# *Dune Vegetation Characterization and Baseline Monitoring*
*Holden Beach, NC*

## *A technical report for the Town of Holden Beach*
*Final Version, January 2021*

(Image Source: Drone Imagery, UNCW)


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## Introduction

### *Holden Beach*

Holden Beach is a 9-mile-long barrier island in Brunswick County, North Carolina which experiences long-term and episodic storm erosion, threatening coastal habitats, recreational beach, tourism, and upland developments. The Town of Holden Beach, referred to herein as "Town", employs a local contractor to plant dune faces along the length of the island primarily with sea oats (*Uniola paniculata*) and with less density and further inland, bitter panicum (*Panicum amarum*). American beachgrass (*Ammophlia breviligulata*) was also planted by the Town, however, this species was not observed during the sampling period (see General Observations).

The Town contracted Dr. Sheri Shiflett and Dr. Joni Backstrom to establish baseline cover of dune vegetation on Holden Beach. Graduate students Will Paynter and Emily Michaud assisted with field data collection in summer 2020. Dr. Jamie Rotenburg piloted an aerial drone over the dunes after on the ground surveys were completed. Will Paynter also assisted Dr. Shiflett with GIS imagery analysis and data analysis. Graduate student Amanda Busch provided background information on dune habitats and sea oats ecology. This report summarizes field sampling and remotely-sensed imagery analysis of drone imagery from summer 2020 and satellite imagery mapping from 2017 - 2019.

### *The Sand Dune System*

Coastal sand dunes are habitats of critical ecological and economic significance (Maun, 1998). They are a pervasive element of the dune-beach system created by the interaction of local sediment, wind, currents and tides forming a unique habitat at the junction of water and land. Coastal sand dunes are typically formed through the trapping of sand by dune vegetation, however, with lack of vegetation, migrating dunes that move with the wind can be formed (Chapman, 1976). From stable to mobile and wet to dry conditions, these dunes establish numerous microhabitats (Martinez *et al.*, 1997), provide characteristic landscapes, and support a wide range of ecosystem services, including provisioning of habitat and shoreline stabilization (Everard *et al.*, 2010). Dunes range in extent and magnitude from 0.5 m to large ridges greater than 100 m in elevation, and from ridges that extend tens of meters from the coast, to extensive geomorphological structures that expand several kilometers inland (Psuty, 2004). These structures protect the coastal environment against wind and floods, serve as a barrier against salt water intrusion, and are important to the ground water recharge process (Psuty, 2004). Additionally, stores of sand in the foredunes re-enters the marine transport system forming new beach profiles after erosion disturbances, allowing coasts to maintain their defense (Everard *et al.*, 2010).

Coastal dune restoration and stabilization are dependent on the development and survival of dune vegetation. Dune plant species are highly adaptable, and several are of economic value. Foredune, interdune, and backdune habitats frequently contain vegetation differences due to resource availability, exposure to disturbances, and vegetation succession (Psuty, 2004; Cicarelli *et al.*, 2012). Fluctuations in several environmental factors including sand erosion and accretion, salinity, salt spray, desiccation, and temperature affect the survival and growth of sand dune plants (Maun, 1994). As distance increases from the shoreline, cation exchange capacity, organic matter accumulation, soil moisture, and most nutrients also increase, whereas salt spray and pH decrease (Lane *et al.*, 2008). According to Lane *et al.* (2008), soil chemistry may be the most important criterion in determining the plant community zonation in dune complexes, whereas several others have concluded that burial and salt spray are the most important factors for the distribution of various plant species (Oosting and Billings, 1942; Maun and Perumal, 1999; Wilson, 1999). In the Southeastern United States along the South Atlantic and gulf coasts, *Uniola paniculata* (sea oats) are a pioneer grass considered the primary dune builders, particularly foredunes (Oosting and Billings, 1942; Wagner, 1964; Seneca, 1972; Arun *et al.*, 1999). Historically, coastal sand dunes in this region were stabilized through the cultivation of both *Ammophlia breviligulata* (American beachgrass) and sea oats (Willis *et al.*, 1959; Woodhouse *et al.*, 1968). However, currently, sea oats are considered the primary stabilizer south of the Virginia, North Carolina border (Burgess *et al.*, 2002; Lonard *et al.*, 2011).

Species-specific differences in morphology can cause differences in foredune morphology. For instance, *U. paniculata* is associated with steeper, narrower foredunes and hummocky dune systems, whereas *A. breviligulata* is associated with tall and wide foredunes and continuous dune systems (Hacker *et al.*, 2019). Experimental revegetation research has demonstrated that dunes built with *U. paniculata* or *P. amarum* monocultures are narrower and steeper than dunes built *with A. breviligulata* (Woodhouse and Hanes 1967, Seneca *et al.*, 1976, Woodhouse *et al.*, 1977). Dunes built with a polyculture (i.e., blend) of all three species did not differ from dunes built with monocultures of *A. breviligulata*. Planting foredunes with polycultures can provide insurance against the shorter life-span of *A. breviligulata*. Other species which co-occur with these grasses also provide dune-building functions. For instance, a recent field experiment showed that while *Spartina patens* is less efficient at sand accretion (i.e., capture) than *A. breviligulata* and *U. paniculata*, it also functions as a dune builder (Mullins *et al.*, 2019). In addition, planting density also contributes to sand accretion efficiency and recent work has shown that dispersed plantings (50 cm apart) of *U. paniculata* lead to more rapid lateral growth compared to clumped plantings (Kirschner 2019).

*Sea Oats (Uniola paniculata)*

Sea oats are a slow growing, long lived perennial, rhizomatous, $C_4$ grass species that grows and produces its seed heads during the warm season in the southeastern United States (Shadow, 2007). It is often the dominant species on foredunes along its range, inhabiting semi-stable and itinerant dune systems and is the prevailing native dune grass used for dune restoration and stabilization in the Southeastern United States (Woodhouse *et al.*, 1968). The geographic range of sea oats extends along the coastline from Virginia to the Gulf of Mexico and can also be found in the Bahamas and Cuba. Although its range spans over 5000 km of coastline, the width is narrower as it typically grows in a linear belt 20-200 m from the coastal high-tide mark (Franks *et al.*, 2004; Lonard *et al.*, 2011). Hence, sea oats have a naturally fragmented, linear distribution (Franks *et al.*, 2004).

Sea oats have minimal nutrient level requirements, and tolerate aerosol salt spray, drought, and high temperatures (Lonard *et al.*, 2011). Although sea oats are very drought tolerant, they can also tolerate brief inundations with salt water, but cannot endure water logging (Shadow, 2007). These tolerations allow sea oats to rapidly establish and colonize promoting sand deposition (Woodhouse *et al.*, 1968). This grass species is considered a notably important and valuable plant for barrier island and coastline protection considering its massive root system holds soil in place amidst extreme weather occurrences. Sea oats also play a crucial role in both the formation and stabilization of primary dunes by trapping sand (Lonard *et al.*, 2011), and are considered the forefront of shoreline protection. Furthermore, sea oat populations are an essential component of the food web for animals, insects, and birds that distinguish this habitat (Wagner, 1964).

Sea oats are an outcrossing and wind-pollinated species, with its caryopses (seeds) being dispersed by both wind and water (Harper and Seneca, 1974; Hester and Mendelssohn, 1987). However, clonal reproduction by the production of rhizomes is more prevalent in sea oats (Wagner, 1964), with a limited supply of new genetic additions by way of sexual reproduction (Sydney, 2002; Braly, 2009). Burial of photosynthetic vegetative components is typically detrimental to plant species (Maun, 1998; Wilson, 1999). However, several studies have found that burial of the sea oat base actually stimulates growth in addition to aiding in the spreading of the plant via rhizomes (Wagner, 1964; Maun and Lapierre, 1986; Maun, 1998; Wilson and Sykes, 1999) by increasing soil contact and relative humidity surrounding roots, suggesting that the sand promotes photosynthesis and growth (Willis *et al.*, 1959). Considering sea oats produce a massive root system, burial is also beneficial by providing new volume for roots to colonize (Willis *et al.*, 1959). Yet, there is a threshold (approximately 15 cm) to the positive correlations to burial, and once passed, burial may reduce seed germination, seedling emergence, survival, and growth of seedlings and mature plants (Maun, 1998). Also detrimental to most plant species including many dune species is exposure to a high volume of salt spray. Although foredune species are more tolerant of salt spray, it has been suggested that sea oats have adapted to obtain important nutrients from salt spray in an otherwise relatively nutrient deficient environment (Gorham 1958, Kraus and Friday, 1988). Foredune sand tends to be richer in carbon, nitrogen, and potassium compared to inland dunes most likely due to exposure to salt spray and shore-line debris (Willis *et al.*, 1959).

Sea oats produce large panicles with numerous spikelets, however, sea oats are not a fruitful seed producer leading to poor seed yields, germination, and seedling survival (Burgess *et al.*, 2002; Valero-Aracama *et al.*, 2007; Braly, 2009 Lonard *et al.*, 2011; Barrios *et al.*, 2014). Very few spikelets ever set seed, and studies consistently show that sea oat plants produce less than two viable seeds per spikelet (Wagner, 1964; Hester and Mendelssohn, 1987; Burgess *et al.*, 2002). Sea oat spikelets contain several bisexual florets, however, the lowest 4-8 florets, as well as several distal florets are sterile (Shadow, 2007). Hester and Mendelssohn (1987) reported that only 30% of florets contain viable ovaries, and that at least 70% of the remaining ovaries abort. It has also been suggested that viable embryos are produced and later abort (Wagner, 1964; Burgess *et al.*, 2002), or that limited seed production could also be from that majority of florets within spikelets being sterile, making seed acquisition from natural environments difficult (Wagner, 1964). Germination rates tend to range from 20-40% (Barrios *et al.*, 2014). Reduced germination rates have also been attributed to seed dormancy and susceptibility to attacks by fungi or bacteria that may reside internally, in the soil, or on the surface of the seed (Wagner, 1964; Hester and Mendelssohn, 1987; Barrios *et al.*, 2014).

*American beachgrass (Ammophila breviligulata)*

American beachgrass is a cool season $C_3$ grass that grows most prolifically in the zone of accretion in the foredune area. Once sand becomes stabilized, it quickly loses vigor and is outcompeted by other species, such as sea oats, that provide long term cover and stabilization. Studies have found *A. breviligulata* to be an inferior competitor compared to *U. paniculata* in manipulative experiments of dune plant spacing and density (Harris *et al.*, 2017, Brown *et al.*, 2018). American beachgrass is the dominant dune grass from Virginia northward, and sea oats is dominant south of Virginia (Goldstein *et al.*, 2018). Literature suggests a southern range limit of Cape Fear, NC for American beachgrass (Goldstein *et al.*, 2018) and studies have shown it is susceptible to mortality above 35 °C/95 °F (Seneca and Cooper 1971, Emery *et al.*, 2014).

*Bitter panicum (Panicum amarum)*

Bitter panicum is a perennial warm-season grass which has a prostrate growth habit. It spreads slowly from short, robust rhizomes that form open clumps and over time these clumps can fuse, forming a dense mat of vegetation. This grass produces little viable seed and therefore must be planted vegetatively (Wootton *et al.*, 2016). It is frequently planted in conjunction with sea oats and American beachgrass.

## Sampling Methods

During June and July 2020, vegetation was sampled in each of five zones identified by the Town (i.e., East End, East Reach, Pier, West Reach, and West Area) and an additional "Inlet" zone (Figure 1). Throughout this report the Inlet and West Area zones are referred to as endpoint zones and the East End – Town West Reach are referred to as interior zones. Active planting of sea oats is occurring in the interior zones, while the endpoint zones serve as reference areas where there is no active planting activity. Inclusion of these zones allow for comparisons to unmanaged areas where there is higher disturbance (Inlet) versus more stability or less disturbance (West Area).

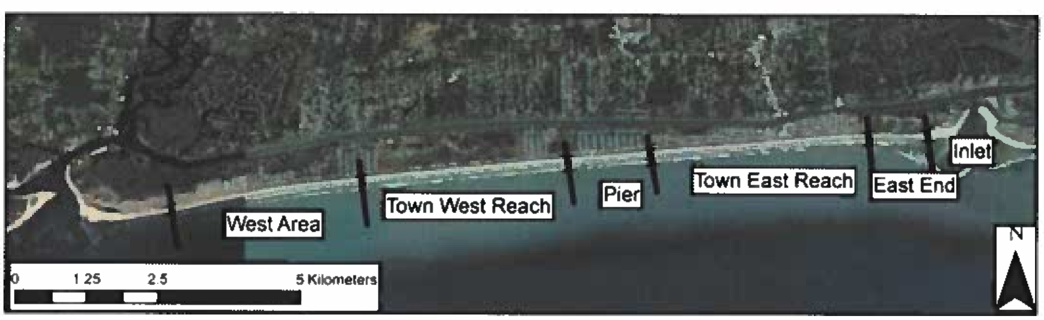


**Figure 1**. Holden Beach, NC and the six sampling regions of interest.

Sampling was conducted along three transects per zone which were perpendicular to the shoreline and the length was the distance from the toe of the primary dune slope or first line of fencing until reaching a resident's yard, a road, or 45 m, whichever condition occurred first.

Plots (1 x 1 m) were sampled at 0 m, 2 m, 4 m, 5 m and then every 5 m thereafter. Plots were located closer together in the first 5 m of sampling to capture sea oats recent planting efforts at the beginning of each transect, where the transplants are likely most vulnerable, and to detect species which may not occur farther inland. Total percent cover for each plot was recorded in addition to percent cover and density of each species within the plots. Elevation was recorded along each transect for each plot location using a real-time kinematics instrument (RTK, Trimble, USA). This device measures the elevation of a point location at regularly-spaced intervals by sending GPS signals between a fixed based station and a moving receiver (i.e., GPS module mounted on the RTK unit). Field images demonstrating sampling methods are located in Appendix B of this report (Figures B2 – B5).

An aerial drone (DJI Phantom) with an attached RBG camera sensor captured imagery above transects within each of the six zones on July 30 and 31, 2020. Image files and a drone methodology document (Appendix C) accompany this report.

Satellite imagery from May 28, 2017 (pre-planting), Jul 19, 2018, and Nov 24, 2019 was mapped in ArcMap 10.5 using false color imagery for each of the sampled zones. For the false-color imagery, the red color band is replaced by the infra-red band to highlight active vegetation growth. Maps showing planting efforts in each zone are included in Appendix D of this report. Satellite imagery from 2017 and 2018 was collected with the WorldView-2 sensor and imagery from 2019 was collected with the WorldView-3 sensor.

## Results

### *Dune Physical Structure – Length and Elevation*

The Inlet and West Town Reach zones had the longest dune fields. While our data collection included distances of up to 45 m, these dune fields extended for over 100 m in several areas. For the rest of the island, the dune field does not extend more than ~30m, except in areas with public beach access. On either side of the access, there may be an additional ~20 m of distance. For the interior island zones (East Area – Town West Reach), dune field distance is limited by either a residential yard, a housing development, or a roadway. Dune widths were measured using Google Earth imagery of Holden Beach from June 2019 for three representative locations of each zone to show variability in dune width for each zone and how far dune width extends beyond our sampling scheme (Figure 2).

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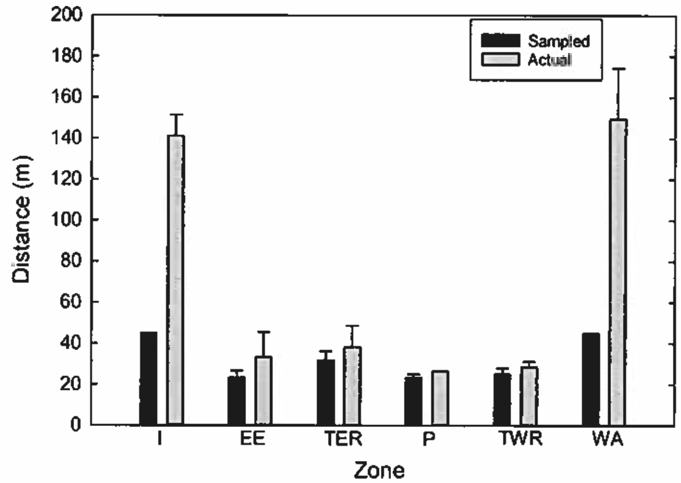


**Figure 2**. Dune field lengths in each zone from the tow of the frontal dune to either a residential yard, a housing development, or a roadway, whichever was first encountered. Sampled lengths are the average of the three sampled transects per zone and actual lengths are derived from measuring dune field length on aerial imagery. Bars represent means ± one standard error of the mean. I = Inlet, EE = East End, TER = Town East Reach, P = Pier, TWR = Town West Reach, and WA = West Area, respectively.

