Mustang and North Padre Island
Beach Maintenance Impacts and Recommendations for Best Management Practices



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Executive Summary

This study was conducted by the Harte Research Institute for Gulf of Mexico Studies under the Coastal Erosion Planning and Response Act (CEPRA) administered by the Texas General Land Office. The goal of the study was to determine potential impacts of beach maintenance practices to beach and dune morphology and vegetation cover and diversity on Mustang and North Padre Islands. For the purposes of this study, beach maintenance refers more specifically to the mechanical removal of trash and seaweed and movement of sand for the purposes of enhanced aesthetics and shore access and the placement of this material offsite or on the backshore or foredune environments.

Methods and frequency of beach maintenance varies across the study area and is performed by three entities: Nueces County, the City of Corpus Christi, and the City of Port Aransas. The relative level of maintenance was determined through field visits, personal communication with parks and recreation departments, and using available reports and beach maintenance plans. HRI utilized field surveys and Geographical Information Systems to derive and analyze data for this project. Data collected include beach and dune topography, vegetation species and cover, dune volume, shoreline and vegetation line position, and storm susceptibility.

Analysis of beach topographic surveys shows that beach maintenance is altering beach slope and beach width in some areas. Analysis of historical shoreline and vegetation line positions also indicated changes to beach width in areas of high maintenance, particularly where the shoreline has progressed seaward compared to the location of the vegetation line. Results from the vegetation survey show that stressors to dune vegetation can come from various sources. Areas of high maintenance correspond to lower species diversity and evenness values, while observations of vegetation cover showed inconsistent results among high maintenance areas. High traffic and high use areas correspond to sections of beach most frequently maintained for access purposes, which may also impact dune vegetation cover. Lastly, foredune volume change, similar to change in beach width, shows a high variability in highly disturbed areas. Although high maintenance areas experienced a large volume change since 2005, there is also high volume loss after an erosion event such as Tropical Storm Don in 2011.

Recommendations include support of public education regarding the role of *Sargassum* in the beach environment and ecosystem services of beaches and dunes and to continue studies of dune habitat. For future studies of the impacts of beach maintenance on dune morphology, an experimental design which looks at changes to an area previously maintained is recommended. It is encouraged that adaptive

beach maintenance and management plans are updated as needed and incorporate up-to-date information from beach monitoring and research results.

Introduction

FIGURE 1. BEACH WRACK ALONG TIDELINE ON MUSTANG ISLAND

The beach and dune environments of the Texas coast are a unique ecological system influenced by both marine and terrestrial processes. These environments provide a number of ecosystem services including habitat for various species, disturbance regulation against the impacts of tropical storm waves, and a wide range of recreational opportunities. As a way to provide better access and a safe beach experience, many communities conduct beach maintenance activities which can include litter removal, raking or grooming of the beach for clearing of wrack and seaweed, and smoothing of the sand surface for improved driving conditions. This study seeks to gain a better understanding of the potential impact of varying levels of beach maintenance on Mustang and North Padre Island; in particular its impacts to the beach and dune morphology, sediment distribution, location of the vegetation line, and impacts to the abundance and diversity of vegetation on coastal foredunes.

Project Goals and Objectives

The goal of this project is to provide information to improve beach maintenance practices while keeping the natural protective function of the beach and dune system. Project objectives are to:

- Identify the effects of beach maintenance practices on beach and dune morphology as well as dune vegetation cover and diversity as they pertain to beach and dune stability;
- Discuss any prior erosion response work, including a listing of any known erosion response studies and investigations in the vicinity of the proposed project, and whether the proposed project compliments existing erosion response measures;
- Identify the effects of beach maintenance practices and the implications they may have on coastal management goals including Erosion Response Plans;
- Identify impacts that beach maintenance has on the position of the legal boundary of the public beach, if any, and;

- Analyze beach and dune morphology to determine the storm surge protection benefit of a particular site.

Beach Maintenance and *Sargassum*

§§61.062 of the Texas Natural Resources Code states that because it is State policy for the public to have “free and unrestricted right of ingress and egress to and from the state-owned beaches bordering on the seaward shore of the Gulf of Mexico”, the state has the responsibility to assist local governments in the cleaning of beaches which are subject to the access rights of the public. Further, §§61.063 clarifies that "clean and maintain" refers to the collection and removal of litter and debris and the supervision and elimination of sanitary and safety conditions that would pose a threat to personal health or safety if not removed or otherwise corrected, and includes the employment of lifeguards, beach patrols, and litter patrols. Observance of beach maintenance activities, and reference to beach maintenance in this study, refers more specifically to the mechanical removal of trash and seaweed and movement of sand for the purpose of enhanced beach access and the placement of this material offsite or on the backshore or foredune environment. On Mustang and North Padre Island, beach maintenance is performed by local governments including the City of Corpus Christi, the City of Port Aransas, and Nueces County.

FIGURE 2. *SARGASSUM* AT THE TIDELINE ON MUSTANG ISLAND, TEXAS.

One of the most common beach maintenance activities is the removal of Gulf Seaweed or *Sargassum*. *Sargassum* is a brown alga from the Sargasso Sea, which normally lives attached as an intertidal, shallow subtidal macrophyte (Britton and Morton 1989). Storm waves can dislodge this macrophyte and cast it afloat where it continues to grow and aggregate with other seaweed clumps as it travels with winds and currents until it is deposited, predominantly at the tide lines of numerous beaches along the Caribbean and the Gulf of Mexico (Figure 2). *Sargassum* can be unsightly and can release a foul odor as it begins to decompose on beaches. Further, beach-cast *Sargassum* can pose a health and safety risk if trash caught within the seaweed contains sharp objects or other hazardous materials. Because of

Figure 3. Removal of *Sargassum* from the beach (top) and deposition at dune toe (bottom) in City of Port Aransas. *Sargassum* removal techniques and equipment vary among jurisdictions.

this, coastal managers are faced with the decision to remove seaweed as part of their beach maintenance efforts or to leave it in place (A. Williams, Feagin, and Stafford 2008). If removed, seaweed is raked or scraped from the beach and deposited offsite or may be pushed up toward the dunes (Figure 3). Heavy machinery is frequently used.

Impacts of Beach Raking and Sargassum Removal

Studies on environmental impacts of beach maintenance, also referred to in the literature as "beach raking," "beach scraping," or "beach grooming," to beaches and dunes are few, and long-term studies are even fewer. In some areas beach scraping is not only a means to remove seaweed and wrack, but can also be used to build the height and width of dunes as a method of dune reinforcement (Wells and McNinch 1991), or to remove or flatten loose sand to improve driving.

Some studies focus on the biological effects of *Sargassum* removal. A study by Dugan et al (2003) suggested that there are significant differences in macrofauna community structure in beach-cast wrack between groomed and ungroomed beaches, which reduced prey available for shorebirds. A different study by Smith, Harrison, and Rowland (2011) did not find a significant difference in beach infauna in scraped and control areas, yet they found that the community varied more than expected during the sampling periods and infauna communities recovered quickly after a disturbance. A study at the Padre Island National Seashore found that benthic microfauna and macrofauna within wrack material was affected by mechanical raking with the highest impact observed three days following a raking event (Engelhard and Withers 1997). After 14 days, there was no observed difference in raked and unraked sites, similar to the results of Smith, Harrison, and Rowland (2011).

Observation of avian species by HDR Engineering Inc. (2013a; 2013b) in Corpus Christi and Port Aransas did not find a statistically significant difference in raked and unraked areas. The authors mention that there is not a clear correlation between *Sargassum* volume and bird use; this is likely due to the fact that maintained beaches also face more vehicular and pedestrian traffic and other beach-use related disruptions. A study of avian species in Galveston Island had similar results; there was not a clear correlation between *Sargassum* on the beach and the number of birds using the beach (A. Williams, Feagin, and Stafford 2008).

FIGURE 4. AEOLIAN SAND DEPOSITION ON *SARGASSUM* WRACK AT MUSTANG ISLAND STATE PARK.

A few studies focus on the impacts to dune and beach vegetation. Dugan and Hubbard (2010) found that groomed beaches have wider unvegetated areas and lower native plant abundance and richness compared to ungroomed beaches. Other disruptions, like trampling of vegetation by pedestrians (Grunewald and Schubert 2007) and driving on the beach and backshore (Houser et al. 2013; McAtee and Drawe 1981), also impact species composition. The loss of vegetation and removal or pulverization of *Sargassum* due to mechanical removal or beach driving may disrupt the process of sediment transport and deposition (Lancaster and Baas 1998; Karl F Nordstrom et al. 2011), which may result in a reduction of backshore and dune-base elevation (Houser et al. 2013) and disruption to the development of embryo dunes (K. F Nordstrom et al. 2009; P. Hesp 2002).

Beach scraping has also been found to impact the rate of aeolian sand transport on beaches of North Carolina (Conaway and Wells 2005) and California (Dugan and Hubbard 2010). Increased sand transport may be due to reduced vegetation at the backshore (Dugan and Hubbard 2010), increased availability of dry unconsolidated sediment at the backshore, modification of foredune height and slope (Conaway and Wells 2005), and the reduction in *Sargassum* and wrack which may serve to trap sand (Figure 4) and build the elevation of the backshore (Karl F. Nordstrom, Jackson, and Korotky 2011). Increased transport may promote the formation of blowouts and reduction of vegetation cover due to sand burial.

Studies of the potential impacts of *Sargassum* removal vary in their results and may be due to sampling methods or geographical differences. This study will analyze some of the potential impacts of *Sargassum* removal in the Texas Coastal Bend region.

Study Area

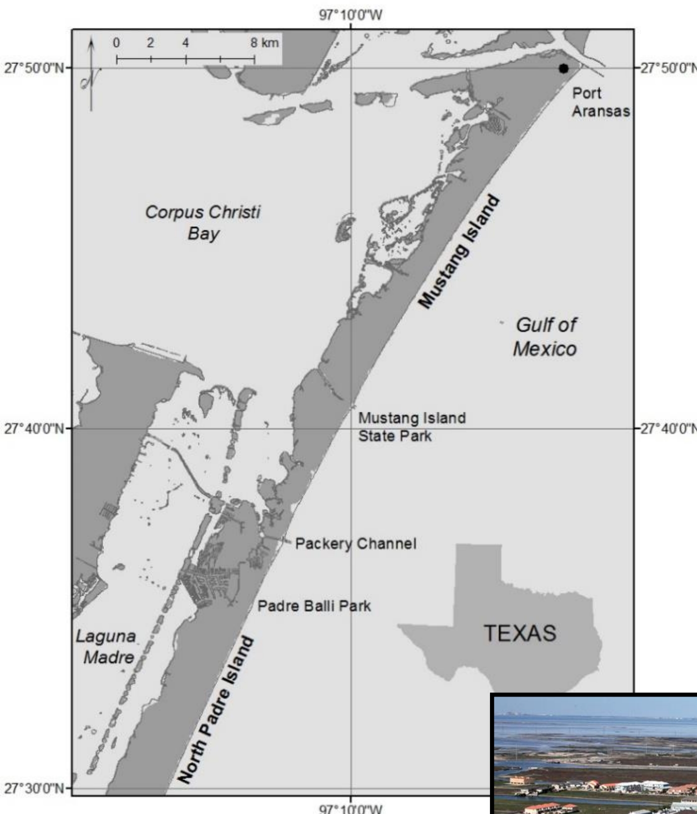

FIGURE 5. STUDY SITE MAP

The study area includes Mustang and the northern portion of North Padre Island, located on the Central Texas Coast (Figure 5) and extends approximately 50 km (~27 mi) south from Aransas Pass. The islands contain a variety of environments including beaches, dunes, vegetated barrier flats, fresh-water marshes and estuarine marshes and wind-tidal flats (Paine, White, and Andrews 2004), providing habitat for a number of species of mammals, birds, and other marine organisms (Britton and Morton 1989) as well as numerous recreational opportunities.

FIGURE 6. BEACH AFTER 2012 NOURISHMENT. PHOTO BY LANMON AERIAL PHOTOGRAPHY INC. AVAILABLE ONLINE AT HTTP://WWW.CBI.TAMUCC.EDU/CHRGIS/NORTH-PADRE-BEACH/

Mustang Island is a high profile, aggradational sandy barrier (Morton 1994), growing vertically in response to abundant sand supply and relative sea level some 4,000 years before present (y.b.p.) (Morton and McGowen 1980). Located on the coastal bend near the center of converging currents (Bullard 1942), historical shoreline changes are minimal as compared to the rest of the Texas coast. Average shoreline change rates from 1930 to 2012 for the study area range from -2.55 to -1.5 m/yr (-8.2 to 4.9 ft) (Paine, Caudle, and Andrews 2014). An area of particular concern is the North Padre Island seawall beach area, just south of Packery Channel. The North Padre Island seawall was constructed in the early 1960's and erosion of the beach limits beach public access in this area (Williams and Kraus 2011). As a result of this, vehicular access is periodically restricted by shore-perpendicular bollards for 305 m (1,000 ft) at the south-end of the seawall. The bollards are removed when the width of the beach from the seawall to mean high tide is greater than 45.7 m (150 ft). As an erosion-response measure, beach nourishment of this section of beach is conducted from sand dredged from Packery Channel. The first beach nourishment was completed between 2005-2006, during the construction of Packery Channel (Williams and Kraus 2011). The second nourishment was completed during the 2012 dredging event (Figure 6).

Barrier morphology can at times be impacted by tropical storms and hurricanes. Hurricane (>= 74 mph) return period for the vicinity of Port Aransas is 16 years and major-hurricane (>=111 mph) return period is 33 years (Blake and Landsea 2011). Major storms in recent history which significantly impacted the area include Hurricanes Celia and Allen. Hurricane Celia (Category 3) in 1970, brought a 2.8 m surge in the vicinity of Port Aransas causing foredune erosion of 45 to 90 m (150-300 ft) on northern Mustang Island (Roth 2000). Hurricane Allen (Category 3) in 1980, brought a 1.5 m surge in the vicinity of Port Aransas and breached the relict tidal inlets of Corpus Christi Pass, Newport Pass, 1852 Pass, and Packery Channel, creating channels up to 2 m in depth (Maynard and Suter 1983). Although Hurricane Ike landed on the upper Texas Coast, the storm tide observed in the study area was close to 1.5 m (NOAA tide station # 8775870, September 12-13, 2008), causing significant dune erosion in the study area.

Foredune system

Dunes are shore parallel features occurring at the backshore, formed through aeolian accumulation of sand deposited among wrack and vegetation (Hesp 2002; Barbour et al, 1985). These geologic features provide habitat to many insect, small mammal, and bird species (Britton and Morton 1989) and also may serve to protect inland development from storm surge if they are of appropriate height (Houser, Hapke, and Hamilton 2008; Stockdon et al. 2007; Taylor et al In-Press).

The foredune complex on Mustang and North Padre Island is generally composed of a large dune ridge fronted by foredune, which is usually lower in height and width. The foredune is the foremost vegetated ridge on the backshore (P. A. Hesp 1991), which may form a continuous dune line or may be broken into smaller hillocks as a result of washover and blowouts. At the seaward edge of the foredune, coppice mounds or an incipient dune platform extends to the edge on the natural line of vegetation. The morphology of incipient dunes or embryo dunes can be affected by the type of vegetation growing at the backshore (Hesp 2002). Vegetation extends seaward across the backshore or may grow from seedlings transported in wrack deposits or by wind. The dune complex in the study area has an average width of 142 m with a standard deviation of ±68 m and average dune heights of 3.4 m (±0.6m), in some areas exceeding 10 m above MSL (Taylor et al 2015).

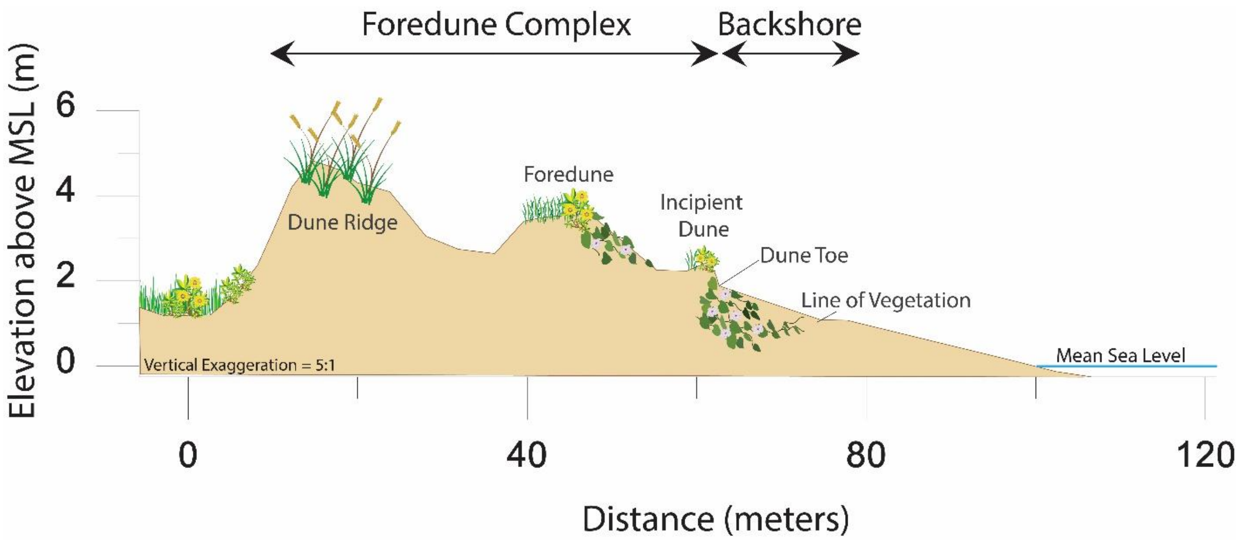

FIGURE 7. FOREDUNE COMPLEX ON A NON-DISTURBED BEACH.

Vegetation

Vegetation varies across the beach and foredune environment. As the distance from the water increases, so does the environmental gradient of wind exposure, salt spray, temperature, soil moisture, soil salinity and nutrients (Barbour, De Jong, and Pavlik 1985; Oosting and Billings 1942). Typically, older dunes have higher diversity in vegetation as they have had more time to establish different plant assemblages (Bitton and Hesp 2013). Environmental gradients and vegetation zonation have been reported for beaches and dunes of North Padre Island (McAtee and Drawe 1981); Typical dune vegetation by zone include:

- Backshore: *Ipomea sp.*, *Amaranthus greggii*, *Sesuvium portulacastrum*
- Foredune: *Ipomea sp.*, *Panicum amarum*, *Croton punctatus*, *Heterotheca subaxillaris*, *Uniola paniculata*
- Backbarrier flats: *Heterotheca subaxillaris*, *Hydrocotyle bonariensis*, *Schizachyrium scoparium*

FIGURE 8. VEGETATION ON MUSTANG ISLAND. BACKSHORE AND INCIPIENT DUNES (LEFT) ARE VEGETATED WITH 2 VARIATIONS OF *IPOMEA* AND COLONIZING SHRUBS LIKE *SESUVIUM* AND *CROTON*. THE DUNE CREST AND DUNE RIDGE (RIGHT) IS VEGETATED WITH SOME SHRUBS (*HETEROTHECA*) AND GRASSES LIKE *PANICCUM* AND *UNIOLA* INTER-DUNE SWALES ARE MOSTLY GRASSY (*SCHIZACHYRIUM*).

Backshore and dune vegetation is exposed to a number of stressors including erosion and development of dune blowouts, trampling by pedestrian or motor traffic (Andersen 1995; McAtee and Drawe 1981), mechanical removal, burial, or other disruptions due to beach maintenance practices (K. F Nordstrom et al. 2009; Dugan and Hubbard 2010). Such disturbance may increase the population of invasive species and cause other ecosystem changes (Espejel et al. 2004).

Beach Maintenance Practices in the Study Area

Beach maintenance in the study area is performed by three different entities: the City of Corpus Christi, the City of Port Aransas, and Nueces County.

City of Corpus Christi

Beach maintenance activities undertaken by The City of Corpus Christi include seaweed removal and maintenance to improve drivability. The following descriptions of maintenance activities were obtained from the City of Corpus Christi USACE Permit No. SWG-2006-00647 and from the City's Adaptive Beach Maintenance Plan (The City of Corpus Christi and Watershore Beach Advisory Committee 2011).

Typically from April to November, maintenance is performed for removal of seaweed and sand. Because driving conditions may deteriorate due to the accumulation of seaweed and soft sand, seaweed and sand is skimmed from a 25 ft. wide roadway and relocated either to the foredune area and placed on the surface or just landward of the mean tide line (MTL), in a shallow trench and buried. During the period of November to April (sand only), sand is repositioned from immediately in front of the dune and distributed over the beach to make it drivable (~ 2” layer applied to all areas except MM 103-62). From MM 103-MM 62, a push up dune is used as a storage location for sand and *Sargassum* or alternatively *Sargassum* may be trenched. Priority Areas of Beach Maintenance for City of Corpus Christi:

- **Priority Area 1**- Areas in front of the seawall, condominiums, and all access roads are considered priority area 1. This includes the stretch of beach from Packery Channel south jetty to Access Rd. 4 and from Packery Channel north jetty to Zahn Rd.
- **Priority Area 2**- Areas in front of housing developments, dune walkovers, and beach area at Zahn Rd. are considered priority area 2, including the stretch of beach from Zahn Rd. to MM 203.
- **Priority Area 3**- All other areas within the City of Corpus Christi are considered priority area 3, including beaches south of Access Rd. 4 and north of MM 203.
- **Special Events Maintenance**- Some sections of beach are designated for maintenance during special events, for example holiday weekends like the 4th of July and Memorial Day weekend. These areas include sections south of MM 253, between Access Rd. 6 and Access Rd. 4, and between Newport Access Rd. to MM 103.

In addition, the City periodically assists the State and Nueces County with maintenance of stretches of beach within their jurisdictions, in particular during special events (Spring Break and Holiday weekends) and in case of emergency maintenance (HDR Engineering, Inc. 2013b).

City of Port Aransas

Port Aransas uses beach maintenance practices to maintain a drivable road and sand surface for driving in 4-wheel or 2-wheel drive and for the clearing of *Sargassum* (McKenna 2006). The City’s Public Works staff generally grades (blades) the vehicular travel way and the beach parking area. Clearing trash and debris from the pedestrian beach area is usually accomplished manually and seaweed removal is done through front end loaders (McKenna 2006). Seaweed and sand may be placed adjacent to the dune toe, at the landward toe of the foredune, or in other areas near the beach. Another method used in this area is the notch-and-fill method; a notch of sand is cut out of the foredune and filled with *Sargassum* and sand scraped from the beach. The original sand from the dune is spread near the waterline. Port Aransas Priority Maintenance Areas:

- **Priority Area A**: Pedestrian beach from Lantana Drive to Access Road 1A (between MM 15 and MM 20). Highest usage of the beach is in this area and therefore is the highest priority for maintenance. Bollards mark the landward limit of the pedestrian beach.
- **Priority Area B**: Beach Parking Area from Access Road 1A to Access Road 1, mostly for vehicular access and beach parking.
- **Priority Area C**: From Access Road 1 and south to the city limits (approximately MM 63), this area of the island is the least developed and receives the fewest visitors within the city.

Nueces County

Nueces County Beaches include the section of Padre Balli Park and the Nueces County Park adjacent to the Aransas Pass south jetty. Both of these parks are considered to be high-use and high-maintenance for the removal of *Sargassum* and grading for beach access. Low-use areas include the beach south of Bob Hall Pier into Kleberg County (Nueces County maintains the section of beach within Kleberg County lines on North Padre Island north of Padre Island National Seashore); these areas experience relatively less maintenance and less frequent trash pickup compared to other County and Corpus Christi beaches (HDR Engineering, Inc. 2013b).

Relative Level of Beach Maintenance

Based on field observations, information about beach maintenance practices provided by the available reports, and through communication with the City of Corpus Christi Parks and Recreation and Nueces County Parks offices, a map of the relative level of beach maintenance for the year 2014-2015 was developed (**Error! Reference source not found.**). Beach maintenance practices have changed through the years and vary with need (i.e. unusual volume of *Sargassum* on beach, post storm, etc). During the summer of 2014, Texas beaches experienced an unusually high level of *Sargassum* deposition, increasing the frequency of *Sargassum* removal in the study area. Beach grooming is not a regular activity within Mustang Island State Park, but during this event some maintenance was undertaken. During winter 2014 through 2015, beach operations were back to moderate levels.

In general, high maintenance areas are scraped or groomed regularly for removal of wrack and smoothing or moving sand to improve driving conditions. Areas identified as having high maintenance are those within the northern part of the City of Port Aransas up to MM 50, and areas adjacent to Packery Channel. Beaches with high maintenance are generally flat and packed. These beaches lack backshore vegetation and embryo dunes –incipient dune features formed by windblown sand coalesced around objects such as beach-cast wrack, driftwood, or even litter. If left to natural processes, embryo dunes can form embryo dune fields and eventually become the seaward edge of future foredunes. On high maintenance beaches, foredunes are generally steep from sand and *Sargassum* that has been pushed up into the foredune by heavy machinery. Steep foredunes composed of pushed-up material are known as pushup dunes and often lie seaward of the natural foredune. Areas identified as having a moderate level of maintenance are adjacent to high maintenance areas and are located on areas of relatively sparse development in Port Aransas and beaches of Nueces County Parks on North Padre Island. Beaches and dunes in moderate-maintenance areas feature more dry sand on the driving paths but still have visible pushup material at the base of the dunes. Area of low maintenance level are typically not scraped for improved driving conditions. In these areas, loose sand covers the backshore allowing growth of backshore vegetation and incipient dunes. Low maintenance areas include sections of Mustang Island State Park and beaches in Kleberg County on North Padre Island. Low maintenance areas exhibit a wide backshore and incipient dune field, with loose sand on the beach and a wide seaward expansion of vegetation.

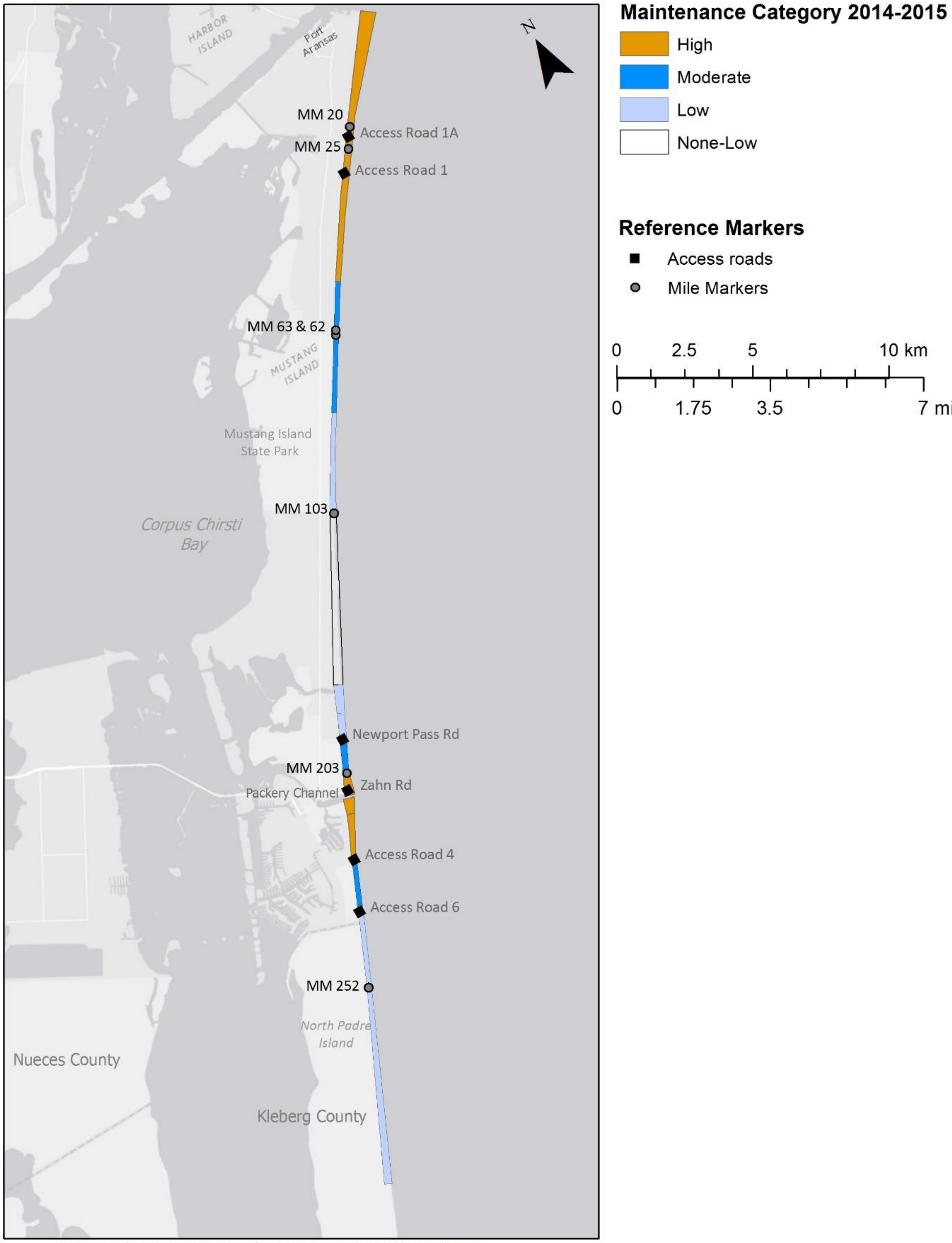

FIGURE 9. BEACH MAINTENANCE CATEGORIES FOR THE YEARS 2014-2015. CATEGORIES ARE BASED ON THE RELATIVE FREQUENCY, TYPE, AND MODIFICATION OF BEACH AND DUNES FOR MAINTENANCE PURPOSES ALONG THE STUDY AREA. BEACH MAINTENANCE PRACTICES VARY AMONG JURISDICTION

Methods

A variety of data and data analysis procedures were used to achieve project tasks. To identify the effects of beach maintenance practices on beach and dune morphology, beach and dune topographic surveys were assessed from 2008 to 2015. Lidar digital elevation models (DEMs) were used to calculate dune volume change along the study area and compare areas of various maintenance categories. In addition, beach width mapped from historical imagery was used to assess variability in beach morphology.

