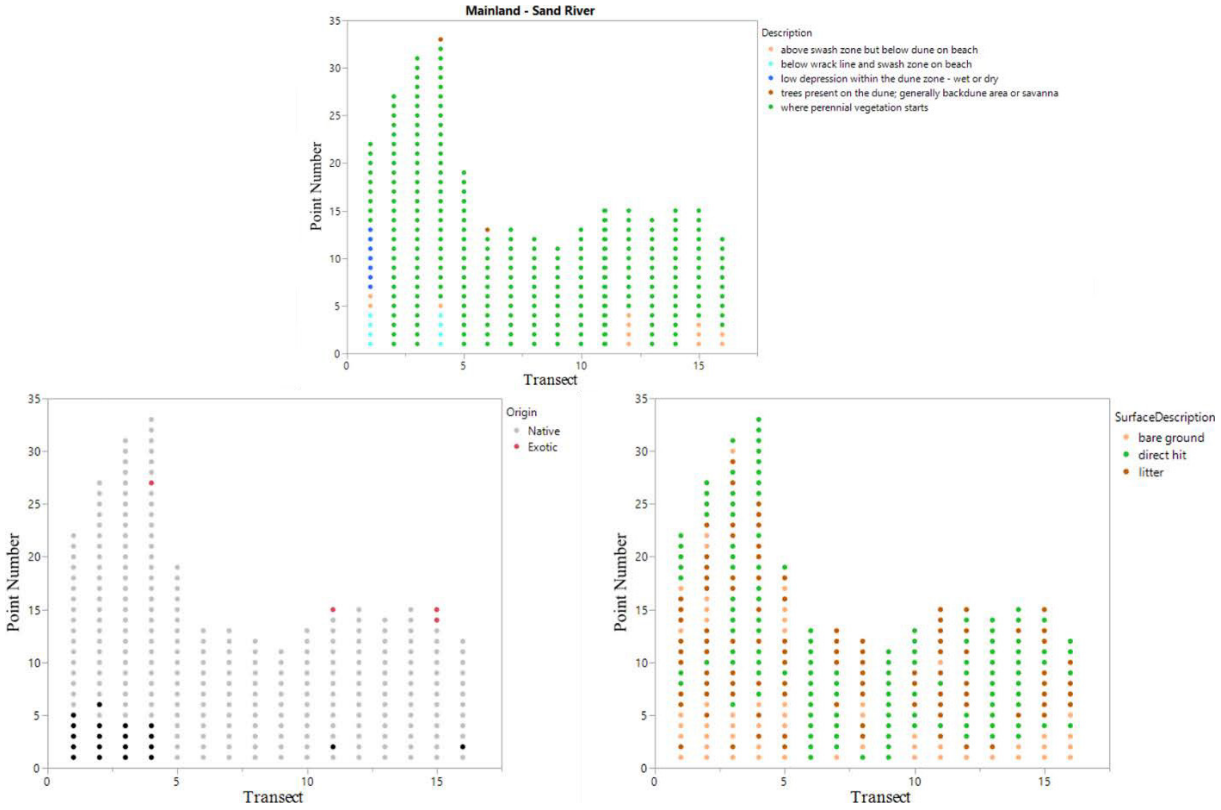


Figure B6. Sandscape profile graphs for Mainland-Sand River. All points are plotted, including any points in zones 1 and 2 below the perennial dune vegetation, to illustrate the profile of sandscape features with all transects starting at the high water line on the beach. Black dots on the Origin graph represent “empty” points with no vegetation.

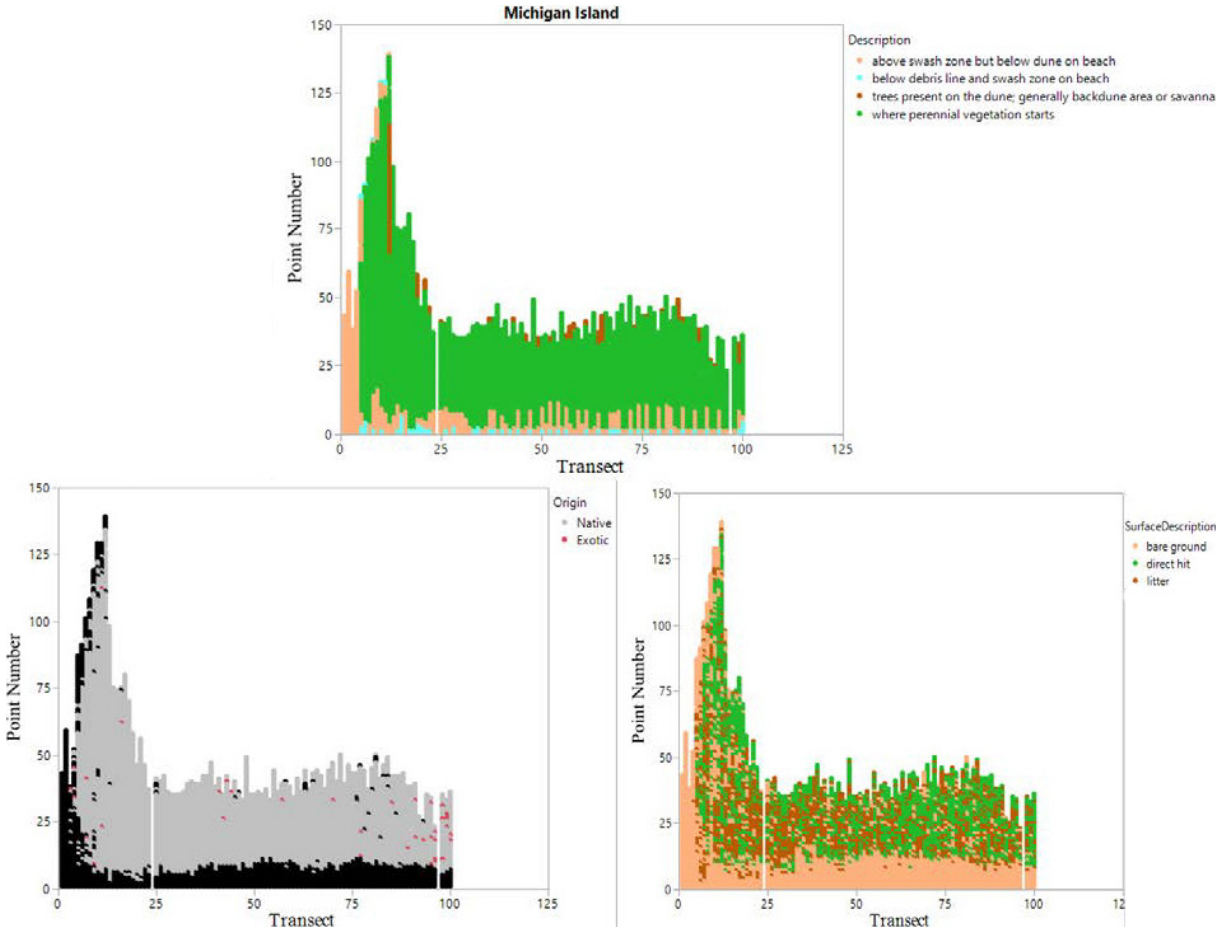


Figure B7. Sandscape profile graphs for Michigan Island. All points are plotted, including any points in zones 1 and 2 below the perennial dune vegetation, to illustrate the profile of sandscape features with all transects starting at the high water line on the beach. Black dots on the Origin graph represent “empty” points with no vegetation.

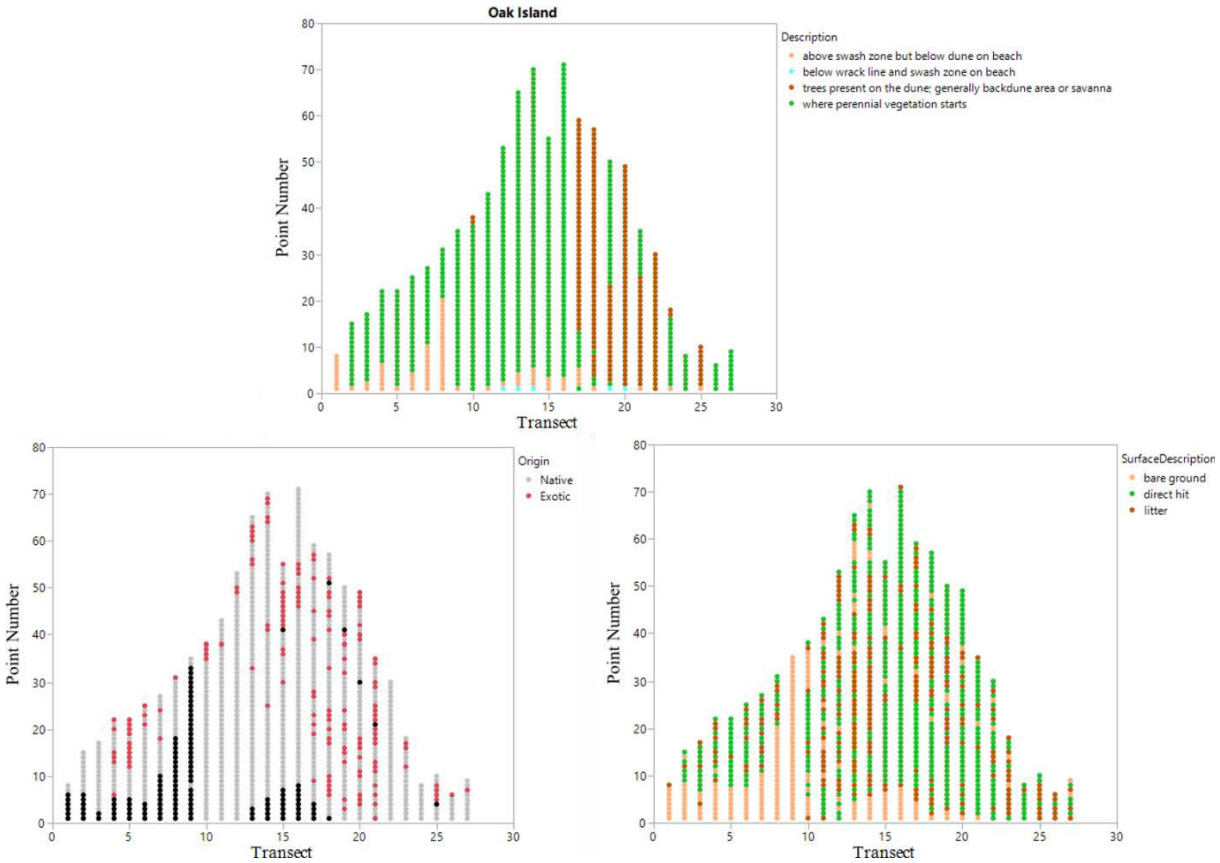


Figure B8. Sandscape profile graphs for Oak Island. All points are plotted, including any points in zones 1 and 2 below the perennial dune vegetation, to illustrate the profile of sandscape features with all transects starting at the high water line on the beach. Black dots on the Origin graph represent “empty” points with no vegetation.

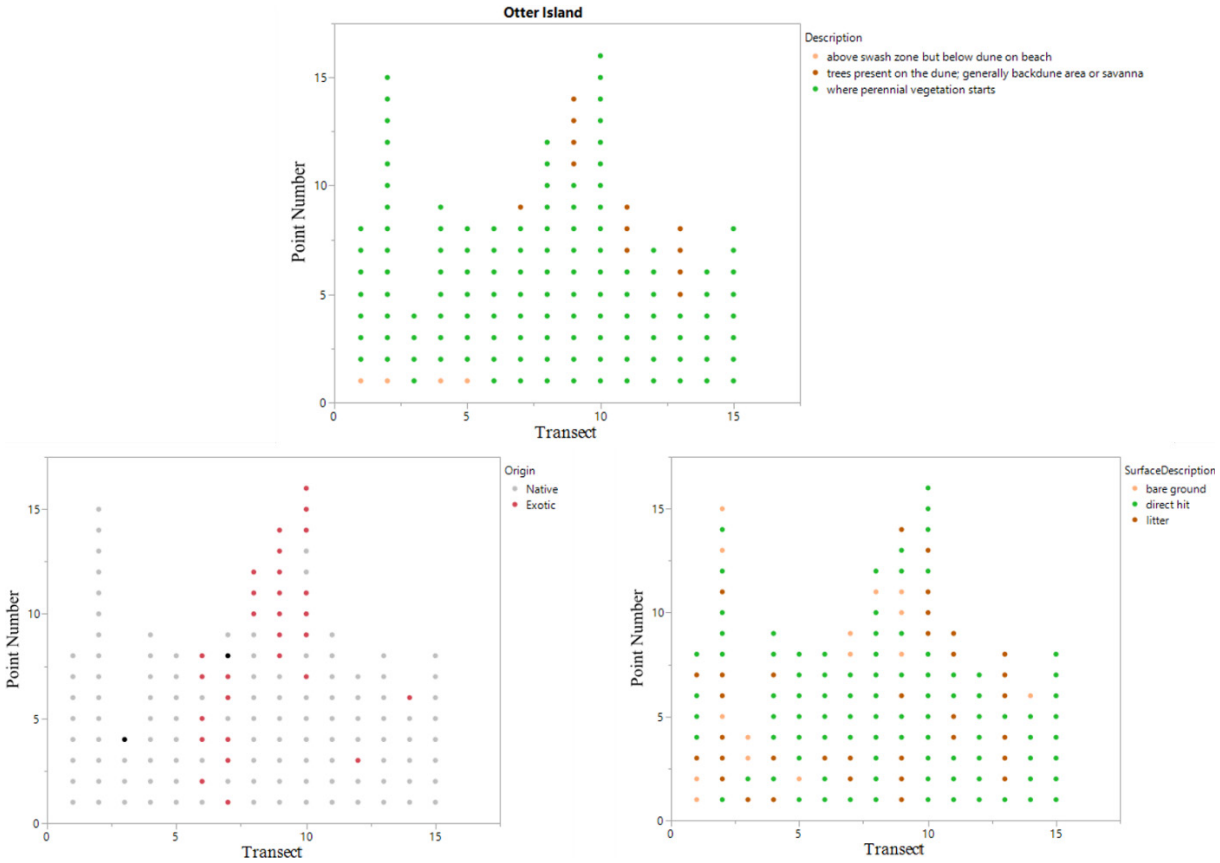


Figure B9. Sandscape profile graphs for Otter Island. All points are plotted, including any points in zones 1 and 2 below the perennial dune vegetation, to illustrate the profile of sandscape features with all transects starting at the high water line on the beach. Black dots on the Origin graph represent “empty” points with no vegetation.

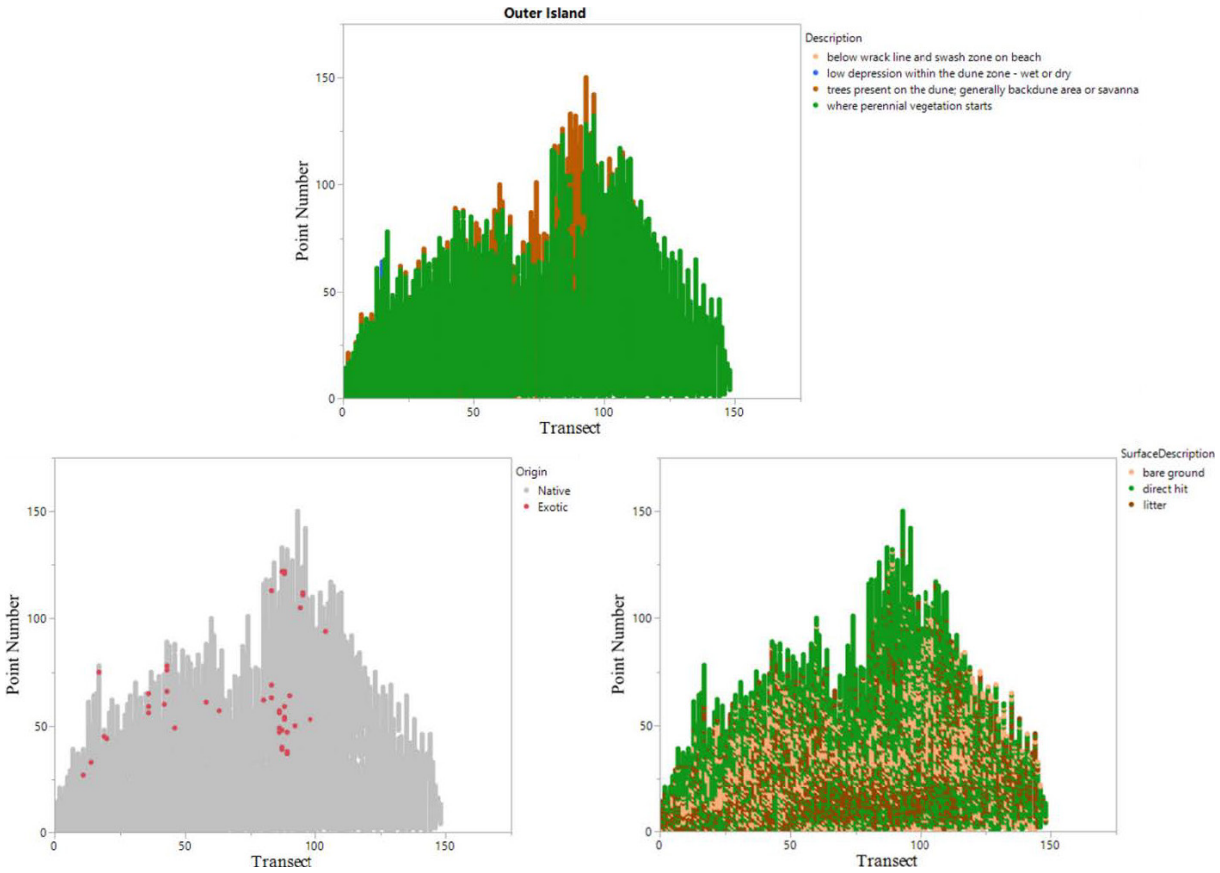


Figure B10. Sandscape profile graphs for Outer Island. All points are plotted, including any points in zones 1 and 2 below the perennial dune vegetation, to illustrate the profile of sandscape features with all transects starting at the high water line on the beach. Black dots on the Origin graph represent “empty” points with no vegetation.