Elevation also showed variation among zones (Figure 3). The Inlet had the lowest starting elevation at ~1.6 m, while the rest of the zones had starting elevations above 2 m. The Town East Reach, Town West Reach, and West Area, all had starting elevations of ~2.5 m. The West Area had the highest overall elevation across the transect, while the Inlet was lower and more variable. All of the interior zones had elevations which dropped off sharply after ~15 - 20 m. There were also a couple zones which rose to a dune peak, declined slightly (~0.5 m), and then rose to a second peak before declining in elevation. The West Reach also showed this pattern, but the swale area (i.e., interdunal depression) was spread out over ~30 m versus ≤ 10 m exhibited by the interior zones (East Area, Town East Reach, Town West Reach).

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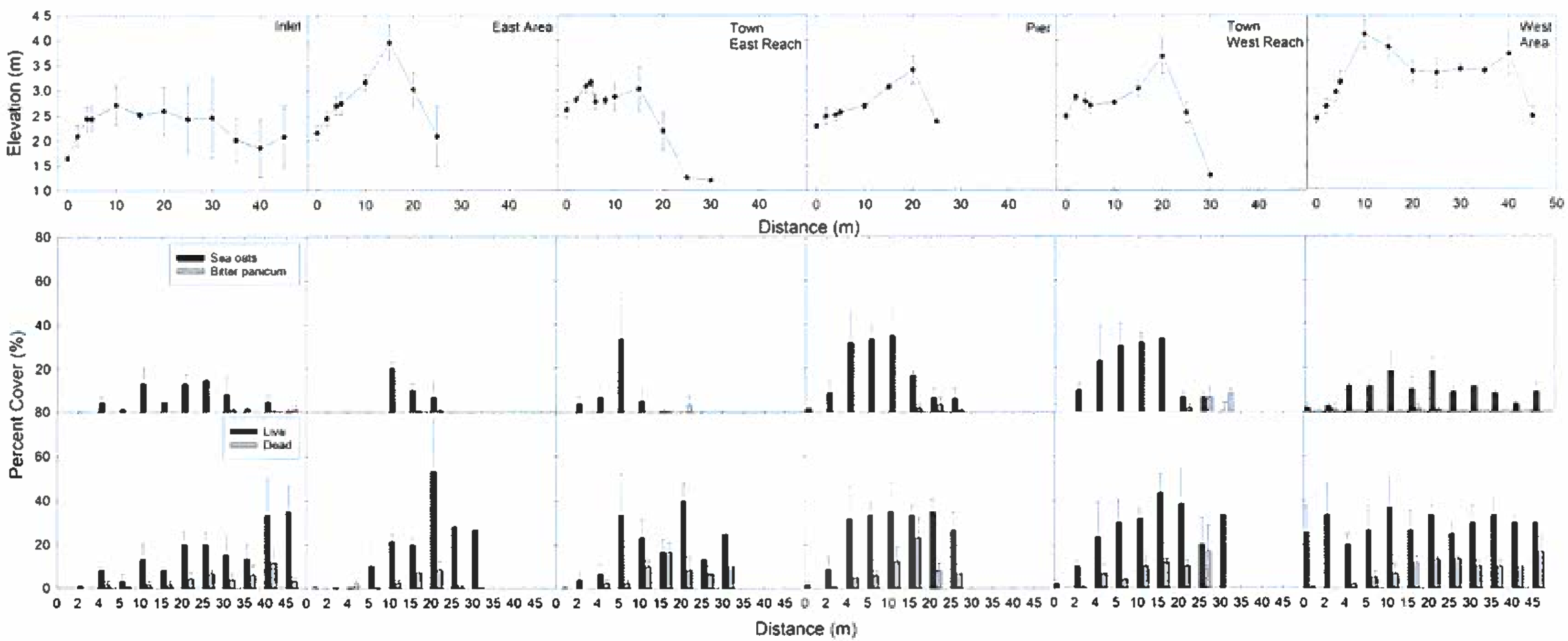


**Figure 3**. **(Top)** Average dune elevation within each of six zones across Holden Beach, NC. **(Middle)** Average percent cover of sea oats and bitter panicum within each zone of Holden Beach, NC, and **(Bottom)** average percent cover of all plant cover (live and dead) within each zone of Holden Beach, NC. Mean values are presented, and where possible, ± standard error is displayed.

*Sea Oats and Bitter Panicum Cover*

The Town has been working with Coastal Transplants, a local restoration specialist, to plant the dunes with sea oats along the frontal dune of most of the island, and with less density, bitter panicum (Figure B1). For this reason, we focused a portion of the analysis on sea oats and bitter panicum cover. At both of the endpoint zones (Inlet and West Area), sea oats were distributed along most of the transect, with peak cover of ~20% between 10 – 20 m (Figure 3, Figure 4). In the interior zones, there was more variation in both the percent cover and the distribution. For instance, percent cover of sea oats was lower at both the East Area and Town East Reach compared to the Pier or Town West Reach (Figure 3, $p < 0.001$). Average sea oats cover varied among zones such that the Inlet, East Area, Town East Reach, and Town West Reach were similar, while the Town East Reach, Town West Reach, Pier, and West Area were also similar ($p < 0.001$, Figure 3, Figure 4). Moreover, statistical analysis also showed that sea oats cover varied with distance to shoreline ($p < 0.001$) where the highest percent covers were observed (in descending order based on mean values, but not statistically different from one another) at distances 10, 5, 15, 45, 4, and 20 m. At East Area and Town East Reach, maximum sea oats cover was observed at 5 and 10 m, respectively, with other plot locations showing substantially less cover, whereas at the Pier and Town West Reach, maximum cover occurred at 10 m, but 4 and 5 m showed similar percent cover. Maximum sea oats cover at any point location was 25, 25, 70, 55, 55, and 35 % across all six zones from east to west (Inlet to West Area).

Bitter panicum was observed in all zones, but it attained much less percent cover than sea oats, with a peak of ~10% at 30 m at the Town West Reach (Figure 3). It was not observed until 15 m for interior zones, whereas at the endpoint zones, observations of bitter panicum were made at 2 m distance (Figure 3).

While cover of sea oats was consistent from 4 – 10 m at the Pier and Town West Reach, field observations outside of the systematic data collection design, indicated some variability in sea oats cover. For instance, along at least one transect at 12 m, sea oats cover was less than 2% (data not shown). Similar observations were made at the East Area and Town East Reach. All zones have areas where sea oats cover is patchy (Figures 5 – 11)

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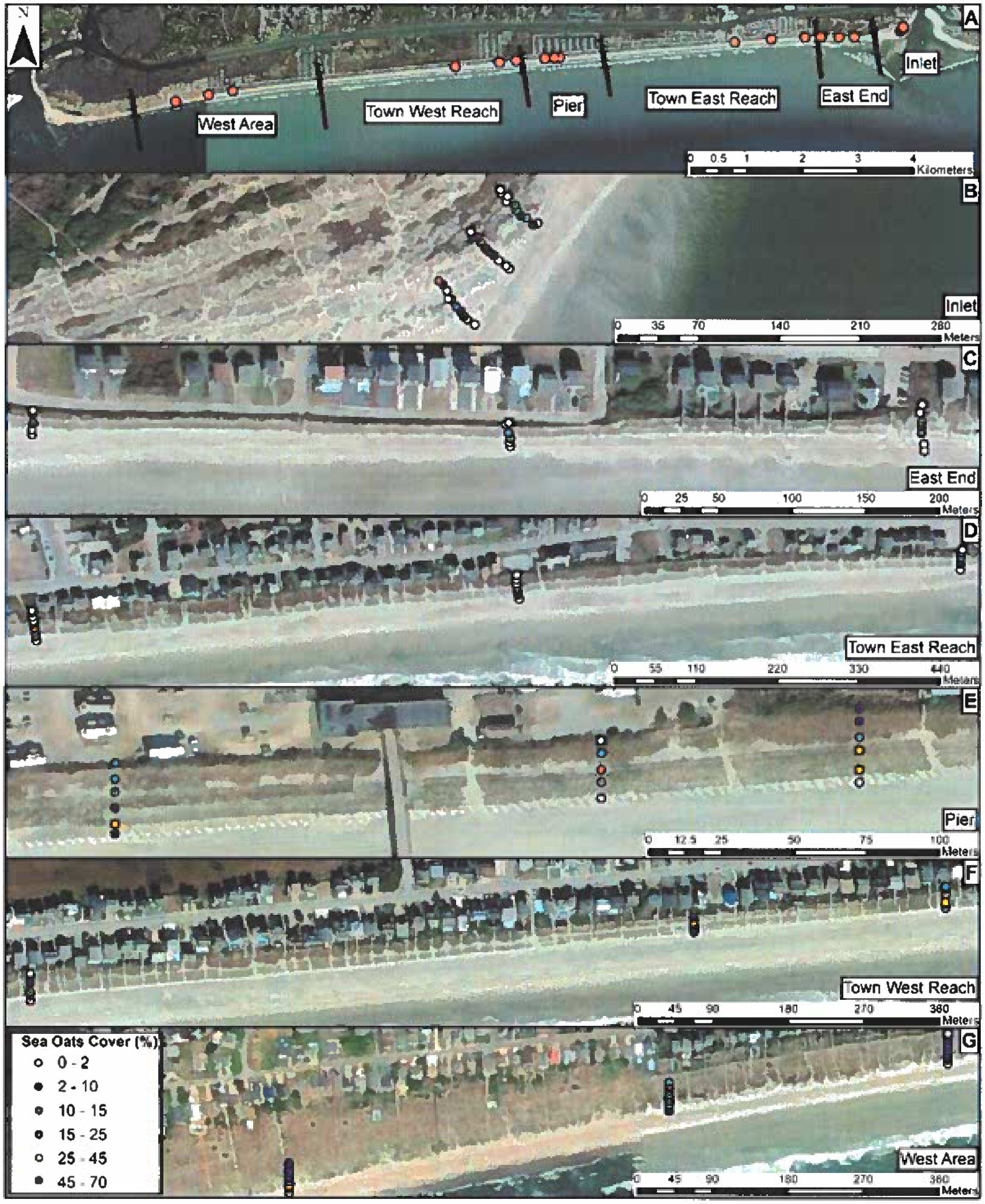


**Figure 4. (A)** Transect sampling locations within each of the six zones of Holden Beach, NC. **(B – G)** Percent cover of sea oats along each transect within each zone. Zones are arranged from east to west.

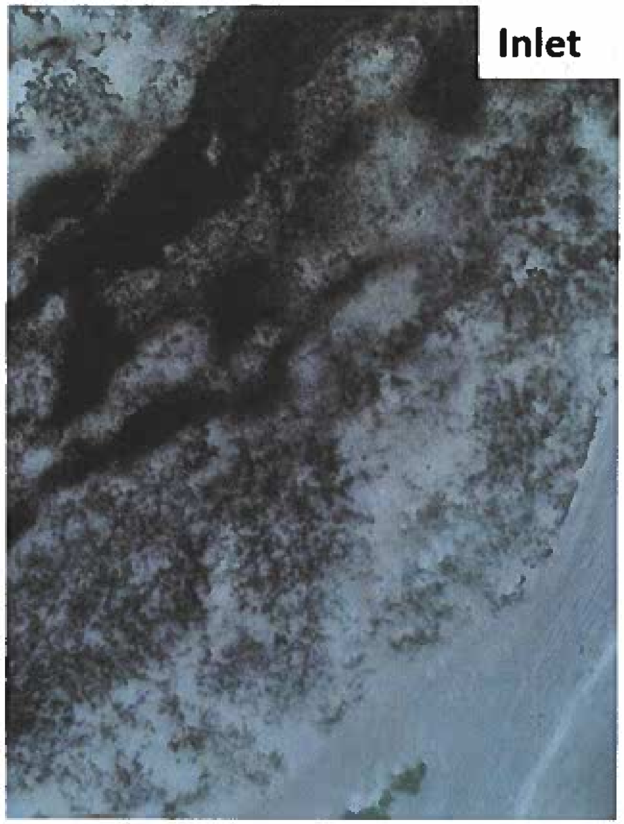


**Figure 5.** Representative drone imagery picture of the Inlet sampling locations. This is a naturally vegetated area and there is no active planting occurring in this zone.

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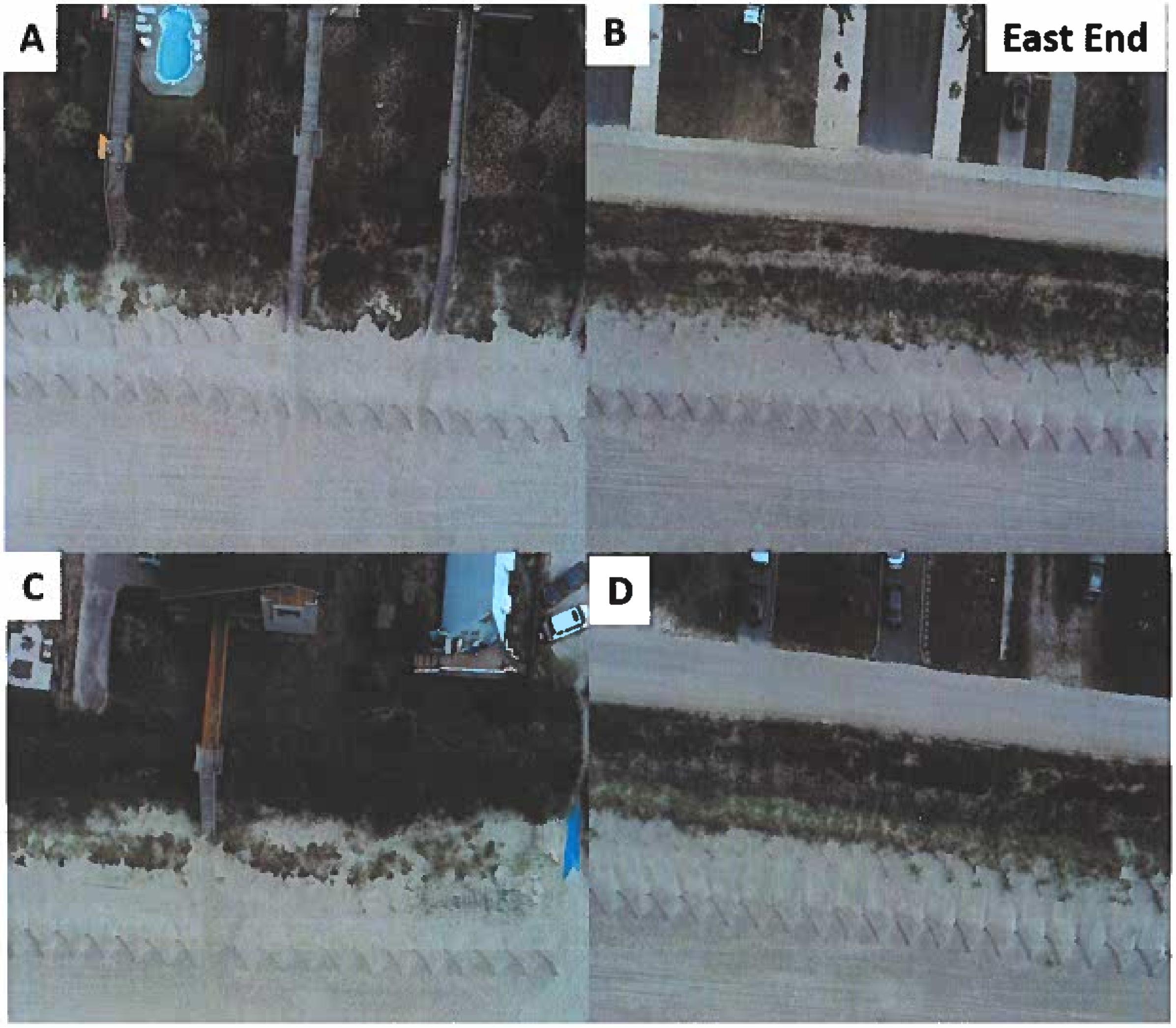


**Figure 6.** Representative drone imagery of the East End sampling locations. Active planting is occurring in this zone.