To assess dune vegetation cover and diversity, vegetation species and cover data were assessed using a diversity index. Impacts of beach maintenance on the apparent position of the legal boundary of the public beach (continuous line of vegetation), were assessed by mapping of the historical vegetation line from 1979-2014.

Lastly, the Storm Susceptibility Index, previously available from HRI, was used to determine the storm surge protection benefit of a particular site and relationship, if any, with beach maintenance activities.

Dune Topographic Surveys

Topographic measurements were taken along shore-perpendicular profiles at locations previously occupied by HRI. Data included in the analysis dates back to 2008, and was used to determine the evolution and dynamics of dune areas which experience different levels of beach maintenance and use **Error! Reference source not found.**). The profile data points were collected using a Sokkia Total Station along pre-determined azimuths and referenced to a datum (buried steel metal pipe) with known coordinates. Magnetic declination was obtained from The NOAA National Geophysical Data Center for correction of compass measurements. Profile data was maintained in a Microsoft Access database; digital copies of field book and GPS-photos were stored in a file database. Surveys were conducted from the datum located landward of the foredune to the waterline.

Profile elevation data was adjusted from NAVD88 to the local MSL Datum using information from the NOAA/NOS station at Bob Hall Pier (#8775870) and based on the GEOID12A model. Data used for this study extends from September 2008 to March 2015. From this data, dune crest elevation, dune toe elevation, beach berm elevation, foredune slope, beach slope, foredune width, and beach width were obtained.

FIGURE 10. TOPOGRAPHIC AND VEGETATION SURVEY SITES IN REFERENCE TO BEACH MAINTENANCE CATEGORIES.

Dune Volume Calculation

Volume calculations of the foredune were performed for the foremost vegetated dune ridge in the backshore; this section may include coppice mounds if present. The foredune landward boundary was mapped using aspect and elevation values extracted from lidar-derived DEMs. Areas of significant volume change from 2005-2010 were considered in the mapping of the foredune. The seaward boundary of the foredune was established using the Potential Vegetation Lines as mapped by the University of Texas Bureau of Economic Geology (BEG) (Paine, J. G, Caudle, and Andrews 2013). The 2010 line was used as the seaward boundary and edited where there was a need to be more inclusive. Foredune polygons were bisected using cross-shore transects 10 m apart (**Error! Reference source not found.**). Volume calculations for each available year were obtained for each 10 m wide bin. Dune walkover structures were removed from the volume calculations.

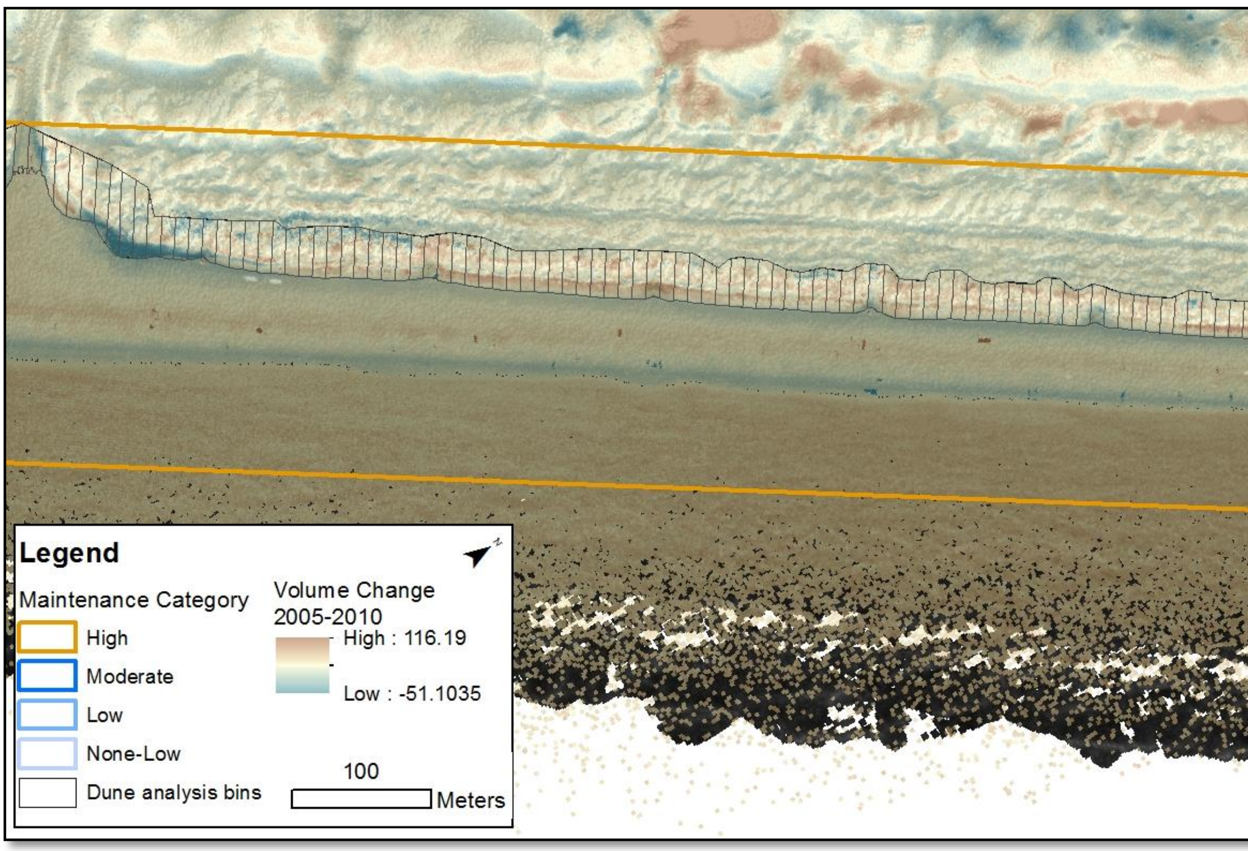

FIGURE 11. EXAMPLE OF FOREDUNE BINS FOR VOLUME ANALYSIS.

Lidar data was collected and processed by the BEG. Collection dates for the study area were: August 24-26, 2005; April 21, 2010; April 6, 2011; and February 25, 2012. The computed RMSE for elevation data between each collection year was 0.198 m, 0.083 m, and 0.176m for the years 2010, 2011, and 2012, respectively. Volume change for each analysis bin was calculated above shoreline elevation at 0.6 m above MSL (0.67 m NAVD88). Data was exported to table format for graphing and dune volume statistics were processed using R Statistical Software (R Core Team 2015).

Historical Vegetation and Shoreline Mapping

Vegetation lines and shorelines were digitized from historic aerial imagery sets from the time period spanning 1979 to 2014 at a scale of 1:1000 using a Wacom digitizing tablet. Vegetation lines were mapped following the continuous vegetation line visible within the given imagery set, and shorelines were mapped by following the visible wet/dry line. Historic imagery was georeferenced using Arcgis 10.2 against the NAIP 2009 half-meter imagery and checked for accuracy. Eleven sets of imagery were used for this project for the years 1979, 1995, 2002, 2004, 2005, 2008, 2009, 2010, 2012, and 2014. Digitized lines were then checked for topology errors and combined into one shoreline-vegetation line file for analysis.

Analysis of these features was performed using the *Analysis of Moving Boundaries Using R* (AMBUR) tool. The AMBUR tool is an extension to R statistical Software (R Core Team 2015; Jackson, Alexander, and Bush 2012). AMBUR facilitated the creation of a baseline and transects for the measurement of line movements. From this analysis long term shoreline and vegetation-line change rates (Linear Regression Rate) were obtained.

Beach Width

Beach width was calculated as the distance between the shoreline and the vegetation line mapped from available aerial imagery. Using the “distance from baseline” output from AMBUR, beach width was calculated for each transect, where both a shoreline and vegetation line were available.

Storm Susceptibility Index

The *Storm Susceptibility Index* (SSI) is a classification which identifies the theoretical level of protection that the beach and foredune complex could provide against surge and erosion resulting from a tropical storm or hurricane. The classification indicates the relative level of protection among profiles of the study area and does not consider wind damage, the type of built or natural environment being protected, potential return flow, or alongshore sediment transport effects during a storm. This data is reported in Paine, Caudle and Andrews (2013) and by Taylor et al. (2015). For this project SSI data was joined with maintenance categories for analysis.

Vegetation Survey

Vegetation diversity was estimated and vegetation cover measured using a quantitative sampling method at seven locations in the study area (**Error! Reference source not found.**). At each location, two transects were established from the seaward boundary of the vegetation (or dune toe if vegetation was not present), landward across the foredune into the dune slack or vegetated flat. The distance between transects was set at 10 m. Each transect was sampled at three-meter intervals with a sampling quadrat of 0.5 m^2. At each sample location vegetation type, percent cover, and height were collected. In addition, topographic data was collected at each sample site using a Trimble R8 Real Time Kinematic (RTK) system. Vegetation classification was based on Richardson (2002). Surveys were conducted in December 2014 and July 2015.

Shannon-Weiner Diversity Index

FIGURE 12. EXAMPLE OF QUADRAT USED FOR SAMPLING OF VEGETATION (LEFT). HRI STAFF TAKING RTK-GPS COORDINATE MEASUREMENTS.

Vegetation species type and abundance data collected during each survey was analyzed with the use of a diversity index. Biological diversity is defined as “the variety and abundance of species in a defined unit of study” (Magurran 2004). Diversity indexes account for species richness and evenness, and therefore can be described as a measure of heterogeneity. Species richness refers to the number of species in the unit of study and evenness describes the relative quantity of species. One of the most widely used indexes and the one used in this study is the Shannon-Weiner Index. Shannon-Wiener diversity index (*H'*) was used to compare variation in vegetation richness and evenness as follows:

$$H' = \sum_{i=1}^{R} p_i \ln p_i$$

Where *R* is the richness and quantifies how many different vegetation types the dataset contain, and p_i is the proportion of the total sample represented by species *i*. The value of the Shannon Index usually falls between 1.5 and 3.5 (Magurran 2004). An evenness value is a measure of the observed diversity to maximum diversity of the sample and ranges from 0 to 1. The index was applied to each profile.

Results

Beach and Dune Topography

Beach and dune topographic data for the 10 sites in the study area was graphed and is included in Appendix A of this report. All profile graphs are presented in 3 epochs: Epoch 1 from 2008-2010, Epoch 2 from 2010-2013, and Epoch 3 from 2013-2015. The graphs illustrate the profile evolution in areas of varying maintenance levels. Average elevation, length, and slope for the beach and foredune of each profile was summarized in the graphs below and in Appendix B.

Profiles exhibited large variability in time and among locations. Because of the nature of the data-- replicates collected over time at each profile location and locations unequally distributed in different maintenance levels-- a nested Analysis of Variance (ANOVA) was conducted to test significance between maintenance levels. ANOVA of profile data confirmed there is large variability among and within sites. This is visible in the profile graphs (Appendix A) and summary graphs (**Error! Reference source not found.** and **Error! Reference source not found.**). **Error! Reference source not found.** and **Error! Reference source not found.** present the mean and standard deviation of dune crest, dune toe, berm elevation, width from foredune crest to dune toe (foredune face width), and from dune toe to berm (beach width), and for slope of dune face and beach. From the graphs and ANOVA results, beach width and beach slope exhibit a significant correlation with beach maintenance. In Figure 13 B., beach width of high maintenance areas, MUI01, MUI03, and NPI08, exceeds those of moderate and low maintenance. Beach slope on average is gentler, ~0.01 degrees, compared to areas of moderate and low maintenance, ~0.03-0.04 degrees. This can be visually confirmed in the profile graphs in Appendix A, where high maintenance areas have a wider and flatter beach.

MUI01 had a slight seaward slope up to 2010. After 2010, the beach is much flatter; maintenance activity at the back beach moved the dune toe landward and beach slope changed from seaward sloping to nearly flat and in some instances the beach slopes downward toward the dune. This beach also appears wider as the dune toe is pushed landward and the shoreline extends seaward in time. The width of beach between the dune toe and the berm increased approximately 50 m during the survey period. The dune toe was maintained at a constant location until June 2014, after that the dune was notched and dune toe was displaced approximately 10 m landward. A similar pattern of beach width and slope is found on MUI03, also a high maintenance level profile, after 2010. The foredune width and dune toe location has been relatively static since late 2010. Although considered a moderate maintenance beach, MUI06 also shows a wider and flatter beach on average after 2010 when compared to low maintenance locations. Lastly, NPI08 (high maintenance), also features a high mean beach width although this beach experiences more variability in beach slope and fewer instances of flat or landward sloping beach. In contrast to MUI01 and MUI03, NPI08 has a highly active foredune. Pushup material is placed at the toe of the dune as in other maintained areas, in addition to a large volume of landward sediment movement causing the foredune to expand, increasing the foredune width by approximately 30 m.

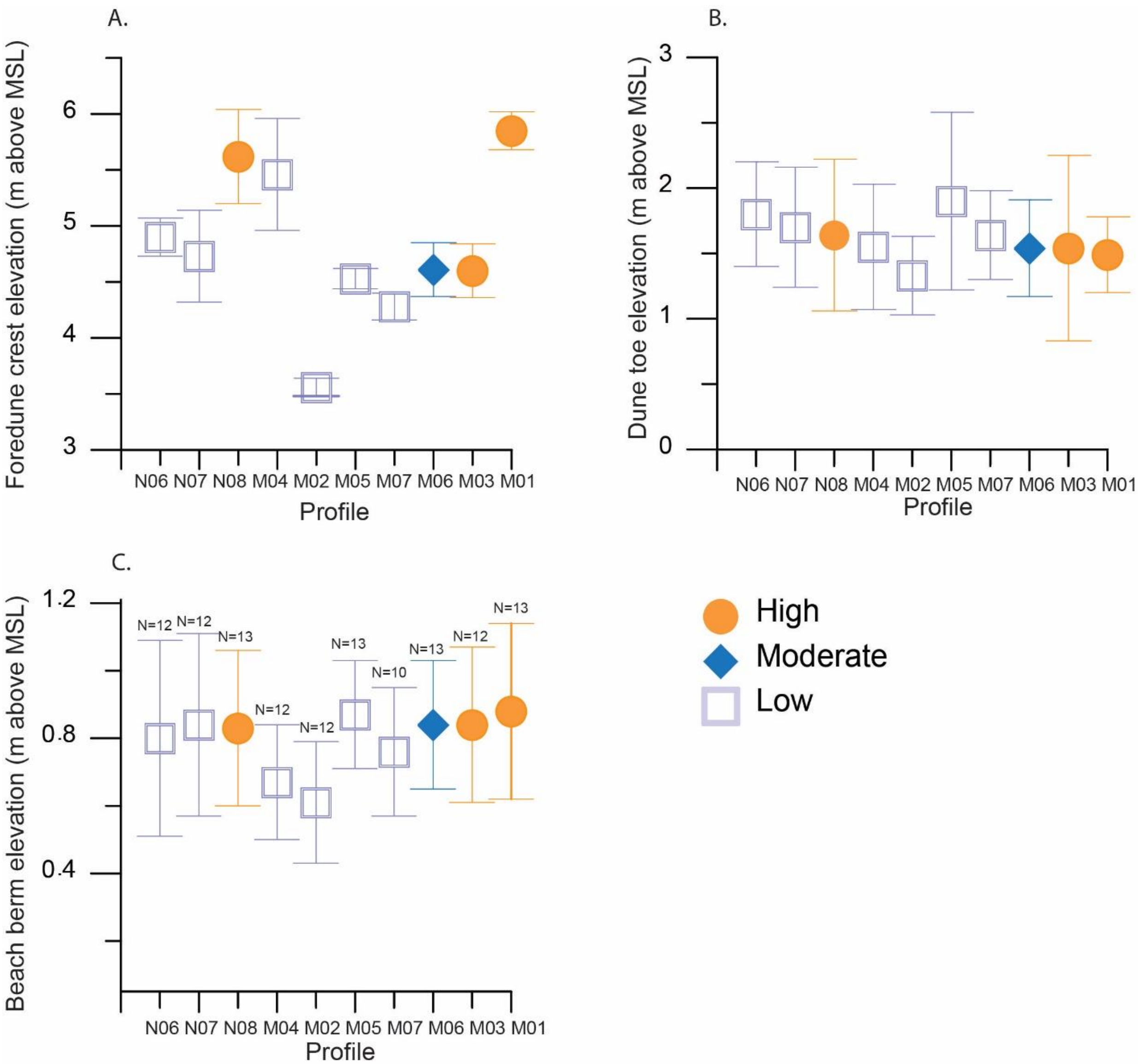

FIGURE 14. AVERAGE FOREDUNE CREST (A.), DUNE TOE (B.), AND BEACH BERM (C.) ELEVATION FOR PROFILES COLLECTED FROM 2008-2014 AND STANDARD DEVIATION OF DATA. ORANGE SYMBOLS REPRESENT PROFILES IN AREAS OF HIGH MAINTENANCE, BLUE SYMBOLS REPRESENT AREAS OF MODERATE MAI

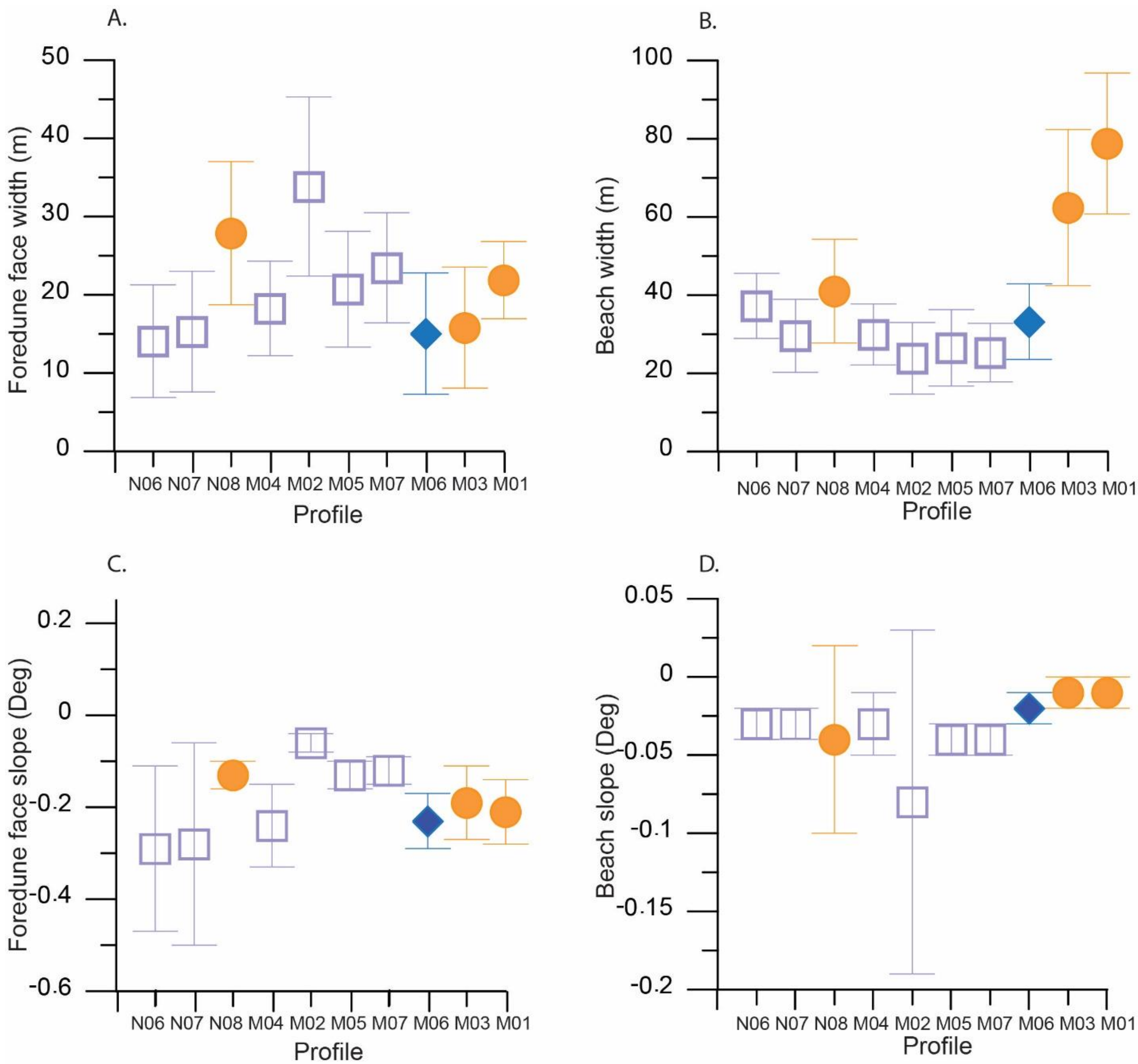

FIGURE 15THE MEAN AND STANDARD DEVIATION OF THE DISTANCE BETWEEN FOREDUNE CREST AND DUNE TOE (A.), DISTANCE FROM DUNE TOE TO BEACH BERM (B.), SLOPE OF THE DUNE FACE (C.), AND SLOPE OF THE UNVEGETATED BEACH (D.). FROM THE GRAPHS AND ANOVA RE

Areas of low maintenance including MUI07, MUI05, MUI02, MUI04, NPI06 and NPI07 experience more variability in beach width and slope. In addition, foredunes have expanded over time as coppice mounds form and grow into a new incipient dune ridge (as in MUI02) or as continued accumulation of sand at the dune toe increases dune width and extends the dune toe seaward. Low maintenance beaches are significantly narrower as compared to high and moderate maintenance areas.

Dune Volume Changes

Foredune volume changes were estimated between the Epochs of August 2005-February 2012, April 2010 – April 2011, and April 2011 -- February 2012. **Error! Reference source not found.** presents the net volume within each 10 m wide section of foredune for the study area. Foredunes closer to inlets, also corresponding to high and moderate maintenance areas, have larger dunes or dunes with more volume per width of beach. Other areas of high volume are blowouts, foredunes of Mustang Island State Park, and dunes adjacent to Newport Pass.

Volume change is graphed alongshore in **Error! Reference source not found.** and the mean of dune volume change for each maintenance category is plotted in **Error! Reference source not found.**. Over the 6.5 year period between Lidar datasets (2005 to 2012) the foredune ridge along the study area experienced variable net volume change. The quantity of volume change corresponds with the size of the foredune: large foredunes accumulated greater volume. When grouped by maintenance category (**Error! Reference source not found.**, top right), the high maintenance group had the highest average dune volume change (227 m^3), as well as a high standard deviation. The low maintenance group had an average dune volume change of -11 m^3, and may correspond with areas of shoreline retreat along Mustang Island. Visual observation of volume change patterns confirmed retreat of foredune due to scarping across most of Mustang Island and on the southern portion of the study area. Dune expansion occurred near jetties of Aransas Pass, Fish Pass, and Packery Channel.

From April 2010 to April 2011, there was an overall increase of dune volume across the study area. During this year, mean dune volume change was very similar between high, low, and low-none maintenance categories (62 m^3, 53 m^3, and 49 m^3, respectively). In the most recent epoch from April 2011- February 2012, all maintenance categories had an average increase in dune volume: 22 m^3, 23 m^3, 23 m^3, and 21 m^3 for high, moderate, low and low-none maintenance categories, respectively. Similar to other time periods, high and moderate maintenance categories had high standard deviations (**Error! Reference source not found.**) and many of the areas experiencing high volume loss were located in high maintenance areas. Much of the volume gaincould be attributed to accretion at the dune toe. From 2011-2012, the variability of volume on the high maintenance section near Aransas Pass was attributed to back stacking and dune notching. High variability in moderate maintenance areas south of Mustang Island State Park and around Padre Balli Park was due to development of localized foredune blowouts.

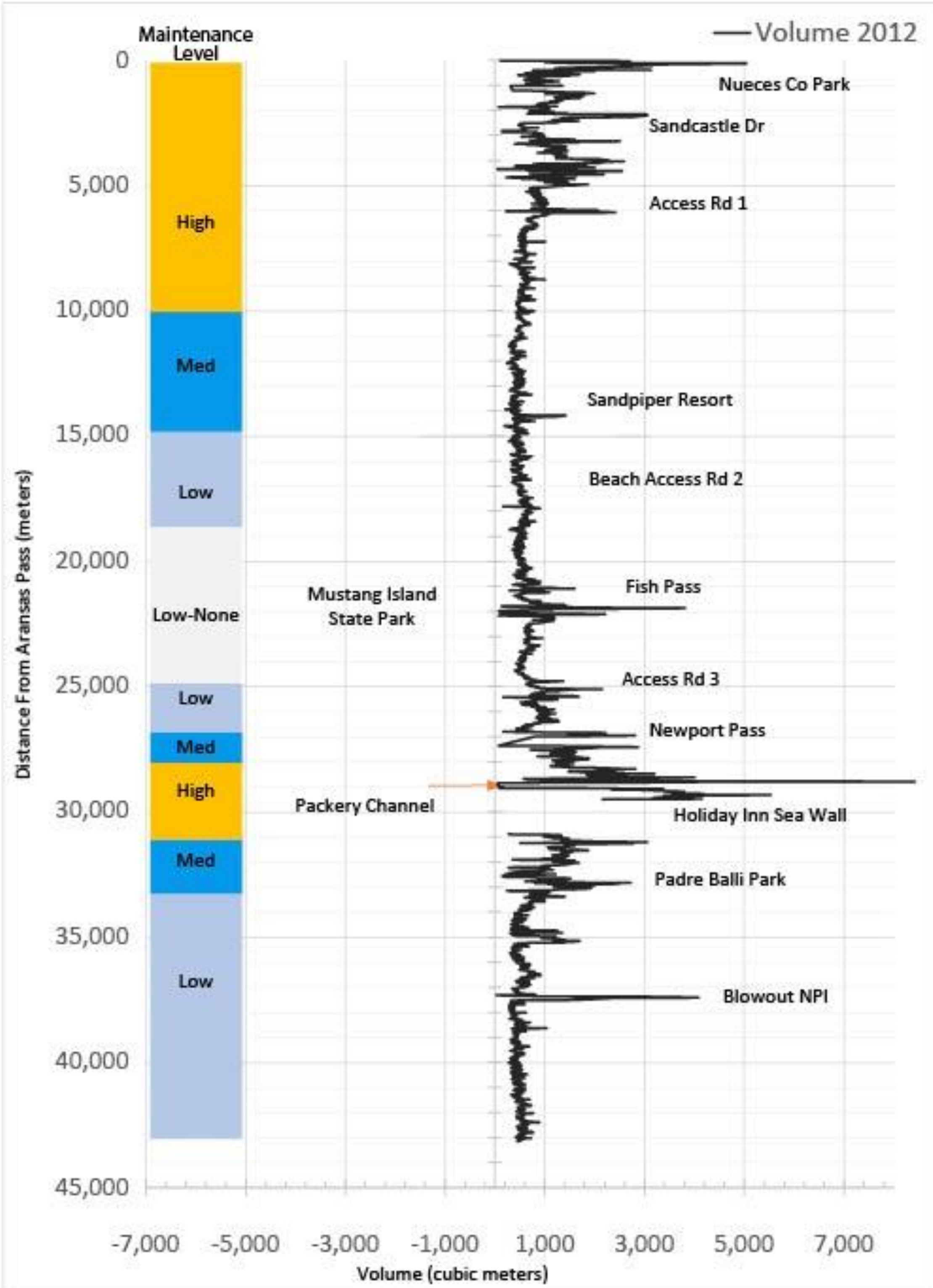

Figure 16. Net dune volume for the year 2012.