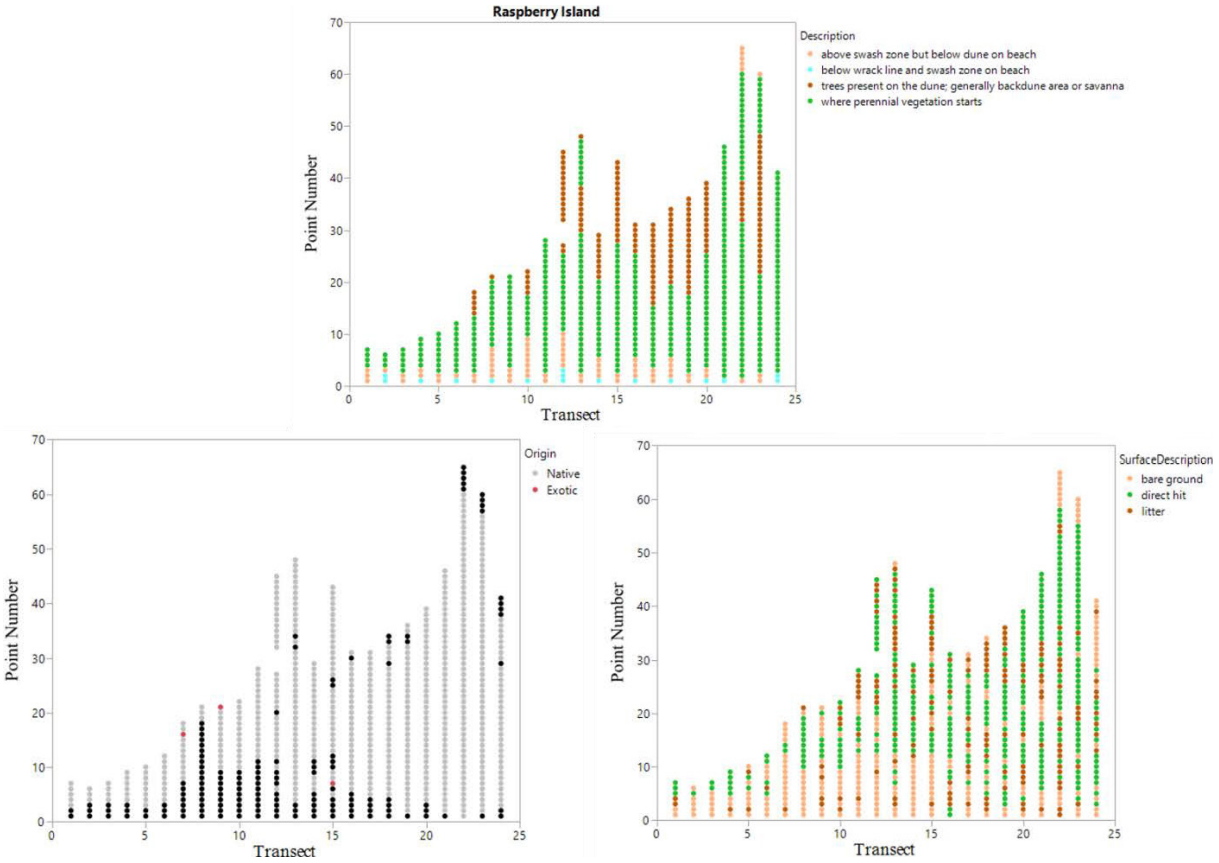


Figure B11. Sandscape profile graphs for Raspberry Island. All points are plotted, including any points in zones 1 and 2 below the perennial dune vegetation, to illustrate the profile of sandscape features with all transects starting at the high water line on the beach. Black dots on the Origin graph represent “empty” points with no vegetation.

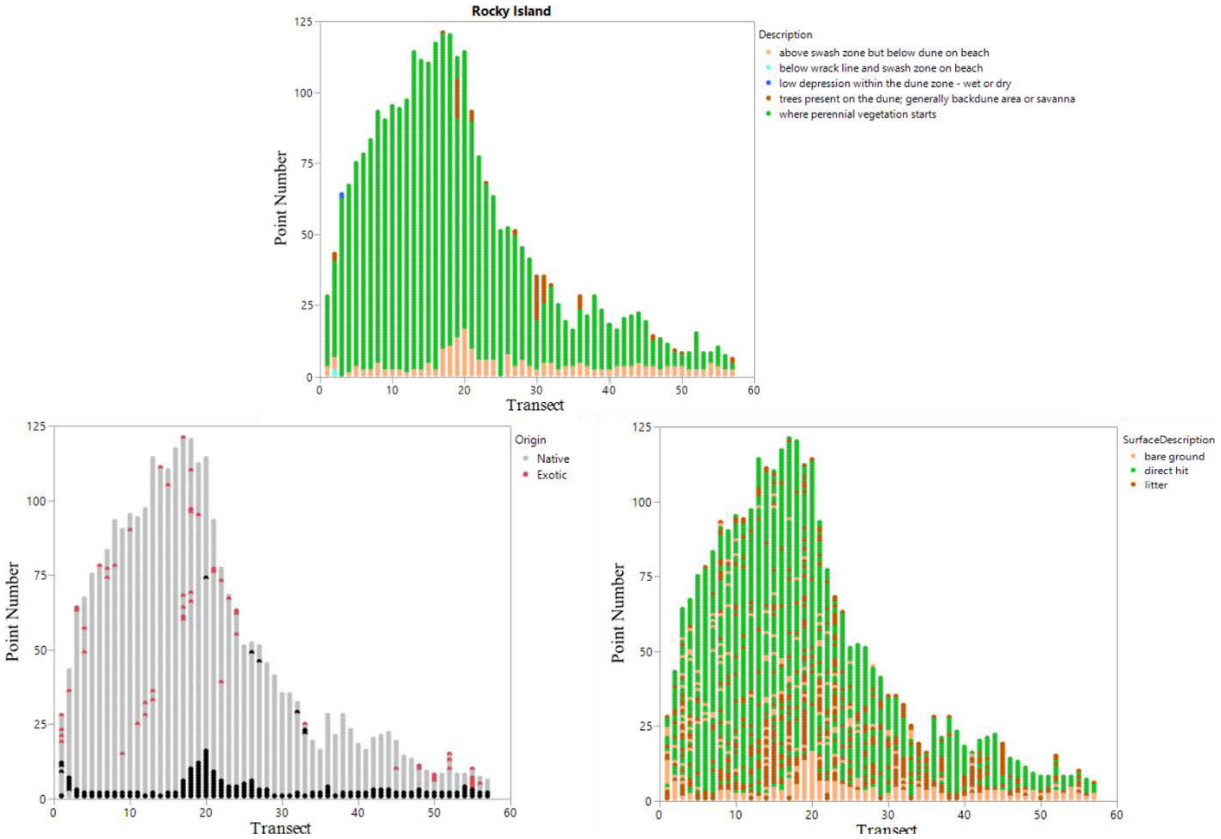


Figure B12. Sandscape profile graphs for Rocky Island. All points are plotted, including any points in zones 1 and 2 below the perennial dune vegetation, to illustrate the profile of sandscape features with all transects starting at the high water line on the beach. Black dots on the Origin graph represent “empty” points with no vegetation.

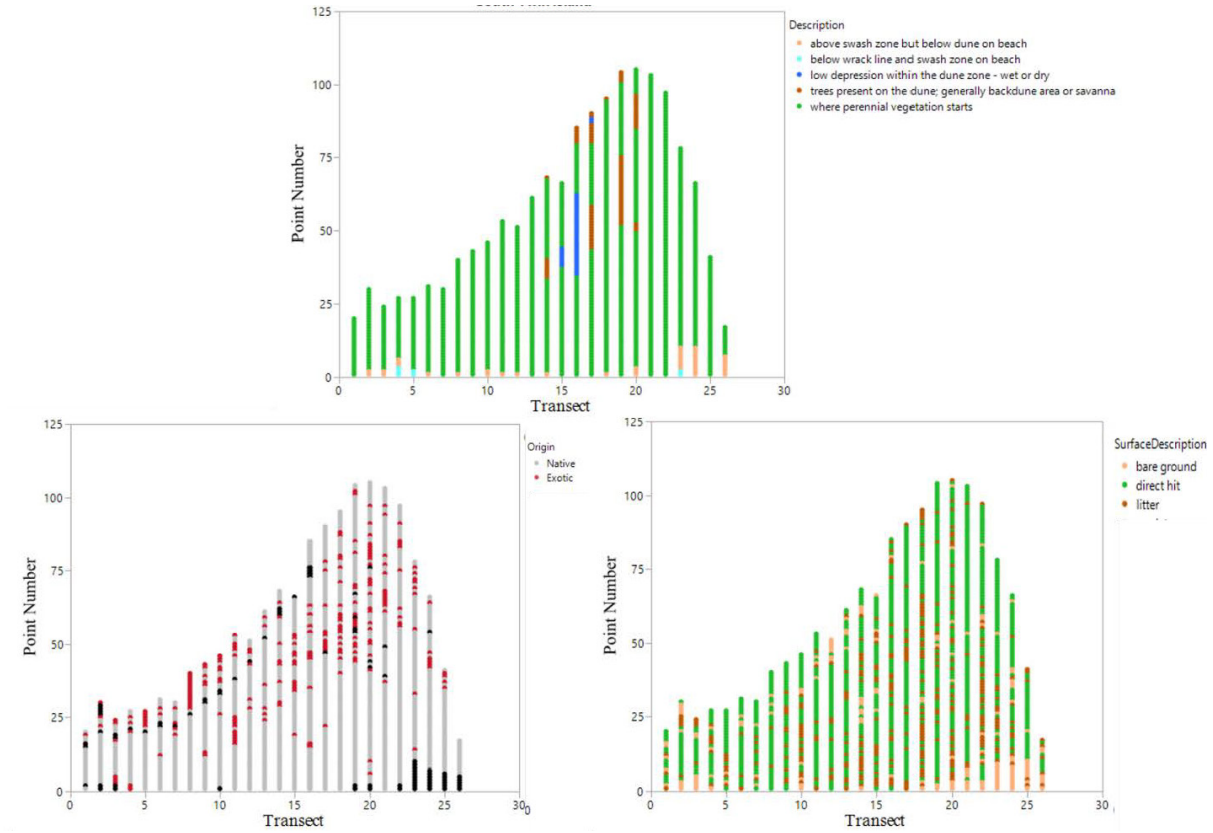


Figure B13. Sandscape profile graphs for South Twin Island. All points are plotted, including any points in zones 1 and 2 below the perennial dune vegetation, to illustrate the profile of sandscape features with all transects starting at the high water line on the beach. Black dots on the Origin graph represent “empty” points with no vegetation.

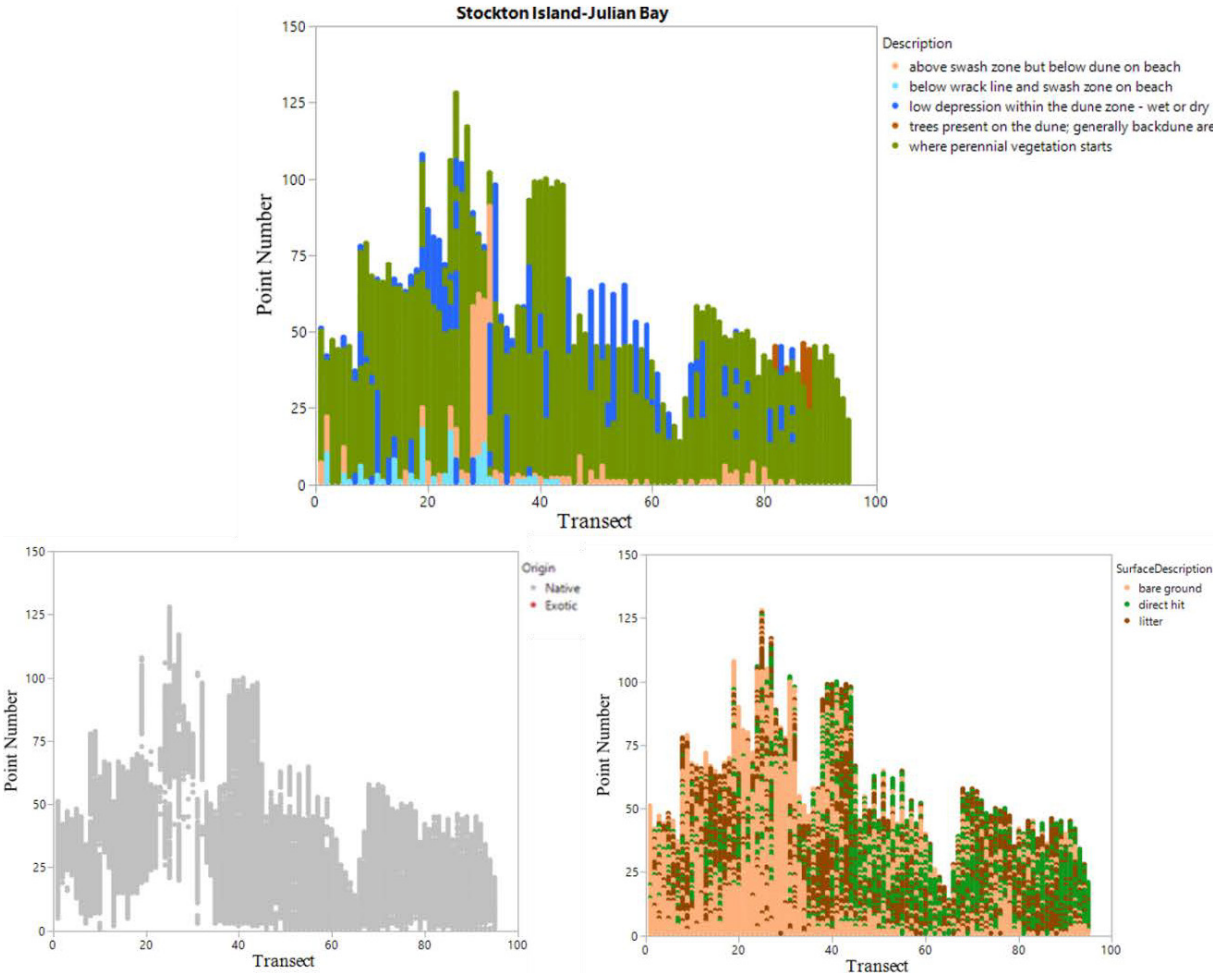


Figure B14. Sandscape profile graphs for Stockton Island – Julian Bay. All points are plotted, including any points in zones 1 and 2 below the perennial dune vegetation, to illustrate the profile of sandscape features with all transects starting at the high water line on the beach. Black dots on the Origin graph represent “empty” points with no vegetation.

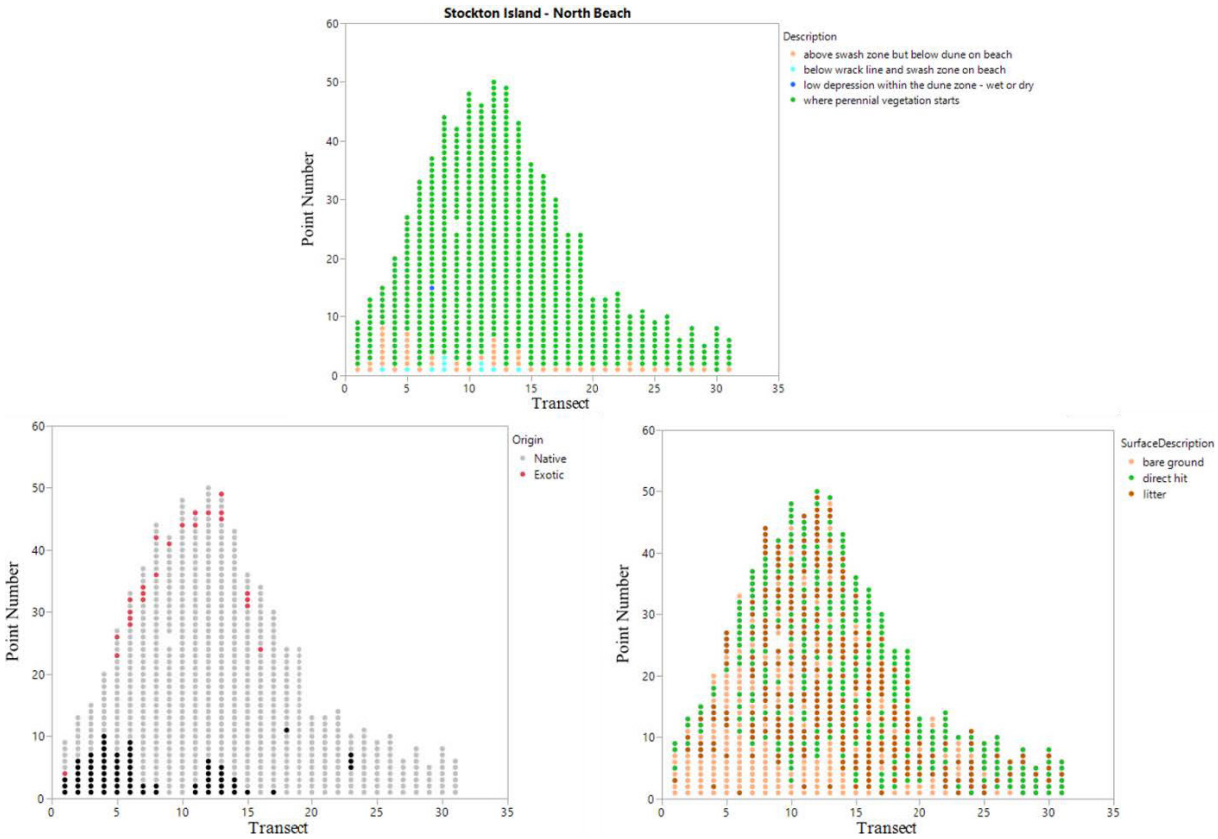


Figure B15. Sandscape profile graphs for Stockton Island- North Beach. All points are plotted, including any points in zones 1 and 2 below the perennial dune vegetation, to illustrate the profile of sandscape features with all transects starting at the high water line on the beach. Black dots on the Origin graph represent “empty” points with no vegetation.