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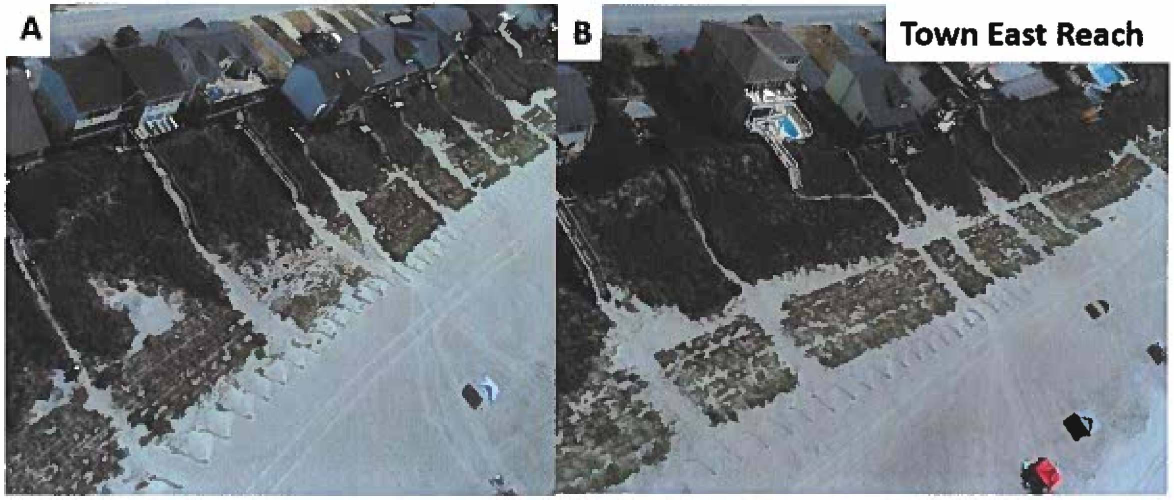


**Figure 7.** Representative drone imagery of the Town East Reach sampling locations. Active planting is occurring in this zone.


**Figure 8.** Representative drone imagery of the Pier sampling locations. Active planting is occurring here.

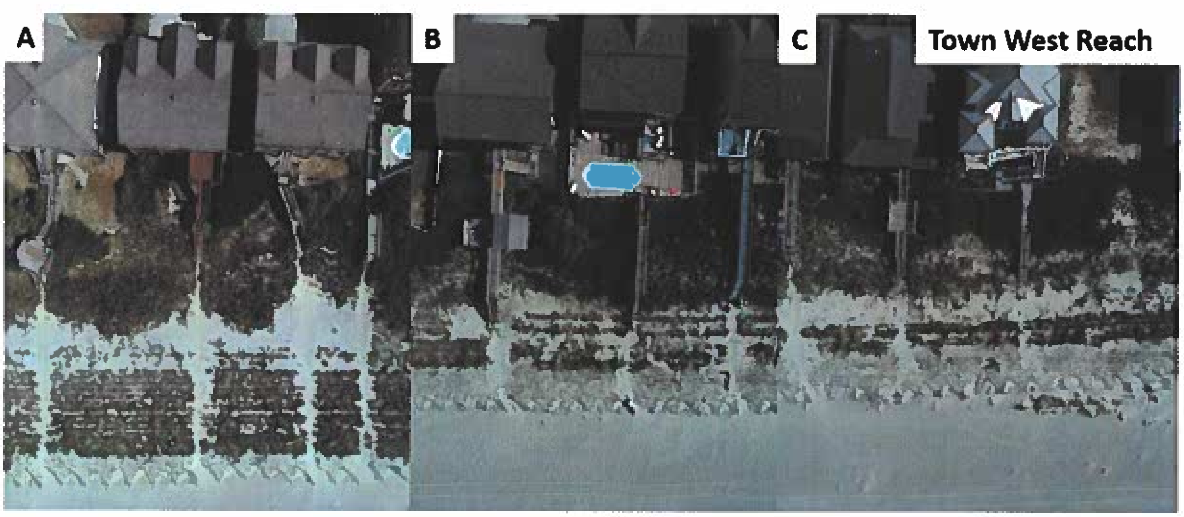


**Figure 9.** Representative drone imagery of the Town West Reach sampling locations. Active planting is occurring in this zone.

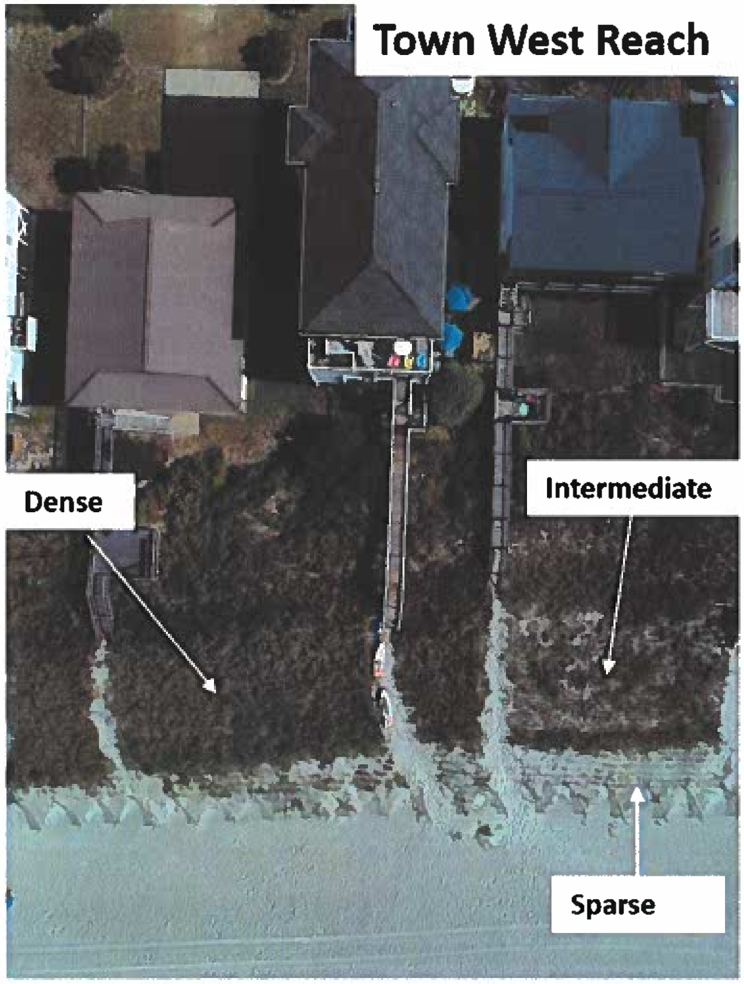


**Figure 10.** Drone imagery of the Town West Reach sampling location. This image shows multiple stages of dune grass growth and filling-in. The sparse area is the most recently planted.

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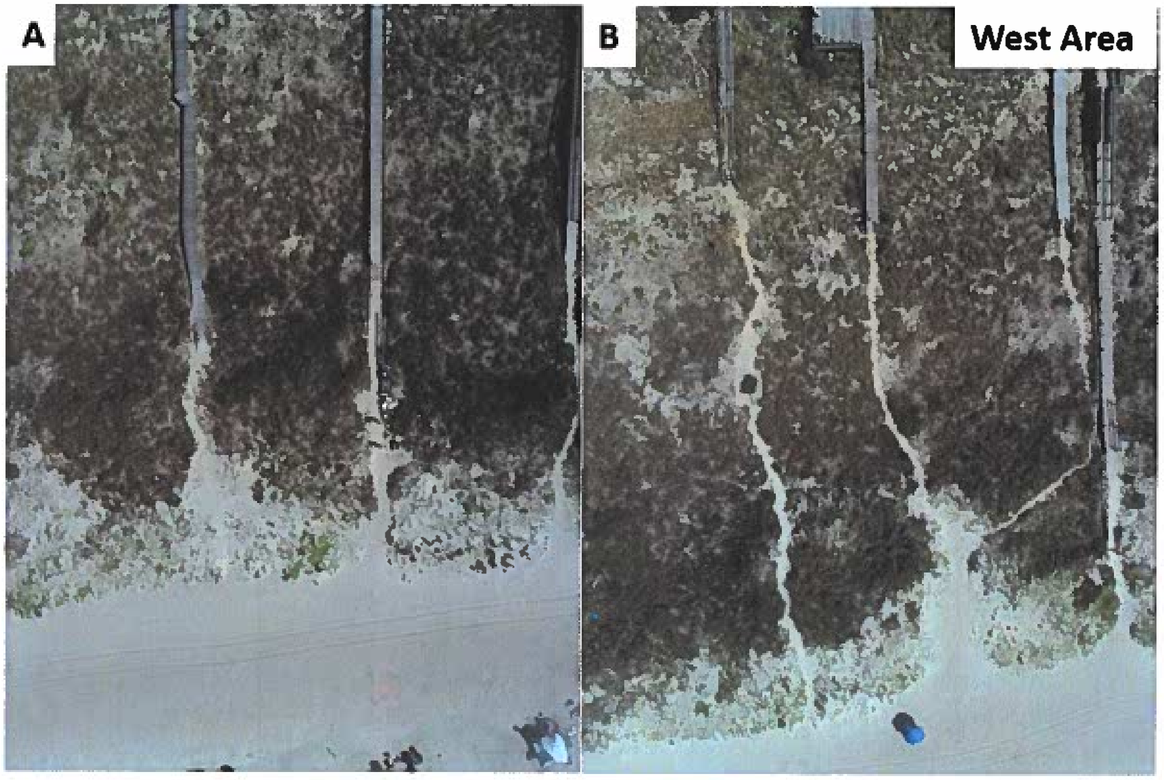


**Figure 11.** Representative drone imagery of the West Area sampling locations. This is a naturally vegetated area and there is no active planting occurring here. This area is accreting (i.e., growing in width).

*Overall Plant Cover*

Total live plant cover, regardless of species, tended to peak around 15 m distance in the interior zones. Consistent with sea oats results, the Pier and Town West Reach showed more stability in maximum plant cover across their respective zones, while the East Area and Town East Reach showed more variability in total plant cover, with fewer plots reaching values near the maximum observed in other plots within those zones. The endpoint zones showed different trends than the interior zones where plant cover consistently increased with distance to shoreline at the Inlet and stayed stable across the zone at the West Area.

*Dune Species Diversity*

A total of 36 species were observed on the sampled dune fields at Holden Beach (Table A1). Several species were observed across all five zones, including UNPA (sea oats), PAAM (bitter panicum), HYBO (largeleaf pennywort), and SPPA (marsh hay) (Table A2). There were also nine species which were only observed in one zone (Table A2). Figures A1 – A18 (Appendix B). show the location of occurrence and percent cover of each species within each sampled transect. These figures are organized by distance of the first observation of a given species, except for sea oats, which is always shown first. There are some species, such as sea oats, or largeleaf pennywort, which tend to occur across the entire dune field, especially at the endpoint zones (Inlet and West Area). Notably, the occurrence of sea oats is much more limited in the East End and Town East Reach. It was only observed within 2 plot locations for three of the six transects in these zones. Some transects, such as East End (H5), had only six species and as evidenced by the plot, and distributions were extremely limited with all species observed at 10 – 20 m distance. Other transects, such as Town West Reach had 17 species and some species were distributed across the entire transect. In general, species richness, or number of species, increased with distance to the shoreline ($p < 0.001$, Figure 12).

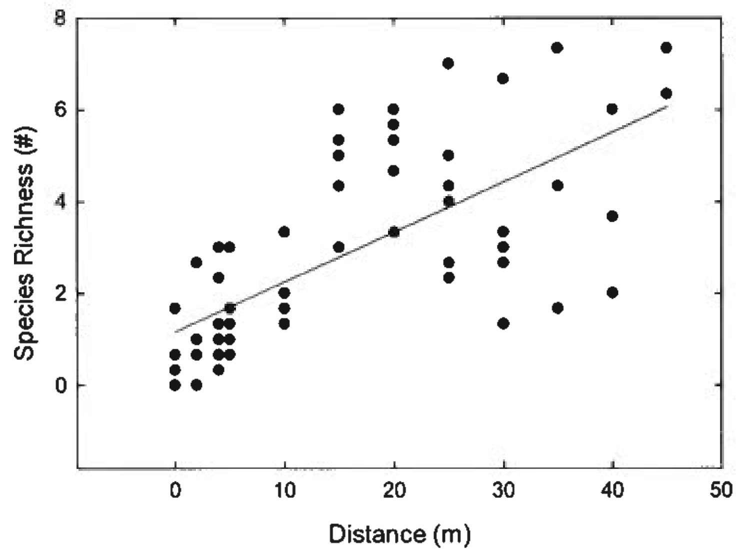


**Figure 12**. Average number of species within each of the sampled zones with increasing distance to shoreline.

## General Observations/Recommendations

At West Area – Transect H17, Dr. Shiflett observed dune morning glory growing as a dense mat (40+% cover) immediately as sampling commenced at 0 and 2 m and it occurred with less cover at 4 and 5 m. This plant can serve as a dune stabilizer by trapping sediments in place and it might be worth testing planting in other zones in starter dune areas. Dr. Shiflett observed dune morning glory in limited locations in other zones (such as East End – Transect H6), but it was further inland (15 – 30 m) and not at the dune toe of slope (Figure B8 – Appendix B).

The figures which show species occurrence at each transect (Figures A1 – A18) could serve as suggestions for diversifying the planting palette in the swale (i.e., interdune zone, 10 – 25 m) at interior zones. For instance, another notable species is seashore elder (*Iva imbricata*), a low-growing woody species adapted to frontal dunes and spreads by seed and vegetatively. It was observed at several transects (and generally along the strand/dune toe in many locations across the island). The NC State Extension suggests that it is useful in areas where American beachgrass dies out (Broome 2005).

American beachgrass was not observed during this study; however, there are several reasons why this may be the case. It may be observation error, especially if it was mixed in with sea oats and there were no visible signs of inflorescence (i.e., a flowering structure). The more likely scenario is that because the southern end of its range is Cape Fear, NC, it experiences heat-induced mortality above 35 °C/95 °F, and is outcompeted by sea oats, there was little to no American beachgrass on the dunes. I was unable to obtain planting reports or detailed information from Coastal Transplants, but a member of their team told me that it was mostly planted at the western end of the island. I would recommend confirming where it was planted and monitoring some of those sites. In future plantings, re-visit sites where it is planted and monitor for mortality. If it survives for at least one season and expands cover during that time, it should still be included in the planting mix. Dune planting guides and multiple studies suggest that American beachgrass establishes quickly and is highly effective at sand capture and can do so more rapidly than sea oats, even if both are planted at the same time. Ultimately sea oats will outcompete it, but this is to be expected, especially at the southern extent of its range. The absence of observation of American beachgrass in this study does not necessarily indicate that it should be removed from the planting palette.

There was slightly higher, though not statistically significant, species richness on more stable portions of the island with the Inlet having a maximum of 14 species on a transect and the West Area having two transects with over 15 species. Only one other transect on the island (East End – Transect H6) had more than 15 species with most being under 10. As dune width increases, there is more area to support more species, but a more diverse plant mixture at 15 - 20 m distance from the frontal dune would aid in sediment stabilization, one such species to consider for this dune location is *S. patens*. The West Area is the most stable portion of the island as evidenced by dune accretion and length and the species diversity present there is an indication of what is possible in terms of species cover and composition as the dune system develops and elongates.

The East End and East Reach need more concentrated efforts at dune stabilization via planting and creation of a primary dune. In the East End, there is dramatic dune scarping, and both the dune field and distance range of plant cover is narrow. There is also no evidence of a developed foredune ridge (Figure 3).

There are several areas where there are notable bare patches in sea oats distribution. One such area is in the Pier zone at approximately 12 m from the dune fencing (Figure B5). Drone imagery included with this report also shows other notably bare areas, such as in the East End, immediately landward of dune fencing (Figure B6).

It is likely that many areas which have been planted will continue to fill in and progress towards achieving higher density as noted in Figure 10 and observable from satellite imagery in Appendix C. Sea oats can reproduce clonally, and once established in an area, it will continue to colonize the immediate vicinity and expand its range. Future planting efforts should therefore be focused on areas which are currently bare and are less likely to be colonized as recently planted plugs become more established.