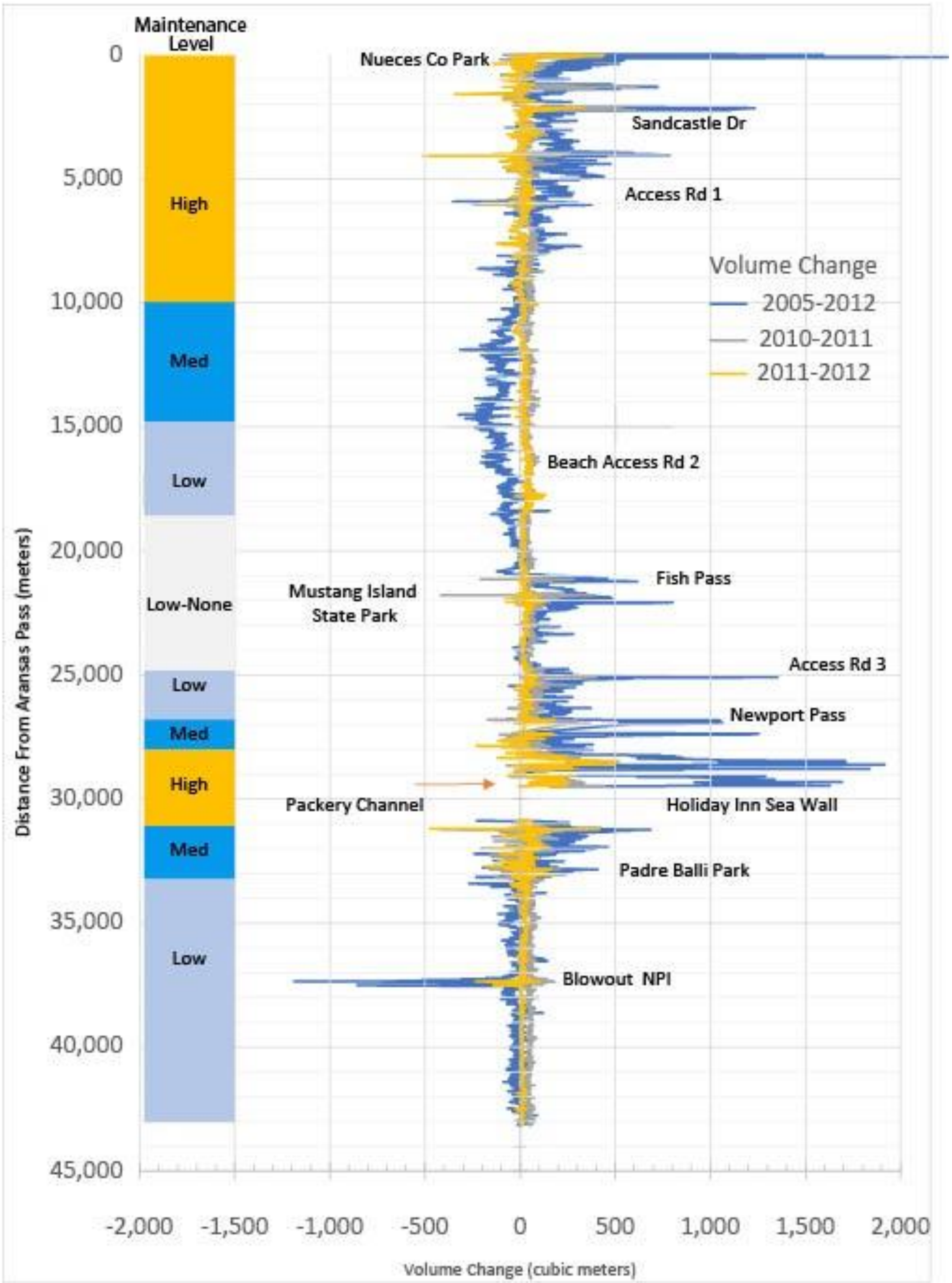

FIGURE 17. DUNE VOLUME CHANGE, CUBIC METERS.

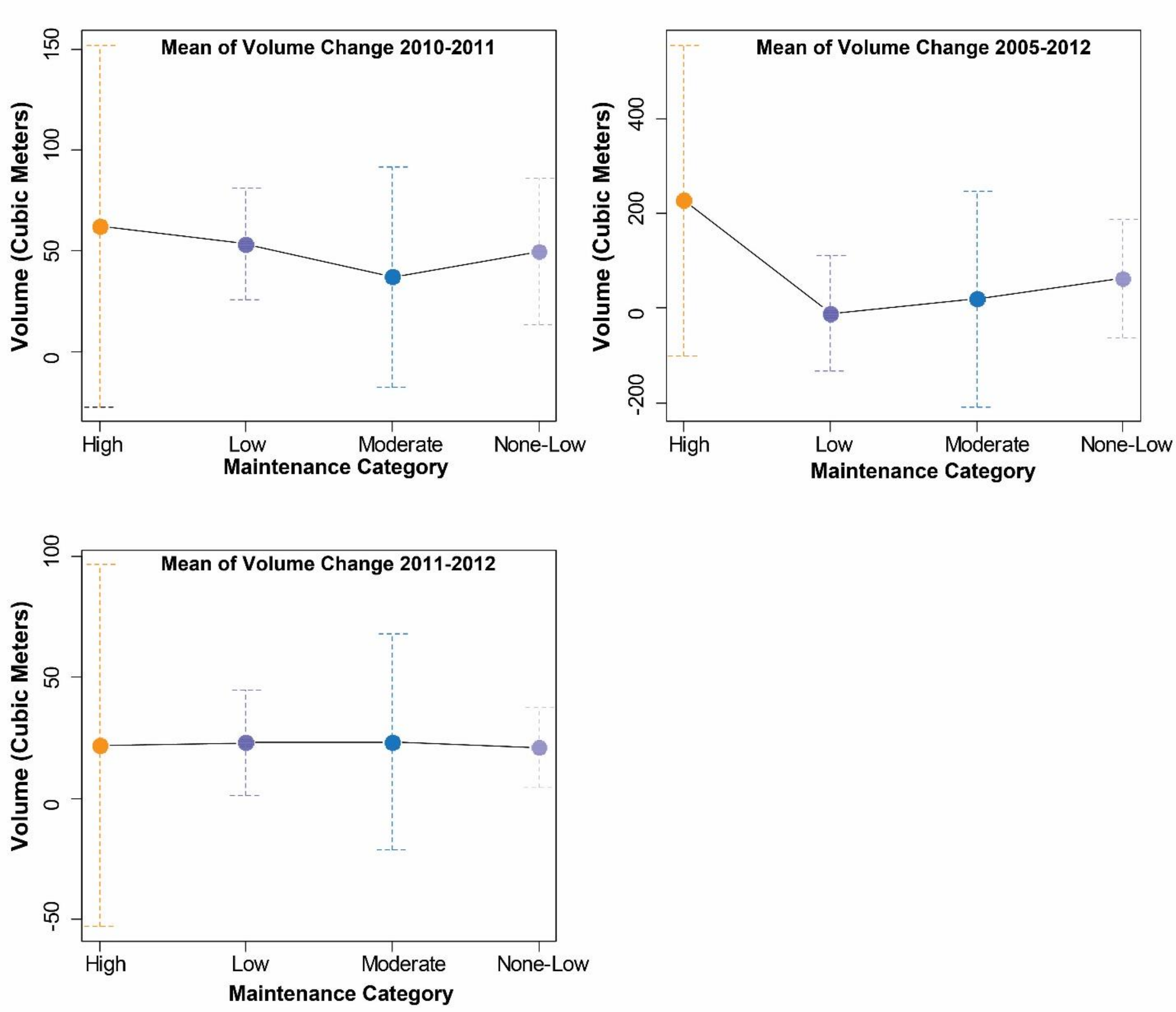

FIGURE 18. VOLUME CHANGE BY MAINTENANCE CATEGORY FOR TIME PERIODS 2010-2011 (TOP LEFT), 2011-2012 (BOTTOM LEFT), AND 2005-2012 (TOP RIGHT). HIGH AND MODERATE MAINTENANCE AREAS EXPERIENCE HIGH SPATIAL VARIABILITY IN DUNE VOLUME CHANGE THROUGH ALL TIME PERIODS.

Dune volume is variable alongshore. A foredune may on average increase in volume by approximately 2 m^3/m/yr unless eroded. Areas near jetties exhibit the largest accumulation of sand and may be associated with a greater sediment supply and wide beaches. Moderate and low maintenance areas of Mustang Island exhibited loss of foredune volume since 2005, which may be a result of dune scarping from the storm events (Hurricane Ike in 2008 and Tropical Storm Don in 2011). This area also featured the narrowest beaches and some of the highest shoreline retreat rates in the study area (See following section).

Shoreline and Vegetation Line Changes and Historical Beach Width

Beach width is affected by a number of processes including the seasonal variability of winds and tides, presence of jetties, long-term shoreline dynamics, and the occurrence of blowouts. In this study shoreline and vegetation line positions were digitized from aerial imagery; the distance between these two features represents the beach width. **Error! Reference source not found.** presents the results of linear regression analysis and rates of change for shoreline and vegetation line features. Beach-width rate of change was calculated as the difference between the shoreline and vegetation line change rates. Therefore, if the shoreline is progressing at a greater rate than the vegetation line, beach width would be increasing. If the shoreline is advancing at a slower rate or retreating in comparison to the vegetation line, then the beach would be narrowing.

On Mustang Island the shoreline progressed seaward near the Aransas Pass Jetty, increasing south to a maximum of 3 m/yr approximately 5,000 m south of the pass. This area is a nodal point which has exhibited long-term (1930-2012) shoreline advancement (Paine, J. G, Caudle, and Andrews 2014). South of the 5,000 m point, shoreline advancement decreased and shoreline retreat began at approximately 15,000 m from Aransas Pass. Shoreline retreat occurred between the moderate- and low-maintenance sections of the islands corresponding to the area of dune volume loss described in the section above. The section of Mustang Island south of Fish Pass has advanced seaward since 1979 at a rate of 0.5 -1.5 m/yr. The vegetation line changes follow the pattern of shoreline change on Mustang Island with a distinct discontinuity at approximately 5,000 m from Aransas Pass, near Access Road 1A. This area corresponds to the Port Aransas pedestrian beach and is an area which receives the most beach maintenance on Mustang Island, falling within Port Aransas beach maintenance Priority Area A. At this location, graders are used to remove *Sargassum* and other heavy machinery is regularly employed for beach grooming and maintaining a stationary driving lane. At this location the rate of shoreline advancement was from 2-3 m/yr while the rate of vegetation line advancement was from 0-1m/yr. Due to the large difference in advancement rate of these two features, beach width at this location has increased from 1-3 m/yr. These results are also reflected in the beach profile analysis (MUI01), where the dune toe location has been kept static since 2010 (See **Error! Reference source not found.** and Appendix A). This discontinuity in beach width becomes apparent after 2002 at 5,000 m (see Appendix C) and then a second discontinuity occurs at distance of 7,000-13,500 m after 2012 (see Appendix D), expanding the width of the beach further south into the moderate-maintenance section. This change in the beach morphology is confirmed in profile MUI06 (See Appendix A). Areas of low and low-none maintenance categories, from ~17,000 to 27,000 m exhibit corresponding shoreline, vegetation line, and beach width change rates. Outliers correspond to recovery of blowouts.

On North Padre Island, the section between 31,000-36,000 m showed shoreline advancement while the section between 36,000-42,000 m showed shoreline retreat (note: the points adjacent to Packery Channel and those associated with the seawall were removed to reduce noise in the graphs). Similar to Mustang Island, areas of low maintenance exhibited a corresponding rate of change for shorelines, vegetation lines, and beach width that is from -1 to 1m/yr. Areas of high and moderate maintenance exhibited a wider beach. A less pronounced discontinuity does occur near the Kleberg-Nueces county line (Access Road 6); the beach south of this point was narrow in comparison, and exhibited less variability. North Padre had more dune blowouts than Mustang Island, represented by outliers in beach width rate.

Storm Susceptibility

The results for assessment of storm protection along the study area are presented in **Error! Reference source not found.** and **Error! Reference source not found.**. Storm protection generally corresponds with the volume of the foredune and varies along the study area. The greatest number of profiles featured in the SSI analysis offer a storm level of protection for a 100 year storm (45%), followed by 200-year storm protection (29%) and 50 year-storm protection (23%). When compared by maintenance level, approximately 85% of high, 65% of moderate, 75% of low, and 65% of low-none profiles offer at least 100-year storm protection. High maintenance areas have the least amount of 50-year storm protection transects

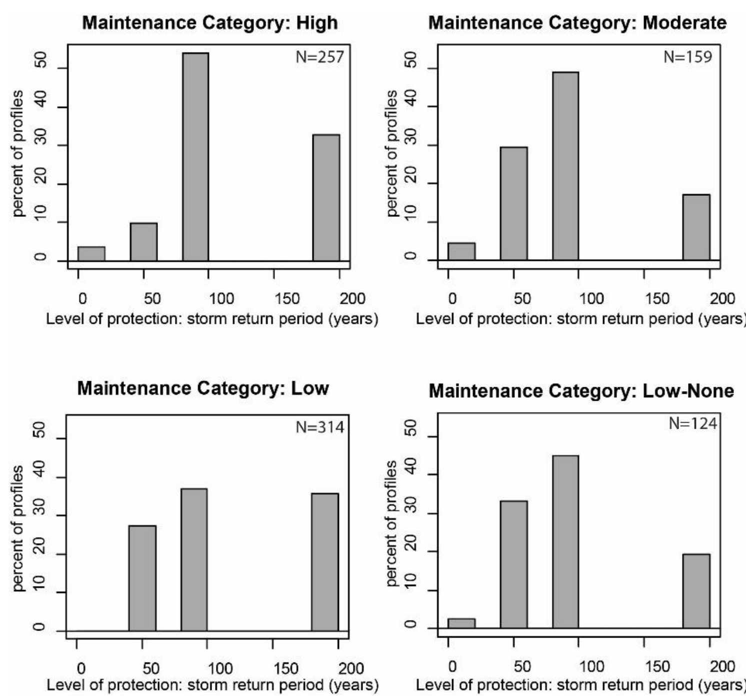

FIGURE 19. PERCENT OF BEACH PROFILES WITHIN EACH MAINTENANCE CATEGORY THAT HAVE A 0-. 50-, 100-, 150-, AND 200- YEAR STORM RETURN PERIOD PROTECTION FROM FLOODING AND EROSION.

(10%) compared to other categories (~30%). The low maintenance category did not exhibit profiles with 0-year storm protection, all others exhibit less than 10%.

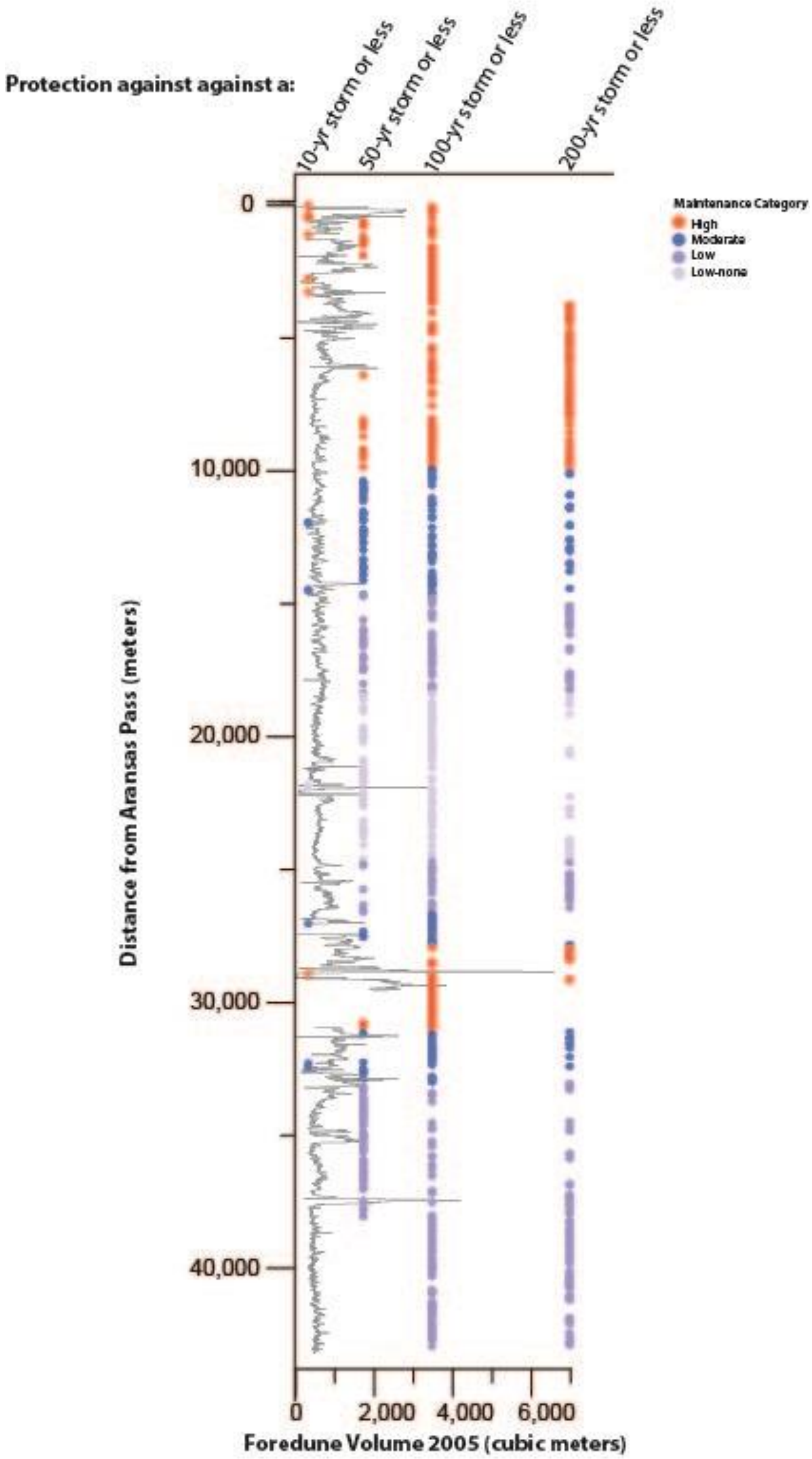

Figure 20. Alongshore pattern of storm protection value for the 4 maintenance categories in the study area. The black line represents the 2015 foredune volume.

Vegetation Diversity Index

During the study period, a total of 25 different species of beach and dune plants were observed in the study area. The number of different species recorded at each transect ranged from 6 to 14. The Shannon-Weiner Diversity Index results are presented in Figure 21. Diversity values for transects within the study area range from 1.08 to 2.08. Overall,profiles located on high maintenance areasscored below the mean for vegetation diversity and evenness values.

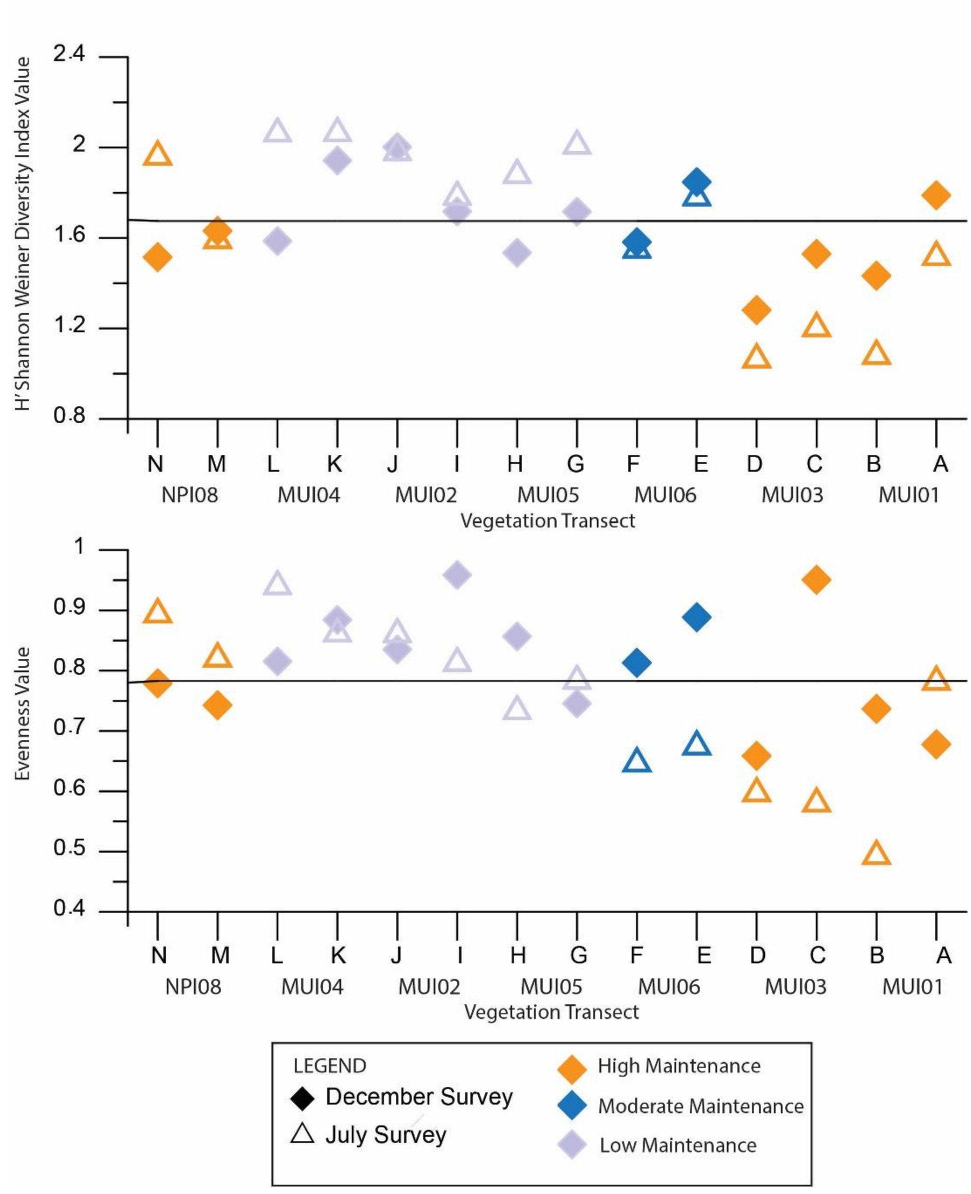

FIGURE 21. RESULTS OF SHANNON-WEINER DIVERSITY INDEX H' (TOP) AND EVENNESS MEASURE (BOTTOM) FOR THE DECEMBER 2014 AND JULY 2015 SURVEYS. THE BLACK LINE REPRESENTS THE MEAN VALUE OF H' AND EVENNESS.

Because data was replicated among sites for two different time periods, a nested ANOVA was conducted to test significance between maintenance levels. ANOVA results show significant difference in mean diversity score (H') at a significance level <0.001, plot of means is shown in Figure 22. The ANOVA results also show a significant difference in evenness among maintenance levels at a significance level of 0.05. Evenness values area very similar for high and moderate sites. Overall, low maintenance sites experience higher diversity and evenness scores, when compared to areas of high or moderate maintenance.

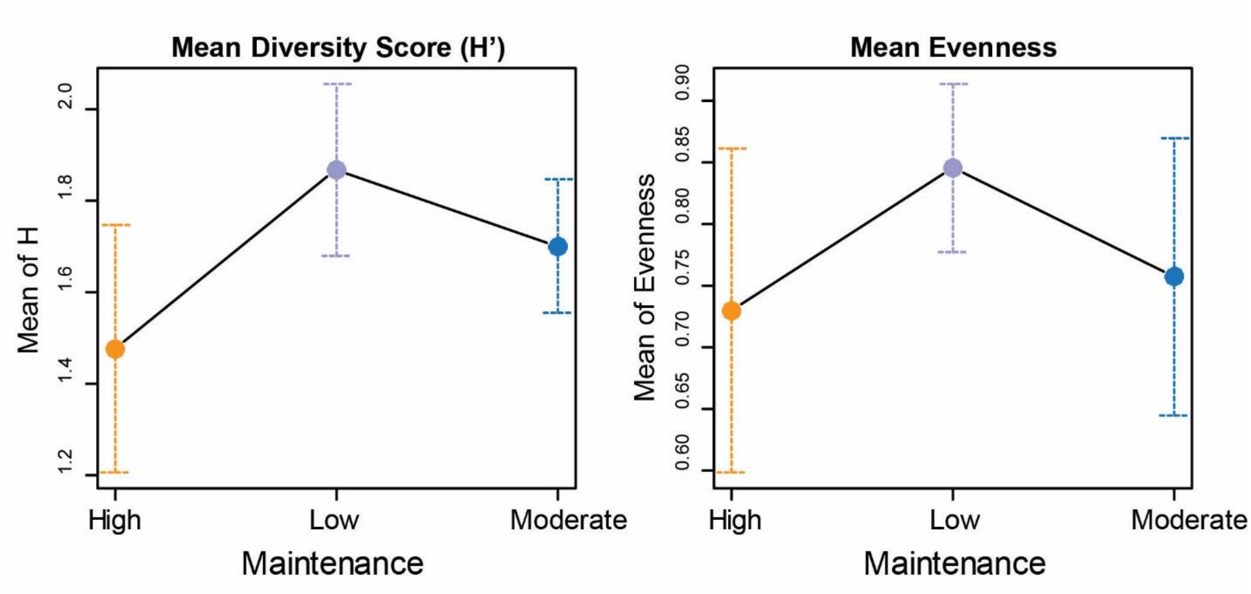

FIGURE 22. PLOT OF MEANS FOR DIVERSITY H' (LEFT) AND EVENNESS SCORE (RIGHT). ERROR BARS REFLECT STANDARD DEVIATION.

ANOVA of vegetation cover did not result in a significant difference between maintenance categories, mainly because of the contrast between high maintenance sites. High maintenance profiles on Mustang Island average 40-60% in vegetation cover (excluding dead vegetation), while the high maintenance profile on North Padre shows a significantly lower percent cover of 25-35%. Although high on vegetation cover, MIU03 is the site of lowest diversity, where Silverleaf Sunflowers cover most of the foredune. Moderate and low maintenance beaches have an average range of 45-65% cover.