Appendix C. Photo-point site descriptions.

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Long Island

Photo Point Site Description and Location

Date (MM/DD/YY): 7-31-2014

Time: —

Observers: Emily Leonard

Island: Long

Location: At the base of trail leading up to the old light house (Figures C1 and C2)

Location Description: Photo taken facing south toward informal trail leading to the lighthouse. Trail eventually connects to boardwalk.

GPS Coordinates: –90.785072 46.729227 Decimal Degrees

No. of Photo Points: 2370

Photo Purpose: To show the informal trails of the sandscape.



Figure C1. Aerial photo showing the location of photo point 2370 and the associated trail.



Figure C2. Example photo taken from photo point 2370.

Outer Island

Photo Point Site Description and Location

Date (MM/DD/YY): 8-5-14

Time: —

Observers: Emily Leonard

Island: Outer

Location: Sand spit (Figures C3 and C4)

Location Description: Facing east at base of beach access trail near shipwreck. Trail runs from beach to old campsite and is located near the middle of the sand spit.

GPS Coordinates: –90.466855 46.994560 Decimal Degrees

No. of Photo Points: 2447

Photo Purpose: To show informal trail



Figure C3. Aerial photo showing the location of photo point 2447 and the associated trails.



Figure C4. Example photo taken from photo point 2447.

Photo Point Site Description and Location
Date (MM/DD/YY): 8-5-14

Time: —

Observers: Emily Leonard

Island: Outer

Location: South tip of sand spit (Figures C5 through C7)

Location Description: —

GPS Coordinates: –90.469073 46.991429 Decimal Degrees

No. of Photo Points: 2449 North and 2450 South

Photo Purpose: Two photos, one facing north and one facing south were taken to show the composition of the southern portion of the sand spit.

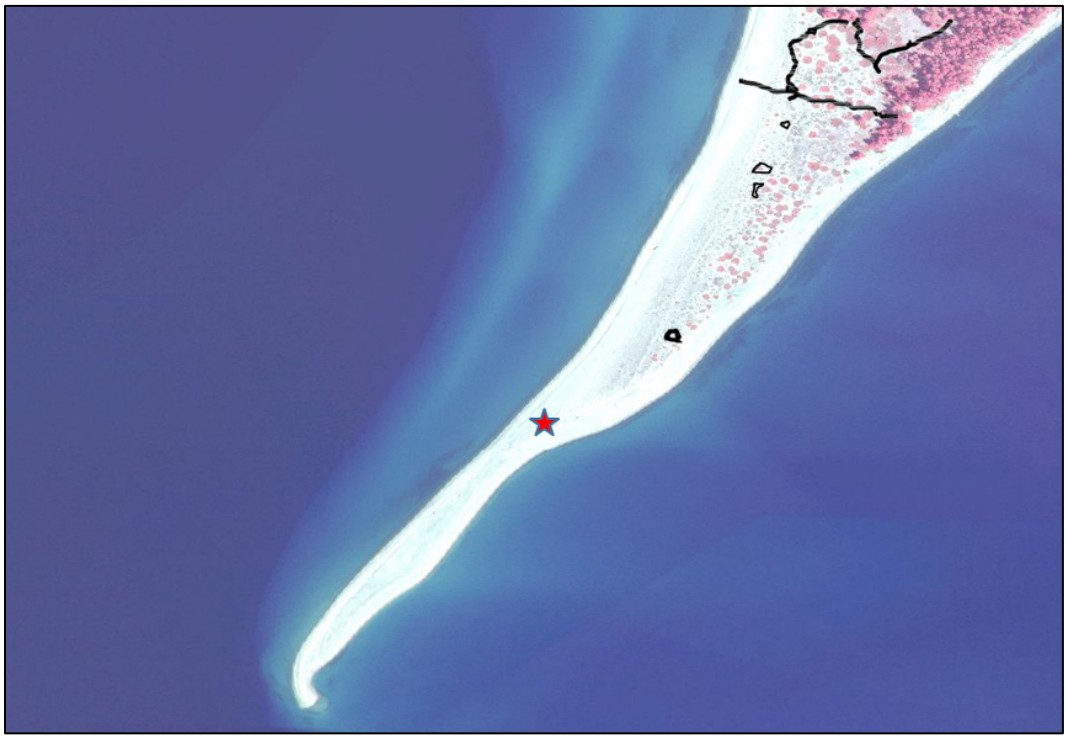


Figure C5. Aerial photo showing the location of photo points 2449 North and 2450 South, and the associated trails.



Figure C6. Example photo taken from photo point 2449 North.



Figure C7. Example photo taken from photo point 2450 South.

Photo Point Site Description and Location
Date (MM/DD/YY): 8-5-15

Time: —

Observers: Emily Leonard

Island: Outer

Location: East Side of island (Figures C8 and C9)

Location Description: Photo taken near where the new campsite trail connects with an informal trail on the sandscape. Trail runs east/west trhough forest and sandscape

GPS Coordinates: –90.465808 46.995512 Decimal Degrees

No. of Photo Points: 2454 West

Photo Purpose: To show informal trail on sand spit.

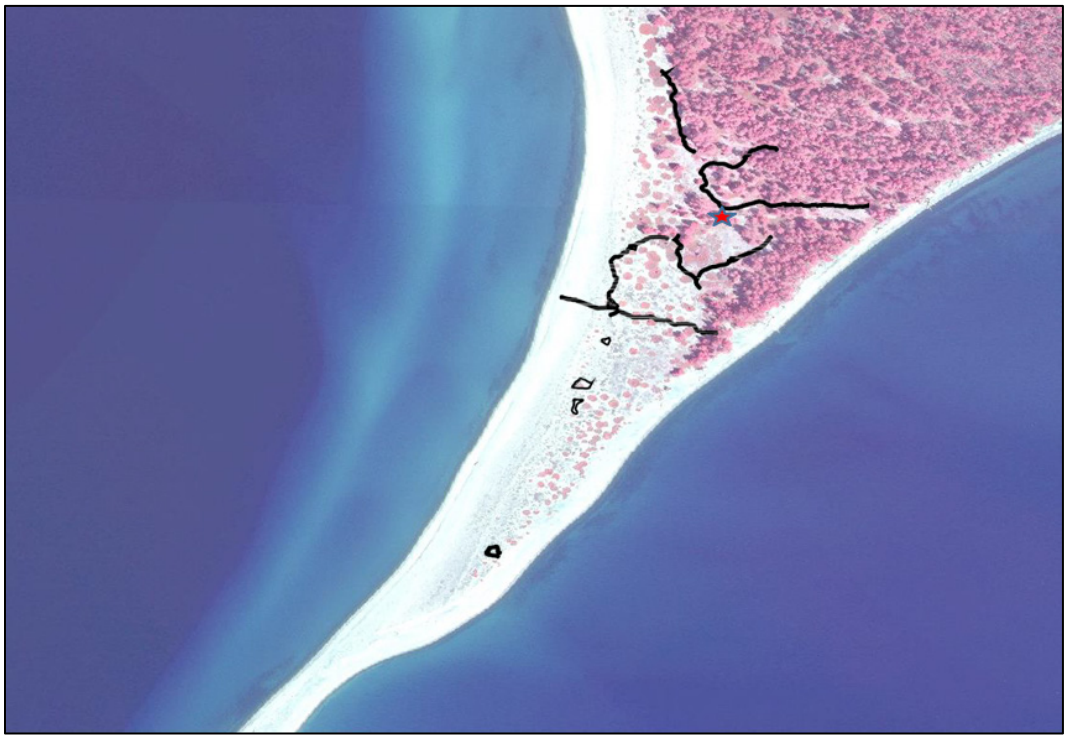


Figure C8. Aerial photo showing the location of photo point 2454 West and the associated trails.



Figure C9. Example photo taken from photo point 2454 West.

Photo Point Site Description and Location
Date (MM/DD/YY): 8-5-15

Time: —

Observers: Emily Leonard

Island: Outer

Location: North end of sand spit south of lagoon (Figures C10 and C11)

Location Description: Informal trail running from the beach to large bare area between Juniper. Trail continues up to forested edge of dune.

GPS Coordinates: –90.466388 46.996911 Decimal Degrees

No. of Photo Points: 2458

Photo Purpose: Photo shows informal trail and bare area on sandscape

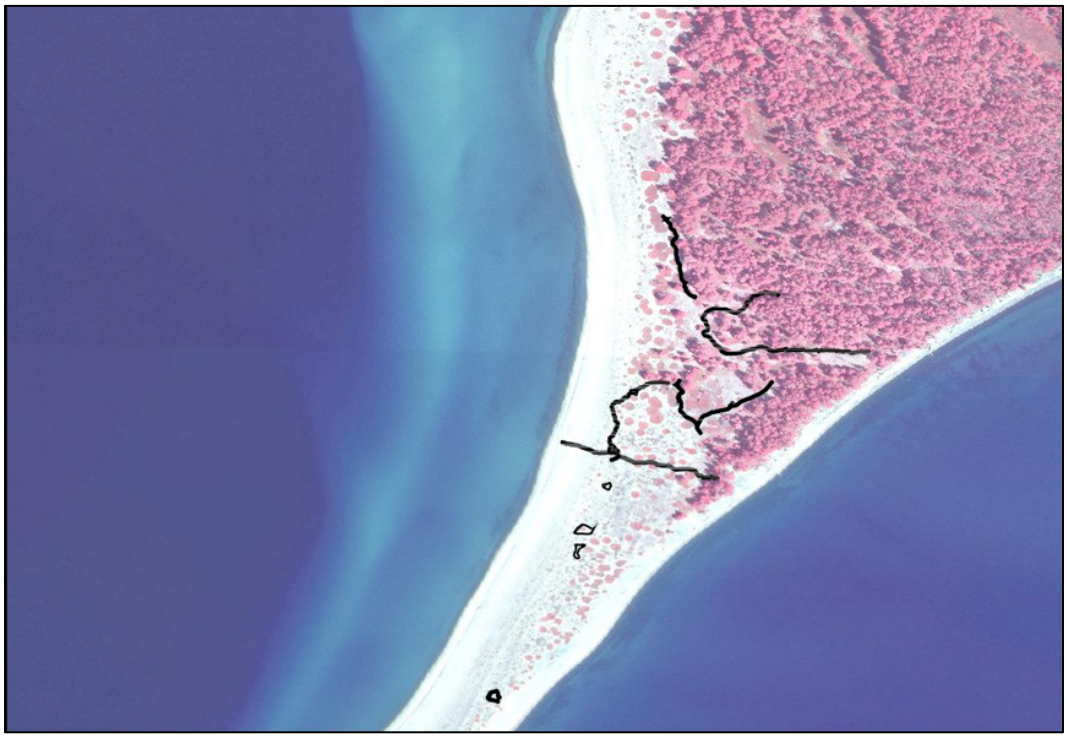


Figure C10. Aerial photo showing the location of photo point 2458 and the associated trails.



Figure C11. Example photo taken from photo point 2458.

Little Sand Bay (Mainland)

Photo Point Site Description and Location

Date (MM/DD/YY): 6-30-14

Time: —

Observers: Emily Leonard

Island: Little Sand Bay

Location: East edge of sandscape at the base of transect one (Figures C12 through C14)

Location Description: Photos taken standing at vegetation edge near the water looking east down beach and west toward heavily used beach access area.

GPS Coordinates: –90.888632 46.947395 Decimal Degrees

No. of Photo Points: 1968 East and 1970 West

Photo Purpose: Photo 1968 shows entire sandscape. Photo 1970 shows large bare area caused by heavy trampling.

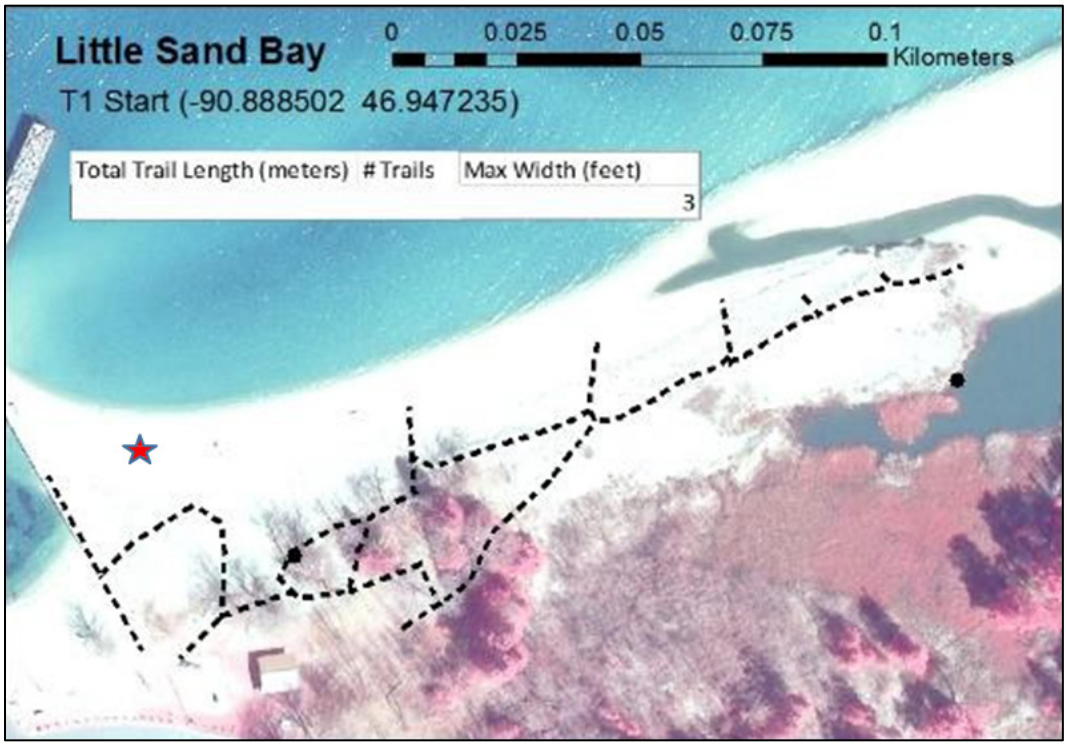


Figure C12. Aerial photo showing the location of photo points 1968 East and 1970 West, and the associated trails.



Figure C13. Example photo taken from photo point 1968 East.



Figure C14. Example photo taken from photo point 1970 West.

Photo Point Site Description and Location
Date (MM/DD/YY): 6-30-15

Time: —

Observers: Emily Leonard

Island: Little Sand Bay

Location: Center of sandscape at 14 meter mark on transect 9 (Figures C15 through C17)

Location Description: Located where dual informal trails meet

GPS Coordinates: –90.887715 46.947489 Decimal Degrees

No. of Photo Points: 1974 Southwest and 1975 Northwest

Photo Purpose: To show informal trails

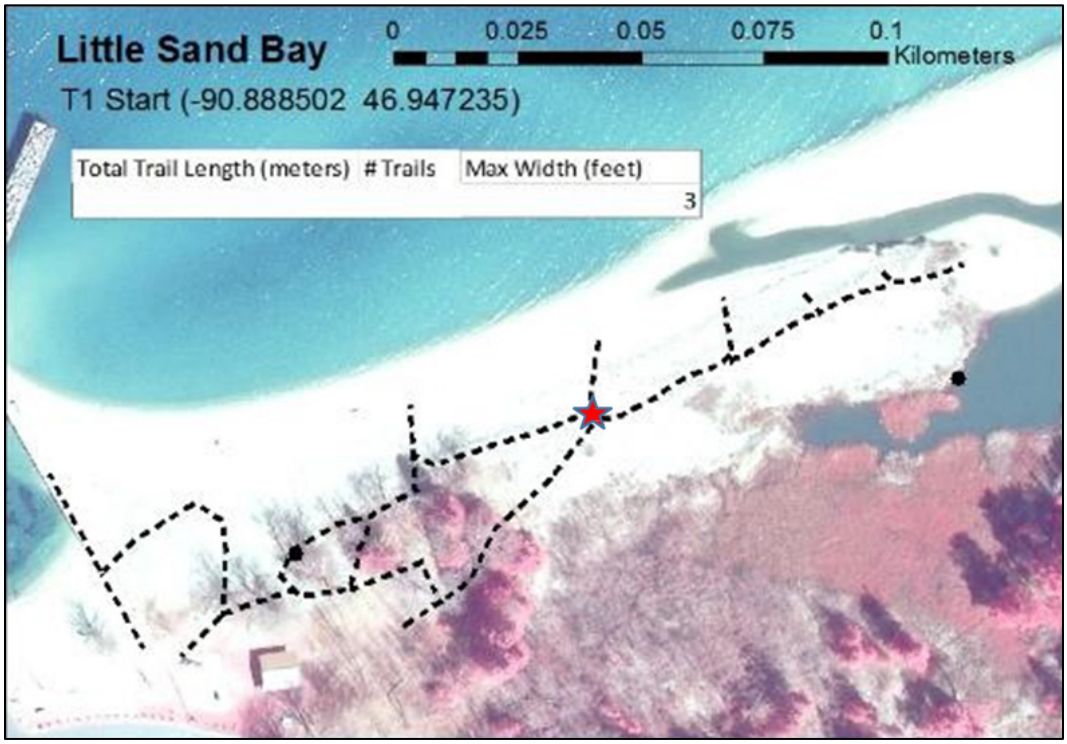


Figure C15. Aerial photo showing the location of photo points 1974 Southwest and 1975 Northwest, and the associated trails.