**Acknowledgements**

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**[Continued on Next Page]**

## Appendix A.

## Dune Vegetation

**Table A1**. Information for dune vegetation species observed at Holden Beach, NC. The species code is a four- letter code derived from the first two letters of the first and last words of the species' Latin name.

| Species Code | Latin Name | Common Name |
|---|---|---|
| AMAR | *Ambrosia artemisiifolia* | ragweed |
| BAHA | *Baccharis halmifolia* | eastern baccharis |
| CAHA | *Cakile harperi* | sea rocket |
| CHGO | *Chrysopsis gossypina* | cottonleaf goldenaster |
| CRPU | *Croton punctatus* | beach croton |
| ERCA | *Erigeron canadensis* | horseweed |
| EREL | *Eragrostis elliottii* | field love grass |
| EROP | *Eremochloa ophiuroides* | centipede grass |
| EUPE | *Eustachys petraea* | dune finger grass |
| EUPO | *Euphorbia polygonifolia* | seaside spurge |
| GAPU | *Gaillardia pulchella* | indian blanket |
| HESU | *Heterotheca subaxillaris* | camphor |
| HYBO | *Hydrocotyle bonariensis* | largeleaf pennywort |
| ILVO | *Ilex vomitoria* | yaupon holly |
| IPIM | *Ipomoea imperati* | beach morning glory |
| IVIM | *Iva imbricata* | beach elder |
| JUVI | *Juniperus virginiana* | eastern red cedar |
| MEAL | *Melilotus albus* | white sweetclover |
| MOCE | *Morella cerifera* | southern wax myrtle |
| NEAB | *Nekemias abrorea* | peppervine |
| OEHU | *Oenothera humifusa* | seabeach evening primrose |
| OPDR | *Opuntia drummondii* | prickly pear |
| PAAM | *Panicum amarum* | bitter panicum |
| PAQU | *Parthenocissus quinqufolia* | Virginia creeper |
| PHWA | *Physalis walteri* | dune ground cherry |
| RUTR | *Rubus trivialis* | southern dewberry |
| SAST | *Sabatia stellaris* | marsh pink |
| SMAU | *Smilax auriculata* | dune greenbriar |
| SMBO | *Smilax bona-nox* | maritime catbriar |
| SOME | *Solidago mexicana* | goldenrod |
| SPPA | *Spartina patens* | salt hay |

| Species Code | Latin Name | Common Name |
|---|---|---|
| SPVI | *Sporobolus virginicus* | seashore dropseed |
| STHE | *Strophostyles helvola* | fuzzy bean |
| TRPU | *Triplasis purpurea* | purple sandgrass |
| UNPA | *Uniola paniculata* | sea oats |
| YUAL | *Yucca alifolia* | Spanish bayonette yucca |

**[Continued on Next Page]**

**Table A2**. Presence of a given species within each sampled zone on Holden Beach, NC. Species codes are defined in Table 1.

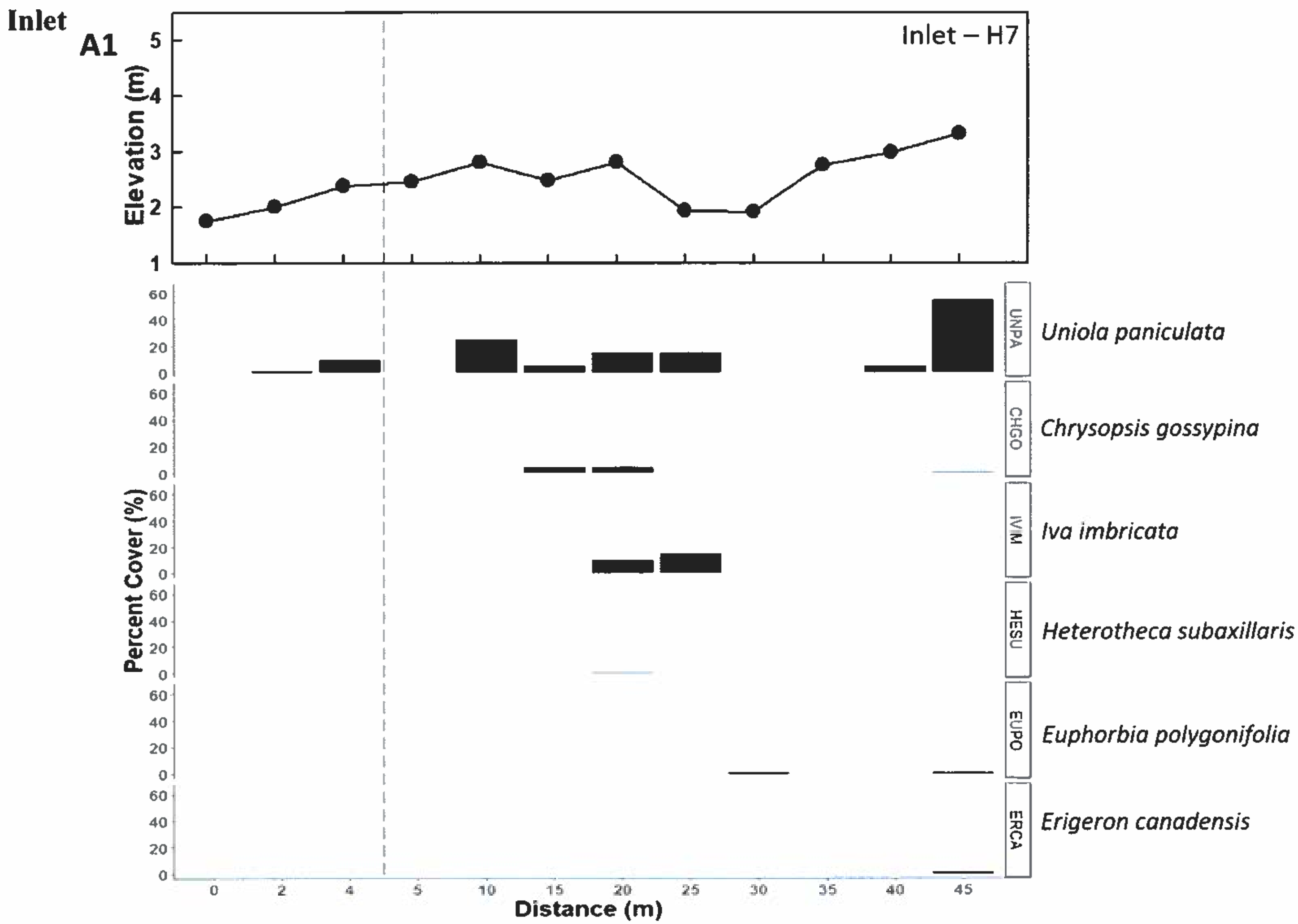
| Species Code | Inlet | East End | Town East Reach | Pier | Town West Reach | West Area |
|---|---|---|---|---|---|---|
| AMAR | | Y | | | | |
| BAHA | | | | | Y | |
| CAHA | | Y | | | | |
| CHGO | Y | | | | | |
| CRPU | | Y | Y | Y | Y | Y |
| ERCA | Y | Y | Y | Y | | Y |
| EREL | | Y | | | | |
| EROP | | | | | Y | |
| EUPE | Y | Y | | | | Y |
| EUPO | Y | Y | | | | Y |
| GAPU | | Y | Y | | | Y |
| HESU | Y | Y | Y | Y | | Y |
| HYBO | Y | Y | Y | Y | Y | Y |
| ILVO | | | Y | | | |
| IPIM | | Y | | | | Y |
| IVIM | Y | Y | | | | Y |
| JUVI | | Y | | | Y | |
| MEAL | | Y | | | | |
| MOCE | | Y | | | Y | |
| NEAB | | Y | | | | |
| OEHU | Y | | | | | Y |
| OPDR | | | | | | Y |
| PAAM | Y | Y | Y | Y | Y | Y |
| PAQU | | Y | | | | |
| PHWA | | Y | | Y | | Y |
| RUTR | | Y | Y | | Y | Y |
| SAST | Y | | | | | |
| SMAU | | | | | | Y |
| SMBO | | | Y | Y | Y | Y |
| SOME | | Y | Y | Y | Y | |
| SPPA | Y | Y | Y | Y | Y | Y |

| Species Code | Inlet | East End | Town East Reach | Pier | Town West Reach | West Area |
|---|---|---|---|---|---|---|
| SPVI | Y | | | | | |
| STHE | | Y | Y | Y | Y | Y |
| TRPU | Y | | | | | |
| UNPA | Y | Y | Y | Y | Y | Y |
| YUAL | | Y | Y | Y | | Y |

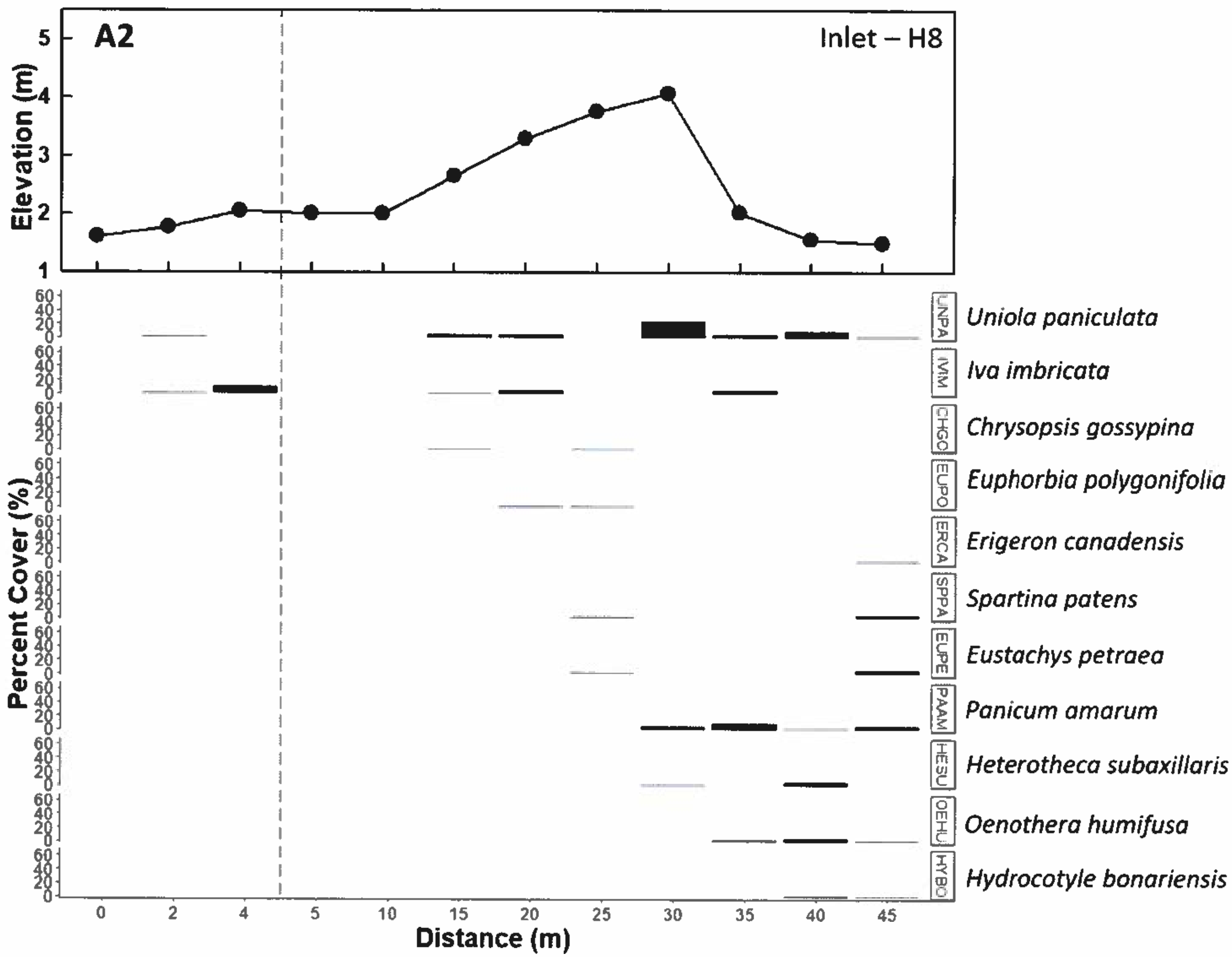
**[Continued on Next Page]**

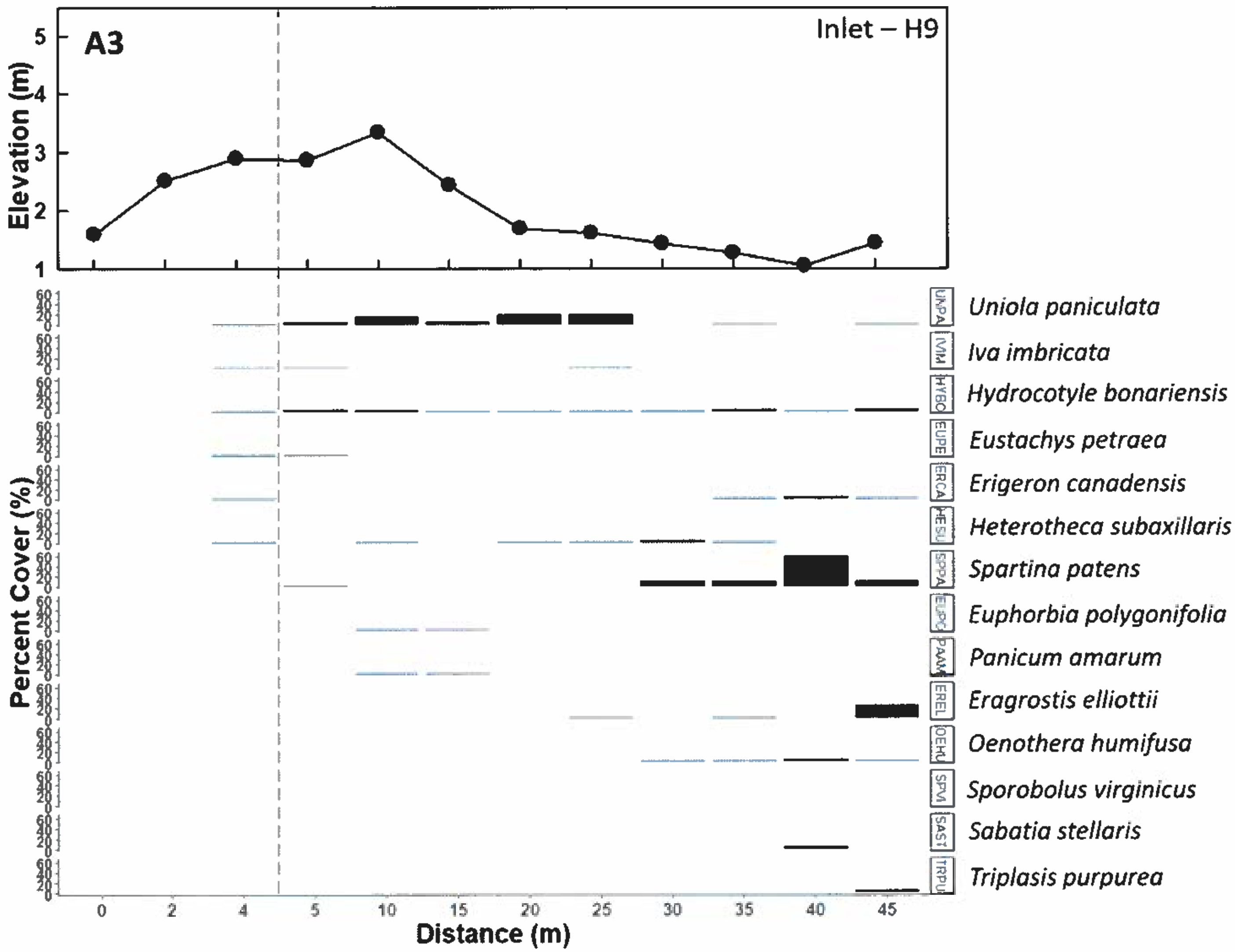
**Figures A1 – A18**. For each set of the following figures, the top panel displays elevation at each plot point along each transect for each of the sampled zones (Inlet, East End, Town East Reach, Pier, West Area, and Town West Reach). The bottom panel for each set shows percent cover of vegetation species which were detected within each plot. Species codes are defined in Table 1 and full Latin names are provided for each species for clarity. At 5 m distance, plots are evenly spaced every 5 m, the start of which is represented by the dashed line. Elevation data are missing for Figure A6 at 30 m.