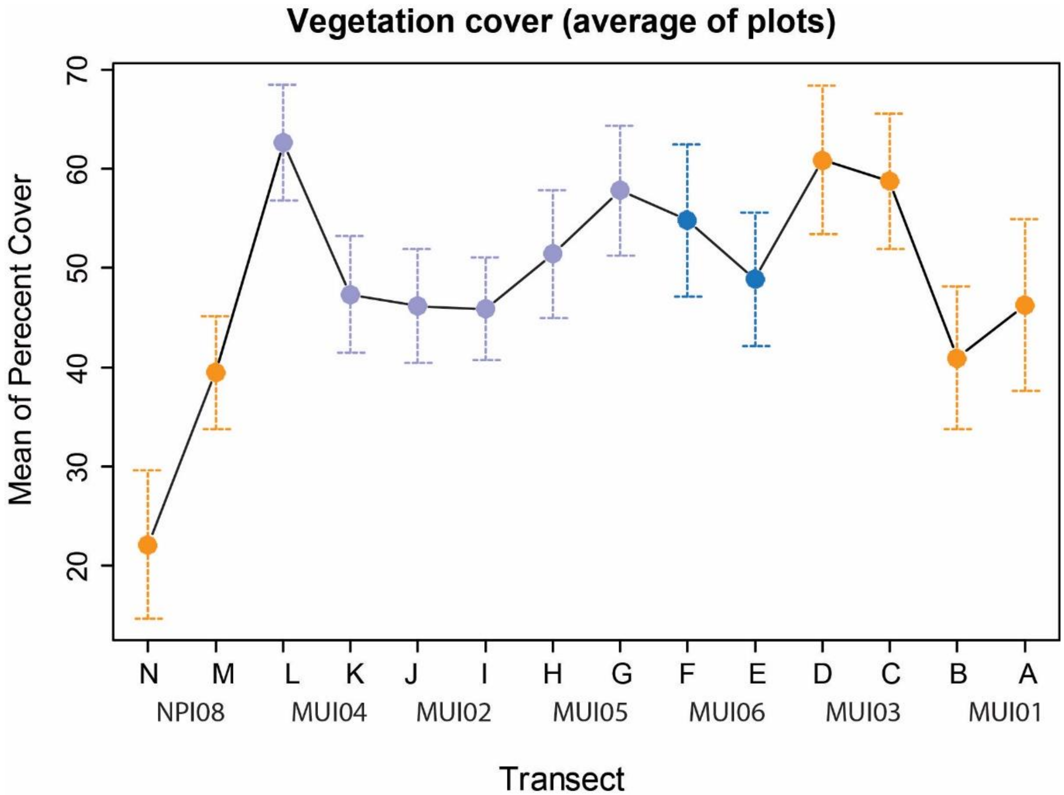

FIGURE 23. MEAN PERCENT COVER OF TRANSECT SITES.

Discussion

Effect of Beach Maintenance Practices on Beach and Dune Morphology

Analysis of beach profile data suggests that beach maintenance affects the natural beach and dune morphology through the removal of incipient dune forms and cut back of the dune toe. Scraping of the beach for driving results in a flatter (lower) beach slope and can result in a wider beach if the dune toe position is artificially maintained while the shoreline advances seaward. Beach width, as analyzed from historical shoreline and vegetation line changes, is a good indicator of the level of beach maintenance compared to vegetation line position alone, as it eliminates the effect of long-term shoreline change on vegetation line position. Although beach width may change throughout the seasons, it remains relatively stable through the years. In the study area, high rates of change of beach width correspons to areas where the natural line of vegetation is being mechanically manipulated.

Foredune volume is greater in areas adjacent to jetties (Port Aransas, Fish Pass, and Packery Channel), some of which correspond to high maintenance areas. The amount of dune volume change that can be attributed to beach maintenance is unclear due to the proximity to jetties which act as sediment trapping structures. But it has been documented in the literature that pushing up sand to the foredune increases the dune volume and helps reinforce dunes (Wells and McNinch 1991). Increase of dune width is visually evident at some locations in the study area, where placement of sand and *Sargasssum* material in front of or behind a dune has widened the foredune. Another pattern evident in the dune volume change analysis is that areas of high maintenance and high dune accretion from 2005-2015 near jetties also correspond to high volume loss from 2011-2012. Dune erosion might have been a result of the occurrence of Tropical Storm Don in July 2011 which resulted in a storm tide of 0.5m as measured by the Bob Hall Pier tide gauge. Although jettied, the dunes near Fish Pass remained stable, suggesting the backbeach at this low maintenance location provided more protection from storm tide than at jettied locations on high maintenance sites.

Effect of Beach Maintenance Practices on Dune Storm Surge Protection Benefit

From the Storm Susceptibility Index, the study area exhibits a similar level of storm surge protection across maintenance categories. Areas of concern exist near sections of dune discontinuity such as areas of beach access (roads or walking paths to homes and businesses) or areas of recovering washovers and blowouts. From the SSI, most areas of 10 yr-storm surge protection or less occur on high maintenance areas, in particular those on Mustang Island. This is not attributed the practice of beach scraping.

Effect of Beach Maintenance Practices on Vegetation Cover and Diversity

Analysis of dune vegetation data suggests there is a significant correlation with high maintenance areas and lower vegetation diversity. The high level of disturbance involved with various beach maintenance practices may prevent the establishment of vegetation communities of later stages of succession. Vegetation cover can also be affected by beach maintenance activity. Maintenance practices may promote the dense growth of plants not typical of coastal dunes, or may increase the rate of sand transport and prevent vegetation from establishing. It should also be noted that areas of high maintenance are also areas of high use and vegetation diversity and cover is also impacted by trampling of vegetation from walking or driving on the dunes.

Effect of Beach Maintenance Practices on State Legal Boundaries

From the analysis of shoreline and vegetation line positions since 1979, there is evidence that beach maintenance can increase the width of the public beach. This is observed in areas where the shoreline has progressed seaward at a faster rate than the vegetation line. The location of the vegetation line may also be impacted by the occurrence of blowouts which can be exacerbated by disturbance to dune vegetation by mechanical removal or trampling. High use areas exhibit more variability in the rate of change of beach width than less disturbed locations.

Potential Implications on Coastal Management Goals

The State of Texas promotes the health and protection of beach and dune environments though the Texas Natural Resource Code and through the support of programs like the Coastal Erosion Planning and Response Act Program and the Coastal Management Program. Beach maintenance activities within within public beaches must align with the goals of these programs. Beach maintenance should ensure that beach and dune habitat is not negatively impacted. From this study, maintenance activities do not appear to reduce dune volume or beach width. But, high use and mechanical manipulation of the beach can result in impacts to the vegetatin cover and diversity. It may be useful to monitor and promote dune vegetation diversity to help ensure the quality and function of this habitat in the future.

Local communities in the study area have developed individual goals for Nueces County, City of Corpus Christi, and City of Port Aransas beaches and dunes, as outlined in the respective Erosion Response Plans (ERP) (Nueces County and City of Corpus Christi, 2012; Mahoney 2011). In Nueces and Corpus

Christi, the joint ERP outlines a goal of obtaining/maintaining 50% vegetation cover of the foredune; from the sites surveyed in this study, the average dune cover is 45-65%. In general, the goal is being met with a few exceptions at locations of blowouts. Another goal for the City of Corpus Christi is to maintain a beach width of approximately 100 ft (~30.5 m) from the line of vegetation to the mean high tide line; from the data this width is maintained at most locations. Beach width naturally fluctuated from 20-50 m throughout the study area (see Appendix D&E) and has been extended at high use areas by scraping of backshore for driving and improved beach access. One area of concern is the seawall just south of Packery Channel; it is periodically nourished using dredge material from Packery Channel (Williams and Kraus 2011). The City of Port Aransas outlines a goal of obtaining 85% cover for the foredune ridge in their ERP. During the study period, all dunes had less than 85%. Dune vegetation cover over 65% may occur periodically but is likely not the natural state for the dunes as climatic conditions may not support more vegetation. Promotion of re-vegetation of foredunes would be recommended only if necessary, for example in areas of dune blowouts or where non-native vegetation is encountered.

Conclusions and Recommendations

This study was conducted to assess the potential impacts of beach maintenance practices to beach and dune morphology and dune vegetation. In the study area, three different entities manage and maintain different portions of the beach, and although these entities do collaborate, the frequency and methods of beach maintenance vary. Results of this study show areas of high maintenance and use experience impacts to vegetation diversity and cover. High maintenance areas also feature wider beaches than areas of less disturbance. Recommendations for beach management and future studies include:

1. Education which focuses on *Sargassum* as a natural part of the beach and dune environment
    a. Public education programs such as the “Bucket Brigades” program in Galveston could help persuade beachgoers that the presence of *SargassumI* on the beach in an indicator of a natural and healthy environment, not “trash” that requires heavy intervention to remove.
    b. Education of city/county staff and machinery operators to avoid removal of *Sargassum* as much as possible, and to avoid removing excess vegetation and sand when *Sargassum* must be removed.
2. Public education on beach and dune habitat and ecosystem services associated with these environments.
3. Studies to improve knowledge of dune habitat use and dune health indicators.
4. Beach user surveys to inform on beach condition and user preferences.
5. Future studies on the effects of beach maintenance should consider an experimental design and discontinue maintenance on a high-maintenance test site, since other factors affect beach and dune morphology including location of jetties, long-term shoreline processes, and variability to wind/wave exposure cannot be modified.
6. Avoid unnecessary maintenance.
    a. Unnecessary maintenance would include any activities besides those that satisfy the basic requirements of public access and public health and safety on the beach.
7. Avoid lowering the backbeach by excess beach scraping which may result in ponding of water.
8. Continue to develop and update adaptive beach maintenance and management plans, which incorporate latest data and monitoring information when available.

One major recommendation of this study is that a coast-wide best practices guidance should be developed. Such guidance should be developed using best available data and focused on specific geographic locations along the coast, acknowledging that beach and dune dynamics and user needs vary along the coast. Data collected could include geophysical data such as accretion/erosion trends, socioeconomic data such as trends in beach use and user experience surveys, and beach maintenance logs, as well as an inventory of common beach and dune plants along the coast.

Harte Research Institute could assist in the development of a coast-wide best practices document. Development of such a document would involve working with beach maintenance practitioners from each municipality to understand how and why the beaches are maintained as they are, disseminating information regarding the impacts of current beach maintenance practices, and devising straightforward management and evaluation standards that can be applied along the coast.

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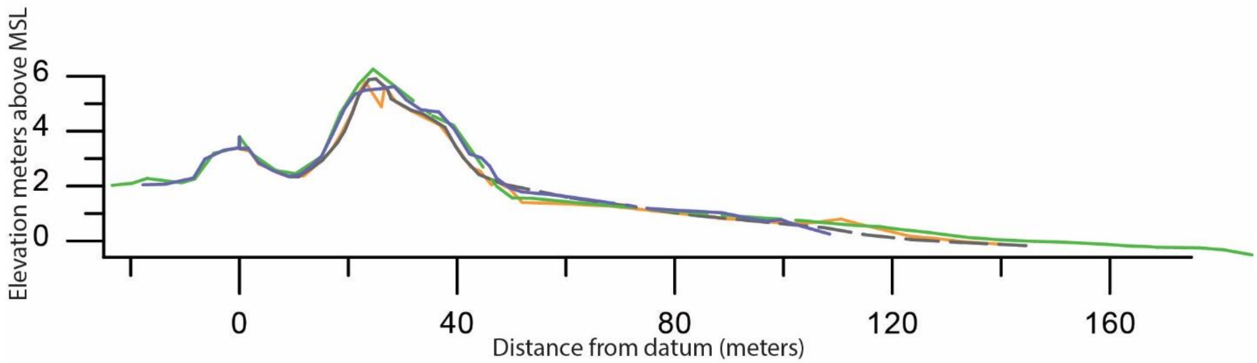
Appendix

A. Beach and Dune Morphology – Beach profile graphs

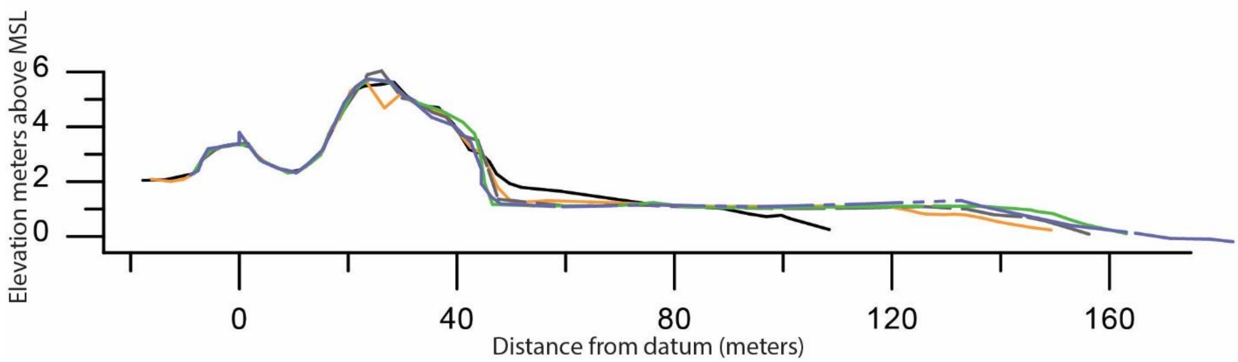
[Continued on next page]

Profile: MUI01
Maintenance Category: High



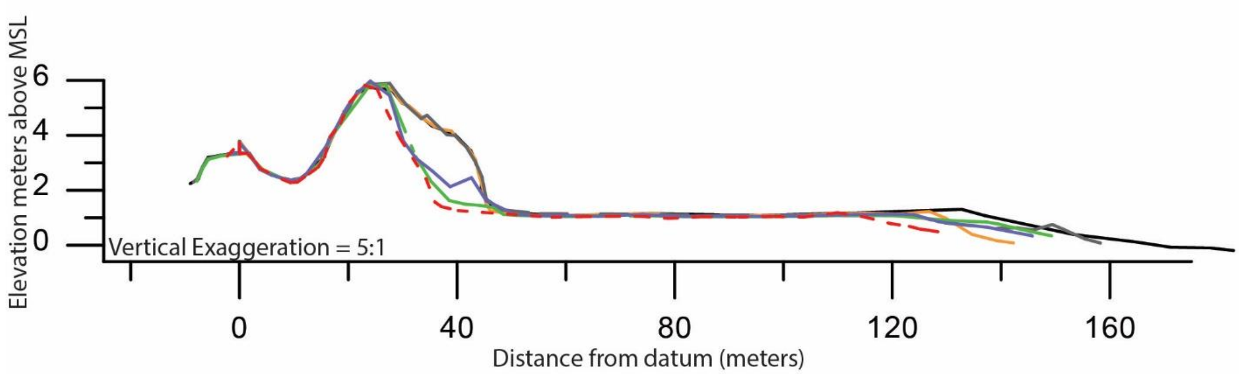
MUI01 - Epoch 1

09/10/2008 11/17/2009
09/18/2008 07/06/2010



MUI01 - Epoch 2

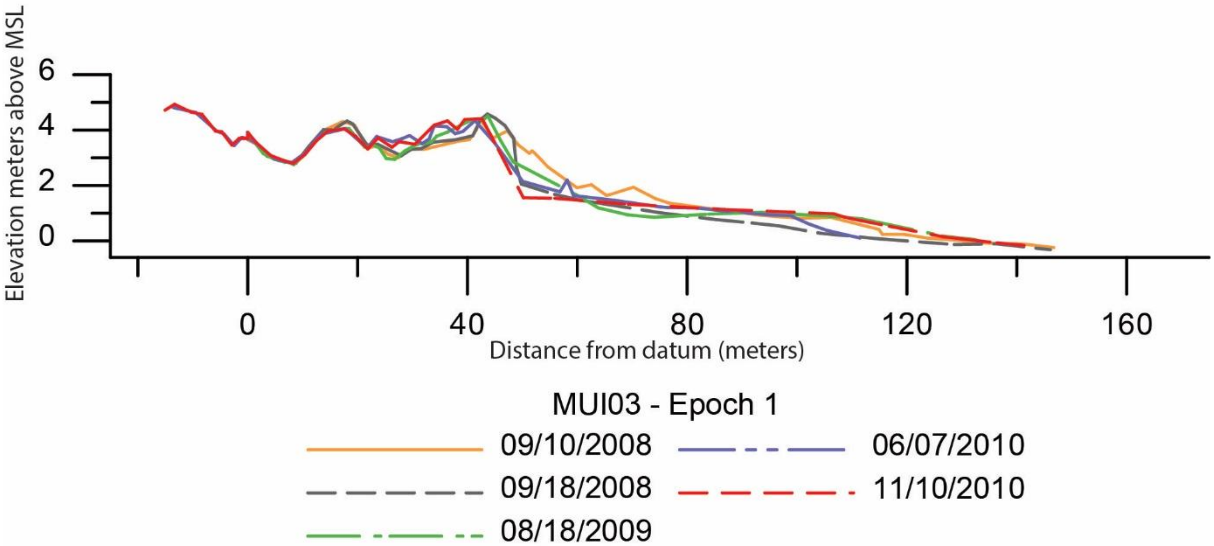
07/06/2010 05/22/2013
06/15/2011 10/07/2013
05/22/2012

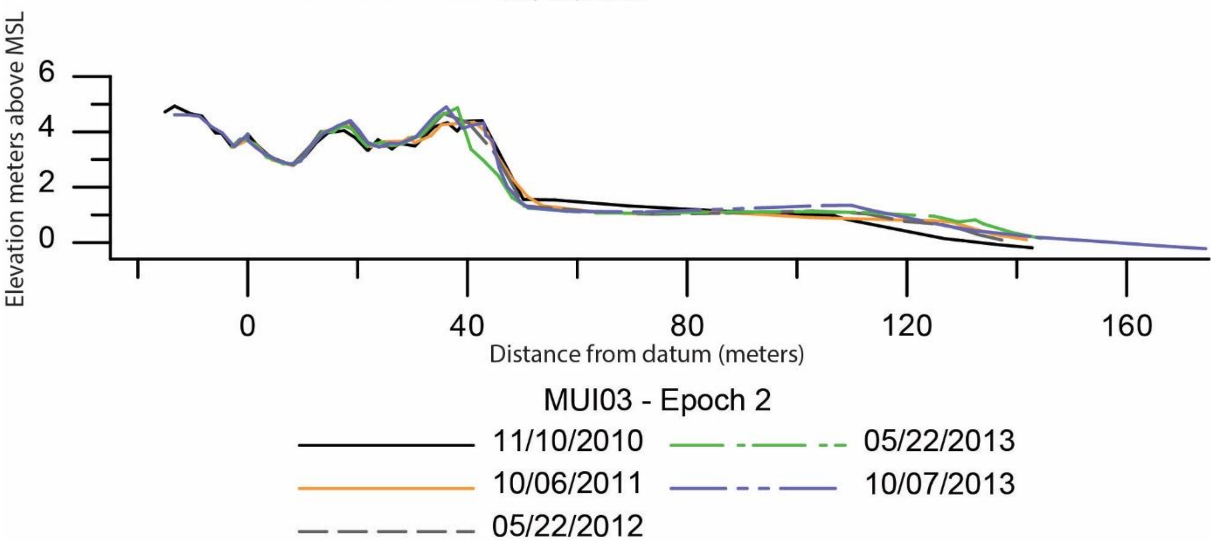


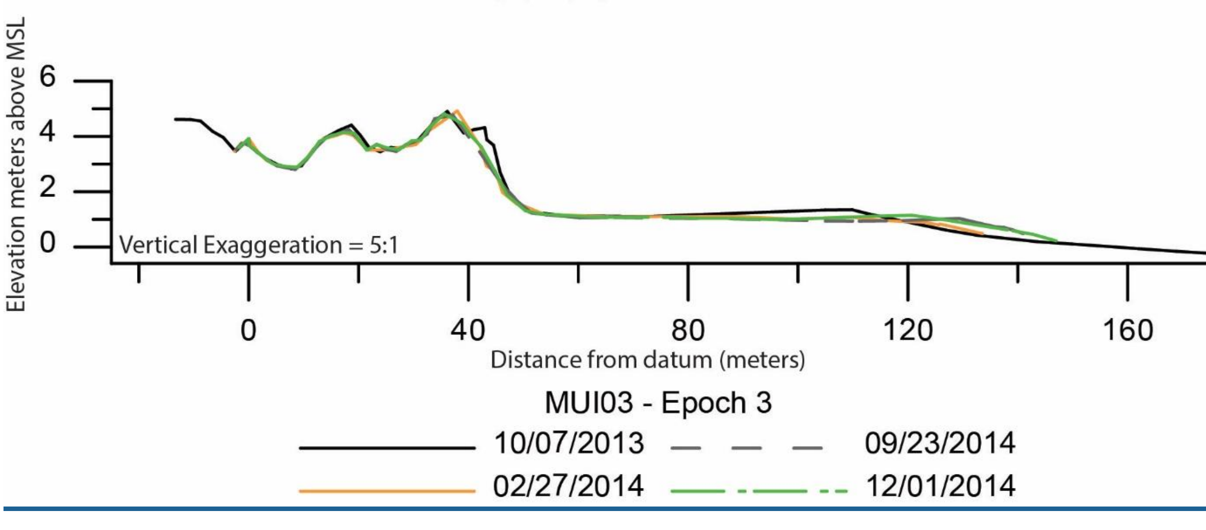
MUI01 - Epoch 3

10/07/2013 09/23/2014
02/27/2014 12/01/2014
06/23/2014 03/11/2015

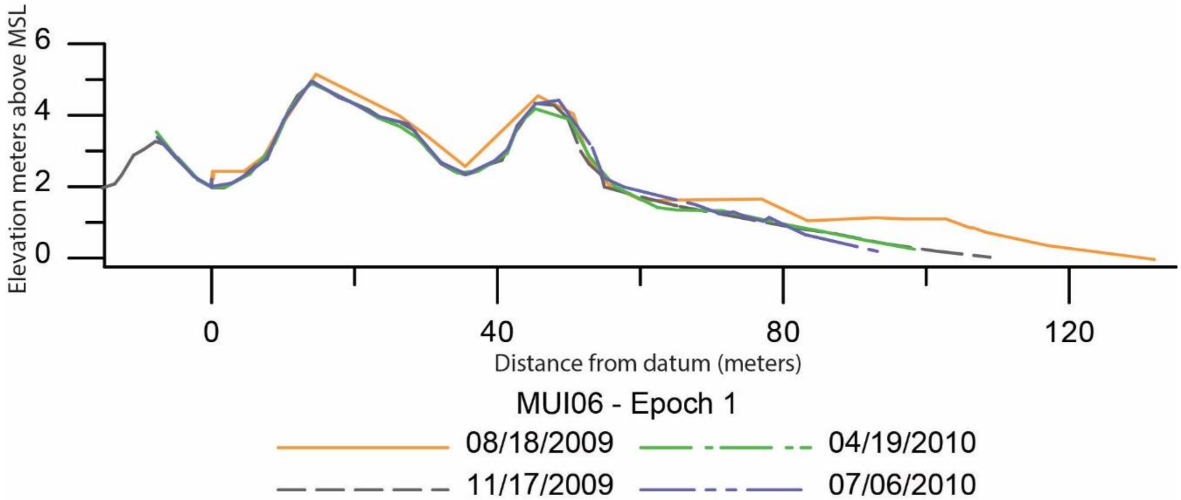
Profile: MUI03
Maintenance Category: High

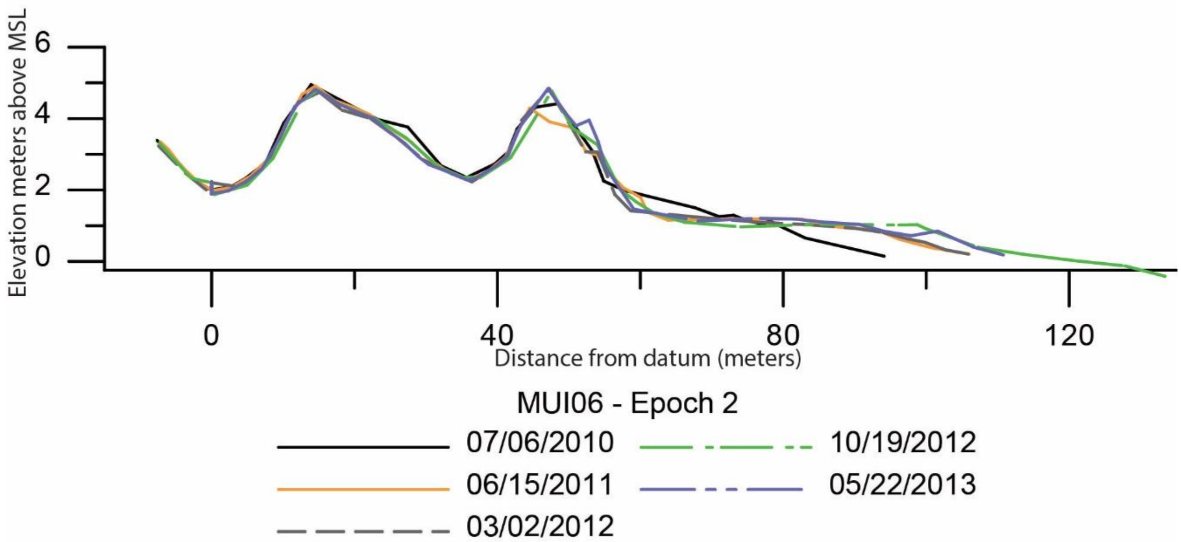


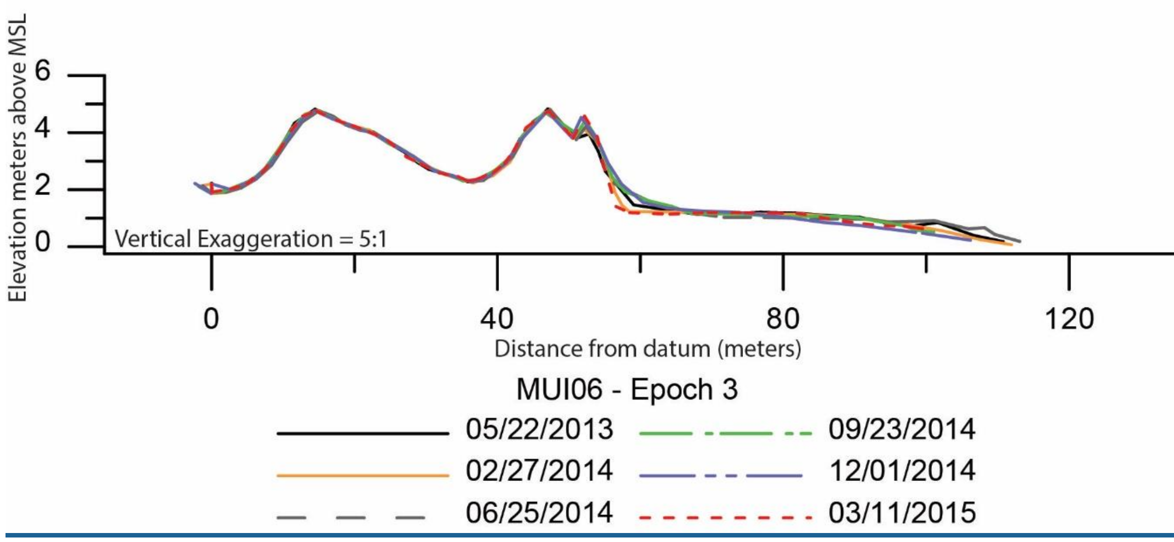




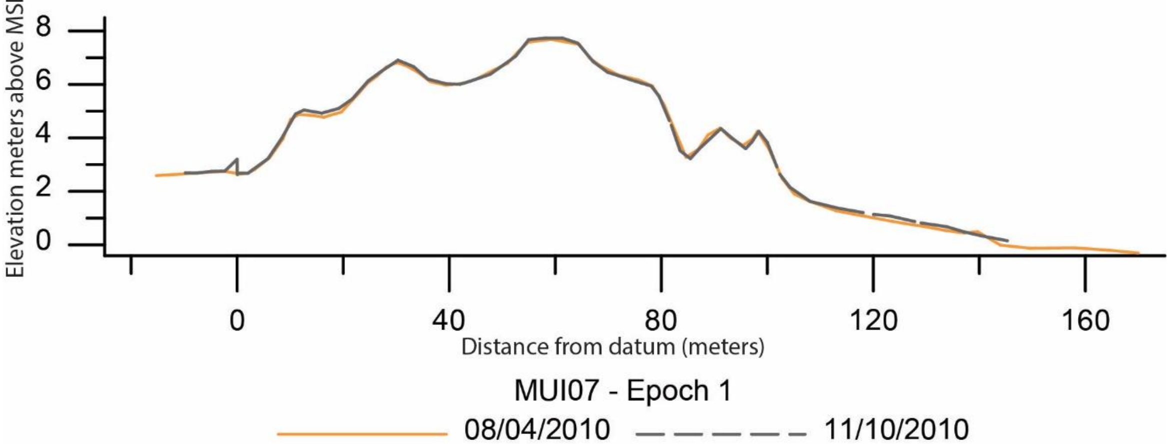
Profile: MUI06
Maintenance Category: Moderate