Figure C16 . Example photo taken from photo point 1974 Southwest.



Figure C17. Example photo taken from photo point 1975 Northwest.

Photo Point Site Description and Location
Date (MM/DD/YY): 6-30-15

Time: —

Observers: Emily Leonard

Island: Little Sand Bay

Location: At base of lagoon (Figures C18 and C19)

Location Description: Photos taken at east edge of the sandscape at the edge of the lagoon looking west toward informal trail.

GPS Coordinates: –90.886909 46.947786 Decimal Degrees

No. of Photo Points: 0988 West

Photo Purpose: To show informal trail on the sandscape

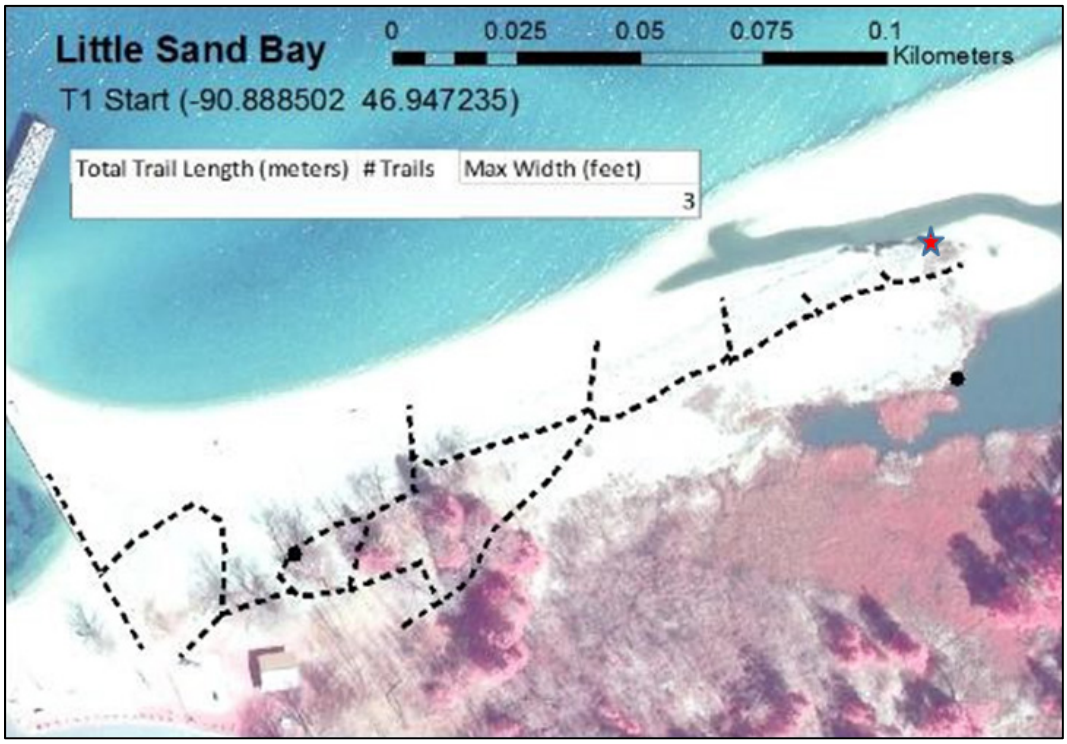


Figure C18. Aerial photo showing the location of photo point 0988 West and the associated trails.



Figure C19. Example photo taken from photo point 0988 West.

Bear Island

Photo Point Site Description and Location

Date (MM/DD/YY): 8-13-14

Time: —

Observers: Emily Leonard

Island: Bear

Location: Standing at the base of transect one facing south toward mainland and north toward transects (Figures C20 through C22)

Location Description: The foreshore and backshore area is very small, banks are high and there is a lot of erosion at this location

GPS Coordinates: –90.748099 47.000117 Decimal Degrees

No. of Photo Points: 2653 South and 2654 North

Photo Purpose: To show the composition of the sandscape and the erosion of the shoreline



Figure C20. Aerial photo showing the location of photo points 2653 South and 2654 North.



Figure C21. Example photo taken from photo point 2653 South.



Figure C22. Example photo taken from photo point 2654 North.

Photo Point Site Description and Location
Date (MM/DD/YY): 8-13-14

Time: —

Observers: Emily Leonard

Island: Bear

Location: Standing at the base of transect 33 (final transect of north end of sandscape) facing south toward mainland and then north facing the forested edge (Figures C23 through C25)

Location Description: Less erosion on this end of sandscape than seen on southern portion. Beach tapers off at this location and transitions into forest.

GPS Coordinates: –90.748640 47.002431 Decimal Degrees

No. of Photo Points: 2655 South and 2656 North

Photo Purpose: To show the composition of the sandscape and the erosion of the shoreline

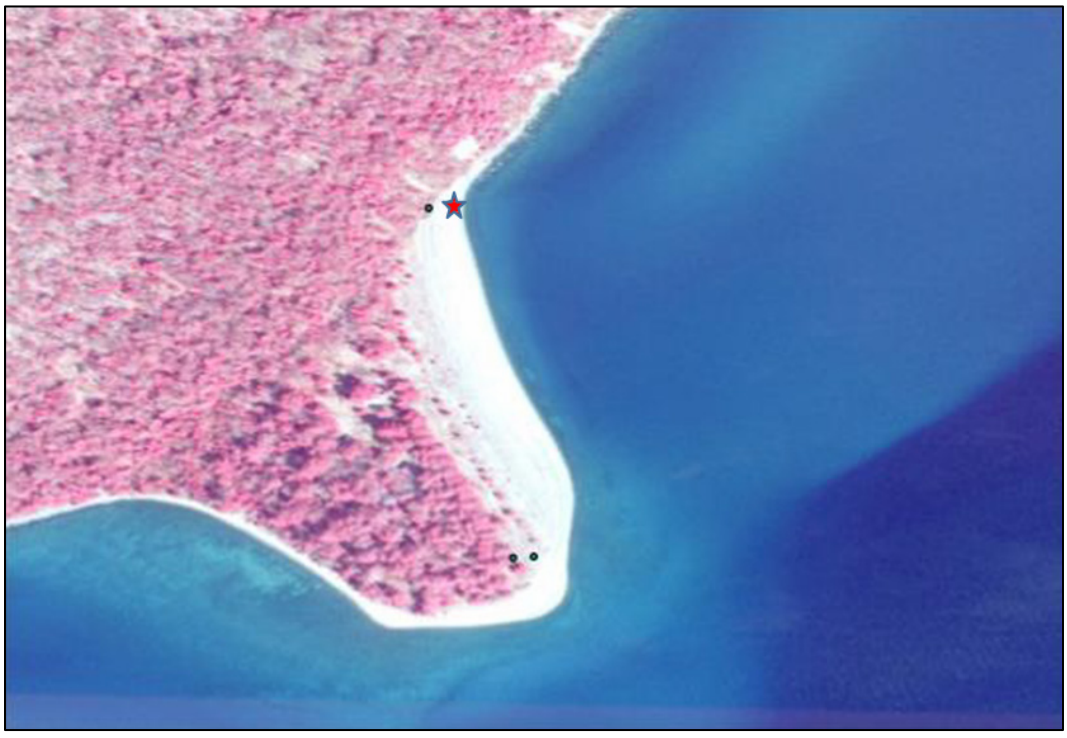


Figure C23. Aerial photo showing the location of photo points 2655 South and 2656 North.



Figure C24. Example photo taken from photo point 2655 South.



Figure C25. Example photo taken from photo point 2656 North.

Otter Island

Photo Point Site Description and Location

Date (MM/DD/YY): 8-13-14

Time: —

Observers: Forrest Rosenbower and Emily Leonard

Island: Otter

Location: Standing at the base of transect one facing north and south on the western side of the sand spit (Figures C26 through C28)

Location Description: The west side of the island has a shoreline composed of cobble rather than fine grained sand. At this location, to the southeast, the sand spit comes to a point with vegetation concentrated to the center of the spit.

GPS Coordinates: –90.695915 46.983885 Decimal Degrees

No. of Photo Points: 2658 Northwest and 2659 Southeast

Photo Purpose: To show the composition of the sandscape and shoreline

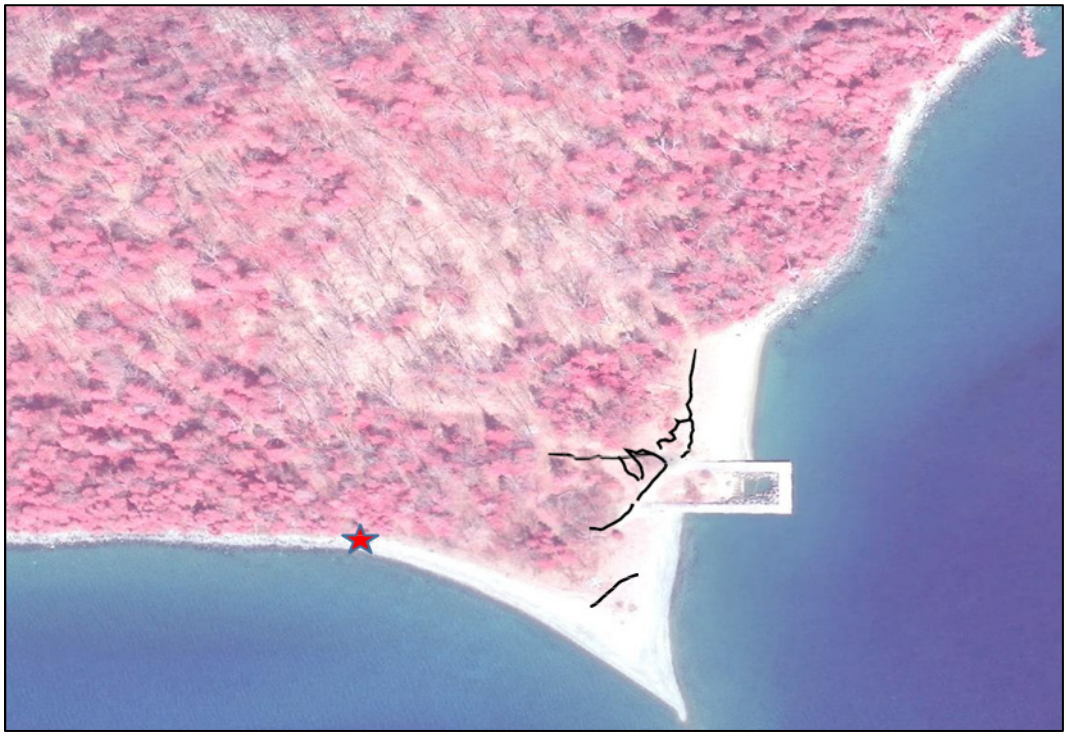


Figure C26. Aerial photo showing the location of photo points 2658 Northwest and 2659 Southeast and the associated trails.



Figure C27. Example photo taken from photo point 2658 Nort West.



Figure C28. Example photo taken from photo point 2659 Sout East.

Photo Point Site Description and Location
Date (MM/DD/YY): 8-13-14

Time: —

Observers: Forrest Rosenbower and Emily Leonard

Island: Otter

Location: Center of vegetated portion of sand spit (Figures C29 and C30)

Location Description: A small informal trail about one-foot wide crosses the vegetated portion of the sand spit on the southeastern tip of sandscape. Trail runs from east to west across spit.

GPS Coordinates: –90.695166 46.983689 Decimal Degrees

No. of Photo Points: 2660 North by Northeast

Photo Purpose: To show the informal trails on the Otter sandscape

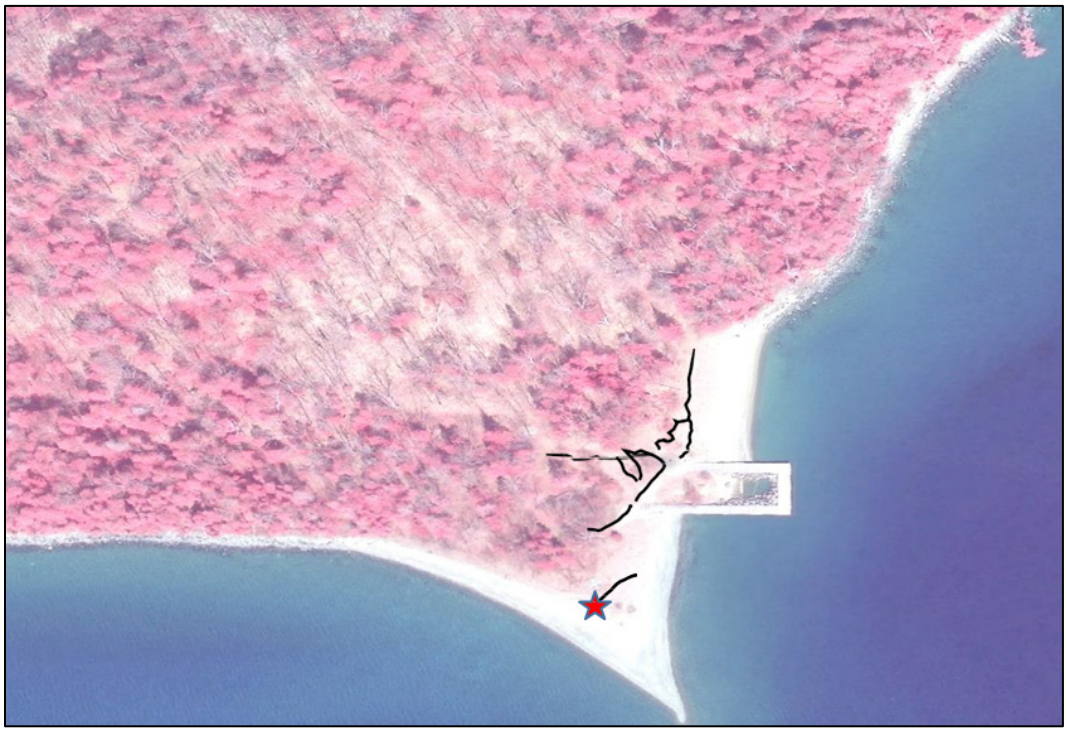


Figure C29. Aerial photo showing the location of photo point 2660 North by Northeast and the associated trails.



Figure C30. Example photo taken from photo point 2660 North by Northeast.

Photo Point Site Description and Location
Date (MM/DD/YY): 8-13-14

Time: —

Observers: Forrest Rosenbower and Emily Leonard

Island: Otter

Location: Base of final transect looking south toward the beach and dock (Figures C31 and C32)

Location Description: The beach zone without vegetation is narrow at this location, and the vegetated dune quickly transitions into forested dune followed by forest

GPS Coordinates: –90.694633 46.984608 Decimal Degrees

No. of Photo Points: 2668 South

Photo Purpose: To show the erosion of the shoreline and the sandscape composition on Otter Island

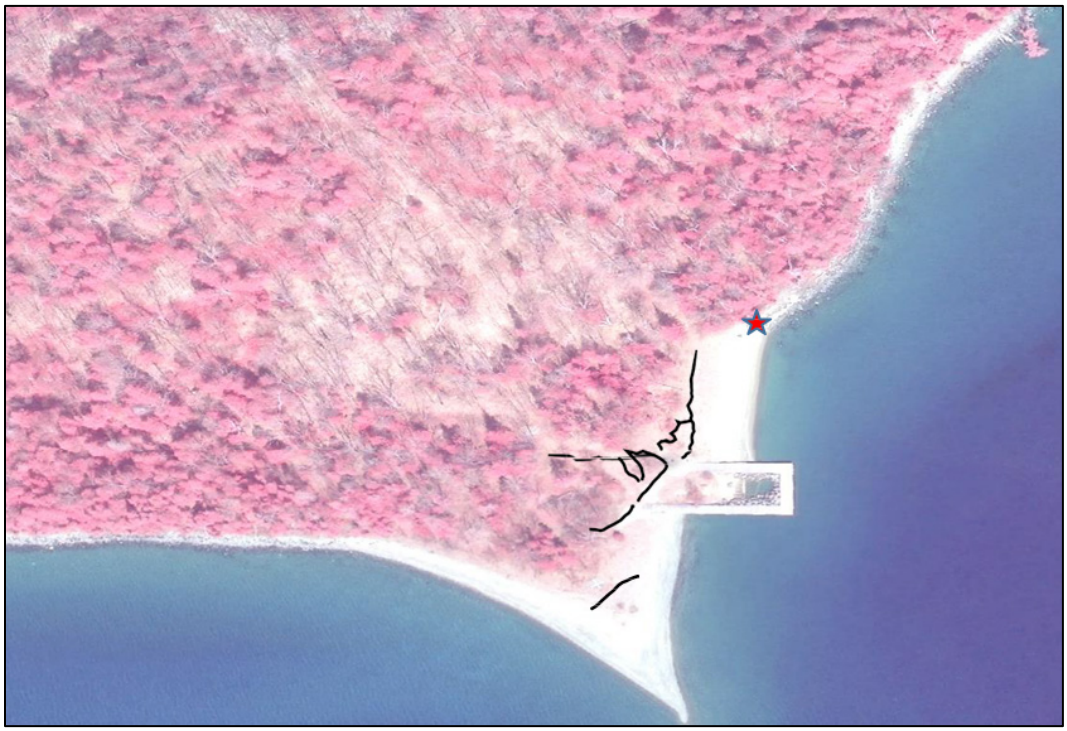


Figure C31. Aerial photo showing the location of photo point 2668 South and the associated trails.



Figure C32. Example photo taken from photo point 2668 South.