**[Continued on Next Page]**

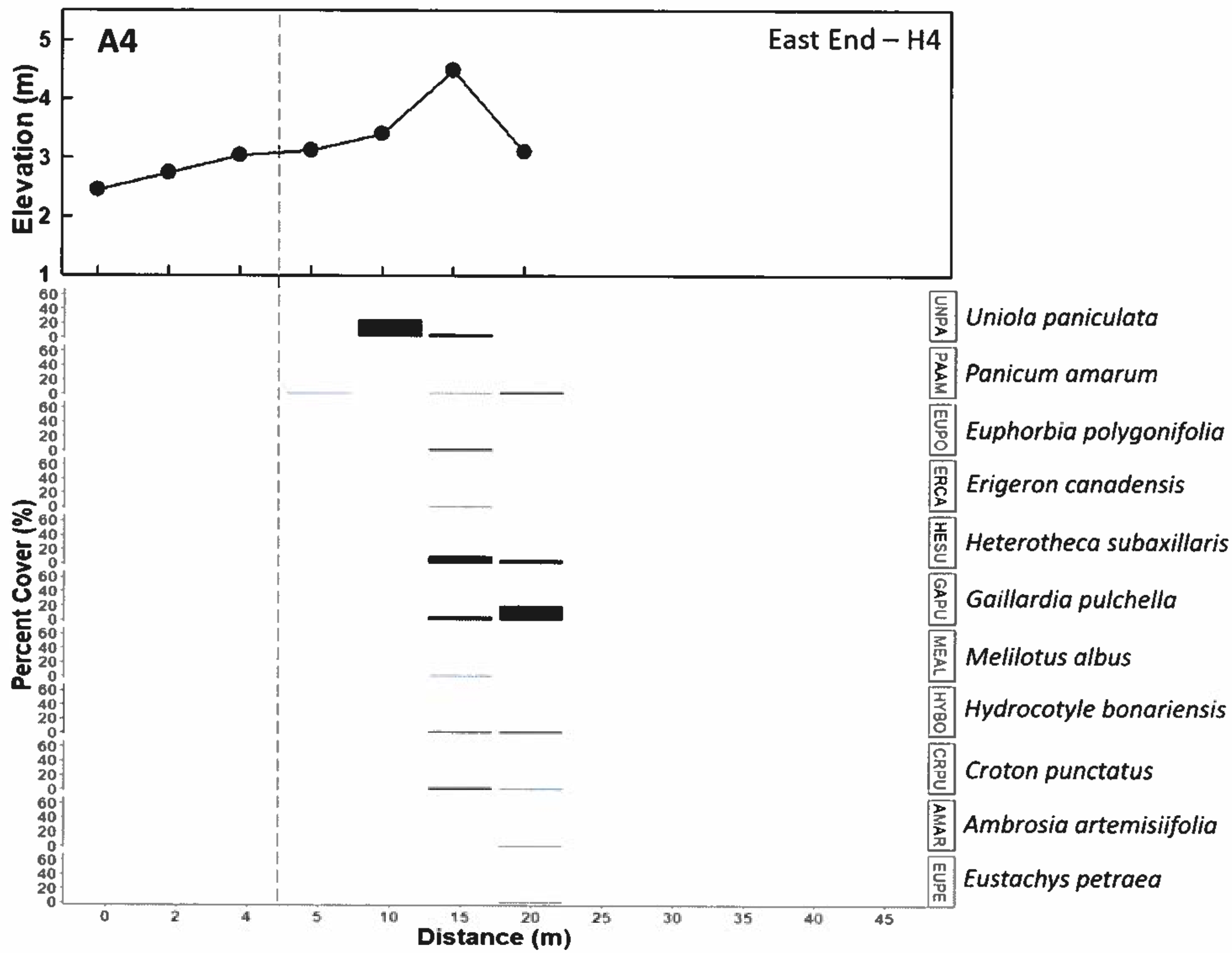


Inlet
A1
Inlet – H7
Elevation (m)
Percent Cover (%)
Distance (m)
0 2 4 5 10 15 20 25 30 35 40 45
UNPA
CHGO
IVIM
HESU
EUPO
ERCA
Uniola paniculata
Chrysopsis gossypina
Iva imbricata
Heterotheca subaxillaris
Euphorbia polygonifolia
Erigeron canadensis

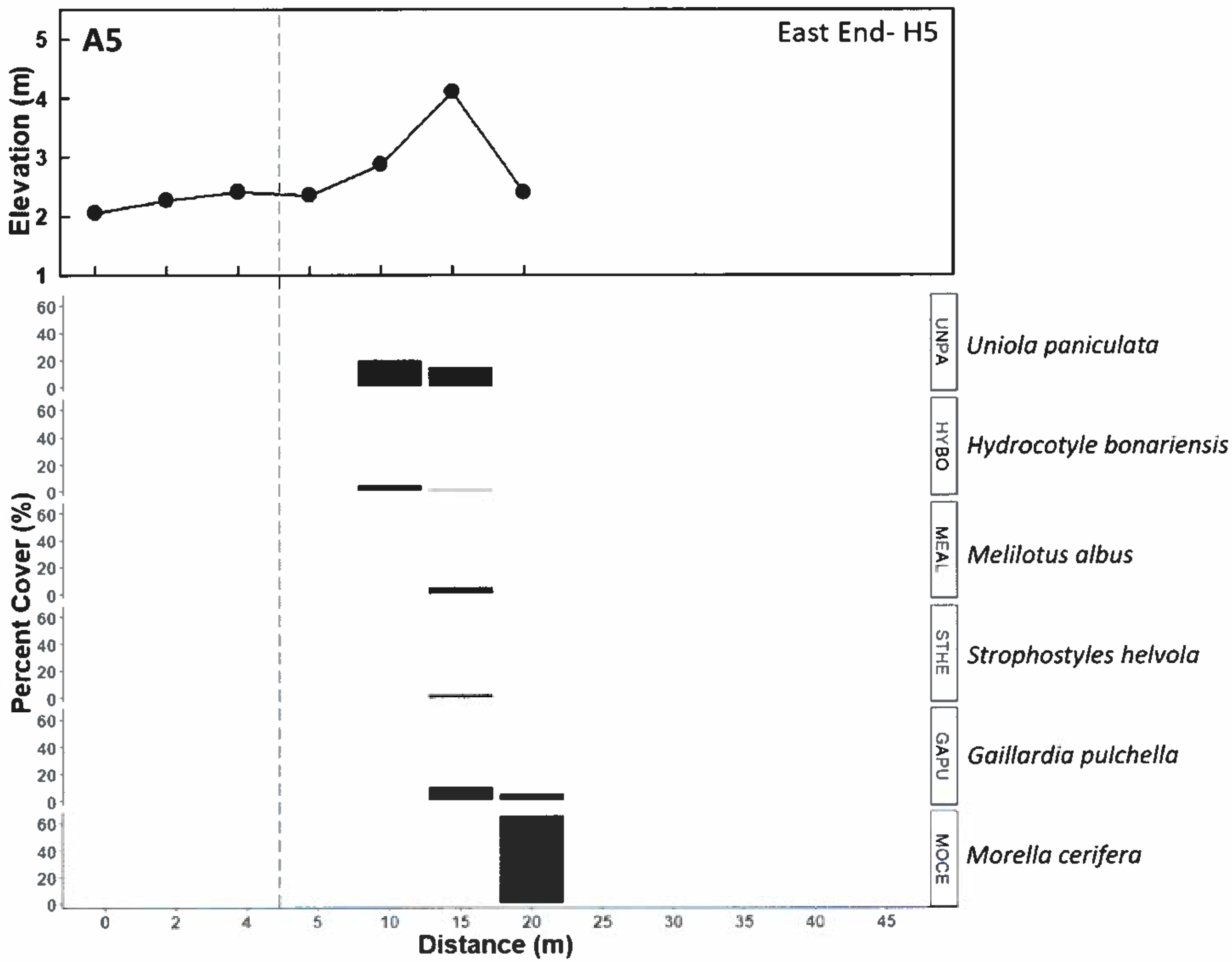

A2
Inlet – H8
Elevation (m)
Percent Cover (%)
Distance (m)
UNPA
IVIM
CHGO
EUPO
ERCA
SPPA
EUPE
PAAM
HESU
OEHU
HYBO
Uniola paniculata
Iva imbricata
Chrysopsis gossypina
Euphorbia polygonifolia
Erigeron canadensis
Spartina patens
Eustachys petraea
Panicum amarum
Heterotheca subaxillaris
Oenothera humifusa
Hydrocotyle bonariensis


A3
Inlet – H9
Elevation (m)
5
4
3
2
1
Percent Cover (%)
60
40
20
0
UNPA
IVIM
HYBO
EUPE
ERCA
HESU
SPPA
EUPO
PAAM
EREL
OEHU
SPVI
SAST
TRPU
Uniola paniculata
Iva imbricata
Hydrocotyle bonariensis
Eustachys petraea
Erigeron canadensis
Heterotheca subaxillaris
Spartina patens
Euphorbia polygonifolia
Panicum amarum
Eragrostis elliottii
Oenothera humifusa
Sporobolus virginicus
Sabatia stellaris
Triplasis purpurea
0
2
4
5
10
15
20
25
30
35
40
45
Distance (m)

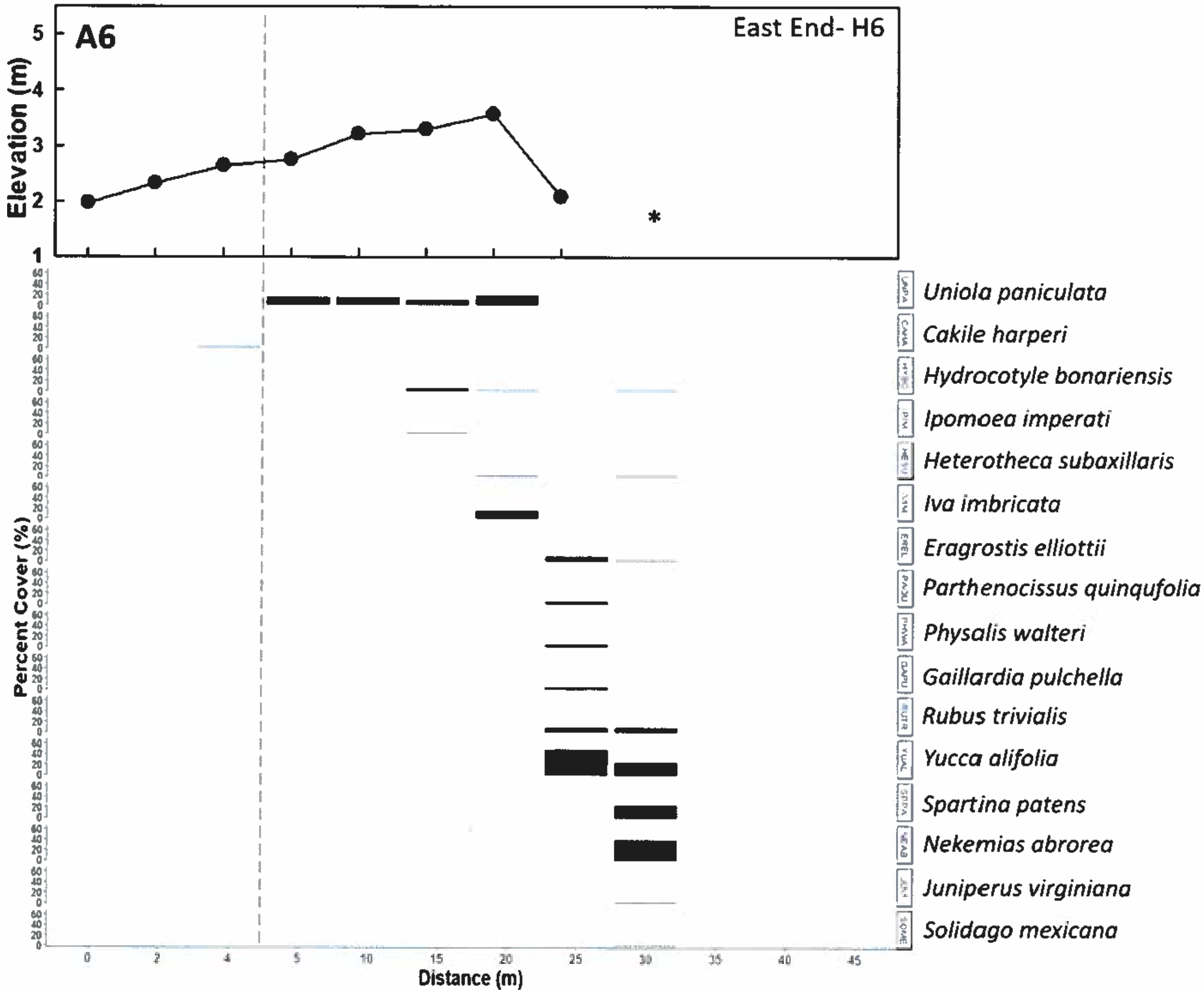
## East End



A4
East End – H4
Elevation (m)
Percent Cover (%)
Distance (m)
UNPA
PAAM
EUPO
ERCA
HESU
GAPU
MEAL
HYBO
CRPU
AMAR
EUPE
Uniola paniculata
Panicum amarum
Euphorbia polygonifolia
Erigeron canadensis
Heterotheca subaxillaris
Gaillardia pulchella
Melilotus albus
Hydrocotyle bonariensis
Croton punctatus
Ambrosia artemisiifolia
Eustachys petraea

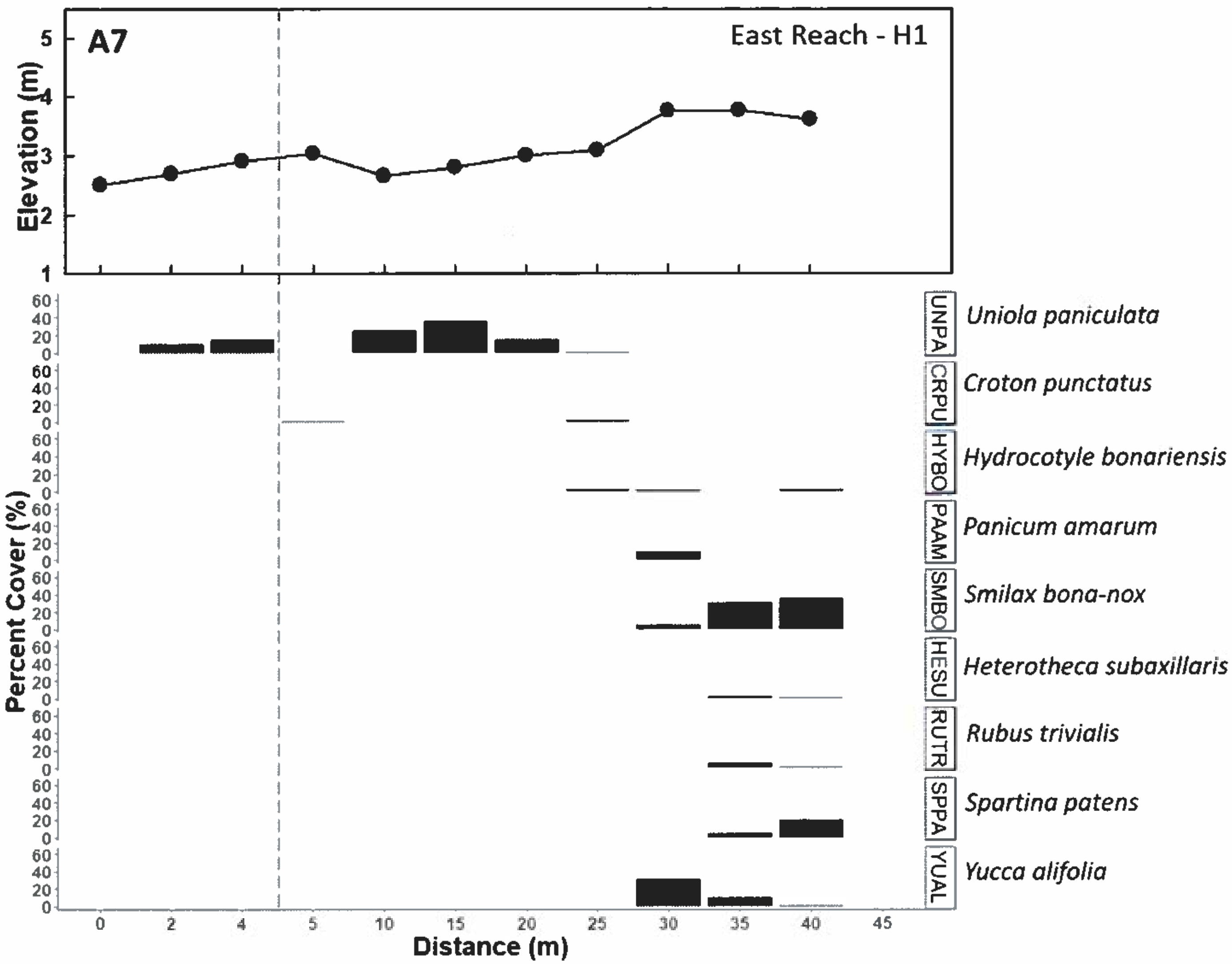


A5
East End- H5
Elevation (m)
5
4
3
2
1
Percent Cover (%)
60
40
20
0
UNPA
HYBO
MEAL
STHE
GAPU
MOCE
Uniola paniculata
Hydrocotyle bonariensis
Melilotus albus
Strophostyles helvola
Gaillardia pulchella
Morella cerifera
0
2
4
5
10
15
20
25
30
35
40
45
Distance (m)