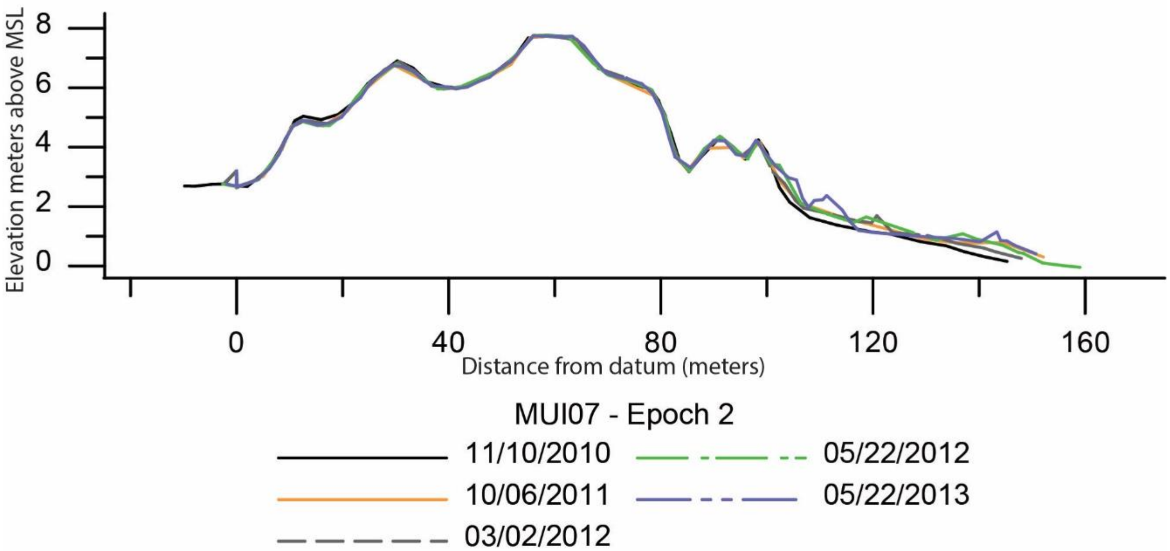


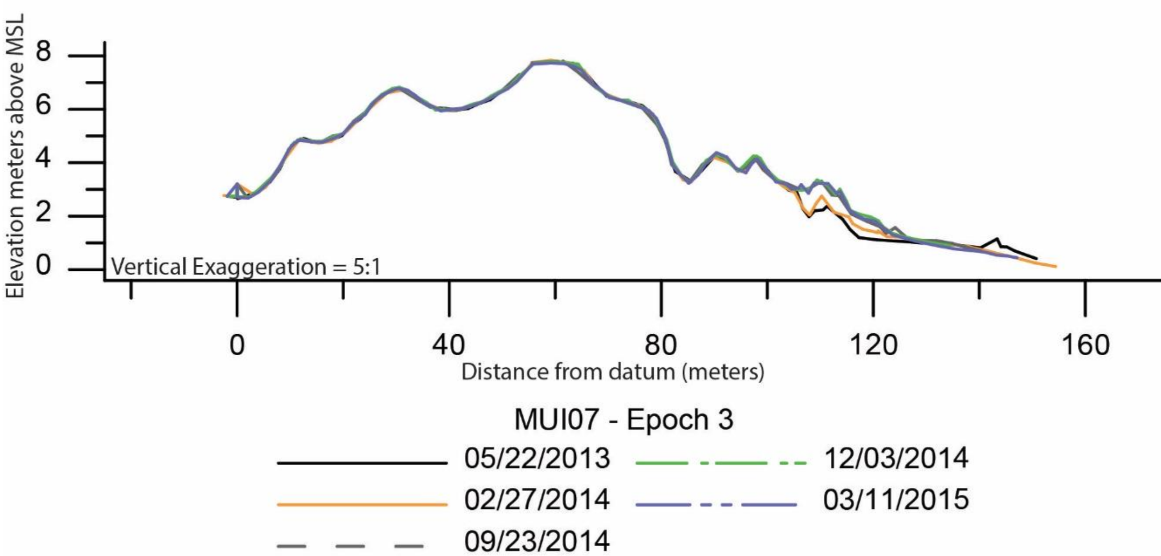




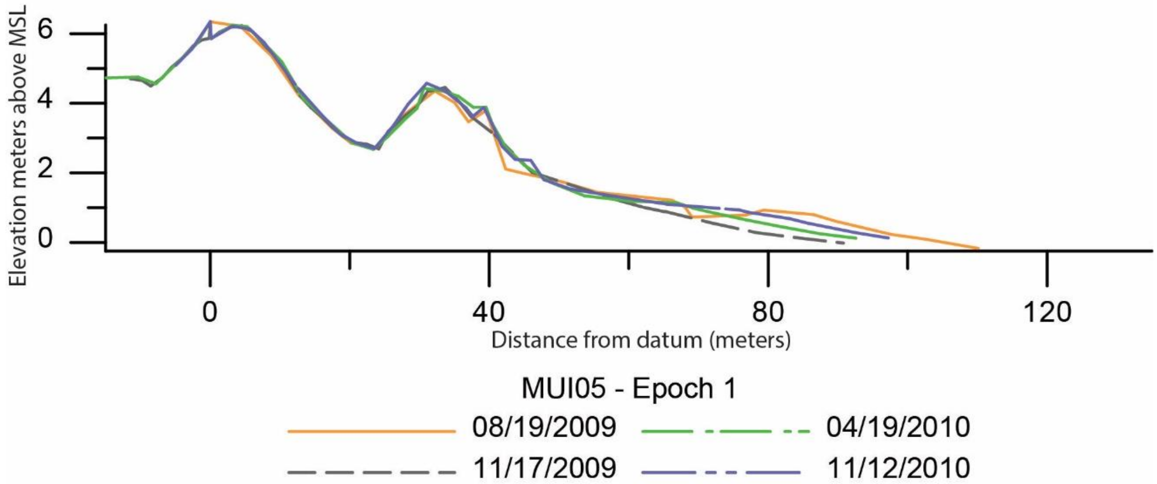
Profile: MUI07
Maintenance Category: Low

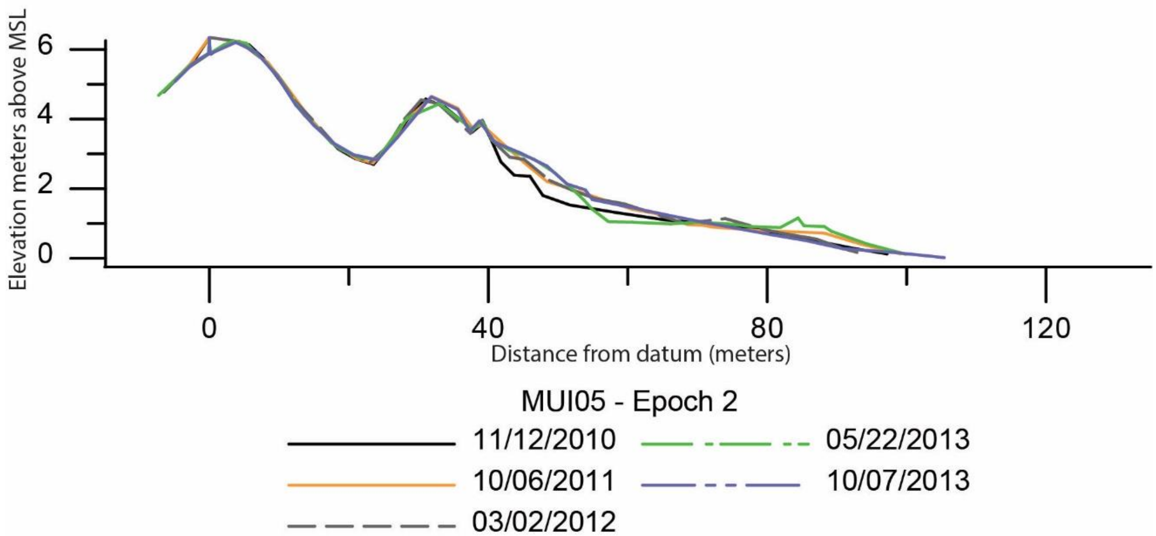


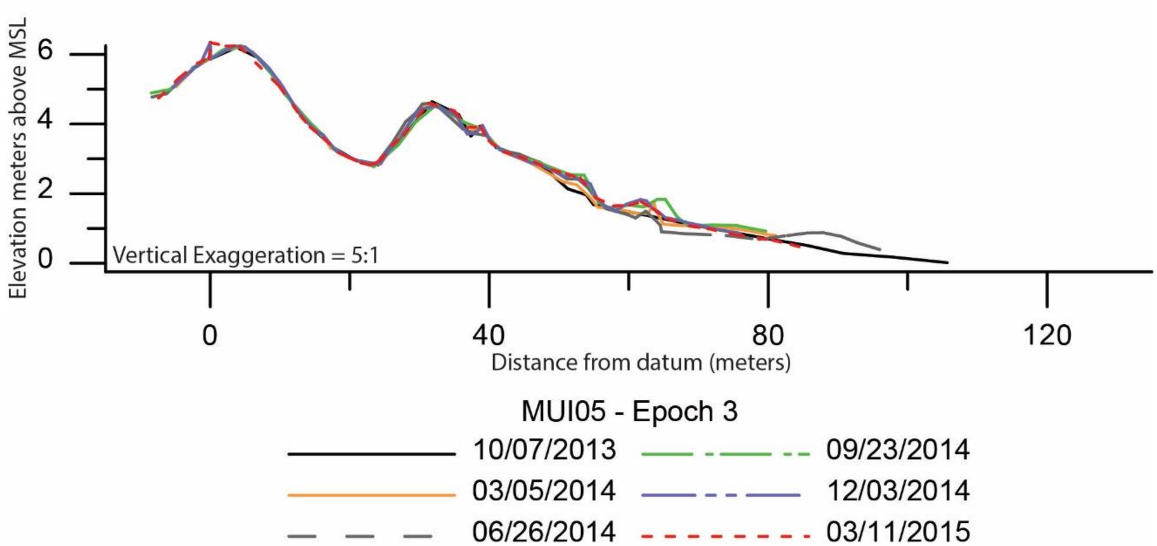




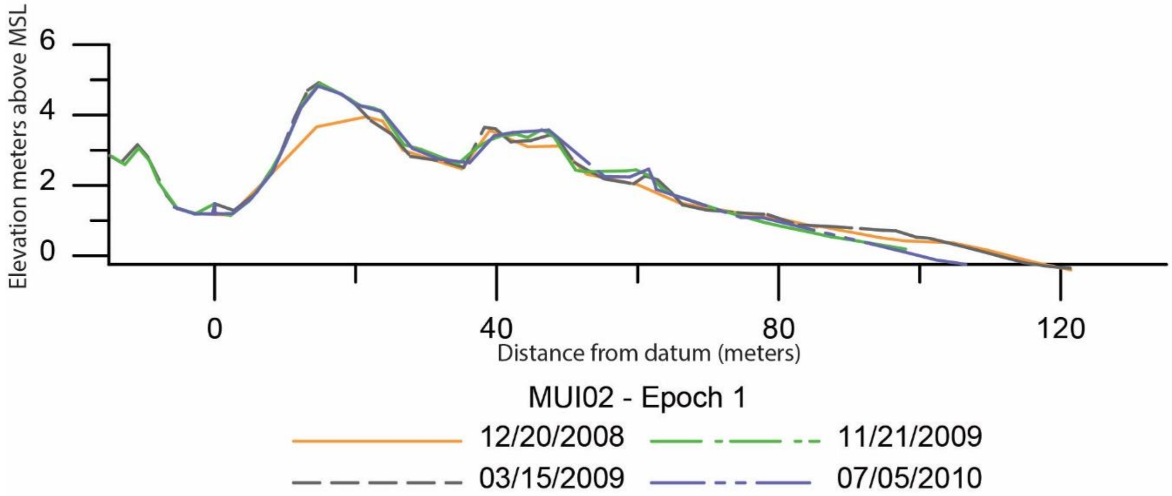
Profile: MUI05
Maintenance Category: Low

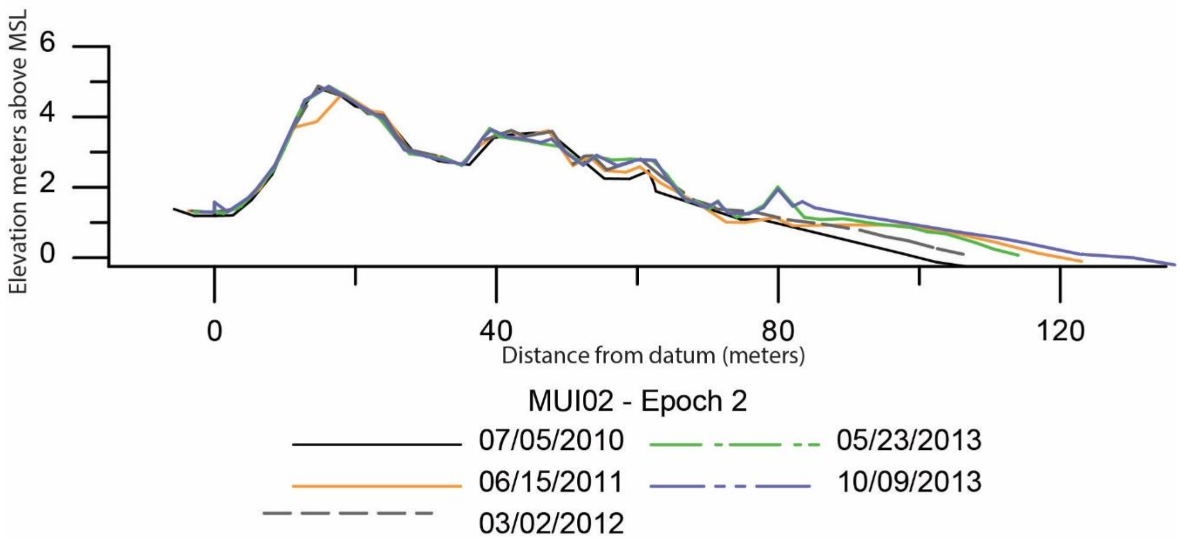


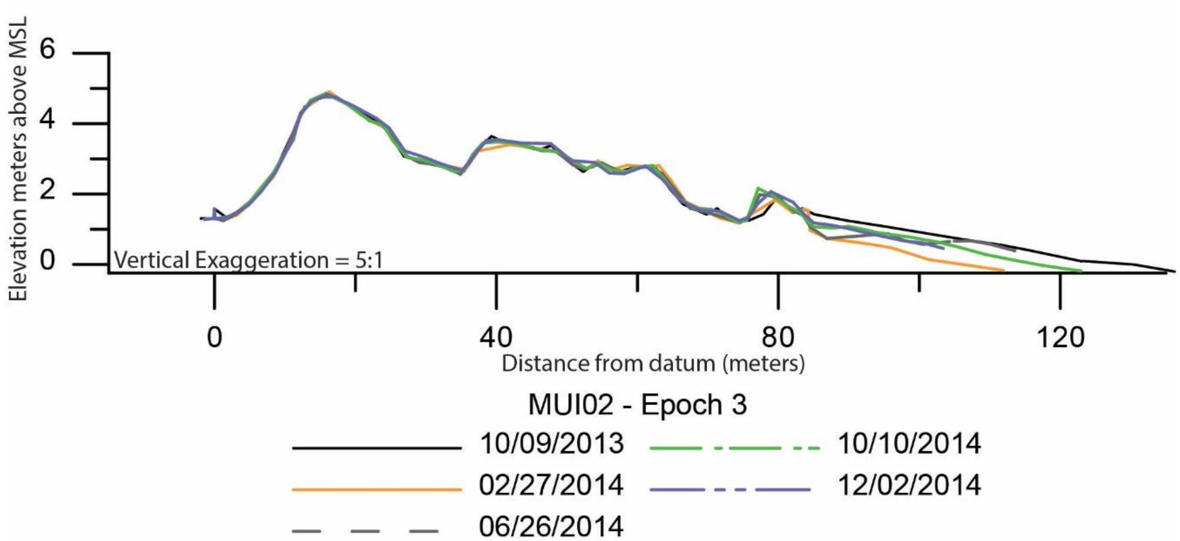




Profile: MUI02
Maintenance Category: Low-None







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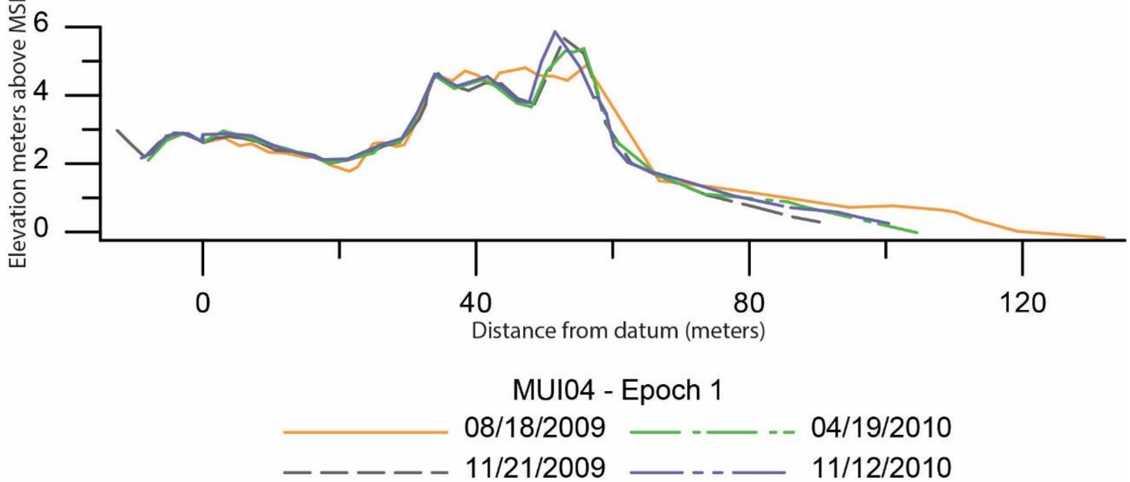
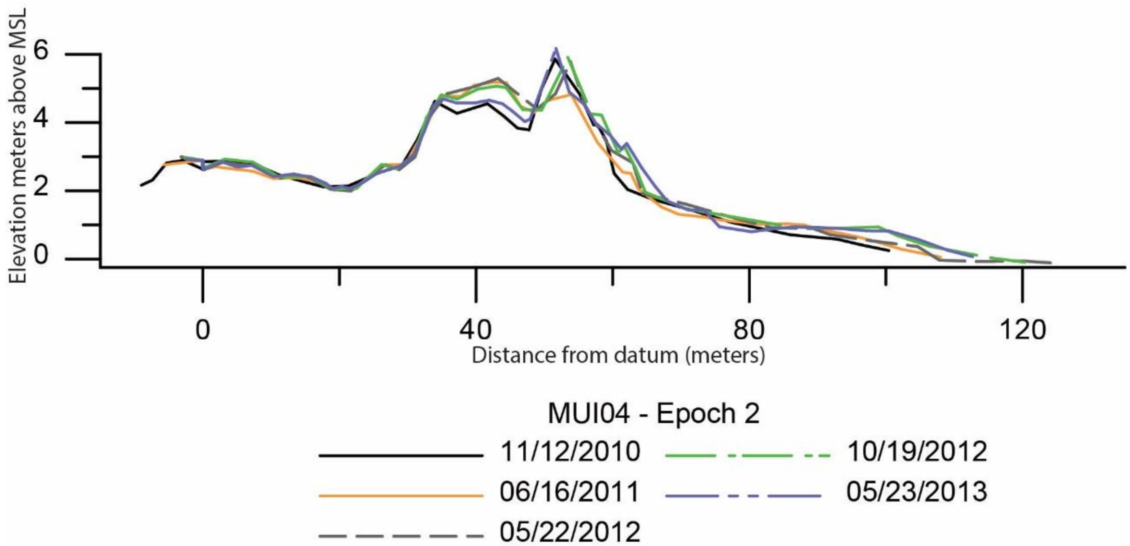
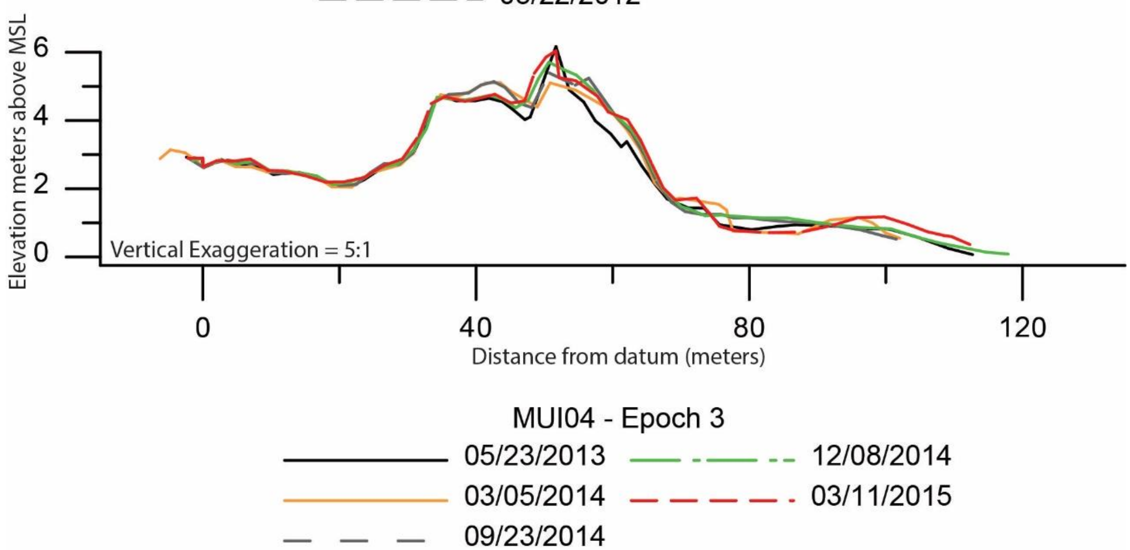
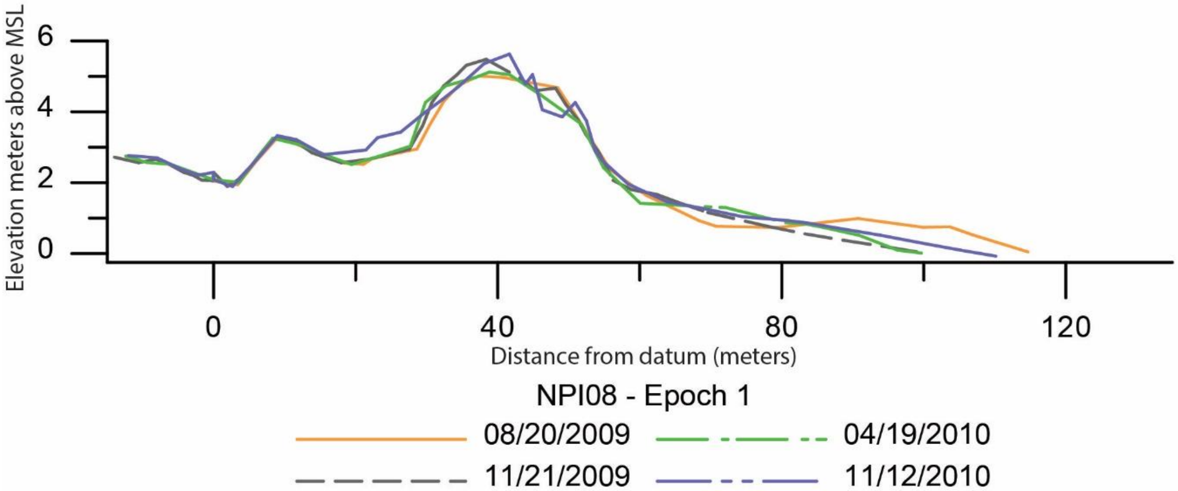
Maintenance Category: Low

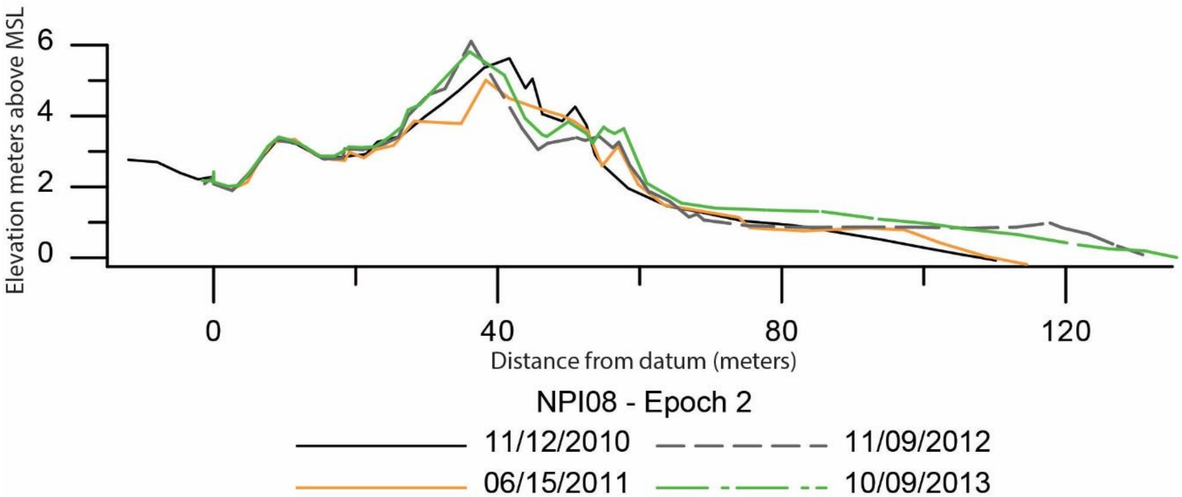


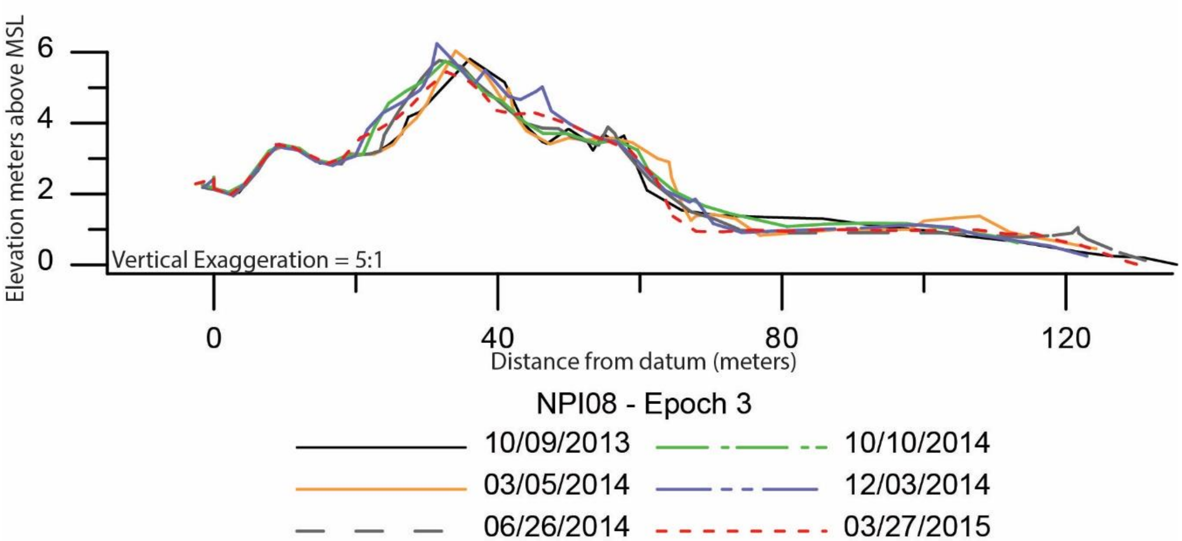




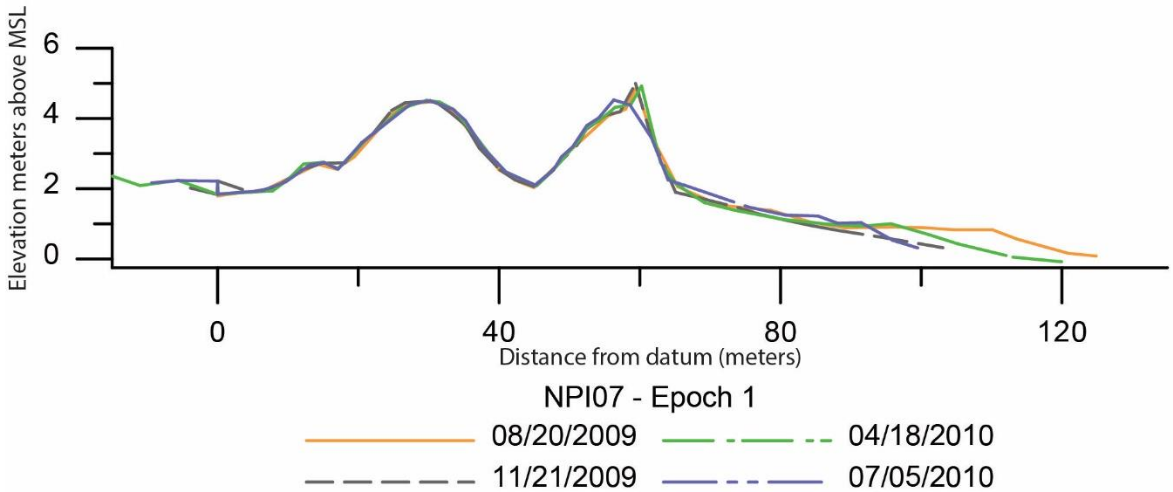
Profile: NPI08
Maintenance Category: High