Cat Island

Photo Point Site Description and Location

Date (MM/DD/YY): 8-18-14

Time: —

Observers: Forrest Rosenbower and Emily Leonard

Island: Cat

Location: Base of transect one on north end of sandscape (Figures C33 through C35)

Location Description: Photo taken facing south shows entire western side of sandscape and photo taken while facing north shows the forested edge

GPS Coordinates: –90.563333 46.999058 Decimal Degrees

No. of Photo Points: 2687 South and 2688 North

Photo Purpose: To show sandscape composition on Cat Island



Figure C33. Aerial photo showing the location of photo points 2687 South and 2688 North, and the associated trails.



Figure C34. Example photo taken from photo point 2687 South.



Figure C35. Example photo taken from photo point 2688 North.

Photo Point Site Description and Location
Date (MM/DD/YY): 8-18-14

Time: —

Observers: Forrest Rosenbower and Emily Leonard

Island: Cat

Location: Southwestern tip of Cat Island**:** sand spit (Figures C36 through C38)

Location Description: Informal path and bare area (about 1 ½ meters wide) running west to east across sandscape

GPS Coordinates: –90.563333 46.997121 Decimal Degrees

No. of Photo Points: 2690 South and 2691 North

Photo Purpose: To show the informal trail and bare area on Cat Island**:** sandscape.



Figure C36. Aerial photo showing the location of photo points 2690 South and 2691 North, and the associated trails.



Figure C37. Example photo taken from photo point 2690 South.



Figure C38. Example photo taken from photo point 2691 North.

Photo Point Site Description and Location
Date (MM/DD/YY): 8-18-14

Time: —

Observers: Forrest Rosenbower and Emily Leonard

Island: Cat

Location: Eastern side of Cat Island**:** sand spit (Figures C39 through C41)

Location Description: Standing at base of final transect facing southwest toward tip of sand spit and looking north toward forested edge of beach

GPS Coordinates: –90.561374 46.996928 Decimal Degrees

No. of Photo Points: 2692 Southwest and 2693 Northeast

Photo Purpose: To show composition of sandscape and show wetlands swale mid-beach on western side of sand spit.



Figure C39. Aerial photo showing the location of photo points 2692 Southwest and 2693 Northeast, and the associated trails.



Figure C40. Example photo taken from photo point 2692 Southwest.



Figure C41. Example photo taken from photo point 2693 Northeast.

Oak Island

Photo Point Site Description and Location

Date (MM/DD/YY): 7-28-14

Time: —

Observers: Forrest Rosenbower and Emily Leonard

Island: Oak

Location: Eastern side of Oak Island at base of final transect (Figures C42 through C44)

Location Description: Standing at base of final transect facing southeast toward transects and campsite. Second photo was taken facing northeast toward forested edge of sandscape.

GPS Coordinates: –90.734915 46.913947 Decimal Degrees

No. of Photo Points: 2299 Southwest and 2298 Northeast

Photo Purpose: To show composition of sandscape eastern side of sandscape

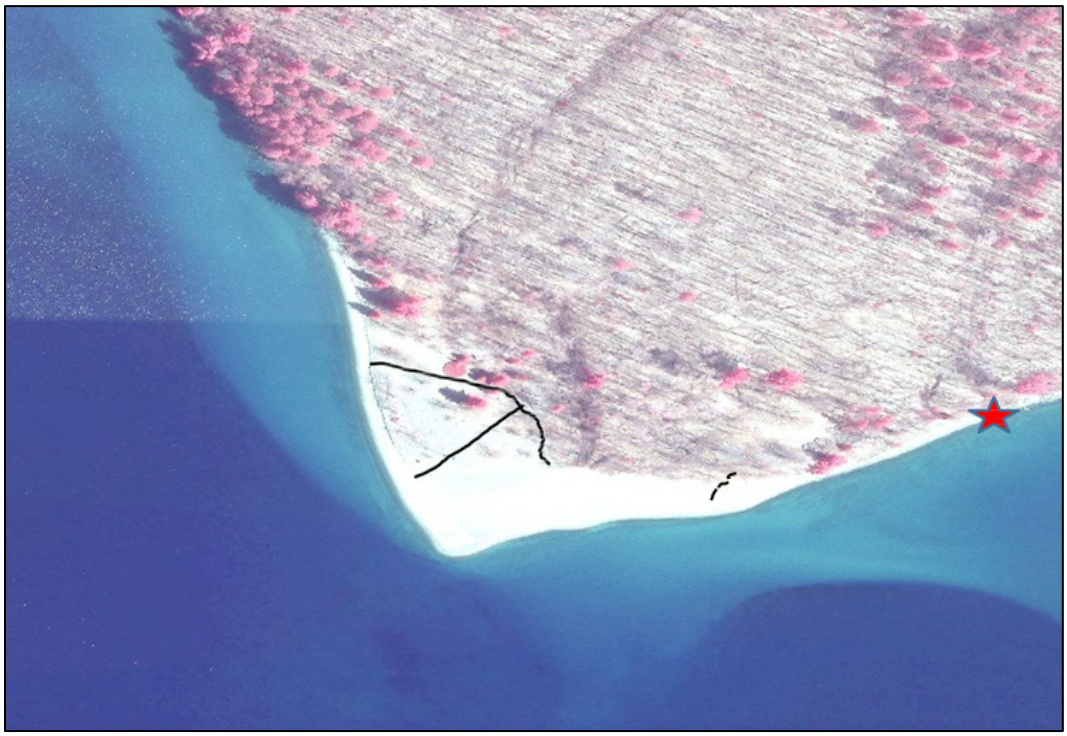


Figure C42. Aerial photo showing the location of photo points 2299 Southwest and 2298 Northeast, and the associated trails.



Figure C43. Example photo taken from photo point 2299 Southwest.



Figure C44. Example photo taken from photo point 2298 Northeast.

Photo Point Site Description and Location
Date (MM/DD/YY): 7-28-14

Time: —

Observers: Forrest Rosenbower, Michael Sinclair, and Emily Leonard

Island: Oak

Location: Near campsite on southern end of the sand spit (Figures C45 and C46)

Location Description: South of the campsite trail, there is a large bare area.

GPS Coordinates: –90.736059 46.913985 Decimal Degrees

No. of Photo Points: 2300 Northwest

Photo Purpose: To show bare area with trampled sandscape vegetation on Oak Island



Figure C45. Aerial photo showing the location of photo point 2300 Northwest and the associated trails.



Figure C46. Example photo taken from photo point 2300 Northwest.

Photo Point Site Description and Location
Date (MM/DD/YY): 7-28-14

Time: —

Observers: Forrest Rosenbower, Michael Sinclair, and Emily Leonard

Island: Oak

Location: Eastern side of sandscape (Figures C47 and C48)

Location Description: Small informal path leading up to the forest behind the dune on the eastern side of the sandscape. Path is about 1 foot wide and the photo was taken facing north.

GPS Coordinates: –90.735333 46.913890 Decimal Degrees

No. of Photo Points: 2304 North

Photo Purpose: To show informal trails with trampled sandscape vegetation on Oak Island

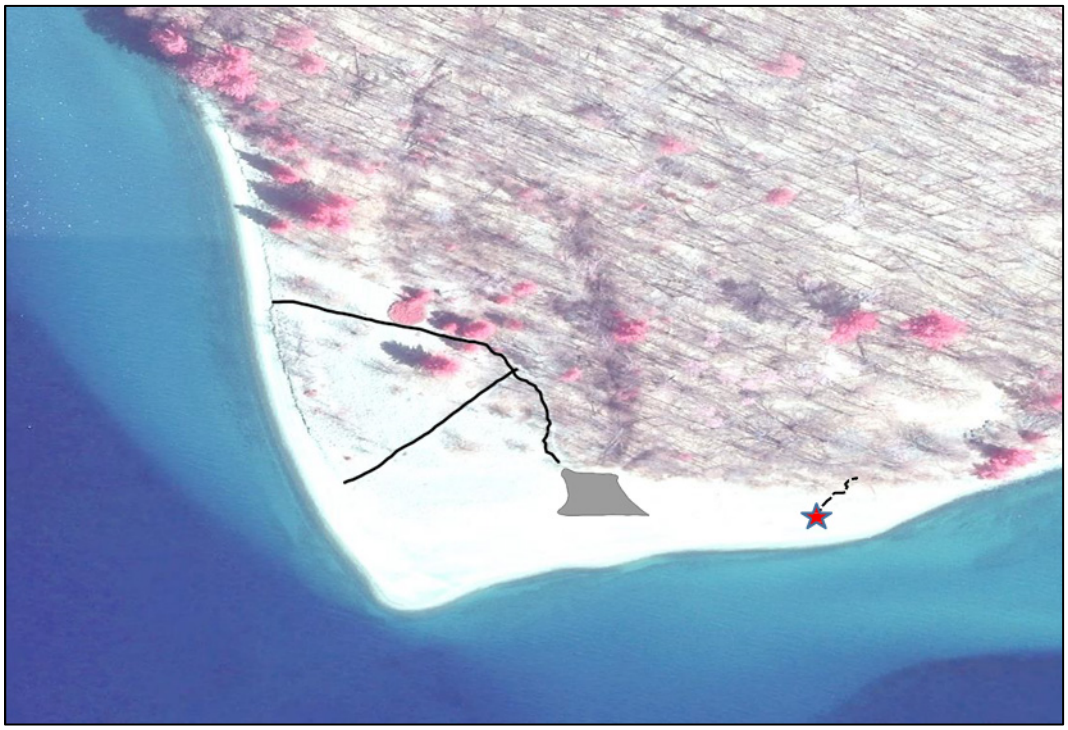


Figure C47. Aerial photo showing the location of photo point 2304 North and the associated trails.



Figure C48. Example photo taken from photo point 2304 North.

Ironwood Island

Photo Point Site Description and Location

Date (MM/DD/YY): 8-12-14

Time:—

Observers: Forrest Rosenbower, Michael Sinclair, and Emily Leonard

Island: Ironwood

Location: Eastern side of sandscape near the base of transect 23 (final transect) (Figures C49 through C51)

Location Description: Sandscape to the west of location and forested edge and fallen trees east of location.

GPS Coordinates: –90.615453 46.990503 Decimal Degrees

No. of Photo Points: 2647 West and 2648 East

Photo Purpose: To show sandscape composition of Ironwood Island

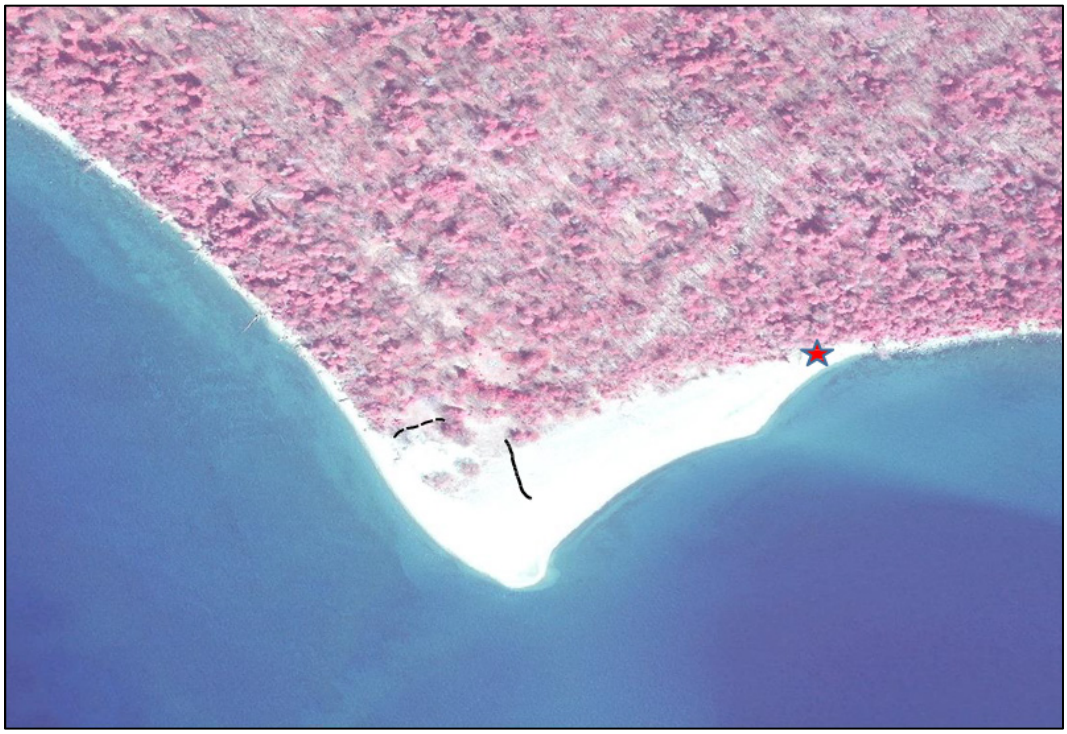


Figure C49. Aerial photo showing the location of photo points 2647 West and 2648 East, and the associated trails.



Figure C50. Example photo taken from photo point 2647 West.



Figure C51. Example photo taken from photo point 2648 East.

Photo Point Site Description and Location
Date (MM/DD/YY): 8-12-14

Time: —

Observers: Forrest Rosenbower, Michael Sinclair, and Emily Leonard

Island: Ironwood

Location: Western side of sandscape near the base of transect one (Figures C52 through C54)

Location Description: Sandscape to the southeast of location and forested edge and northwest of location.

GPS Coordinates: –90.618044 46.990299 Decimal Degrees

No. of Photo Points: 2650 Southeast and 2651 Northwest

Photo Purpose: To show sandscape composition of Ironwood Island

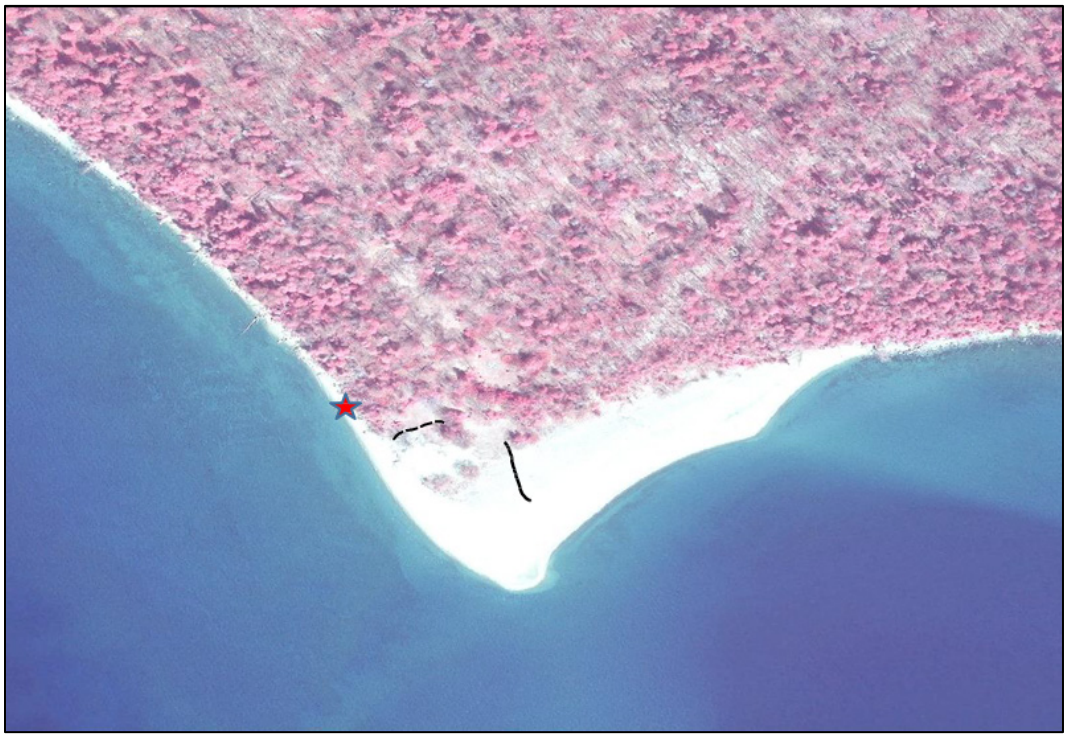


Figure C52. Aerial photo showing the location of photo points 2650 Southeast and 2651 Northwest, and the associated trails.



Figure C53. Example photo taken from photo point 2650 Southeast.



Figure C54. Example photo taken from photo point 2651 Northwest.

Photo Point Site Description and Location
Date (MM/DD/YY): 8-12-14

Time: —

Observers: Forrest Rosenbower, Michael Sinclair, and Emily Leonard

Island: Ironwood

Location: Western side of sandscape near campsite (Figures C55 and C56)

Location Description: Small informal trail at this location running east to west. Trail is less than 1ft wide.