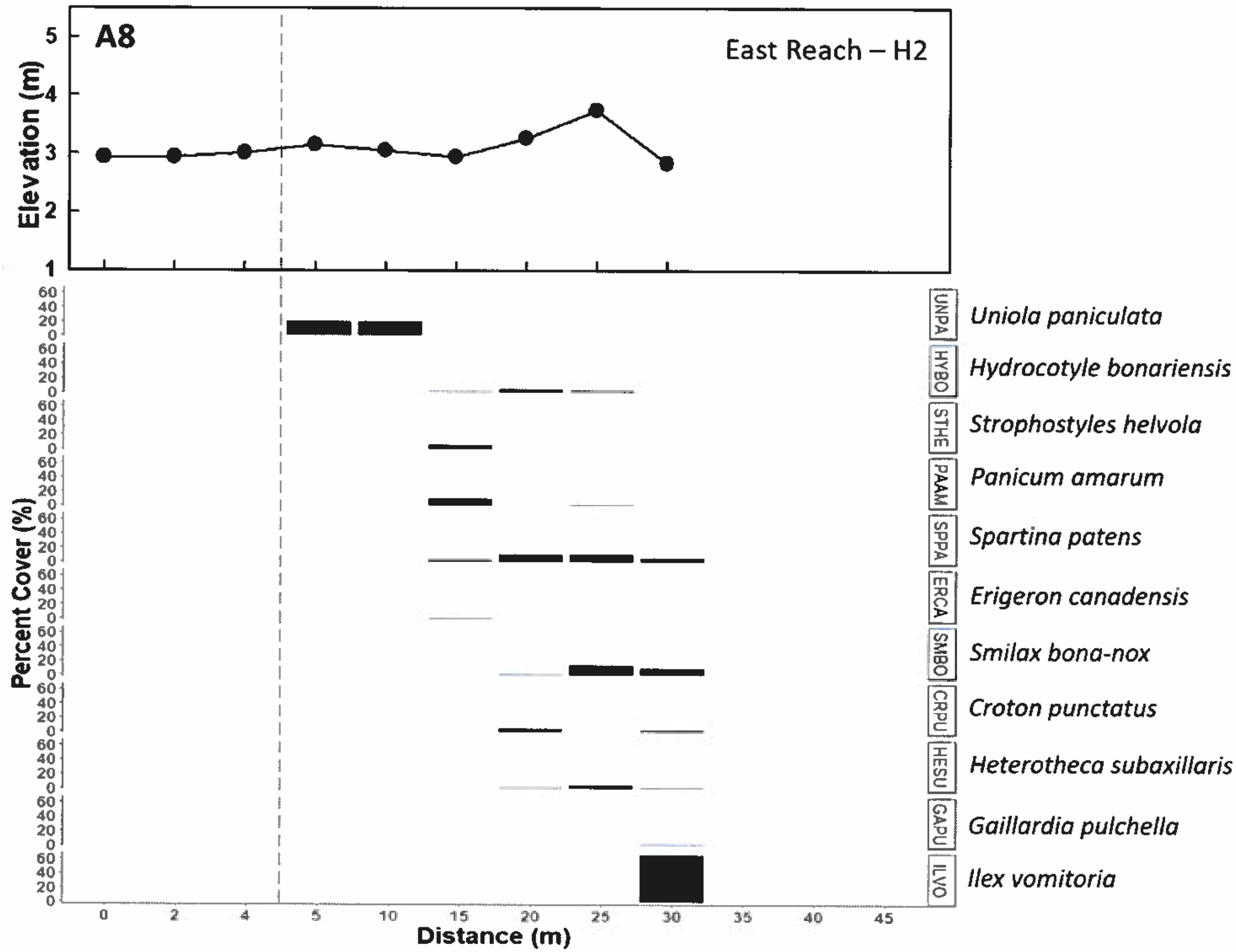


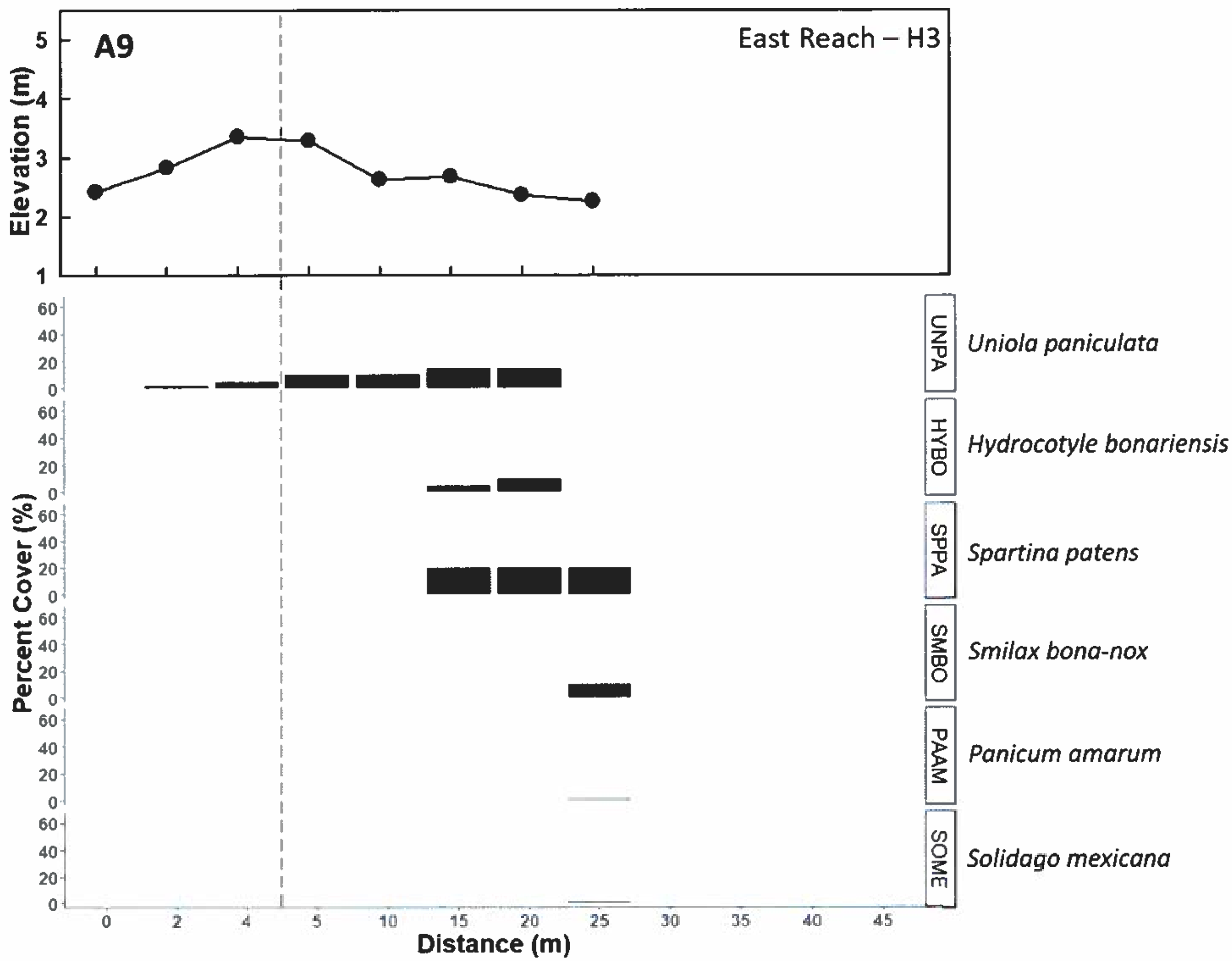
A6
East End- H6
Elevation (m)
Percent Cover (%)
Distance (m)
Uniola paniculata
Cakile harperi
Hydrocotyle bonariensis
Ipomoea imperati
Heterotheca subaxillaris
Iva imbricata
Eragrostis elliottii
Parthenocissus quinqufolia
Physalis walteri
Gaillardia pulchella
Rubus trivialis
Yucca alifolia
Spartina patens
Nekemias abrorea
Juniperus virginiana
Solidago mexicana

## East Reach

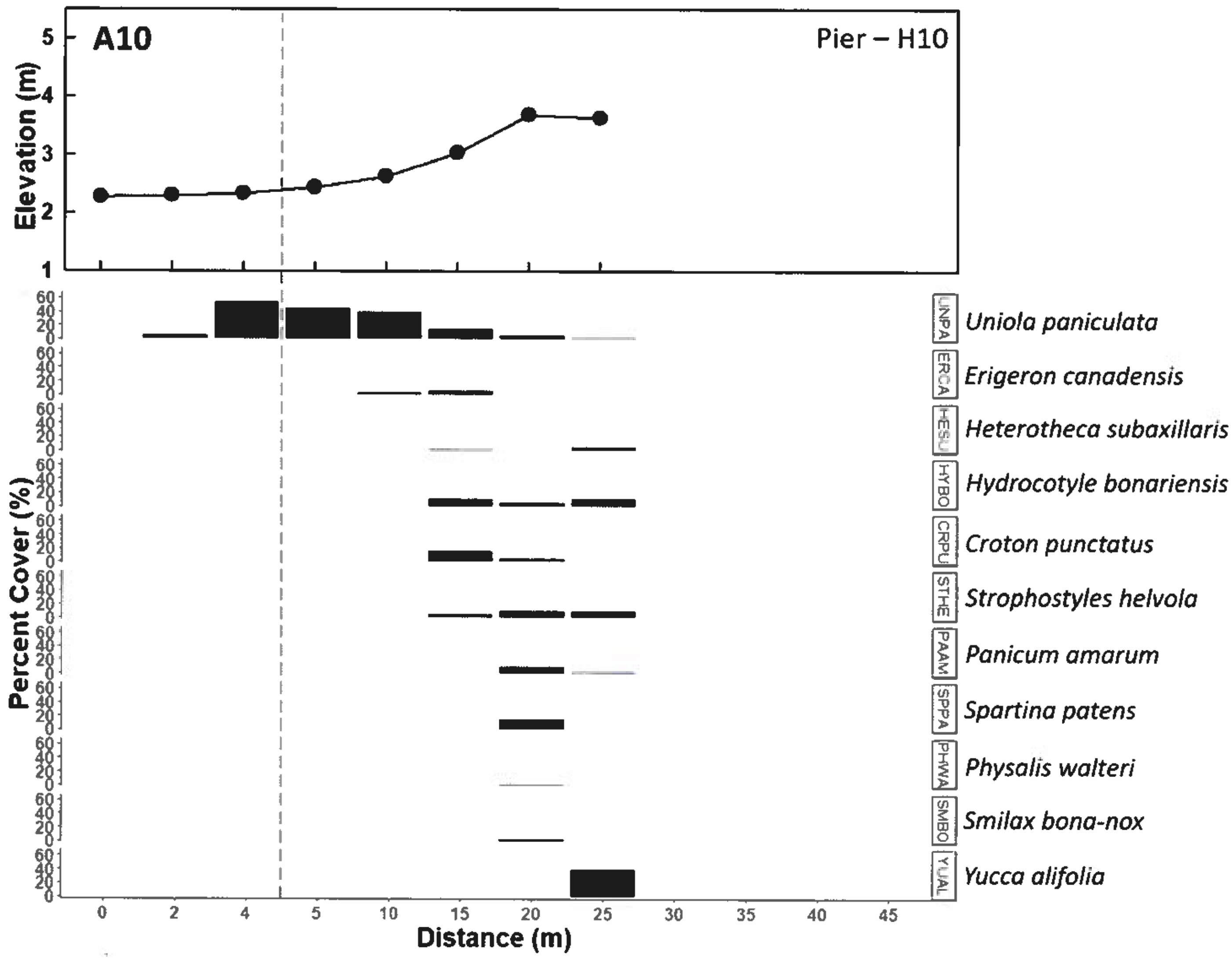


A7
East Reach - H1
Elevation (m)
Percent Cover (%)
Distance (m)
UNPA
CRPU
HYBO
PAAM
SMBO
HESU
RUTR
SPPA
YUAL
Uniola paniculata
Croton punctatus
Hydrocotyle bonariensis
Panicum amarum
Smilax bona-nox
Heterotheca subaxillaris
Rubus trivialis
Spartina patens
Yucca alifolia

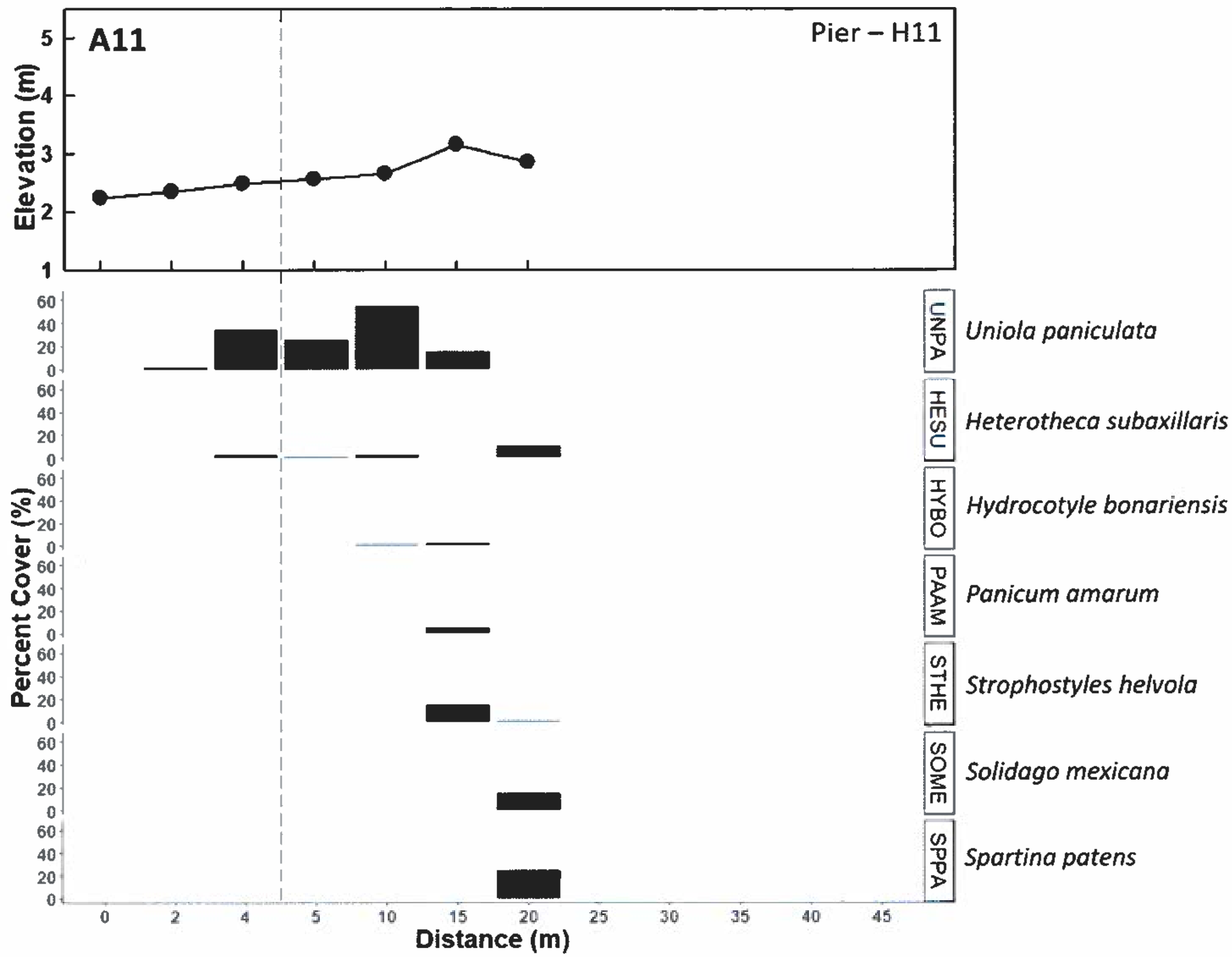

A8
East Reach – H2
Elevation (m)
Percent Cover (%)
Distance (m)
UNPA
HYBO
STHE
PAAM
SPPA
ERCA
SMBO
CRPU
HESU
GAPU
ILVO
Uniola paniculata
Hydrocotyle bonariensis
Strophostyles helvola
Panicum amarum
Spartina patens
Erigeron canadensis
Smilax bona-nox
Croton punctatus
Heterotheca subaxillaris
Gaillardia pulchella
Ilex vomitoria