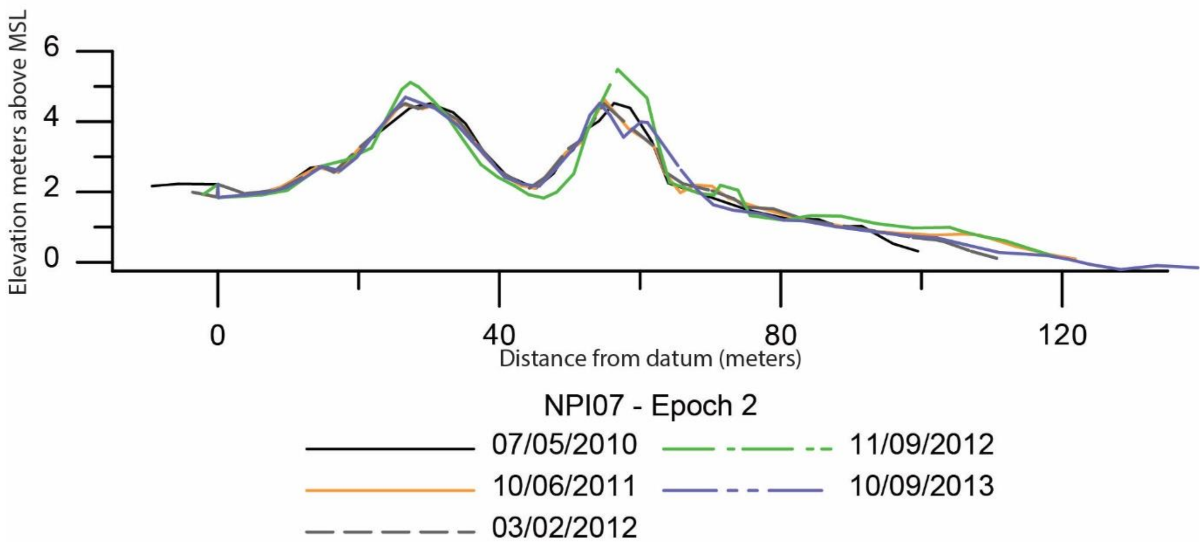


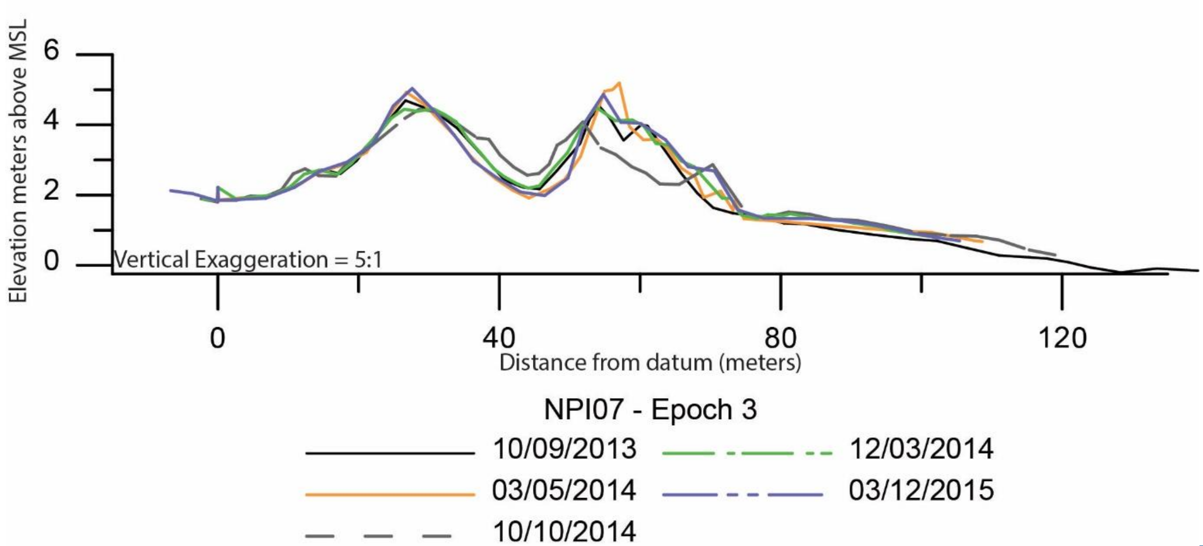




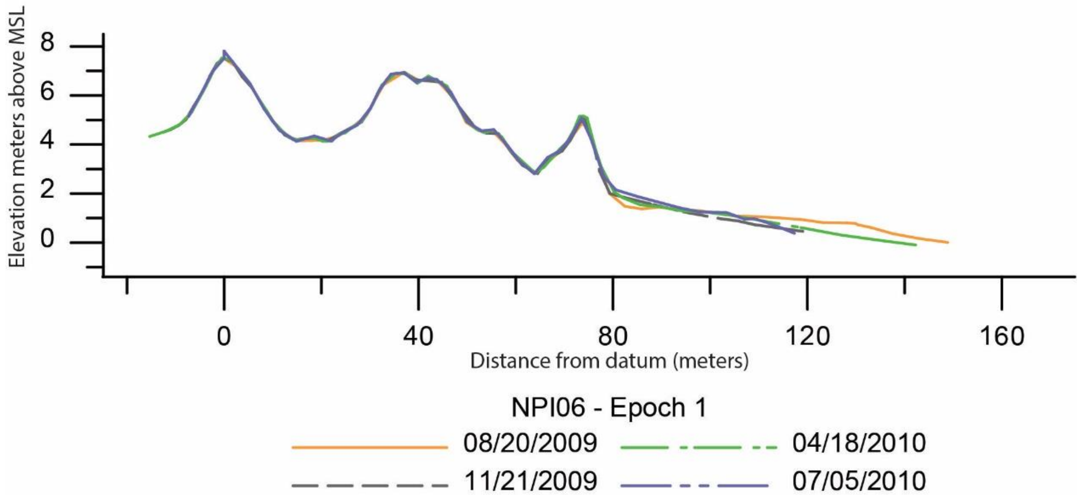
Profile: NPI07
Maintenance Category: Low

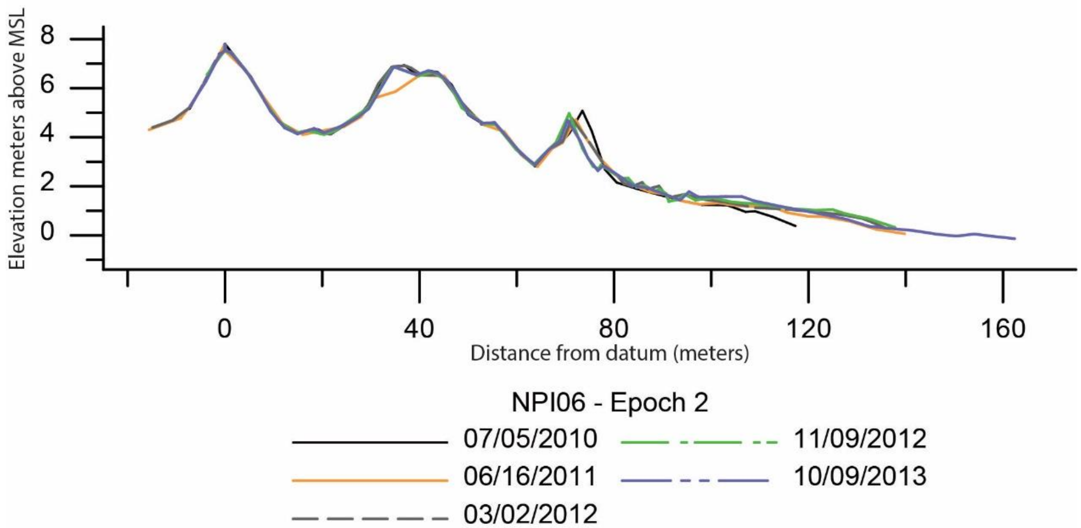


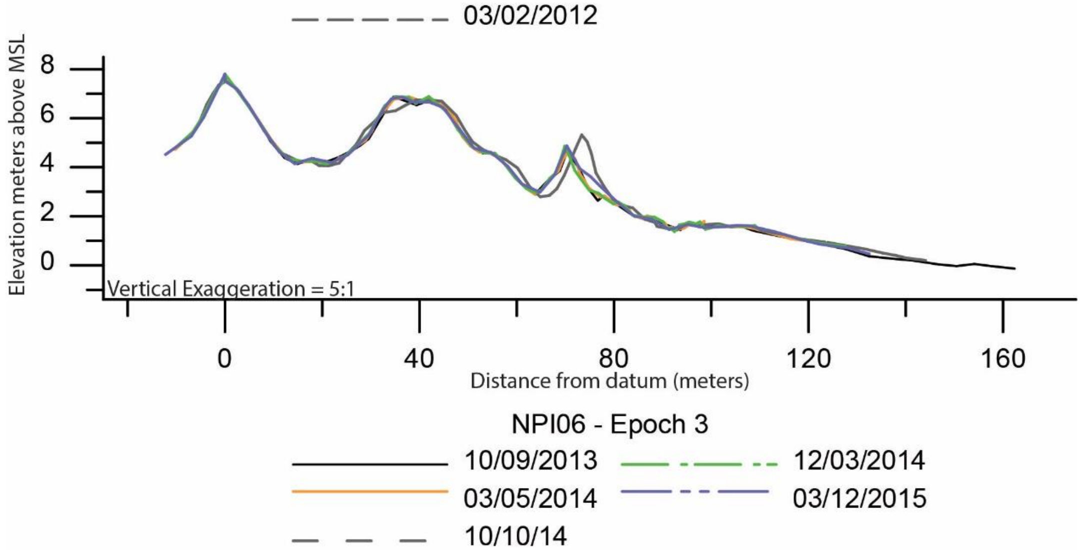




Profile: NPI06
Maintenance Category: Low





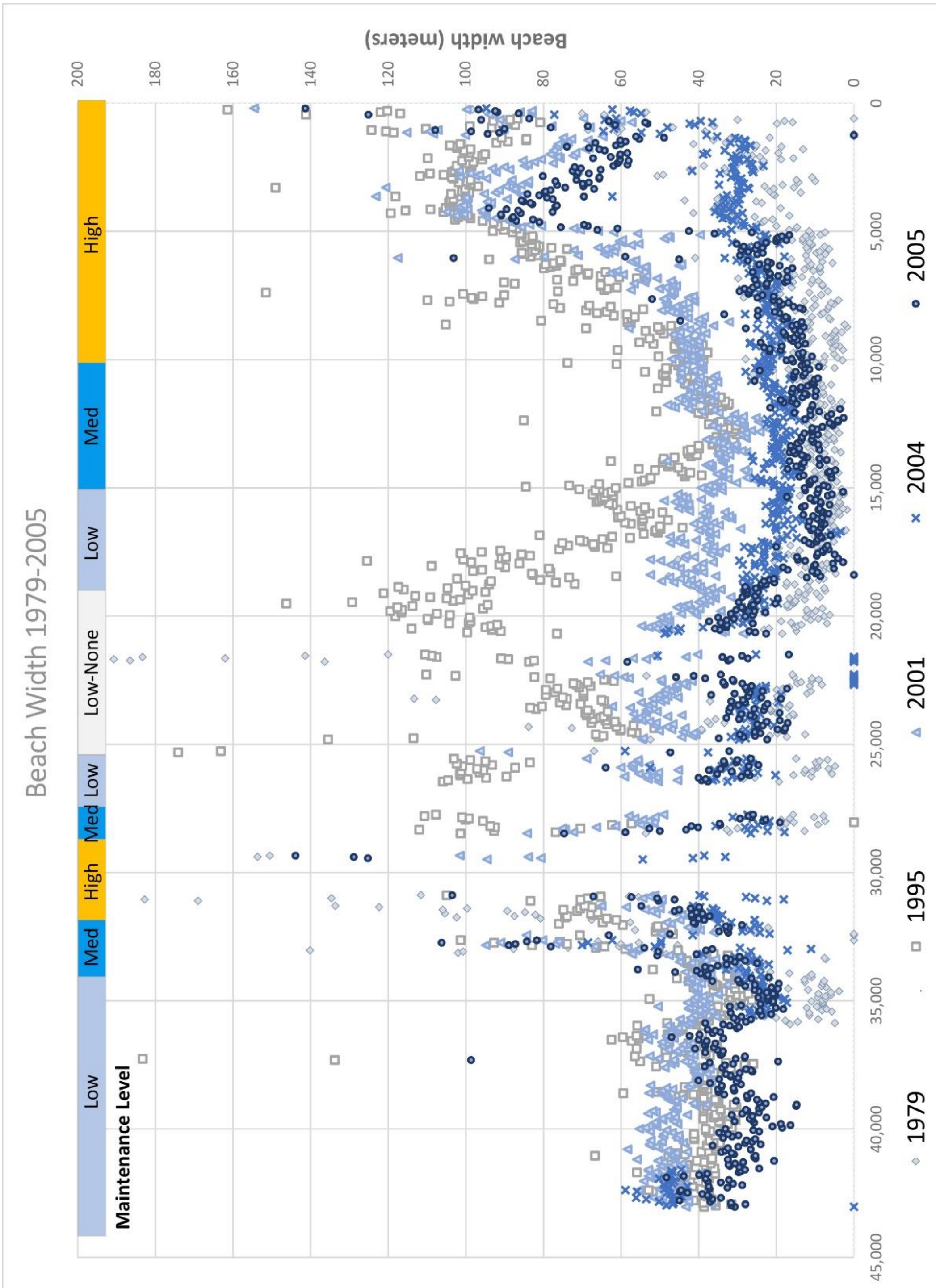


B. Beach and Dune Morphology – Beach profile summary statistics

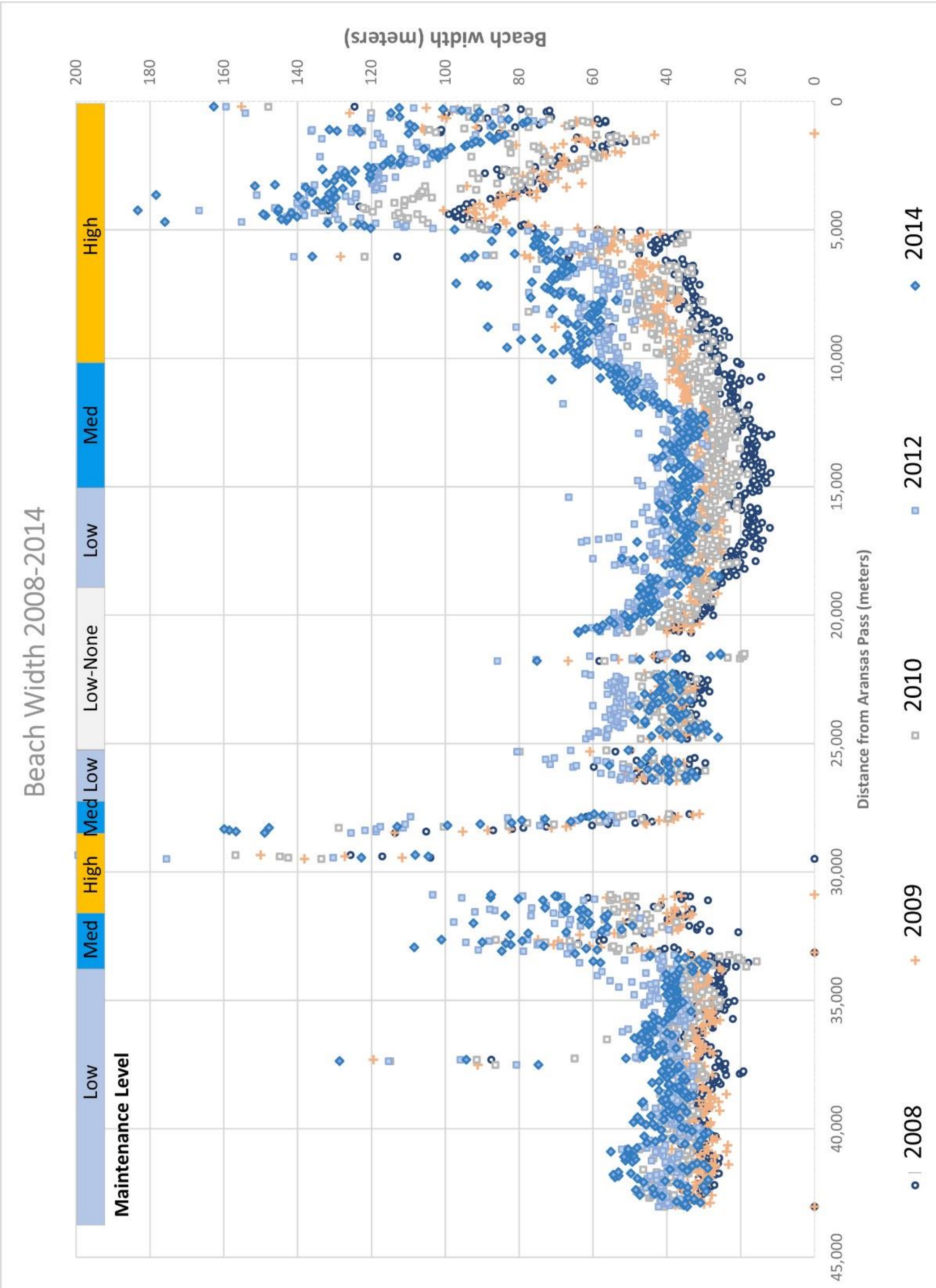
		Elevation						Length			
		Foredune		Dune Toe		Berm		Foredune		Beach	
Profile	N	Average	Std Dev	Average	Std Dev	Average	Std Dev	Average	Std Dev	Average	Std Dev
MUI01	13	5.85	0.17	1.49	0.29	0.88	0.26	21.89	4.93	78.8	18.01
MUI03	12	4.6	0.24	1.54	0.71	0.84	0.23	15.8	7.74	62.4	19.95
MUI06	13	4.61	0.24	1.54	0.37	0.84	0.19	15.05	7.76	33.22	9.67
MUI07	10	4.28	0.12	1.64	0.34	0.76	0.19	23.46	7.04	25.29	7.5
MUI05	13	4.53	0.09	1.9	0.68	0.87	0.16	20.72	7.4	26.53	9.76
MUI02	12	3.56	0.08	1.33	0.3	0.61	0.18	33.84	11.45	23.86	9.15
MUI04	12	5.46	0.5	1.55	0.48	0.67	0.17	18.26	6.05	29.94	7.82
NPI08	13	5.62	0.42	1.64	0.58	0.83	0.23	27.88	9.15	41.02	13.27
NPI07	12	4.73	0.41	1.7	0.46	0.84	0.27	15.3	7.71	29.61	9.33
NPI06	12	4.9	0.17	1.8	0.4	0.8	0.29	14.07	7.2	37.26	8.32

		Slope				
		Foredune		Beach		Maintenance
Profile	N	Average	Std Dev	Average	Std Dev	Level
MUI01	13	-0.21	0.07	-0.01	0.01	High
MUI03	12	-0.19	0.08	-0.01	0.01	High
MUI06	13	-0.23	0.06	-0.02	0.01	Moderate
MUI07	10	-0.12	0.03	-0.04	0.01	Low
MUI05	13	-0.13	0.03	-0.04	0.01	Low
MUI02	12	-0.06	0.02	-0.08	0.11	Low
MUI04	12	-0.24	0.09	-0.03	0.02	Low
NPI08	13	-0.13	0.03	-0.04	0.06	High
NPI07	12	-0.28	0.22	-0.03	0.01	Low
NPI06	12	-0.29	0.18	-0.03	0.01	Low