GPS Coordinates: –90.617483 46.990194 Decimal Degrees

No. of Photo Points: 2649 West

Photo Purpose: To show informal trails on Ironwood sandscape

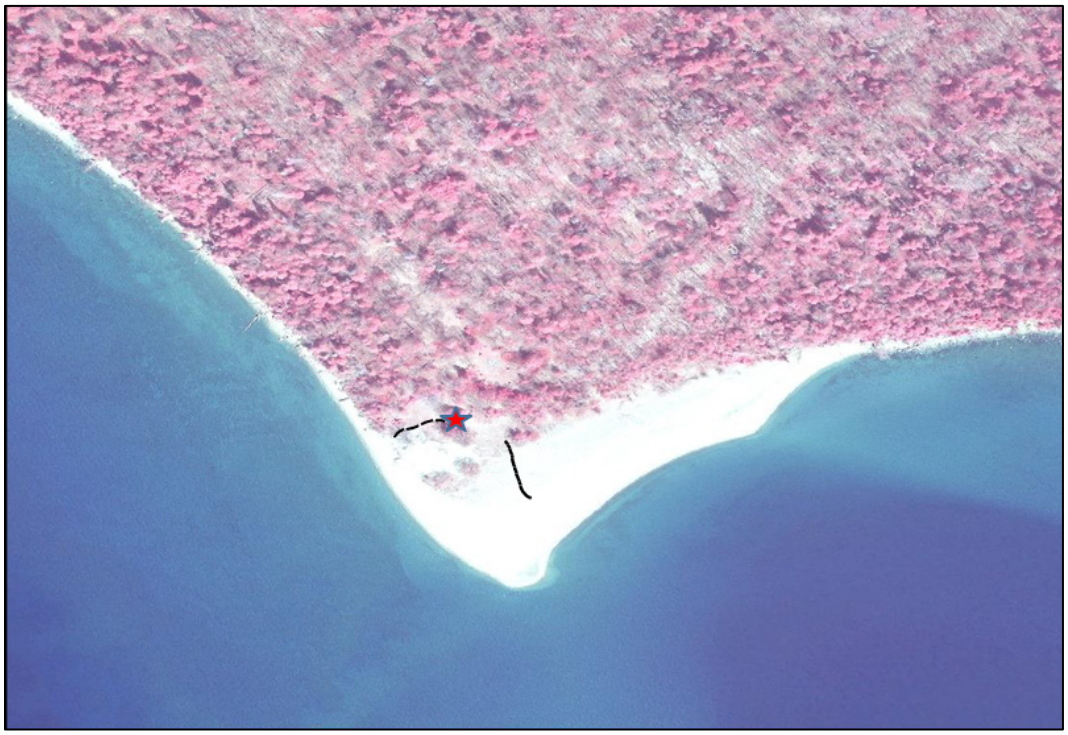


Figure C55. Aerial photo showing the location of photo point 2649 West and the associated trails.



Figure C56. Example photo taken from photo point 2649 West.

Rocky Island

Photo Point Site Description and Location

Date (MM/DD/YY): 7-16-14

Time:—

Observers: Forrest Rosenbower, Michael Sinclair, Jim Sinclair, Lori Neumann, Sarah Johnson, and Emily Leonard

Island: Rocky

Location: Western side of sandscape near the transect start point (Figures C57 through C59)

Location Description: Cobble shoreline on western side of sandscape. Erosion caused the dunes to be much higher than foreshore and backshore. Photos taken facing northwest and southeast.

GPS Coordinates: –90.680978 47.019232 Decimal Degrees

No. of Photo Points: 2120 Northwest and 2121 Southeast

Photo Purpose: To show informal trails on Rocky sandscape

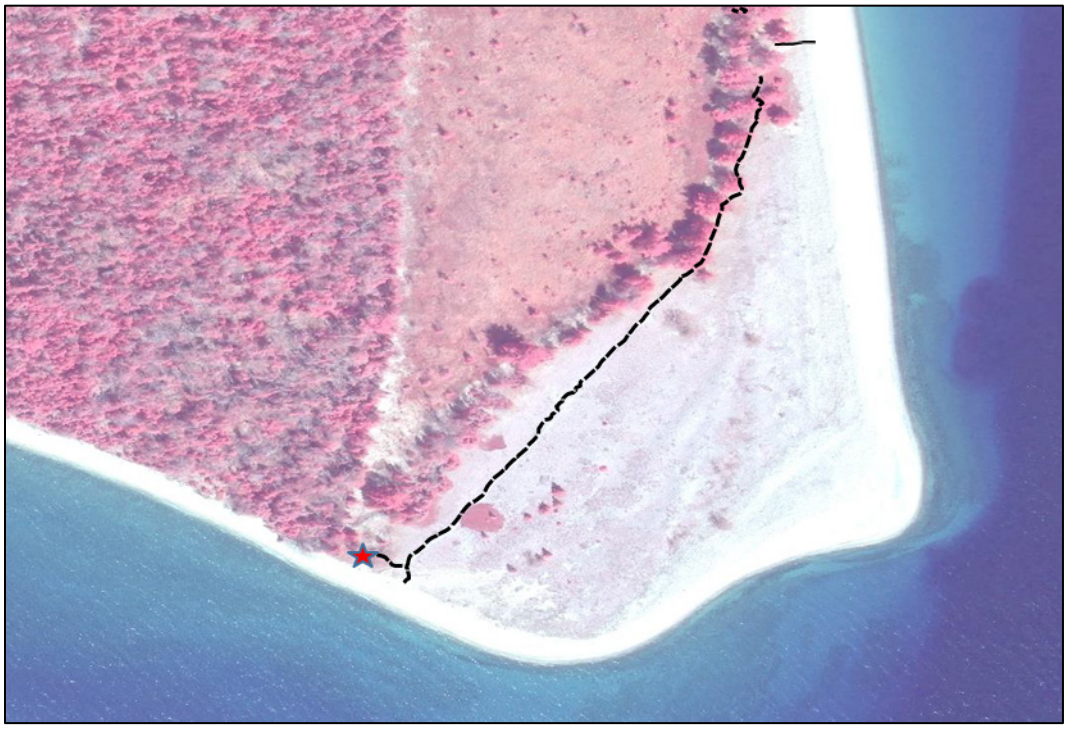


Figure C57. Aerial photo showing the location of photo points 2120 Northwest and 2121 Southeast, and the associated trails.



Figure C58. Example photo taken from photo point 2120 Northwest.



Figure C59. Example photo taken from photo point 2121 Southeast.

Photo Point Site Description and Location
Date (MM/DD/YY): 7-16-14

Time: —

Observers: Forrest Rosenbower, Michael Sinclair, Jim Sinclair, Lori Neumann, Sarah Johnson, and Emily Leonard

Island: Rocky

Location: Southern tip of sandscape (Figures C60 through C64)

Location Description: Along transect 15 and between transects 15 and 16 there is evidence of Beach Grass dieback.

GPS Coordinates:

No. of Photo Points: 6133,6134,6135,6136

Photo Purpose: To show beach grass dieback on Rocky Island: along transect 15.



Figure C60. Aerial photo showing the location of photo points 6133,6134,6135,6136, and the associated trails.



Figure C61. Example photo taken from photo point 6133.

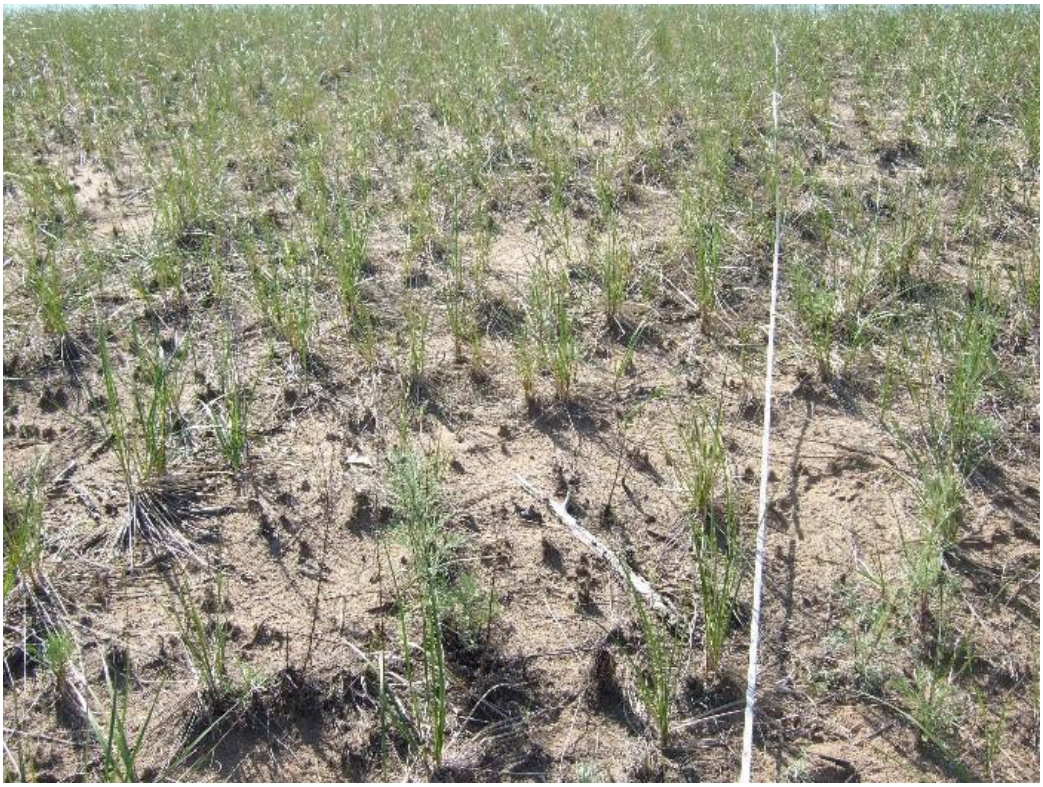


Figure C62. Example photo taken from photo point 6134.



Figure C63. Example photo taken from photo point 6135.



Figure C64. Example photo taken from photo point 6136.

Photo Point Site Description and Location
Date (MM/DD/YY): 7-16-14

Time: —

Observers: Forrest Rosenbower, Michael Sinclair, Jim Sinclair, Lori Neumann, Sarah Johnson, and Emily Leonard

Island: Rocky

Location: Southwestern edge of sandscape on dune (Figures C65 and C66)

Location Description: Informal trail running southwest to northeast across sandscape. Trail starts near transect one

GPS Coordinates: –90.680665 47.019332 Decimal Degrees

No. of Photo Points: 2119 Northeast

Photo Purpose: To show informal trails on Rocky Island



Figure C65. Aerial photo showing the location of photo point 2119 Northeast and the associated trails.



Figure C66. Example photo taken from photo point 2119 Northeast.

Photo Point Site Description and Location
Date (MM/DD/YY): 7-16-14

Time:

Observers: Forrest Rosenbower, Michael Sinclair, Jim Sinclair, Lori Neumann, Sarah Johnson, and Emily Leonard

Island: Rocky

Location: Northeastern side of sandscape near forested edge (Figures C67 and C68)

Location Description: Forest northeast of location and sandscape south of location. Sandscape composition is very different on this side on sandscape compared to the southern tip and southwestern beach. Location has less vegetation and a narrowed vegetated dune area.

GPS Coordinates: –90.678866 47.024671 Decimal Degrees

No. of Photo Points: 2126 South

Photo Purpose: To show sandscape composition on eastern side of Rocky Island: spit



Figure C67. Aerial photo showing the location of photo point 2126 South and the associated trails.



Figure C68. Example photo taken from photo point 2126 South.

Raspberry Island

Photo Point Site Description and Location

Date (MM/DD/YY): 7-21-14

Time: —

Observers: Forrest Rosenbower, Michael Sinclair, Sarah Johnson, and Emily Leonard

Island: Raspberry

Location: West side of sandscape at base of transect one (Figures C69 through C71)

Location Description: Beach transitions into forest west of location and the rest of the sandscape is to the east of location. Dunes are very eroded with Beach Grass falling into the water near forested edge.

GPS Coordinates: –90.792824 46.970226 Decimal Degrees

No. of Photo Points: 2133 East and 2134 West

Photo Purpose: To show sandscape composition on western side of Raspberry Island

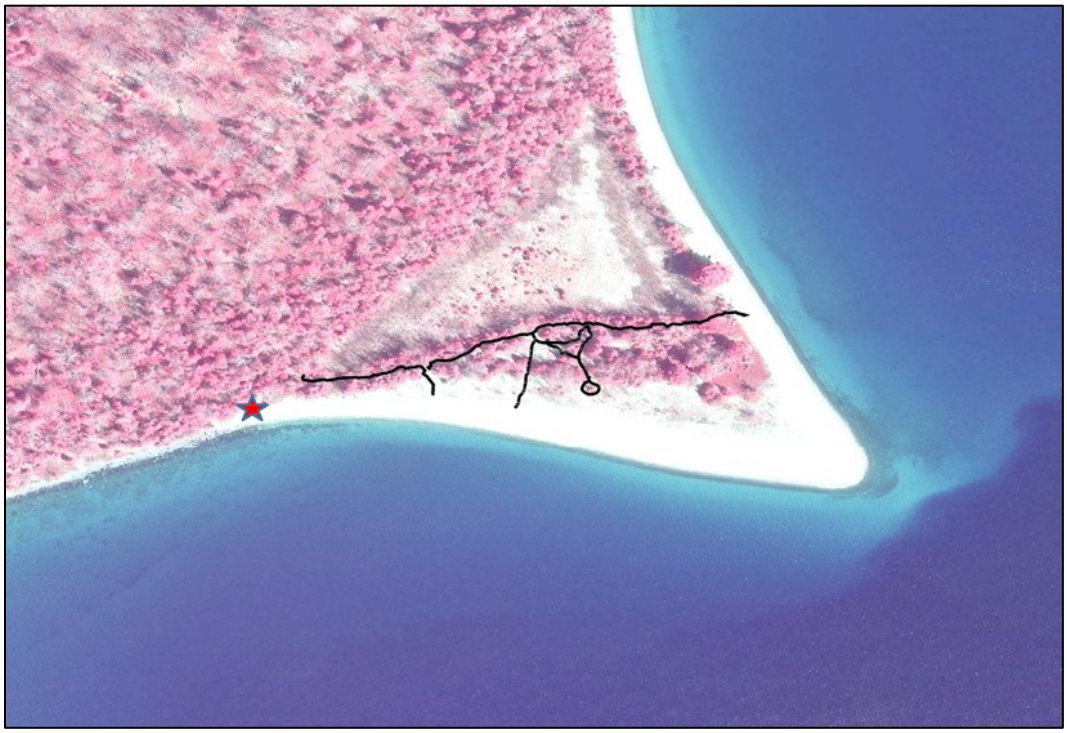


Figure C69. Aerial photo showing the location of photo points 2133 East and 2134 West, and the associated trails.



Figure C70. Example photo taken from photo point 2133 East.



Figure C71. Example photo taken from photo point 2134 West.

Photo Point Site Description and Location
Date (MM/DD/YY): 7-21-14

Time: —

Observers: Forrest Rosenbower, Michael Sinclair, Sarah Johnson, and Emily Leonard

Island: Raspberry

Location: West side of sandscape at base of stairs (Figures C72 and C73)

Location Description: At base of stairs there are signs of vegetation trampling and stairs and buried in sand.

GPS Coordinates: –90.791885 46.970348 Decimal Degrees

No. of Photo Points: 2135 North

Photo Purpose: To show bare area near the base of the stairs on Raspberry sandscape

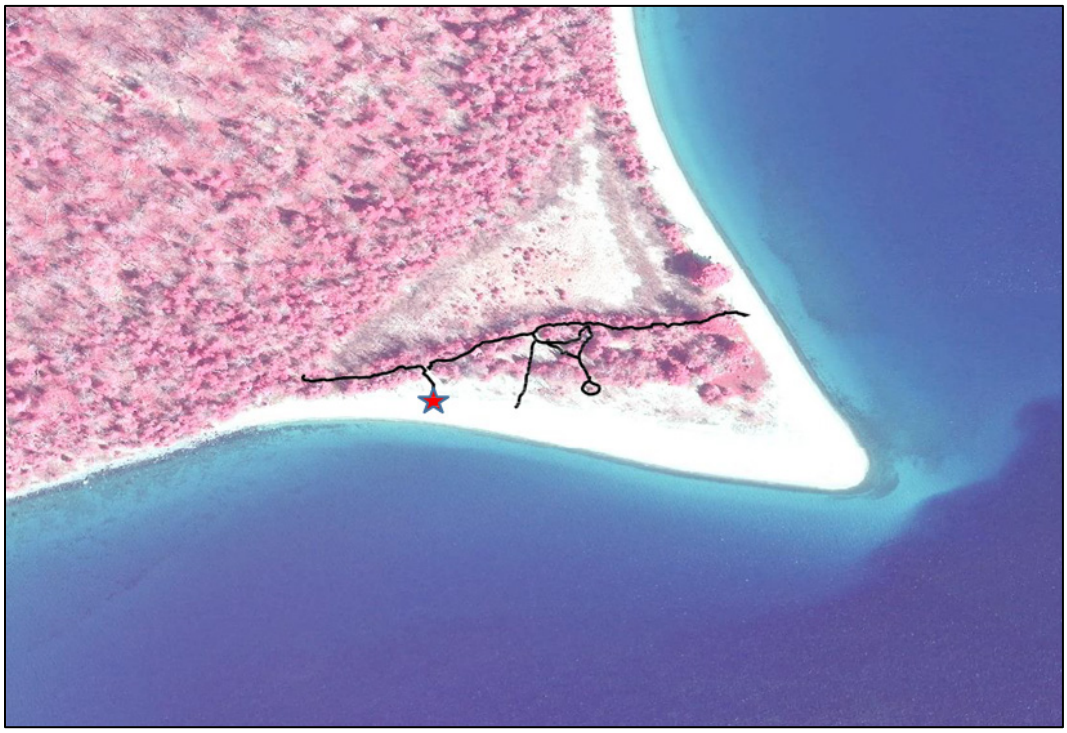


Figure C72. Aerial photo showing the location of photo point 2135 North and the associated trails.



Figure C73. Example photo taken from photo point 2135 North.

Photo Point Site Description and Location
Date (MM/DD/YY): 7-21-14

Time: —

Observers: Forrest Rosenbower, Michael Sinclair, Sarah Johnson, and Emily Leonard

Island: Raspberry

Location: Center of sandscape in forested dune behind bathroom (Figures C74 through C76)

Location Description: Informal trails connect formal trails and boardwalks in forested dune behind outhouse creating bare areas and trails where vegetation is trampled. Trail is about 3ft at widest point.