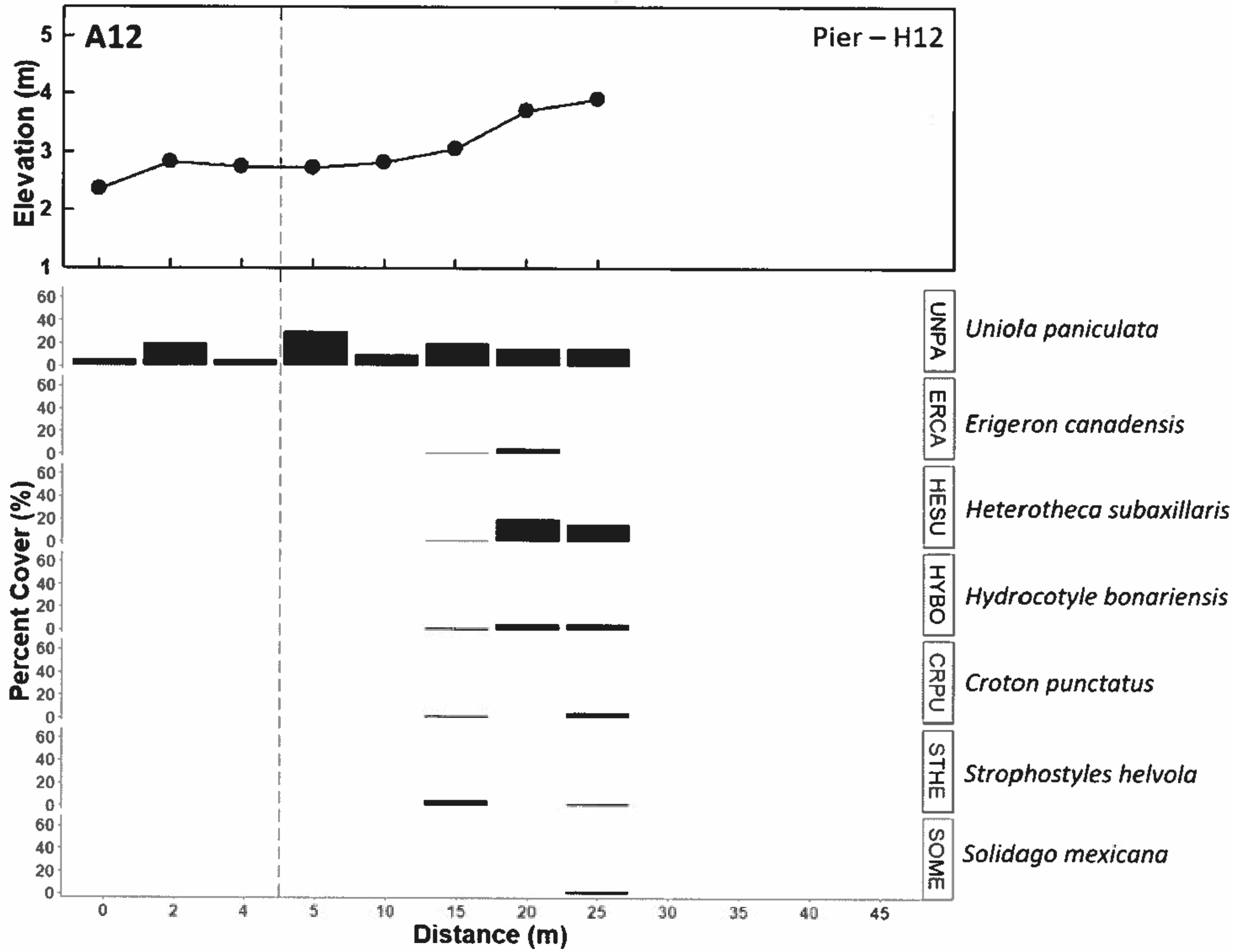

A9
East Reach – H3
Elevation (m)
Percent Cover (%)
UNPA
HYBO
SPPA
SMBO
PAAM
SOME
Uniola paniculata
Hydrocotyle bonariensis
Spartina patens
Smilax bona-nox
Panicum amarum
Solidago mexicana
Distance (m)

## Pier

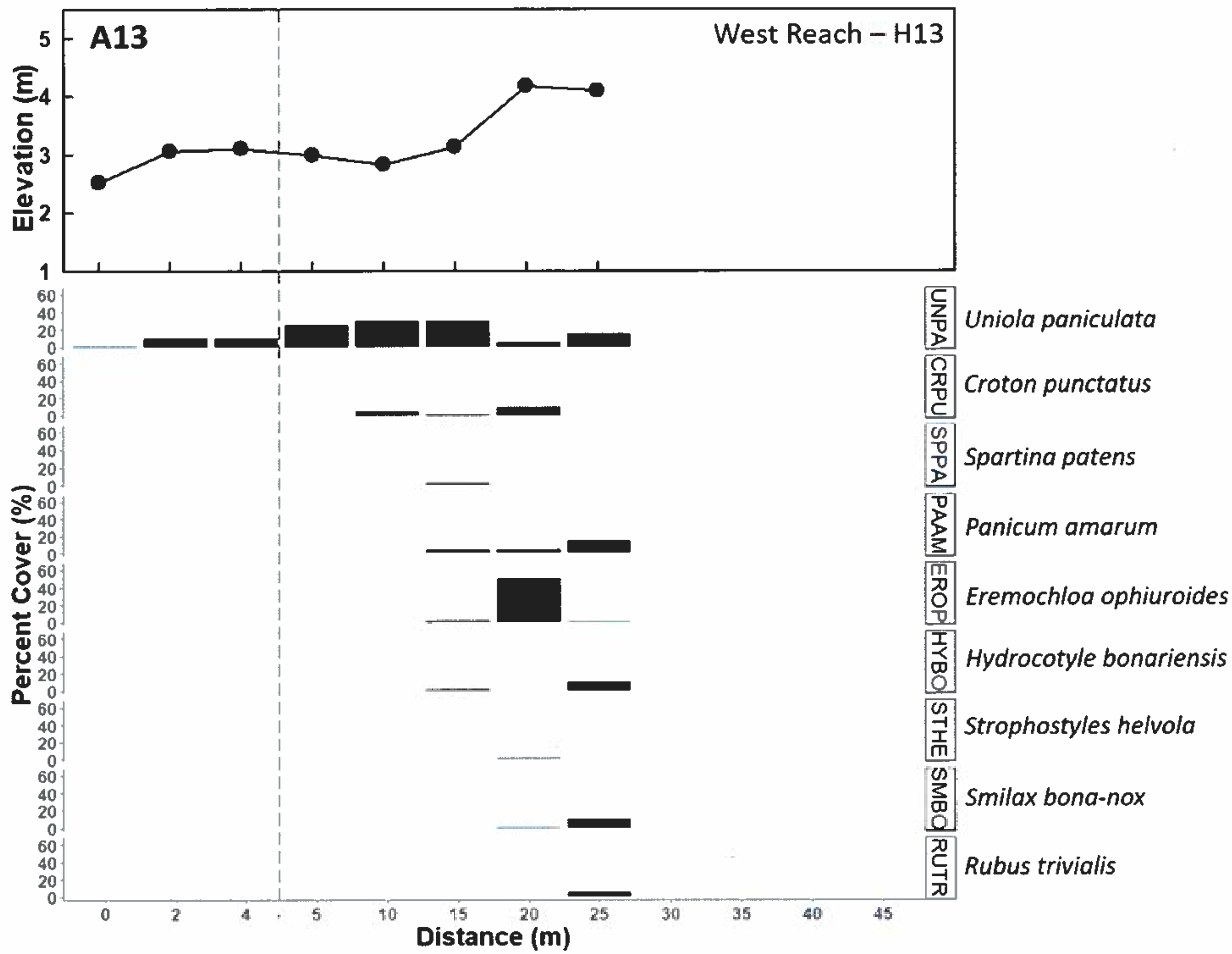


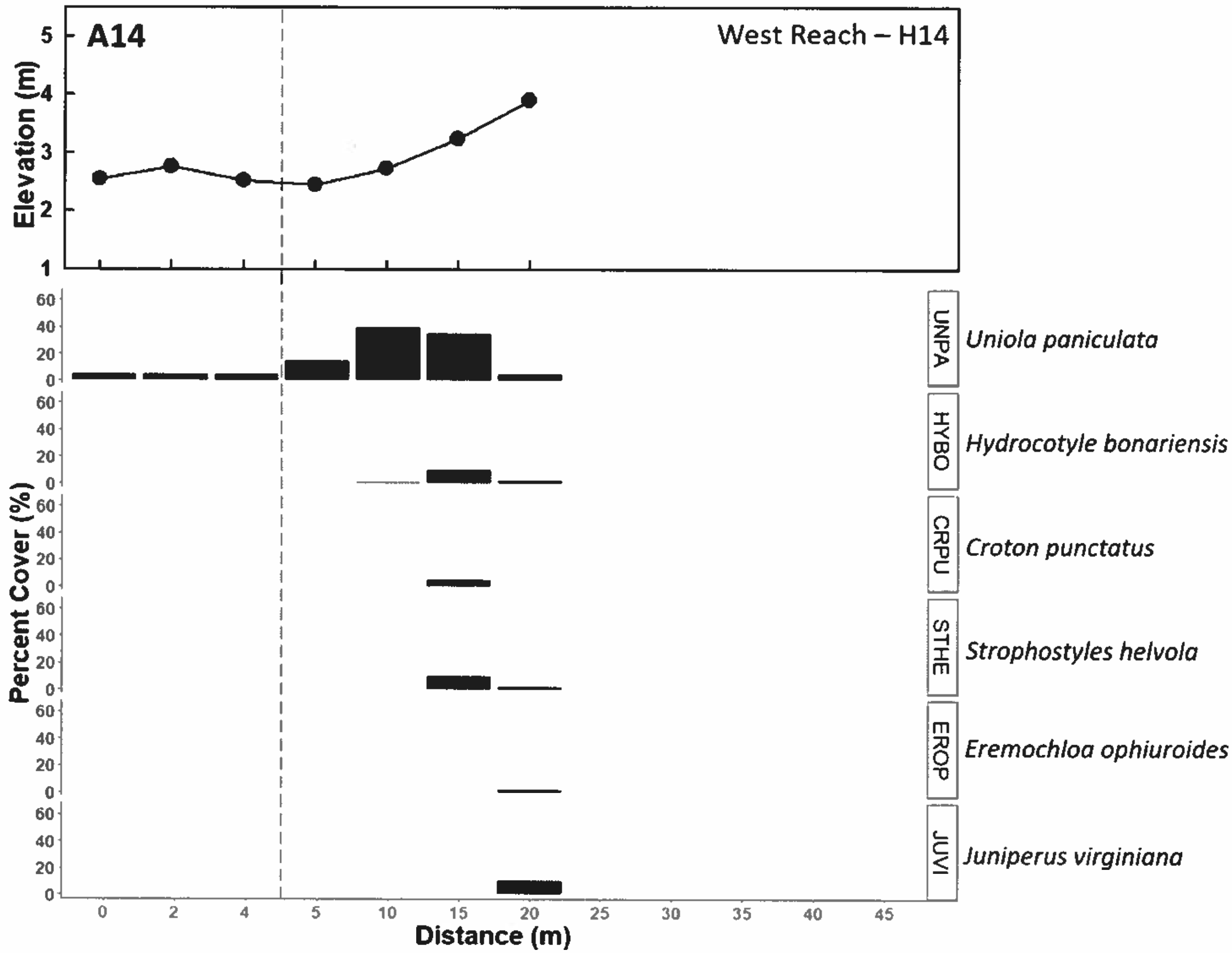
A10
Pier – H10
Elevation (m)
Percent Cover (%)
Distance (m)
UNPA Uniola paniculata
ERCA Erigeron canadensis
HESU Heterotheca subaxillaris
HYBO Hydrocotyle bonariensis
CRPU Croton punctatus
STHE Strophostyles helvola
PAAM Panicum amarum
SPPA Spartina patens
PHWA Physalis walteri
SMBO Smilax bona-nox
YUAL Yucca alifolia


A11
Pier – H11
Elevation (m)
5
4
3
2
1
Percent Cover (%)
60
40
20
0
UNPA
HESU
HYBO
PAAM
STHE
SOME
SPPA
Uniola paniculata
Heterotheca subaxillaris
Hydrocotyle bonariensis
Panicum amarum
Strophostyles helvola
Solidago mexicana
Spartina patens
0
2
4
5
10
15
20
25
30
35
40
45
Distance (m)

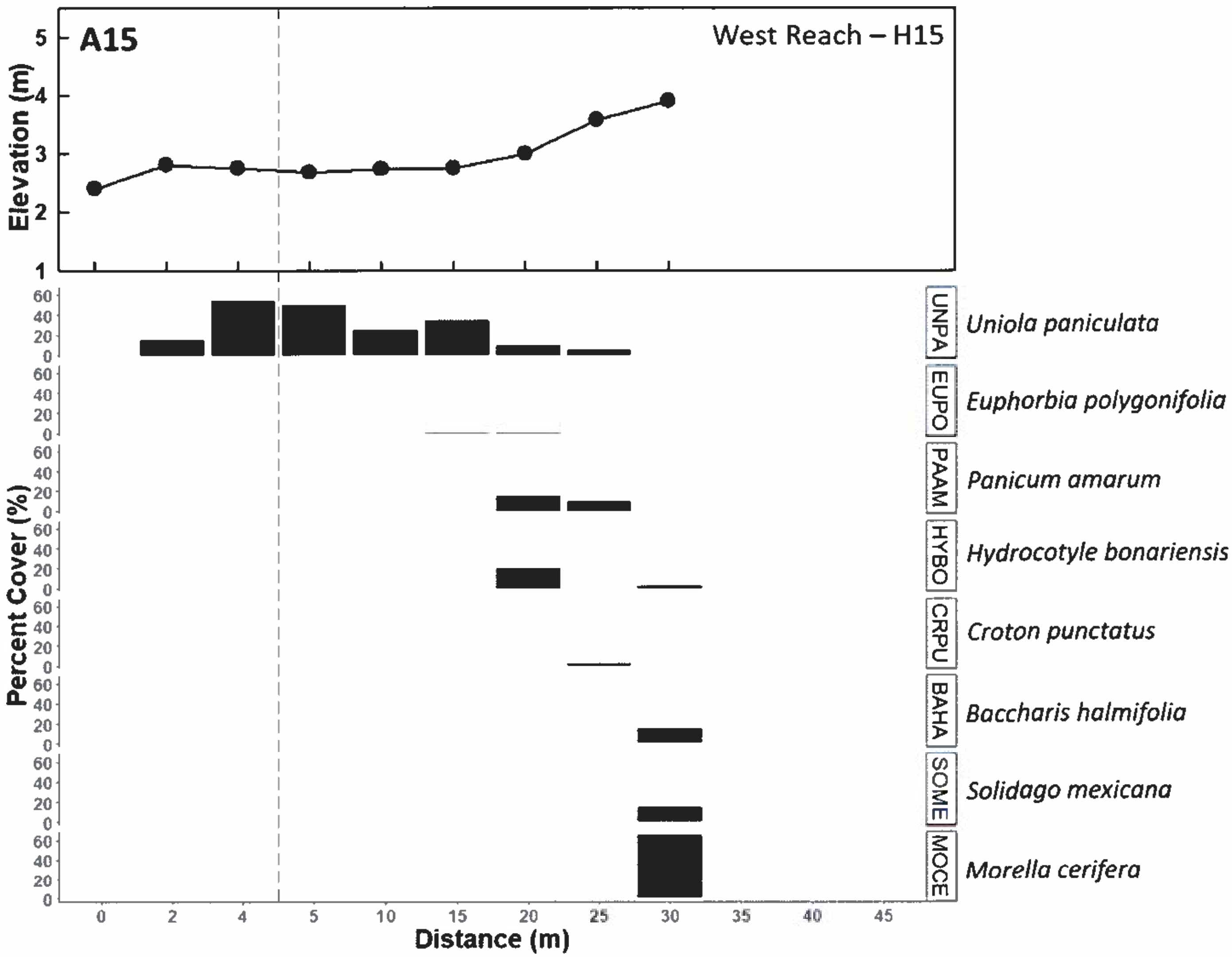

A12
Pier – H12
Elevation (m)
Percent Cover (%)
Distance (m)
UNPA
ERCA
HESU
HYBO
CRPU
STHE
SOME
Uniola paniculata
Erigeron canadensis
Heterotheca subaxillaris
Hydrocotyle bonariensis
Croton punctatus
Strophostyles helvola
Solidago mexicana