C. Beach Width from 1979-2005

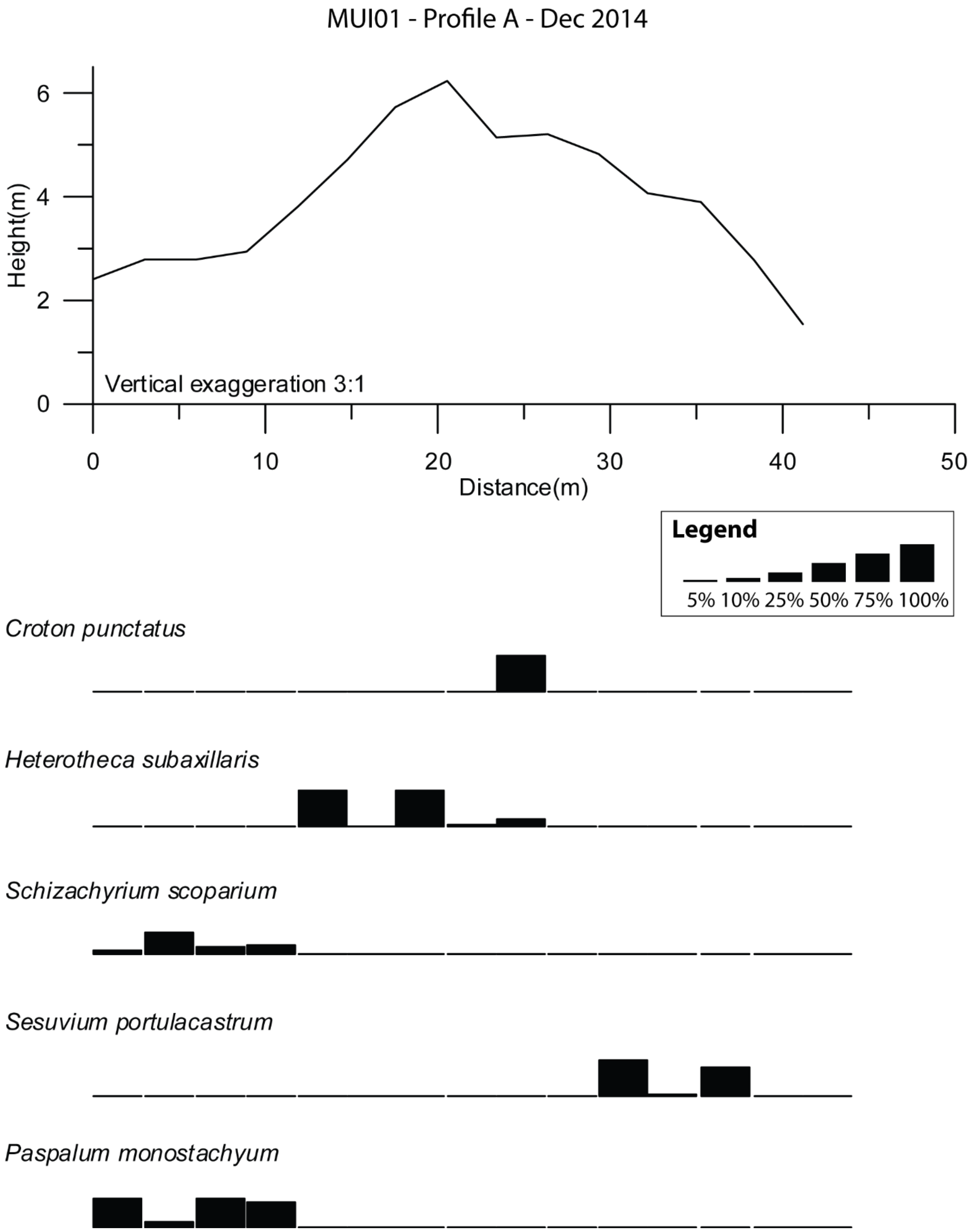


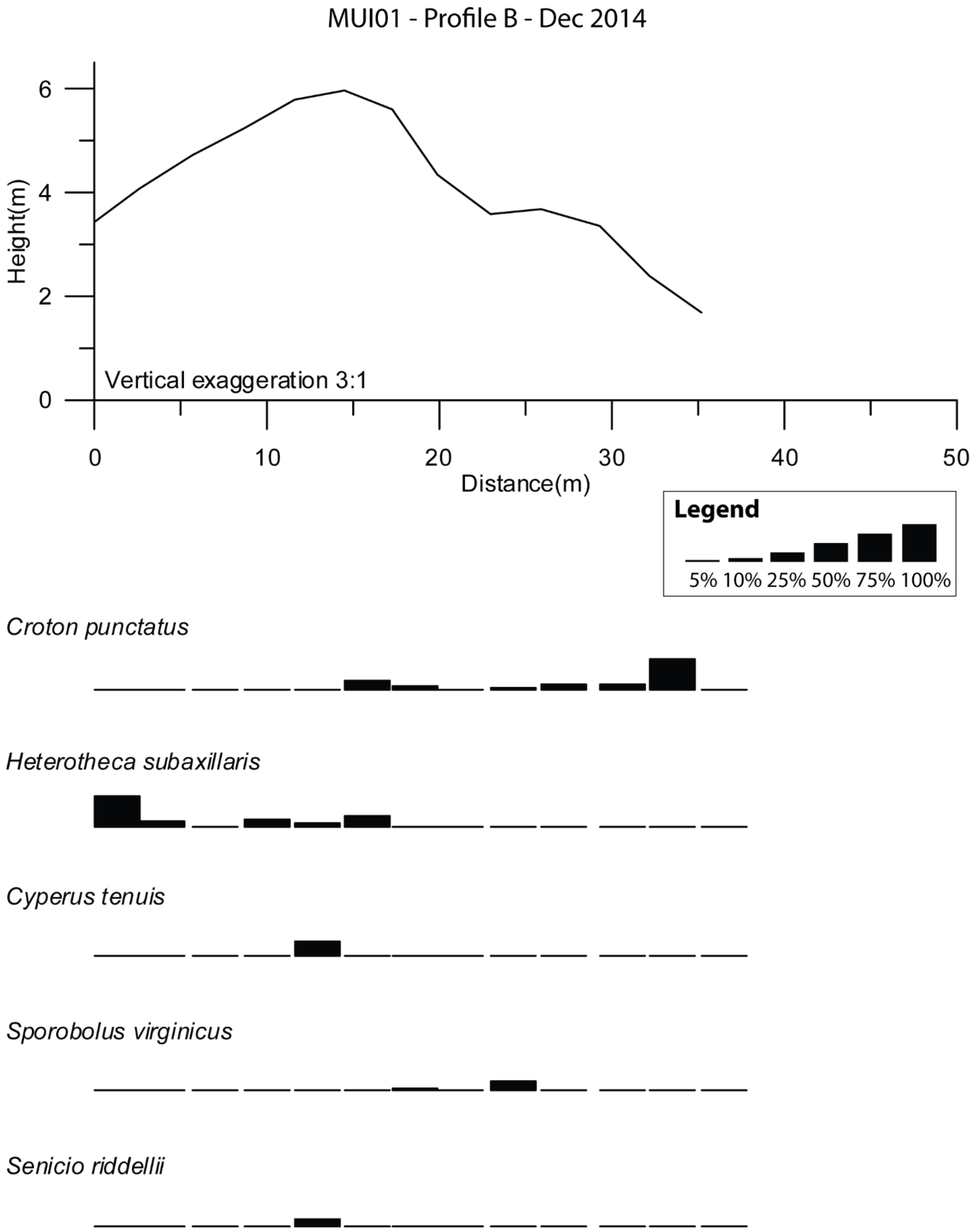
D. Beach Width from 2008-2014

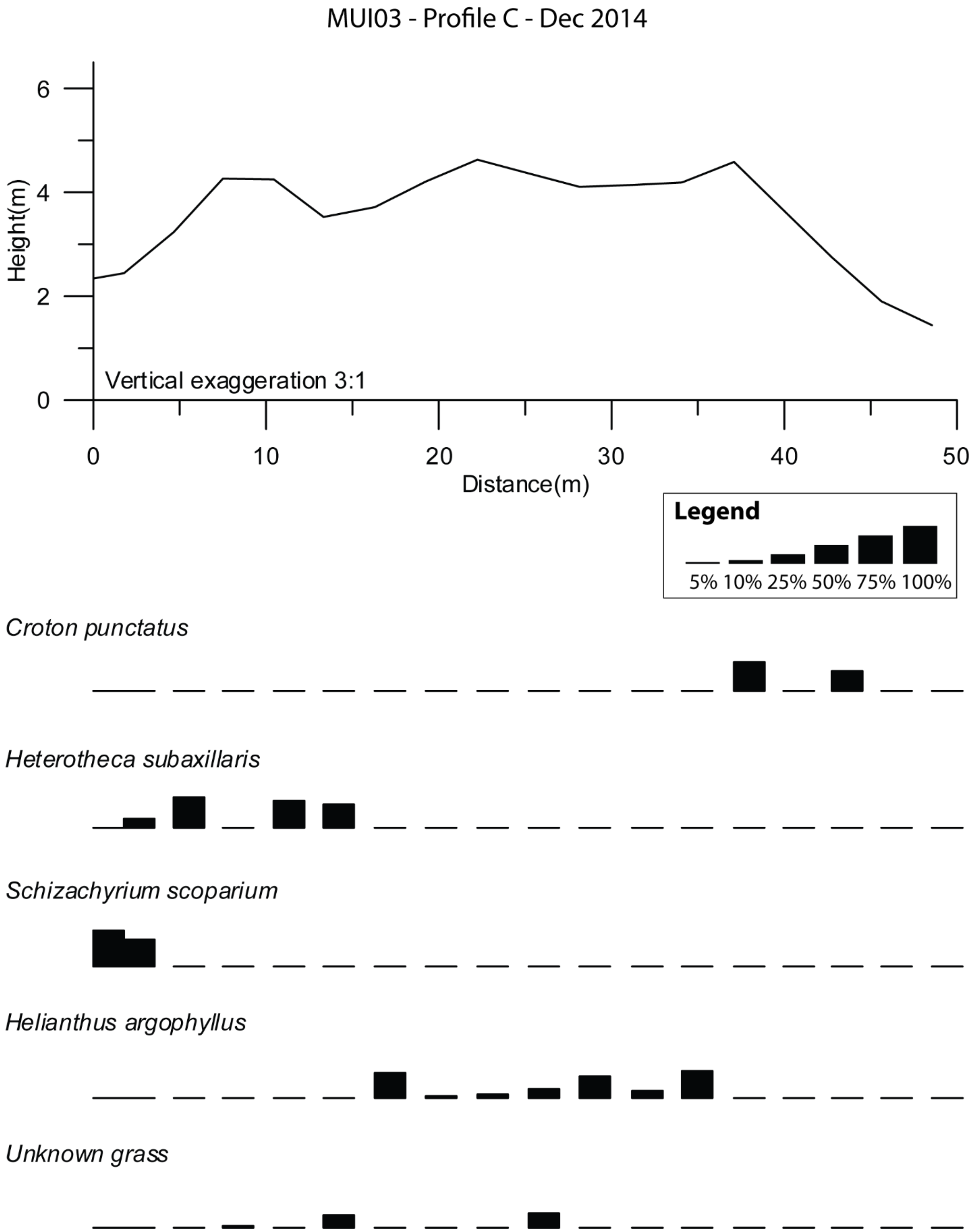


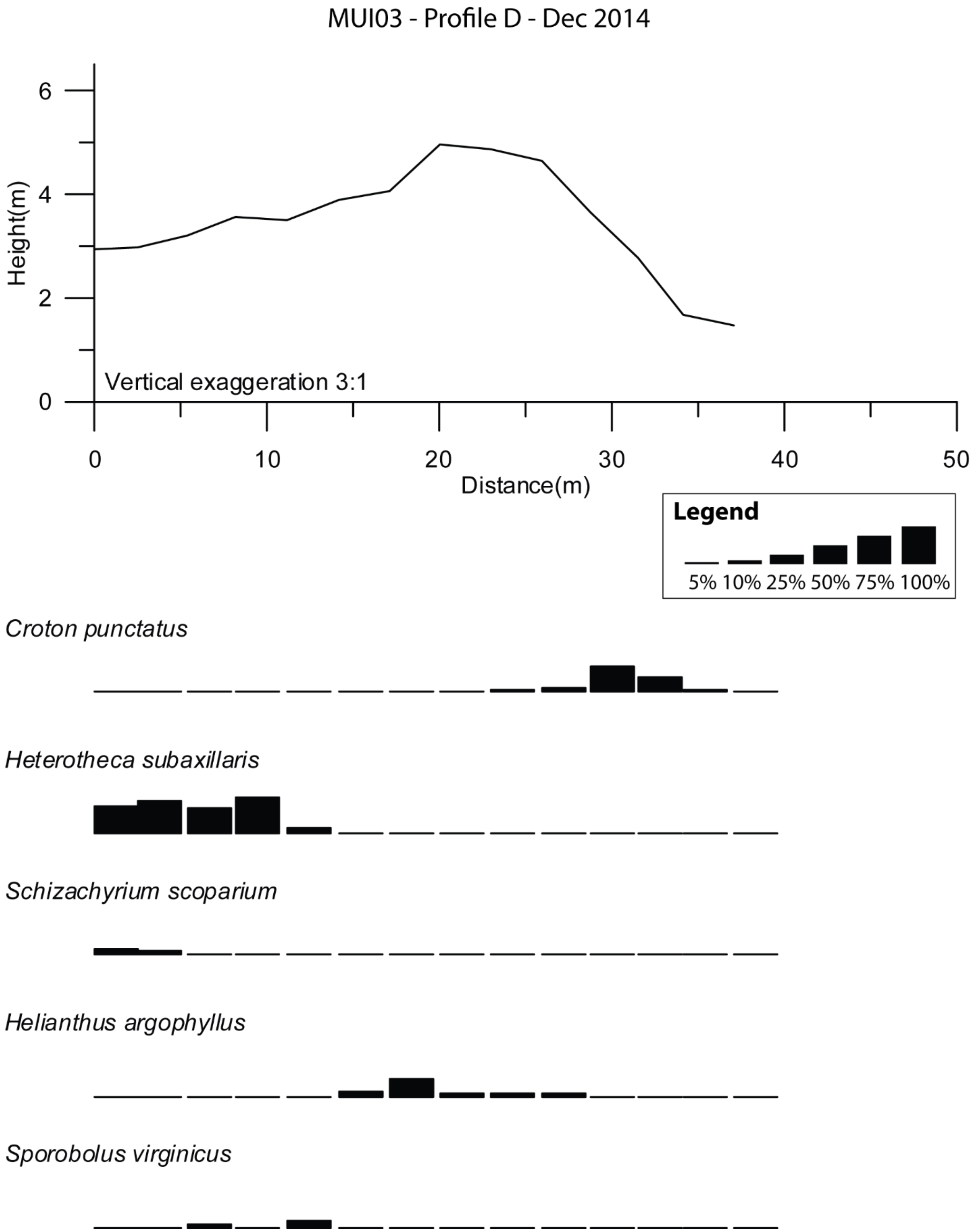
E. Vegetation Transect Data- December 2014 Survey

[Continued on next page]

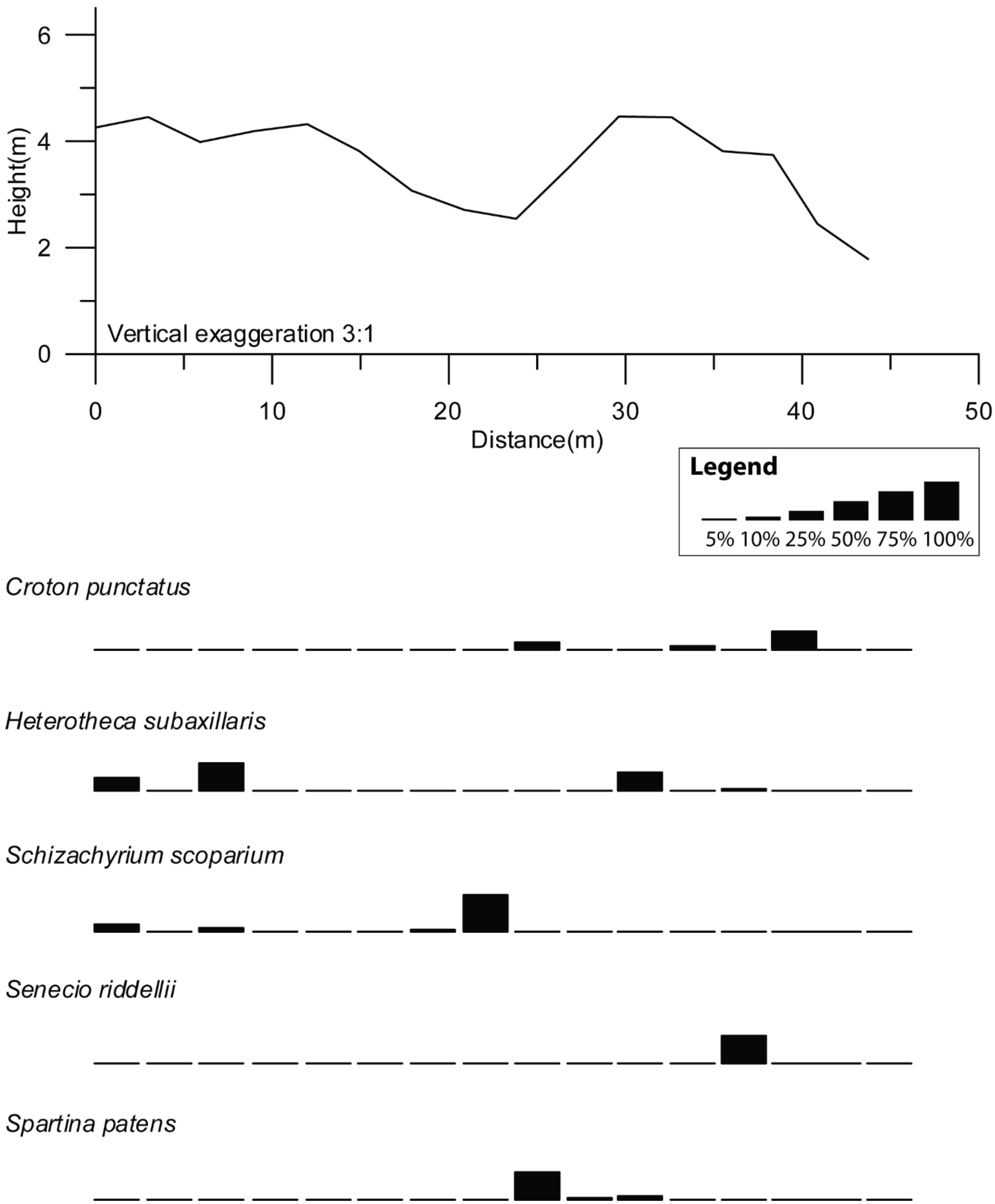

MUI01 - Profile A - Dec 2014
Height(m)
6
4
2
0
Vertical exaggeration 3:1
0
10
20
30
40
50
Distance(m)
Legend
5% 10% 25% 50% 75% 100%
Croton punctatus
Heterotheca subaxillaris
Schizachyrium scoparium
Sesuvium portulacastrum
Paspalum monostachyum

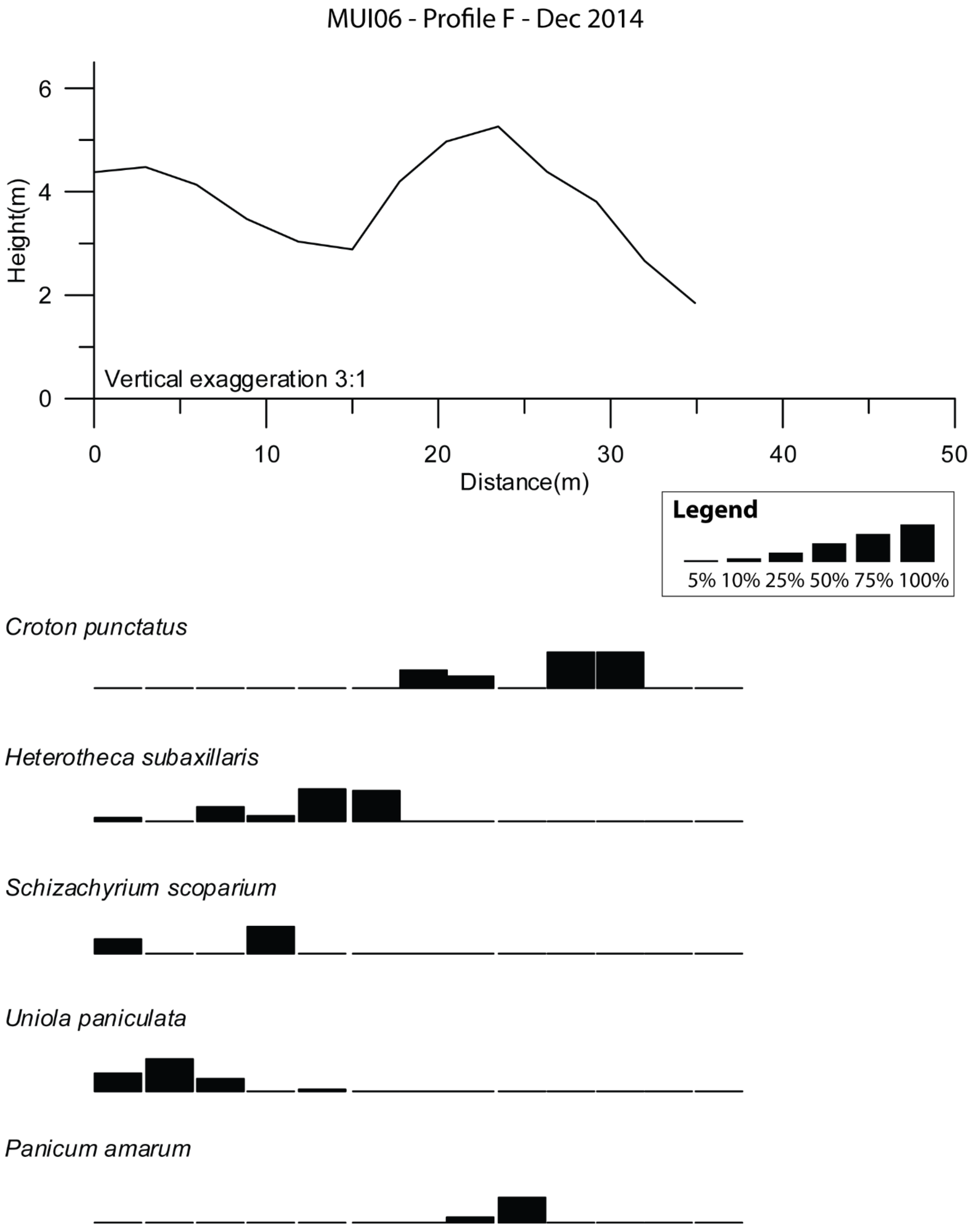

MUI01 - Profile B - Dec 2014
Height(m)
6
4
2
0
Vertical exaggeration 3:1
0
10
20
30
40
50
Distance(m)
Legend
5% 10% 25% 50% 75% 100%
Croton punctatus
Heterotheca subaxillaris
Cyperus tenuis
Sporobolus virginicus
Senicio riddellii

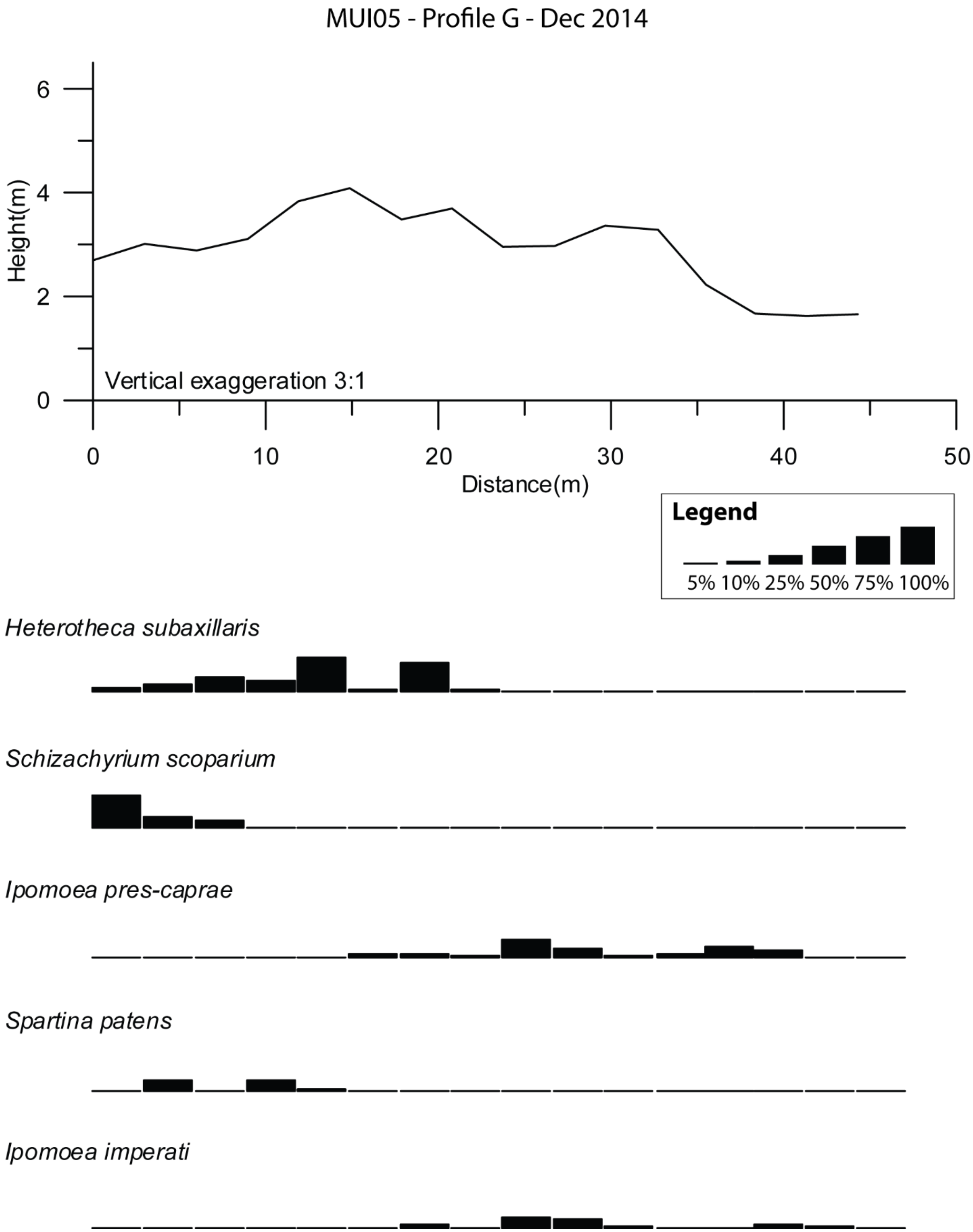

MUI03 - Profile C - Dec 2014
Height(m)
6
4
2
0
Vertical exaggeration 3:1
0
10
20
30
40
50
Distance(m)
Legend
5% 10% 25% 50% 75% 100%
Croton punctatus
Heterotheca subaxillaris
Schizachyrium scoparium
Helianthus argophyllus
Unknown grass


MUI03 - Profile D - Dec 2014
Height(m)
6
4
2
0
Vertical exaggeration 3:1
0
10
20
30
40
50
Distance(m)
Legend
5% 10% 25% 50% 75% 100%
Croton punctatus
Heterotheca subaxillaris
Schizachyrium scoparium
Helianthus argophyllus
Sporobolus virginicus

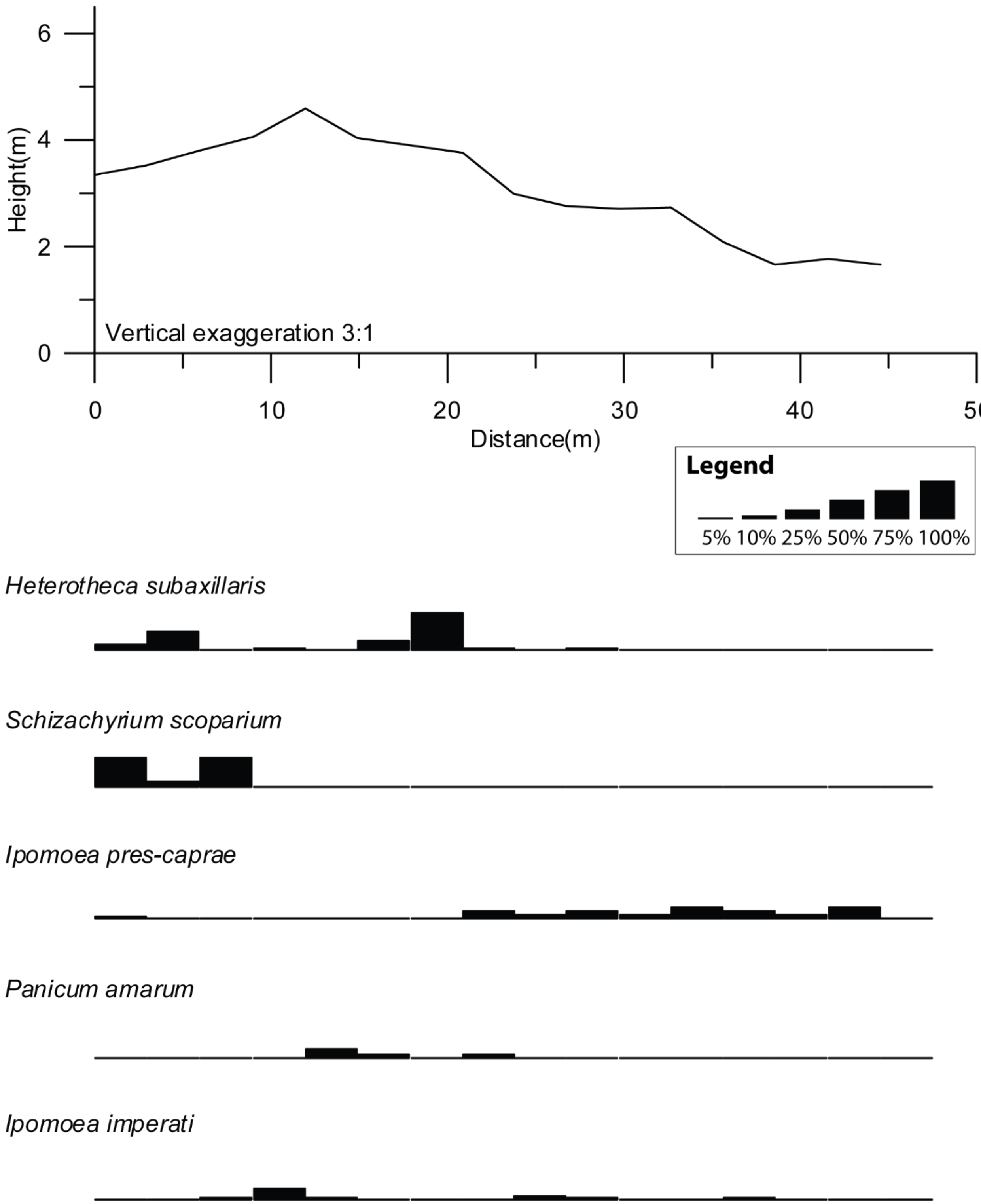
MUI06 - Profile E - Dec 2014



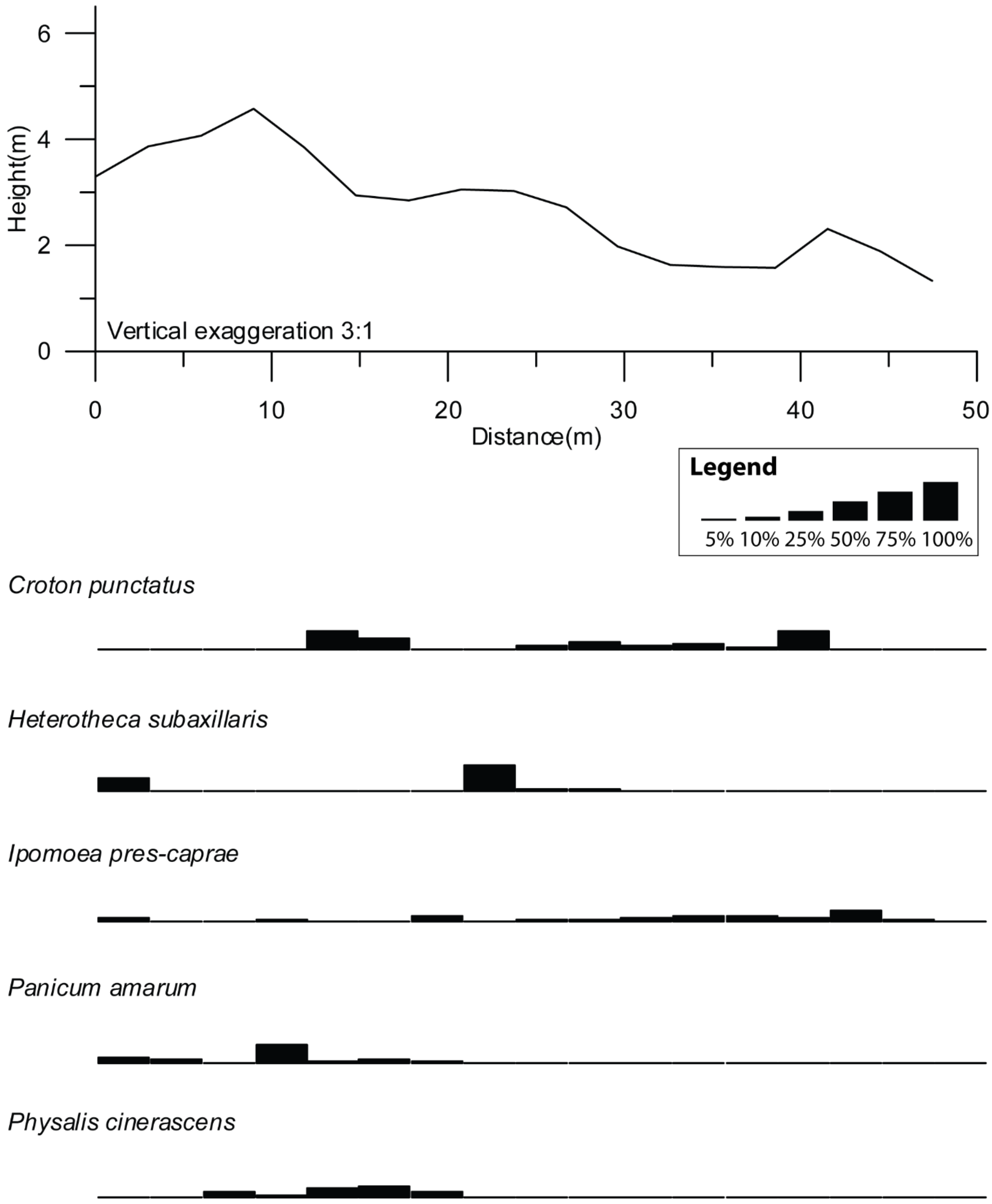

MUI06 - Profile F - Dec 2014
6
4
2
0
Height(m)
Vertical exaggeration 3:1
0
10
20
30
40
50
Distance(m)
Legend
5% 10% 25% 50% 75% 100%
Croton punctatus
Heterotheca subaxillaris
Schizachyrium scoparium
Uniola paniculata
Panicum amarum