GPS Coordinates: –90.791259 46.970595 Decimal Degrees

No. of Photo Points: 2140 East and 2141 West

Photo Purpose: To show informal trails on Raspberry Sandscape

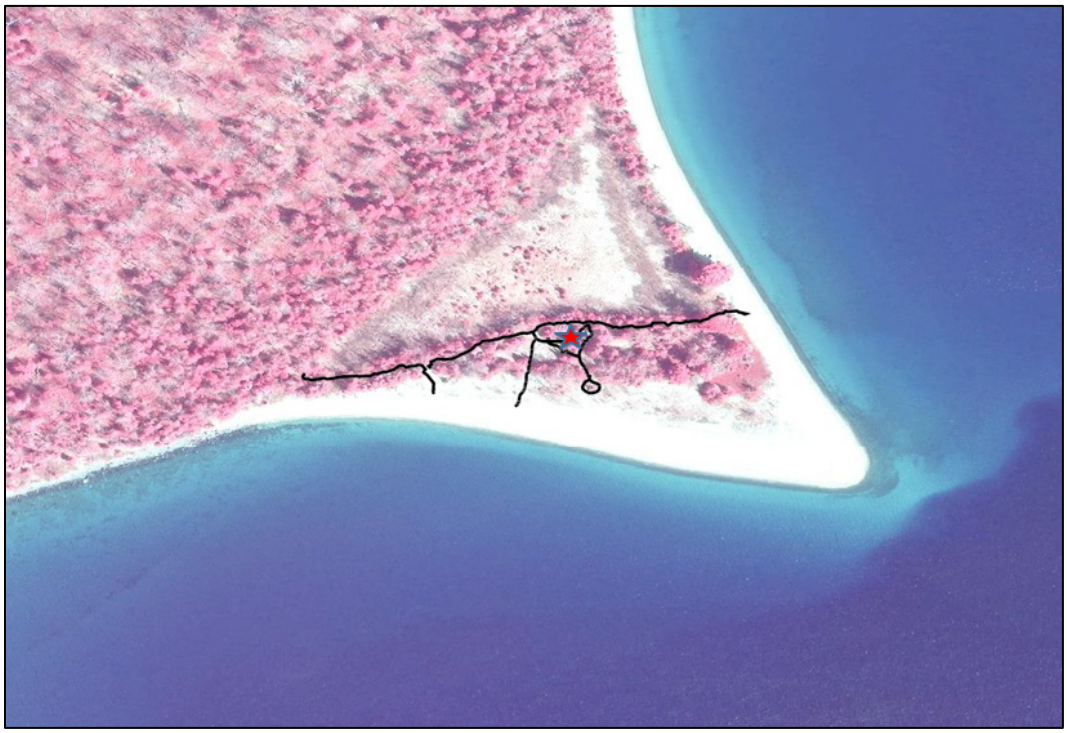


Figure C74. Aerial photo showing the location of photo points 2140 East and 2141 West, and the associated trails.



Figure C75. Example photo taken from photo point 2140 East.



Figure C76. Example photo taken from photo point 2141 West.

Photo Point Site Description and Location
Date (MM/DD/YY): 7-21-14

Time: —

Observers: Forrest Rosenbower, Michael Sinclair, Sarah Johnson, and Emily Leonard

Island: Raspberry

Location: Northeastern side of sandscape (Figures C77 through C79)

Location Description: Located at base of final transect. Photo taken southeast of location shows the sandscape and transects on west side of the sandscape and north of this location there is a long stretch of beach with no dune vegetation.

GPS Coordinates: –90.790957 46.972518 Decimal Degrees

No. of Photo Points: 2145 Southeast and 2146 Northeast

Photo Purpose: To show sandscape composition on Raspberry Island

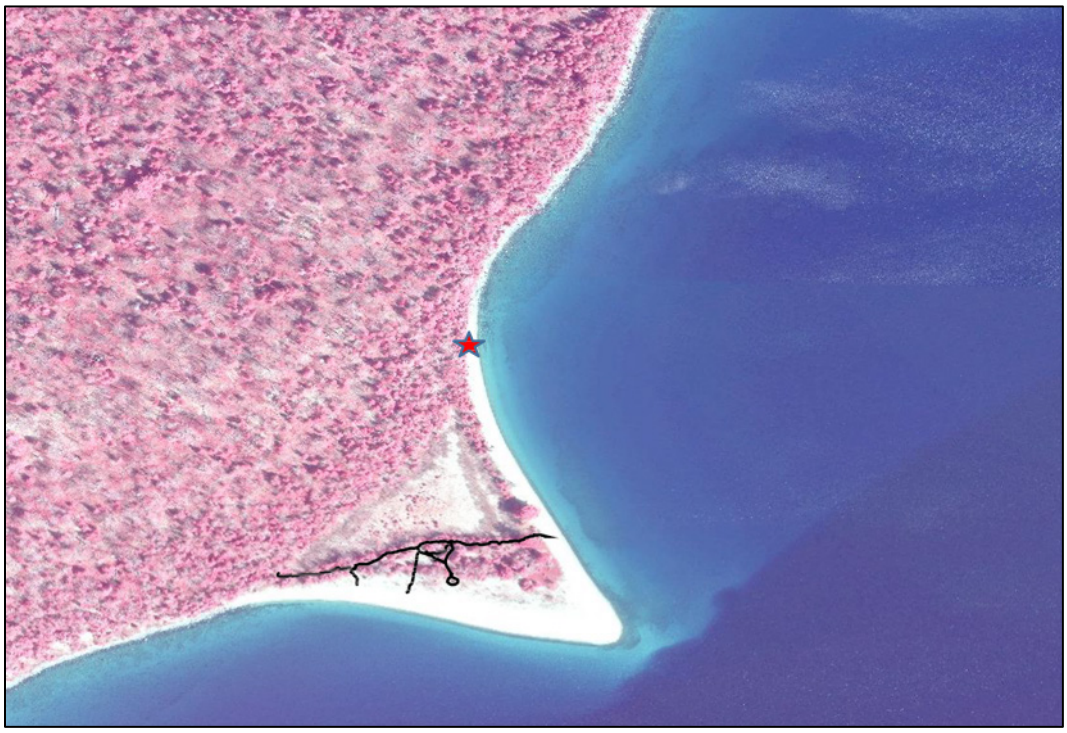


Figure C77. Aerial photo showing the location of photo points 2145 Soth East and 2146 Northeast, and the associated trails.



Figure C78. Example photo taken from photo point 2145 Southeast.



Figure C79. Example photo taken from photo point 2146 Northeast.

Sand River (Mainland)

Photo Point Site Description and Location

Date (MM/DD/YY): 7-15-14

Time: —

Observers: Forrest Rosenbower, Michael Sinclair, and Emily Leonard

Island: Sand River

Location: West side of sandscape (Figures C80 through C82)

Location Description: Photos taken at base of transect one with the mouth of the Sand River west of location and the entire sandscape east of the location. The beach is very narrow at this location with a lot of flooding and debris on the beach.

GPS Coordinates: –90.933975 46.933201 Decimal Degrees

No. of Photo Points: 2032 West and 2033 East

Photo Purpose: To show sandscape composition and erosion on the Sand River sandscape. Sandbar shown on map is now gone also.

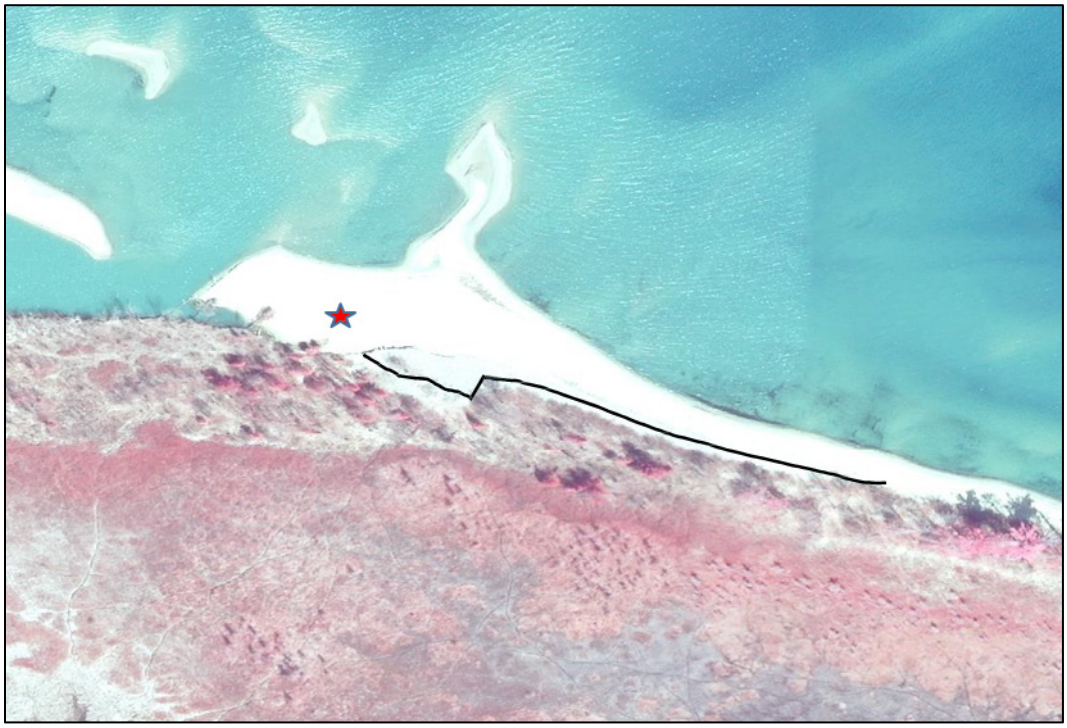


Figure C80. Aerial photo showing the location of photo points 2032 West and 2033 East, and the associated trails.



Figure C81. Example photo taken from photo point 2032 West.



Figure C82. Example photo taken from photo point 2033 East.

Photo Point Site Description and Location
Date (MM/DD/YY): 7-15-14

Time: —

Observers: Forrest Rosenbower, Michael Sinclair, and Emily Leonard

Island: Sand River

Location: Western side of sandscape (Figures C83 through C85)

Location Description: Mid-dune behind 5th transect there is a small deer or foot path that is less than 1 foot wide. Path is overgrown with Beach Grass and runs from the west side of the sandscape to the east.

GPS Coordinates: –90.933791 46.932936 Decimal Degrees

No. of Photo Points: 2034 West and 2035 East

Photo Purpose: To show informal trails on the Sand River sandscape



Figure C83. Aerial photo showing the location of photo points 2034 West and 2035 East, and the associated trails.



Figure C84. Example photo taken from photo point Photo 2034 West.



Figure C85. Example photo taken from photo point Photo 2035 East.

Photo Point Site Description and Location
Date (MM/DD/YY): 7-15-14

Time: —

Observers: Forrest Rosenbower, Michael Sinclair, and Emily Leonard

Island: Sand River

Location: Central sandscape on trail (Figures C86 and C87)

Location Description: Fore-dune facing mouth and running west to east there is a two-track ATV path.

GPS Coordinates: –90.932976 46.932755 Decimal Degrees

No. of Photo Points: 2037 East

Photo Purpose: To show informal trails on the Sand River sandscape



Figure C86. Aerial photo showing the location of photo point 2037 East and the associated trails.



Figure C87. Example photo taken from photo point 2037 East.

Photo Point Site Description and Location
Date (MM/DD/YY): 7-15-14

Time: —

Observers: Forrest Rosenbower, Michael Sinclair, and Emily Leonard

Island: Sand River

Location: Eastern side of sandscape at the base of final transect (Figures C88 through C90)

Location Description: Sandscape, river mouth and transects west of location and forested edge of sandscape east of location

GPS Coordinates: –90.931145 46.932327 Decimal Degrees

No. of Photo Points: 2038 West and 2039 East

Photo Purpose: To show composition of Sand River sandscape

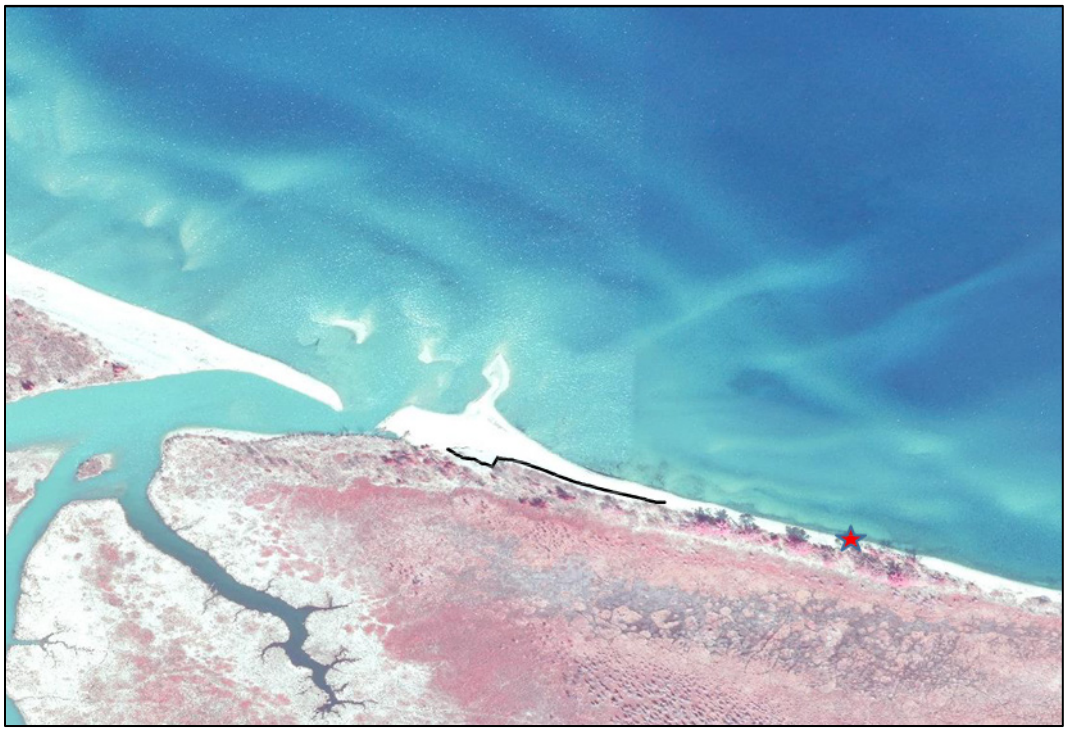


Figure C88. Aerial photo showing the location of photo points 2038 West and 2039 East, and the associated trails.



Figure C89. Example photo taken from photo point 2038 West.



Figure C90. Example photo taken from photo point 2039 East.

Stockton Island—Julian Bay

Photo Point Site Description and Location

Date (MM/DD/YY): 7-8-14

Time: —

Observers: Emily Leonard, Michael Sinclair, Forrest, Rosenbower, Sarah Johnson, Jim Sinclair, and Lori Neumann

Island: Stockton Island, Julian Bay Sandscape

Location: South end of beach, south end of boardwalk (Figures C91 through CS93)

Location Description: Standing at end of board walk on south end of beach, south of 1st sandscape transect

GPS Coordinates: –90.543597 46.914100 Decimal Degrees

No. of Photo Points: 6439 South and 6440 South

Photo Purpose: to show view from southern end of sandscape

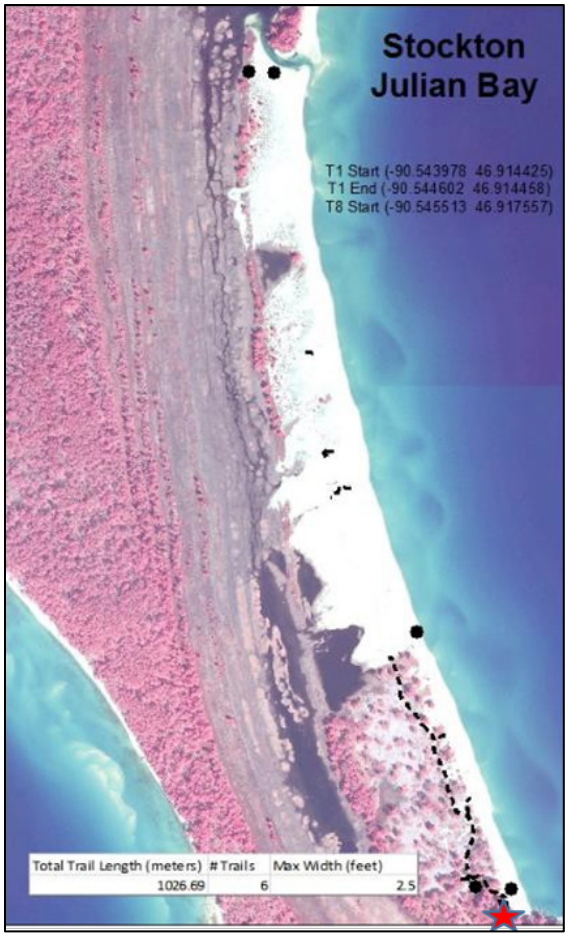


Figure C91. Aerial photo showing the location of photo points 6439 South and 6440 South, and the associated trails.



Figure C92. Example photo taken from photo point 6439 South.



Figure C93. Example photo taken from photo point 6440 North.