## West Reach

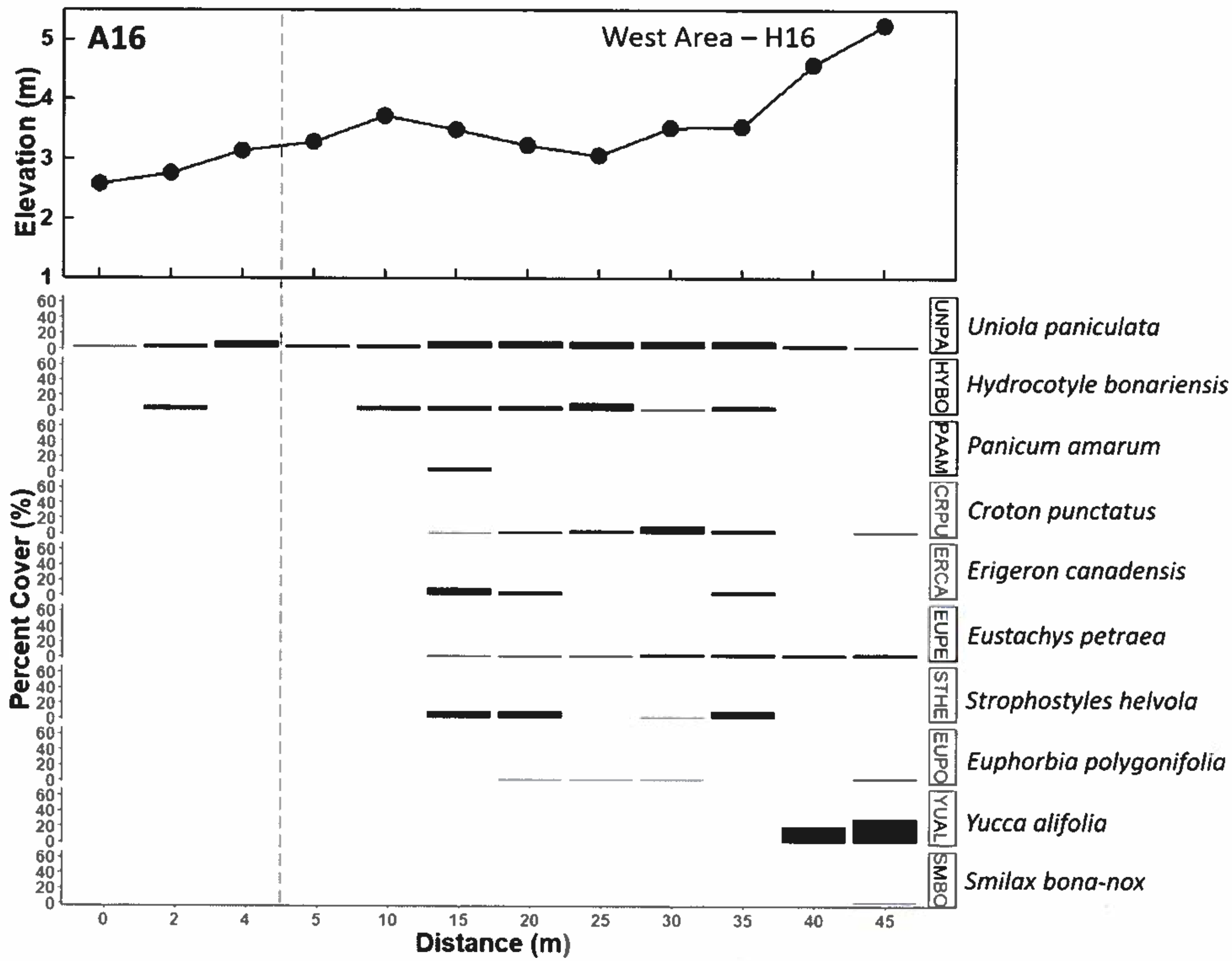

A13
West Reach – H13
Elevation (m)
5
4
3
2
1
Percent Cover (%)
60
40
20
0
UNPA
CRPU
SPPA
PAAM
EROP
HYBO
STHE
SMBO
RUTR
Uniola paniculata
Croton punctatus
Spartina patens
Panicum amarum
Eremochloa ophiuroides
Hydrocotyle bonariensis
Strophostyles helvola
Smilax bona-nox
Rubus trivialis
0
2
4
5
10
15
20
25
30
35
40
45
Distance (m)



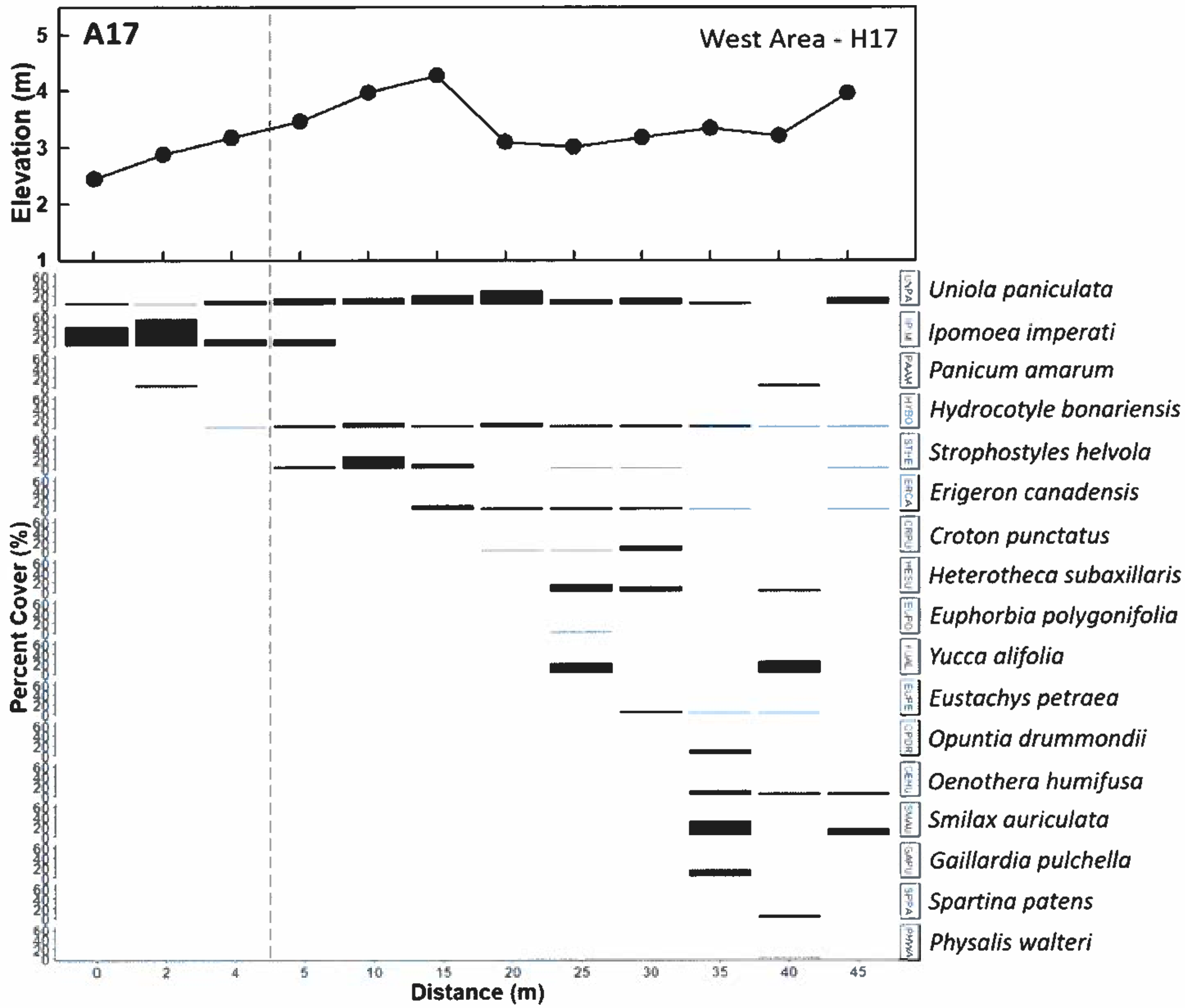
A14
West Reach – H14
Elevation (m)
5
4
3
2
1
Percent Cover (%)
60
40
20
0
UNPA
HYBO
CRPU
STHE
EROP
JUVI
Uniola paniculata
Hydrocotyle bonariensis
Croton punctatus
Strophostyles helvola
Eremochloa ophiuroides
Juniperus virginiana
0
2
4
5
10
15
20
25
30
35
40
45
Distance (m)

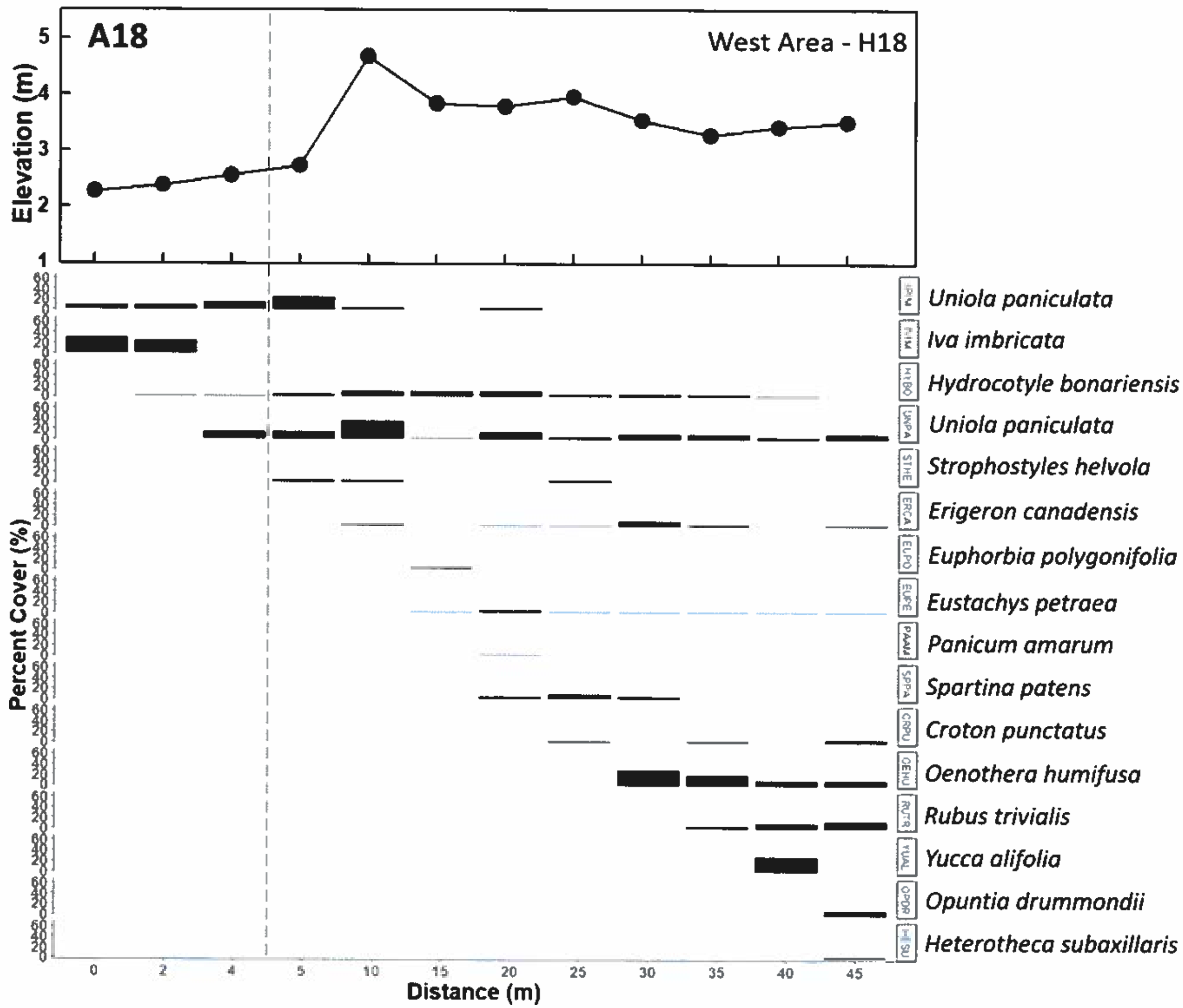

A15
West Reach – H15
Elevation (m)
Percent Cover (%)
Distance (m)
UNPA
EUPO
PAAM
HYBO
CRPU
BAHA
SOME
MOCE
Uniola paniculata
Euphorbia polygonifolia
Panicum amarum
Hydrocotyle bonariensis
Croton punctatus
Baccharis halmifolia
Solidago mexicana
Morella cerifera

## West Area



A16
West Area – H16
Elevation (m)
Percent Cover (%)
Distance (m)
UNPA
HYBO
PAAM
CRPU
ERCA
EUPE
STHE
EUPO
YUAL
SMBO
Uniola paniculata
Hydrocotyle bonariensis
Panicum amarum
Croton punctatus
Erigeron canadensis
Eustachys petraea
Strophostyles helvola
Euphorbia polygonifolia
Yucca alifolia
Smilax bona-nox


A17
West Area - H17
Elevation (m)
Percent Cover (%)
Distance (m)
UNPA
IPIM
PAAM
HYBO
STHE
ERCA
CRPU
HESU
EUPO
YUAL
EUPE
OPDR
OEHU
SMAU
GAPU
SPPA
PHWA
Uniola paniculata
Ipomoea imperati
Panicum amarum
Hydrocotyle bonariensis
Strophostyles helvola
Erigeron canadensis
Croton punctatus
Heterotheca subaxillaris
Euphorbia polygonifolia
Yucca alifolia
Eustachys petraea
Opuntia drummondii
Oenothera humifusa
Smilax auriculata
Gaillardia pulchella
Spartina patens
Physalis walteri



A18
West Area - H18
Elevation (m)
Percent Cover (%)
Distance (m)
Uniola paniculata
Iva imbricata
Hydrocotyle bonariensis
Uniola paniculata
Strophostyles helvola
Erigeron canadensis
Euphorbia polygonifolia
Eustachys petraea
Panicum amarum
Spartina patens
Croton punctatus
Oenothera humifusa
Rubus trivialis
Yucca alifolia
Opuntia drummondii
Heterotheca subaxillaris