Photo Point Site Description and Location
Date (MM/DD/YY): 7-8-14

Time: —

Observers: Emily Leonard, Michael Sinclair, Forrest Rosenbower, Sarah Johnson, Jim Sinclair, and Lori Neumann

Island: Stockton Island, Julian Bay Sandscape

Location: South end of sandscape (Figures C94 through C96)

Location Description: Standing at south end of beach South of previous photopoint near the no camping/no fires sign at base of foot path

GPS Coordinates: –90.543789 46.914060 Decimal Degrees

No. of Photo Points: 6441 South and 6442 North

Photo Purpose: show southern edge of sandscape

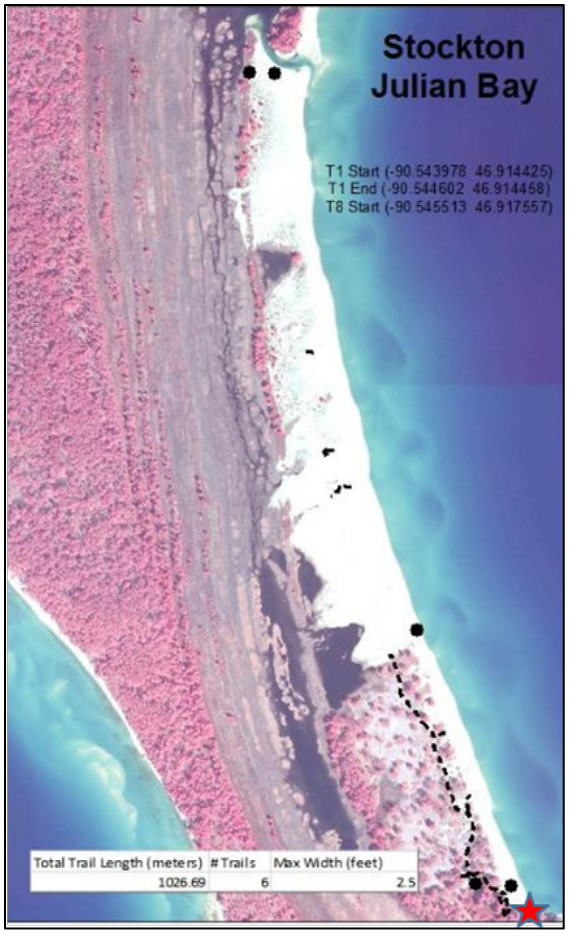


Figure C94. Aerial photo showing the location of photo points 6441 South and 6442 North, and the associated trails.



Figure C95. Example photo taken from photo point 6441 South.



Figure C96. Example photo taken from photo point 6442 North.

Photo Point Site Description and Location
Date (MM/DD/YY): 7-8-14

Time: —

Observers: Emily Leonard, Michael Sinclair, Forrest Rosenbower, Sarah Johnson, Jim Sinclair, and Lori Neumann

Island: Stockton Island, Julian Bay Sandscape

Location: Sandscape, Meeting of informal trail and boardwalk, south of end of boardwalk (Figures C97 through C101)

Location Description: Standing at point where foot path meets board walk just north of blow out area and south of restoration area and end of board walk, path is about 2 feet wide, blowout is about 2 meters

GPS Coordinates: –90.544739 46.915308 Decimal Degrees

No. of Photo Points: 6443 North, 6444 East, 6445 South, 6446 West

Photo Purpose: to show effects of humans around boardwalk and informal trail

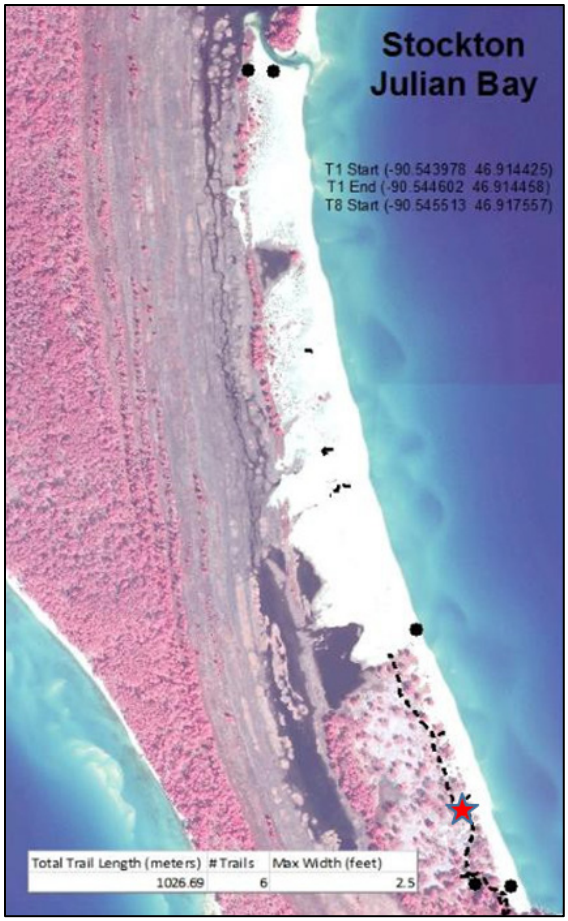


Figure C97. Aerial photo showing the location of photo points 6443 North, 6444 East, 6445 South, 6446 West, and the associated trails.



Figure C98. Example photo taken from photo point.6443 North.



Figure C99. Example photo taken from photo point Photo 6444 East.



Figure C100. Example photo taken from photo point 6445 South.



Figure C101. Example photo taken from photo point 6446 West.

Photo Point Site Description and Location
Date (MM/DD/YY): 7-8-14

Time: —

Observers: Emily Leonard, Michael Sinclair, Forrest Rosenbower, Sarah Johnson, Jim Sinclair, and Lori Neumann

Island: Stockton Island, Julian Bay Sandscape

Location: Informal trail north of the floating boardwalk (Figure C102 through C104)

Location Description: Standing on foot path north of the end of the boardwalk facing south looking at blowout and small footpath on edge of dune on left hand side; facing north toward foot path leading down to lagoon. Next to birch and red pine on western side

GPS Coordinates: –90.545117 46.916286 Decimal Degrees (We are not 100% confident)

No. of Photo Points: 6447 South and 6448 North

Photo Purpose: show blowout and informal trail

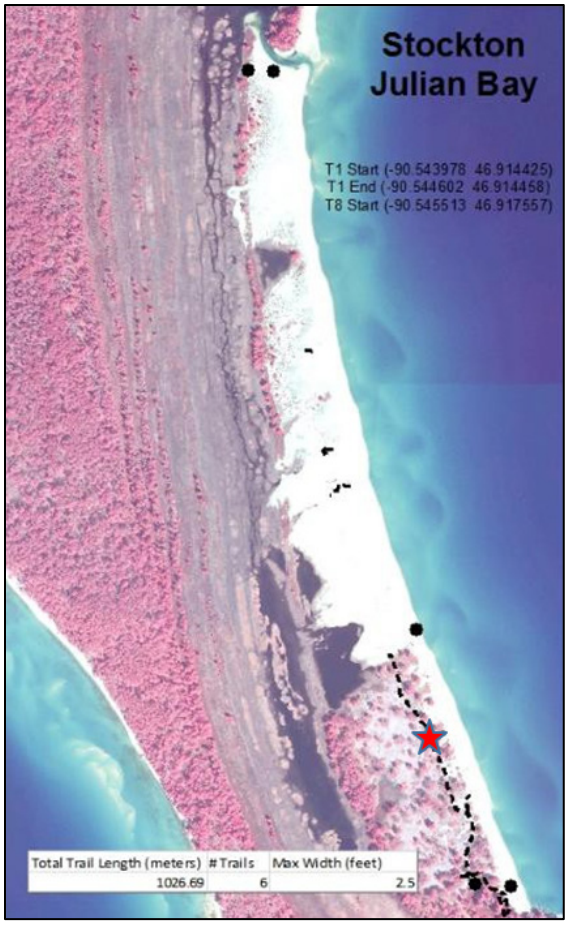


Figure C102. Aerial photo showing the location of photo points 6447 South and 6448 North, and the associated trails.



Figure C103. Example photo taken from photo point 6447 South.



Figure C104. Example photo taken from photo point 6448 North.

Photo Point Site Description and Location
Date (MM/DD/YY): 7-8-14

Time: —

Observers: Emily Leonard, Michael Sinclair, Forrest Rosenbower, Sarah Johnson, Jim Sinclair, and Lori Neumann

Island: Stockton Island, Julian Bay Sandscape

Location: Northern portion of savannah area on sandscape (Figures C105 through C107)

Location Description: Standing on top of dune next to "Fragile Vegetation" sign on a footpath leading from lake to lagoon. South of exposed dune area (beach grass-dominated area) and north of the final photopoint path about 2 feet

GPS Coordinates: –90.545067 46.916307 Decimal Degrees (Not 100% sure)

No. of Photo Points: 6449 West and 6450 East

Photo Purpose: show impact of footpath

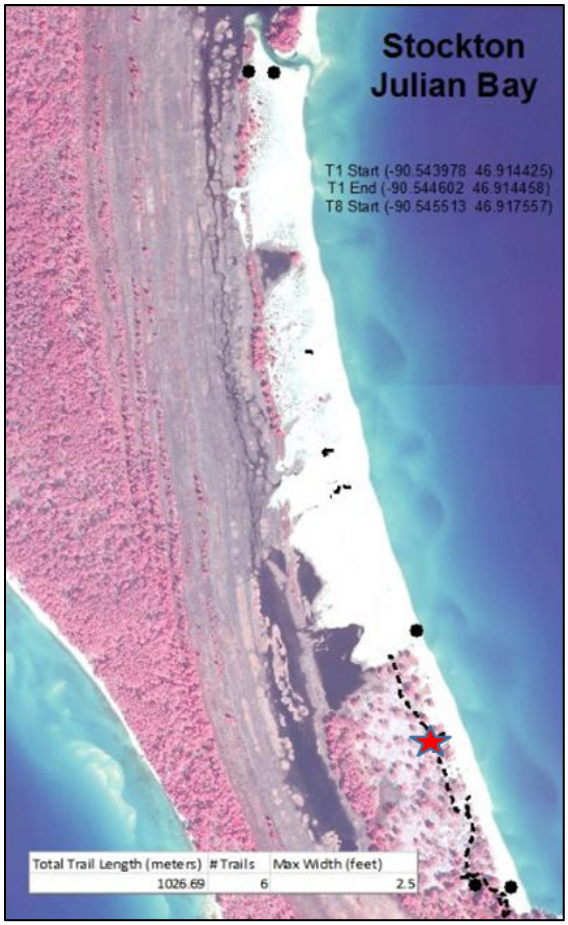


Figure C105. Aerial photo showing the location of photo points 6449 West and 6450 East, and the associated trails.



Figure C106. Example photo taken from photo point 6449 West.



Figure C107. Example photo taken from photo point 6450 East.

Photo Point Site Description and Location
Date (MM/DD/YY): 7-8-14

Time: —

Observers: Emily Leonard, Michael Sinclair, Forrest Rosenbower, Sarah Johnson, Jim Sinclair, and Lori Neumann

Island: Stockton Island, Julian Bay Sandscape

Location: On shoreline, at edge of savanna and at edge beach grass-dominated areas (Figures C108 through C110)

Location Description: Standing at north end of beach before open dune area on edge of savanna, looking south toward transects and north toward dunes with beach grass and outlet

GPS Coordinates: –90.545503 46.917357 Decimal Degrees

No. of Photo Points: 6451 South and 6452 North

Photo Purpose: show any change in shoreline and extent of savanna

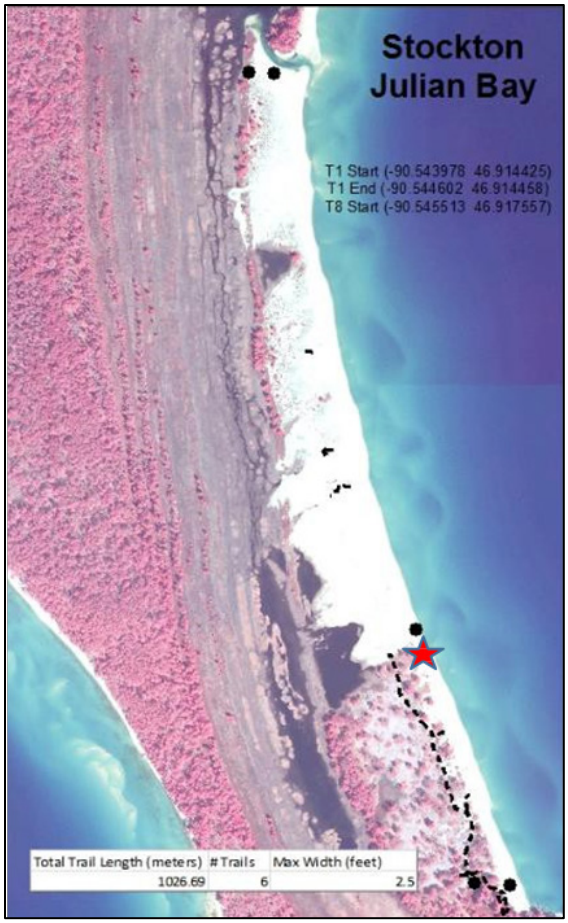


Figure C108. Aerial photo showing the location of photo points 6451 South and 6452 North, and the associated trails.



Figure C109. Example photo taken from photo point 6451 South.



Figure C110. Example photo taken from photo point 6452 North.

Stockton Island—Northwest

Photo Point Site Description and Location

Date (MM/DD/YY): 7-25-14

Time: —

Observers: Forrest Rosenbower, Michael Sinclair, and Emily Leonard

Island: Stockton Northwest Sandscape

Location: Southwestern corner of sandscape (Figures C111 through C113)

Location Description: Photos taken at the base of the final transect. Photo taken facing southwest shows forested edge of sandscape and photo taken at location facing northeast shows the sandscape and transects.

GPS Coordinates: –90.636641 46.942107 Decimal Degrees

No. of Photo Points: 2644 Northeast and 2645 Southwest

Photo Purpose: To show composition on sandscape



Figure C111. Aerial photo showing the location of photo points2644 Northeast and 2645 Southwest, and the associated trails.



Figure C112. Example photo taken from photo point 2644 Northeast.



Figure C113. Example photo taken from photo point 2645 Southwest.

Photo Point Site Description and Location
Date (MM/DD/YY): 7-25-14

Time: —

Observers: Forrest Rosenbower, Michael Sinclair, and Emily Leonard

Island: Stockton Northwest Sandscape

Location: Western side of sandscape (Figures C114 and C115)

Location Description: Informal trail at this location runs east to west. It is located near the final transects on western side of sandscape and is about 1.5 feet wide.

GPS Coordinates: –90.638105 46.940251 Decimal Degrees

No. of Photo Points: 2646 Northeast

Photo Purpose: To show informal trail on Stockton Northwest sandscape



Figure C114. Aerial photo showing the location of photo point 2646 Northeast and the associated trails.



Figure C115. Example photo taken from photo point 2646 Northeast.

Michigan Island

Photo Point Site Description and Location

Date (MM/DD/YY): 7-24-14

Time: —

Observers: Forrest Rosenbower, Michael Sinclair, and Emily Leonard

Island: Michigan

Location: Western tip of sandscape (Figures C116 and C117)

Location Description: Looking south at the base of small, informal trail that leads to open dune area with little dune vegetation

GPS Coordinates: –90.516458 46.876117 Decimal Degrees

No. of Photo Points: 2169 North

Photo Purpose: To show informal trail and bare area on Michigan sandscape



Figure C116. Aerial photo showing the location of photo point 2169 North and the associated trails.



Figure C117. Example photo taken from photo point 2169 North.

South Twin Island

Photo Point Site Description and Location

Date (MM/DD/YY): 7-16-14

Time: —

Observers: Forrest Rosenbower, Michael Sinclair, Jim Sinclair, Lori Neumann, Sarah Johnson, and Emily Leonard

Island: South Twin

Location: Southern portion on sandscape on boardwalk (Figures C118 and C119)

Location Description: Looking west at the base of small, informal trail that leads to water (beach access trail)

GPS Coordinates: –90.651276 47.033071 Decimal Degrees

No. of Photo Points: 2046 West

Photo Purpose: To show informal trail on South Twin sandscape



Figure C118. Aerial photo showing the location of photo point 2046 West and the associated trails.



Figure C119. Example photo taken from photo point 2046 West.

Photo Point Site Description and Location
Date (MM/DD/YY): 7-16-14

Time: —

Observers: Forrest Rosenbower, Michael Sinclair, Jim Sinclair, Lori Neumann, Sarah Johnson, and Emily Leonard

Island: South Twin

Location: Center, back-dune portion on sandscape (Figures C120 and C121)

Location Description: Trail about 2 feet wide leads from picnic platform to beach on north end of sandscape.

GPS Coordinates: –90.650901 47.033696 Decimal Degrees

No. of Photo Points: 2048 North

Photo Purpose: To show informal trail on South Twin sandscape



Figure C120. Aerial photo showing the location of photo point 2048 North and the associated trails.



Figure C121. Example photo taken from photo point 2048 North.

Photo Point Site Description and Location
Date (MM/DD/YY): 7-16-14

Time: —

Observers: Forrest Rosenbower, Michael Sinclair, Jim Sinclair, Lori Neumann, Sarah Johnson, and Emily Leonard

Island: South Twin

Location: North end of sandscape on informal trail (Figures C122 through C124)

Location Description: Trail about 1.8 feet wide leads from picnic platform to beach on north end of sandscape to the water.

GPS Coordinates: –90.651086 47.034360 Decimal Degrees

No. of Photo Points: 2052 South and 2053 North

Photo Purpose: To show informal trail on South Twin sandscape



Figure C122. Aerial photo showing the location of photo points 2052 South and 2053 North, and the associated trails.



Figure C123. Example photo taken from photo point 2052 South.



Figure C124. Example photo taken from photo point.2053 North.

Photo Point Site Description and Location
Date (MM/DD/YY): 7-16-14

Time: —

Observers: Forrest Rosenbower, Michael Sinclair, Jim Sinclair, Lori Neumann, Sarah Johnson, and Emily Leonard

Island: South Twin

Location: Southern end of sandscape near top of transect one on boardwalk (Figures C125 through C127)

Location Description: Entire sandscape monitored is north of this location and the sandscape transitions into forest south of this location. Boardwalks cross at this location.

GPS Coordinates: –90.651490 47.032679 Decimal Degrees

No. of Photo Points: 2044 North and 2045 South

Photo Purpose: To show sandscape composition on South Twin Island



Figure C125. Aerial photo showing the location of photo points 2044 North and 2045 South, and the associated trails.



Figure C126. Example photo taken from photo point 2044 North.



Figure C127. Example photo taken from photo point 2045 South.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 633/180274, April 2021



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