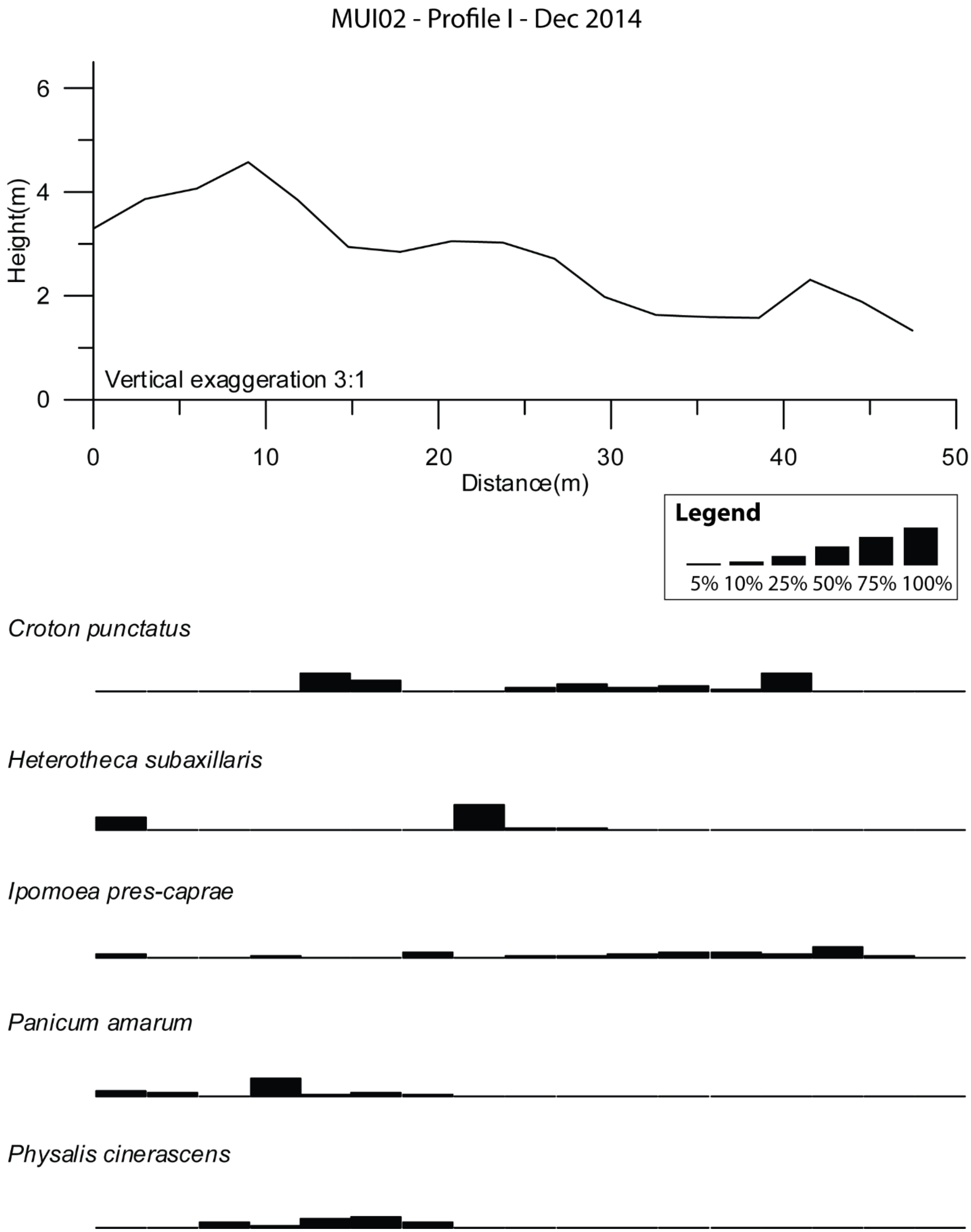

MUI05 - Profile G - Dec 2014
Height(m)
6
4
2
0
Vertical exaggeration 3:1
0
10
20
30
40
50
Distance(m)
Legend
5% 10% 25% 50% 75% 100%
Heterotheca subaxillaris
Schizachyrium scoparium
Ipomoea pres-caprae
Spartina patens
Ipomoea imperati

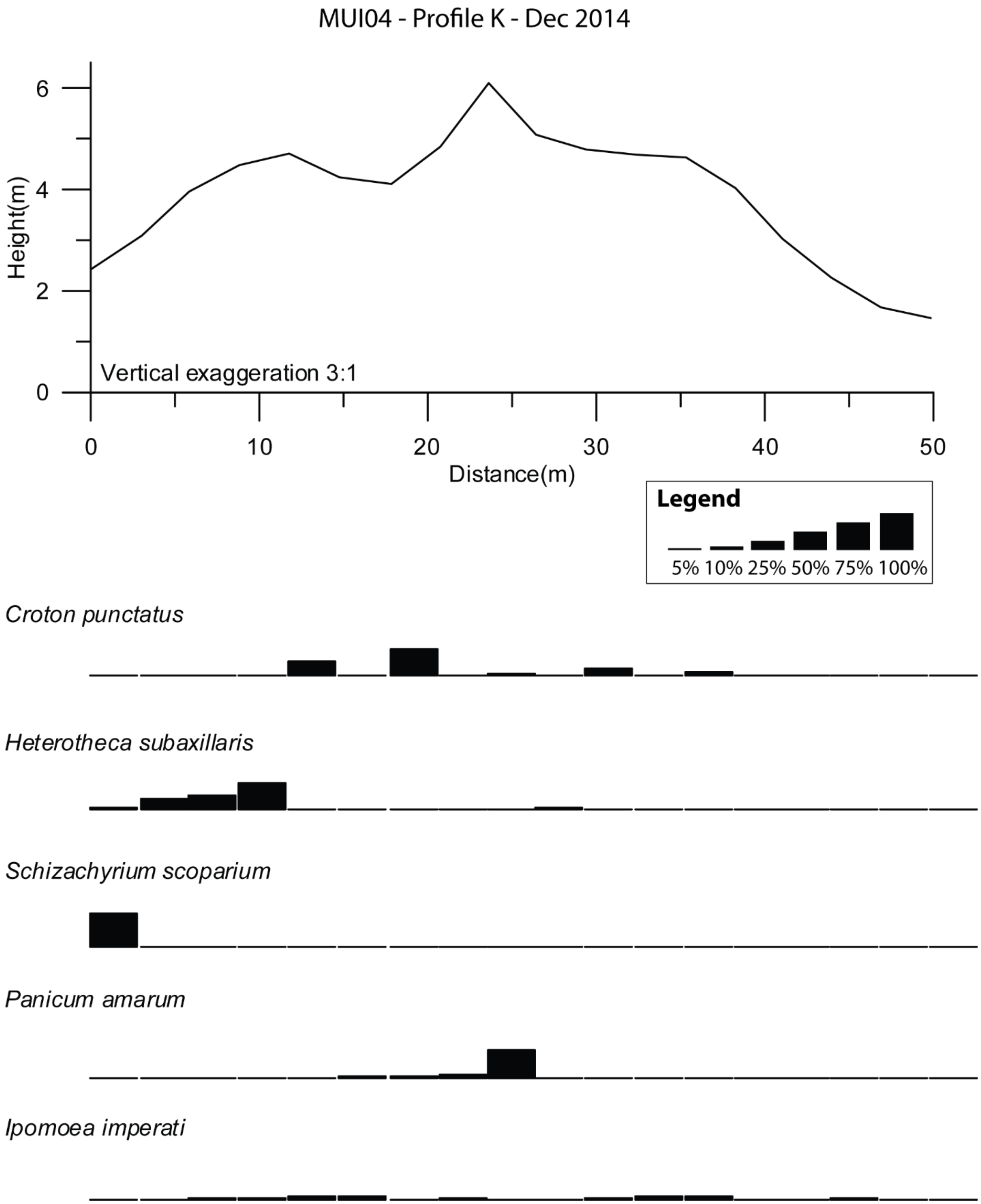
MUI05 - Profile H - Dec 2014

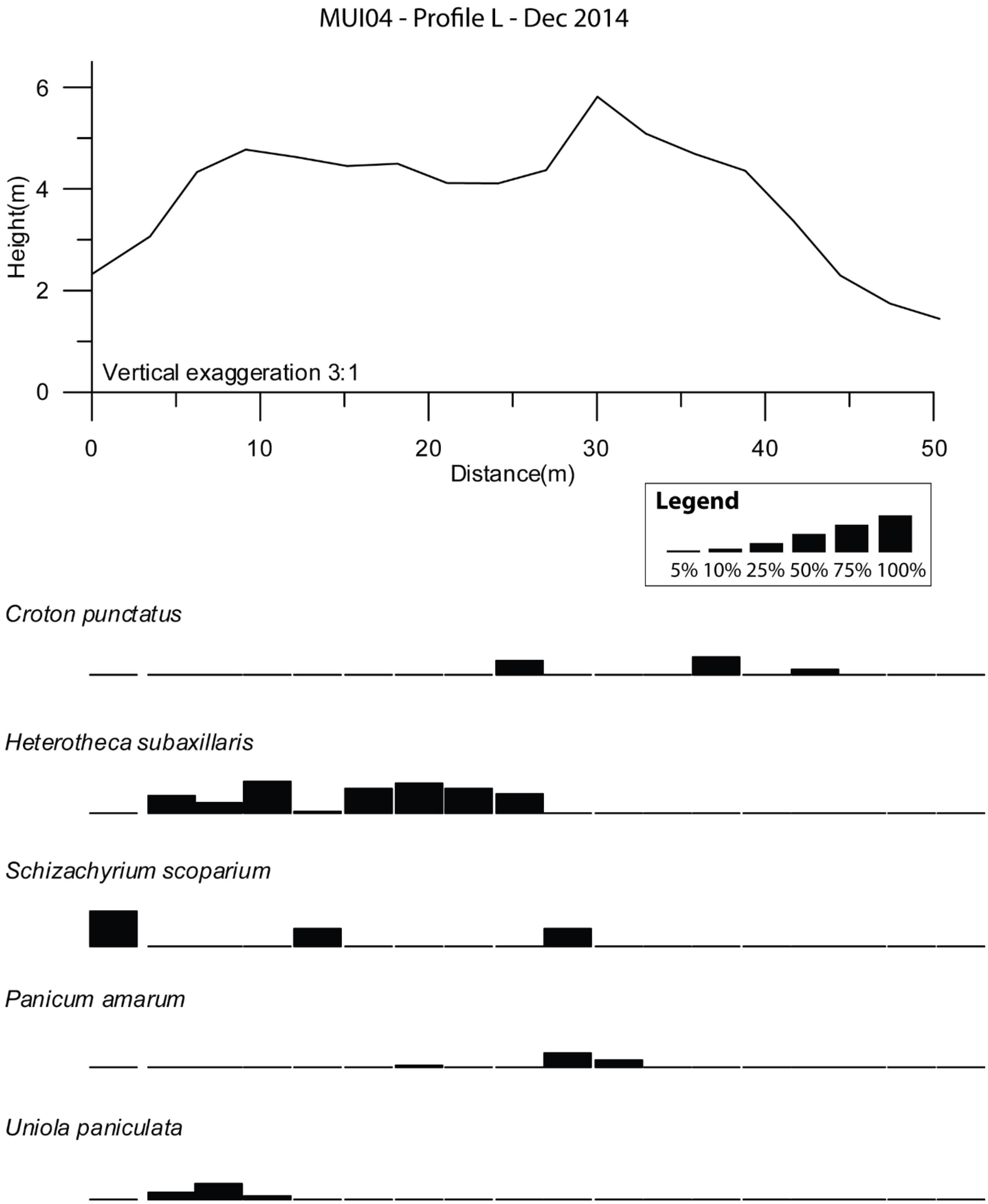


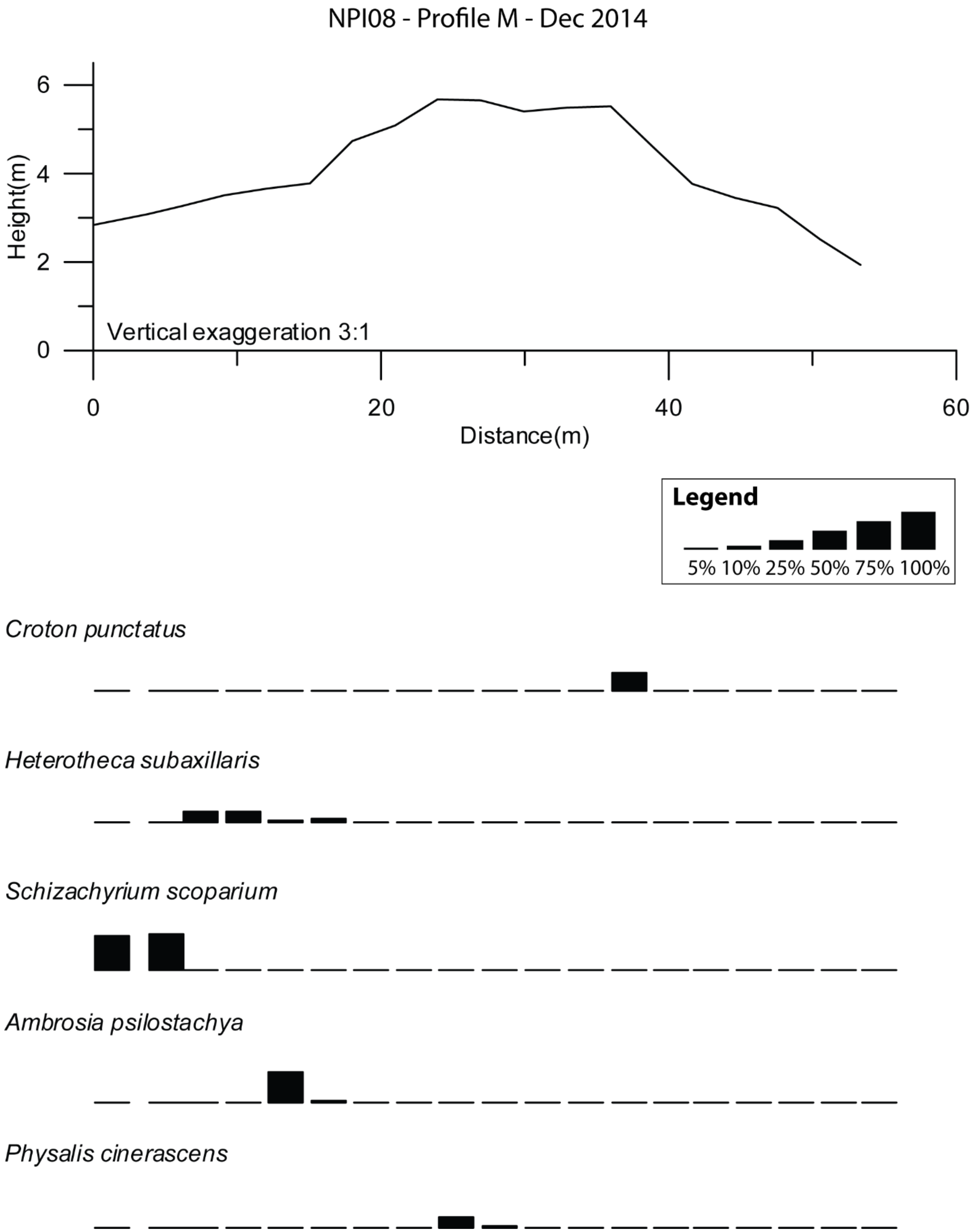
MUI02 - Profile I - Dec 2014

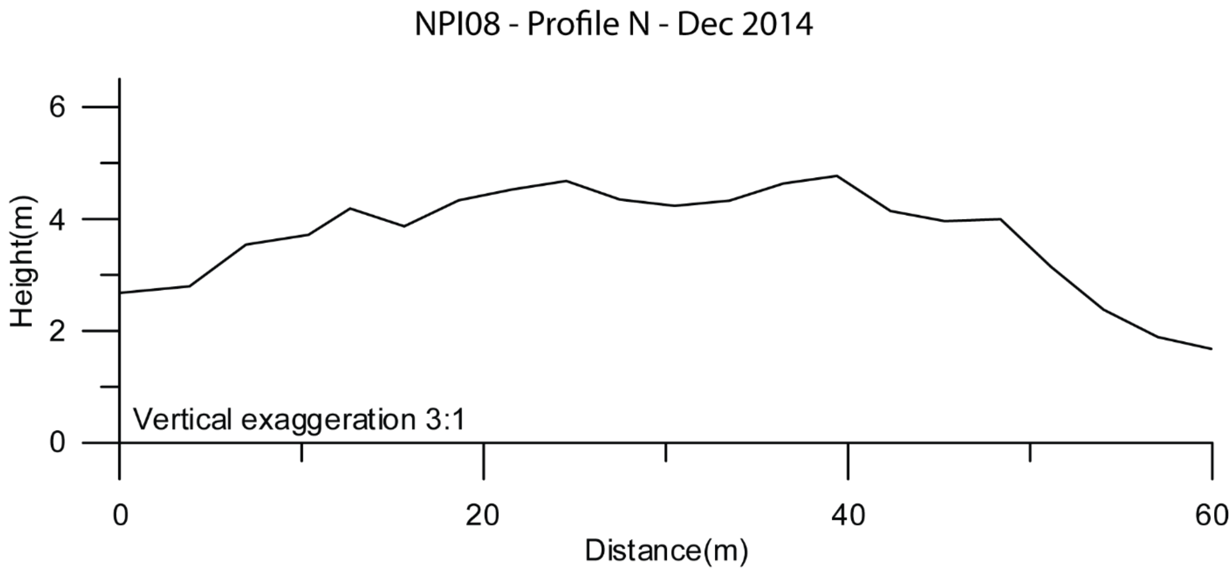


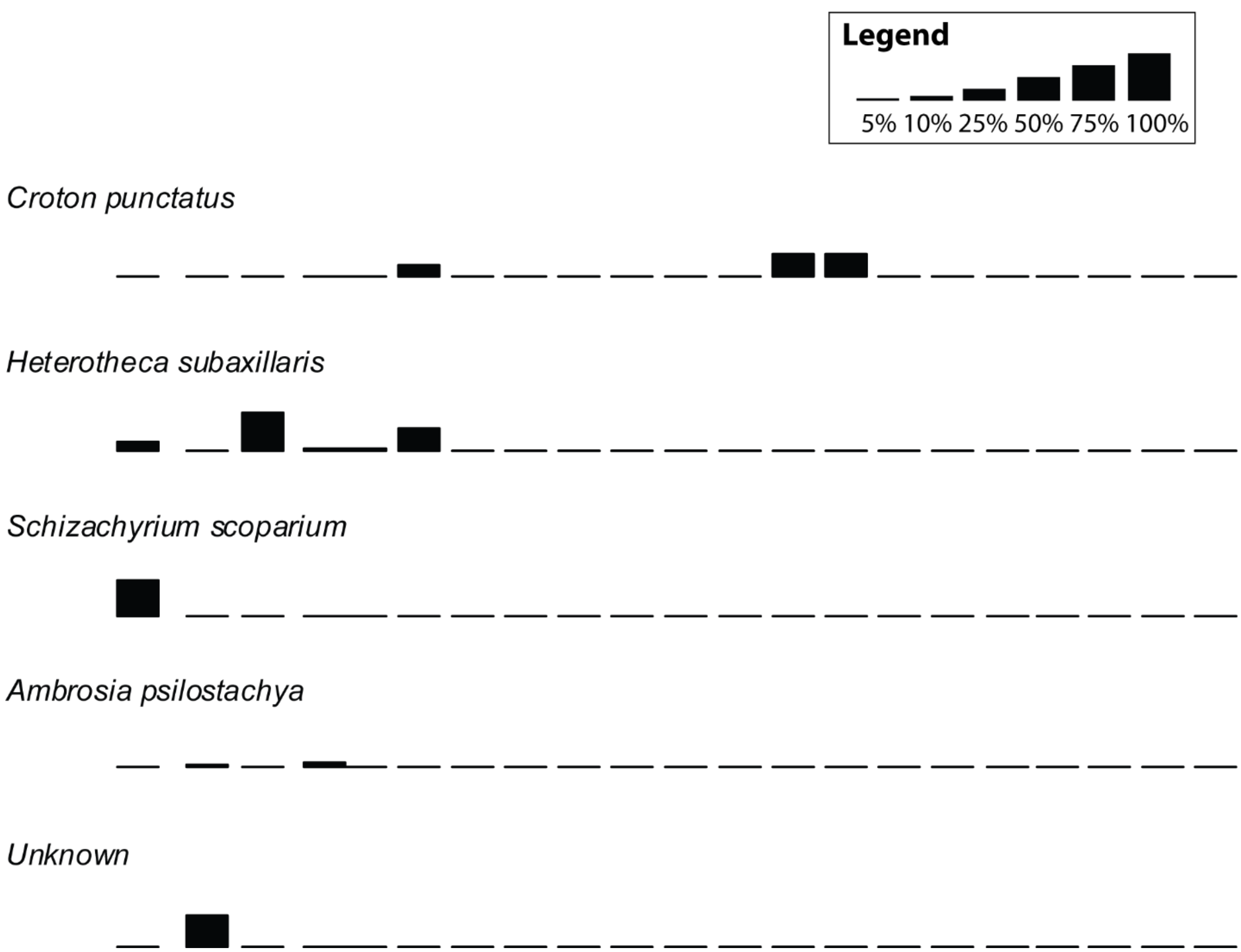

MUI02 - Profile I - Dec 2014
6
4
2
0
Height(m)
Vertical exaggeration 3:1
0
10
20
30
40
50
Distance(m)
Legend
5% 10% 25% 50% 75% 100%
Croton punctatus
Heterotheca subaxillaris
Ipomoea pres-caprae
Panicum amarum
Physalis cinerascens


MUI04 - Profile K - Dec 2014
Height(m)
0
2
4
6
Vertical exaggeration 3:1
0
10
20
30
40
50
Distance(m)
Legend
5% 10% 25% 50% 75% 100%
Croton punctatus
Heterotheca subaxillaris
Schizachyrium scoparium
Panicum amarum
Ipomoea imperati


MUI04 - Profile L - Dec 2014
Height(m)
0
2
4
6
Vertical exaggeration 3:1
0
10
20
30
40
50
Distance(m)
Legend
5% 10% 25% 50% 75% 100%
Croton punctatus
Heterotheca subaxillaris
Schizachyrium scoparium
Panicum amarum
Uniola paniculata


NPI08 - Profile M - Dec 2014
Height(m)
6
4
2
0
Vertical exaggeration 3:1
0
20
40
60
Distance(m)
Legend
5% 10% 25% 50% 75% 100%
Croton punctatus
Heterotheca subaxillaris
Schizachyrium scoparium
Ambrosia psilostachya
Physalis cinerascens

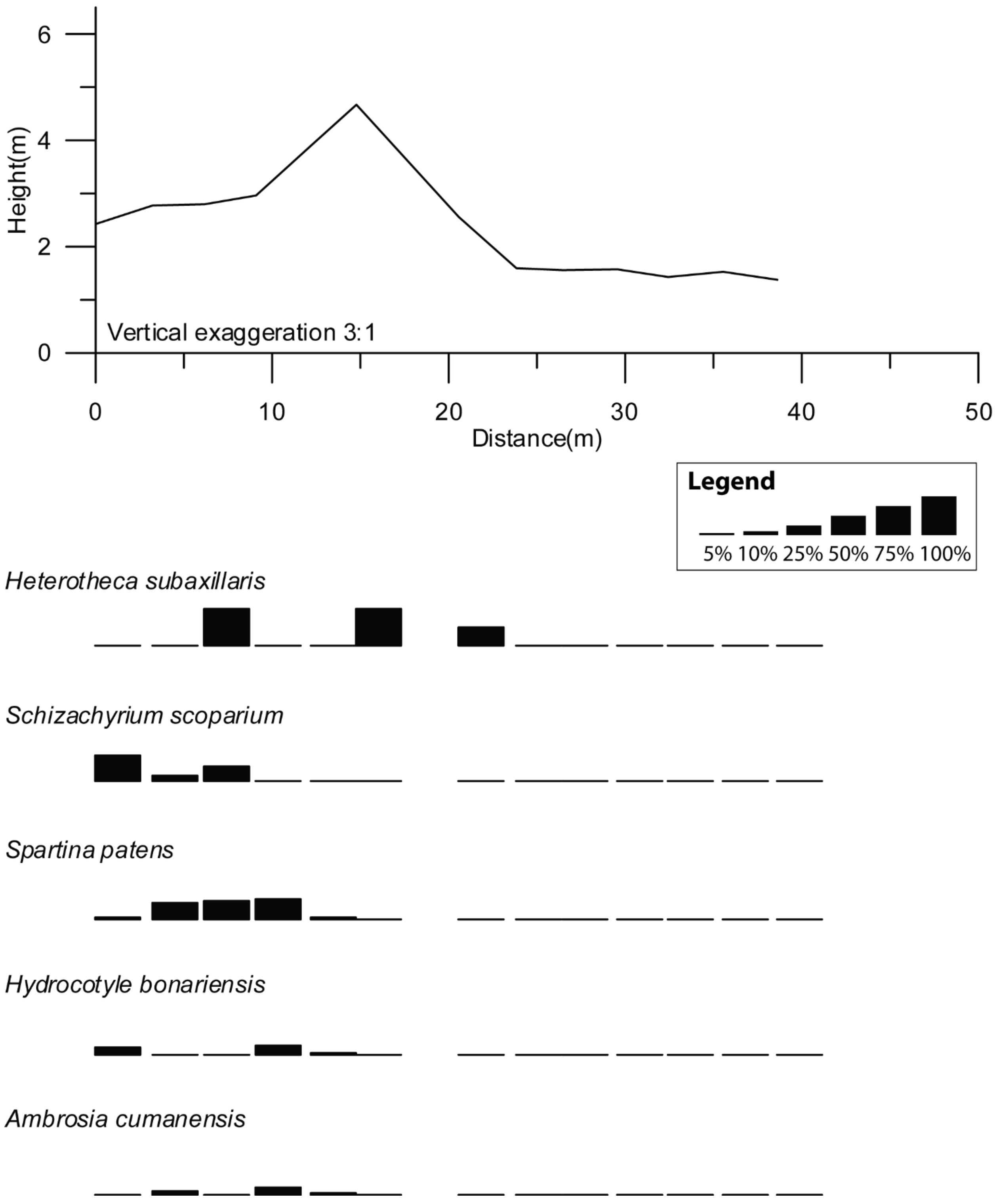

NPI08 - Profile N - Dec 2014
Height(m)
6
4
2
0
Vertical exaggeration 3:1
0
20
40
60
Distance(m)


Legend
5% 10% 25% 50% 75% 100%
Croton punctatus
Heterotheca subaxillaris
Schizachyrium scoparium
Ambrosia psilostachya
Unknown

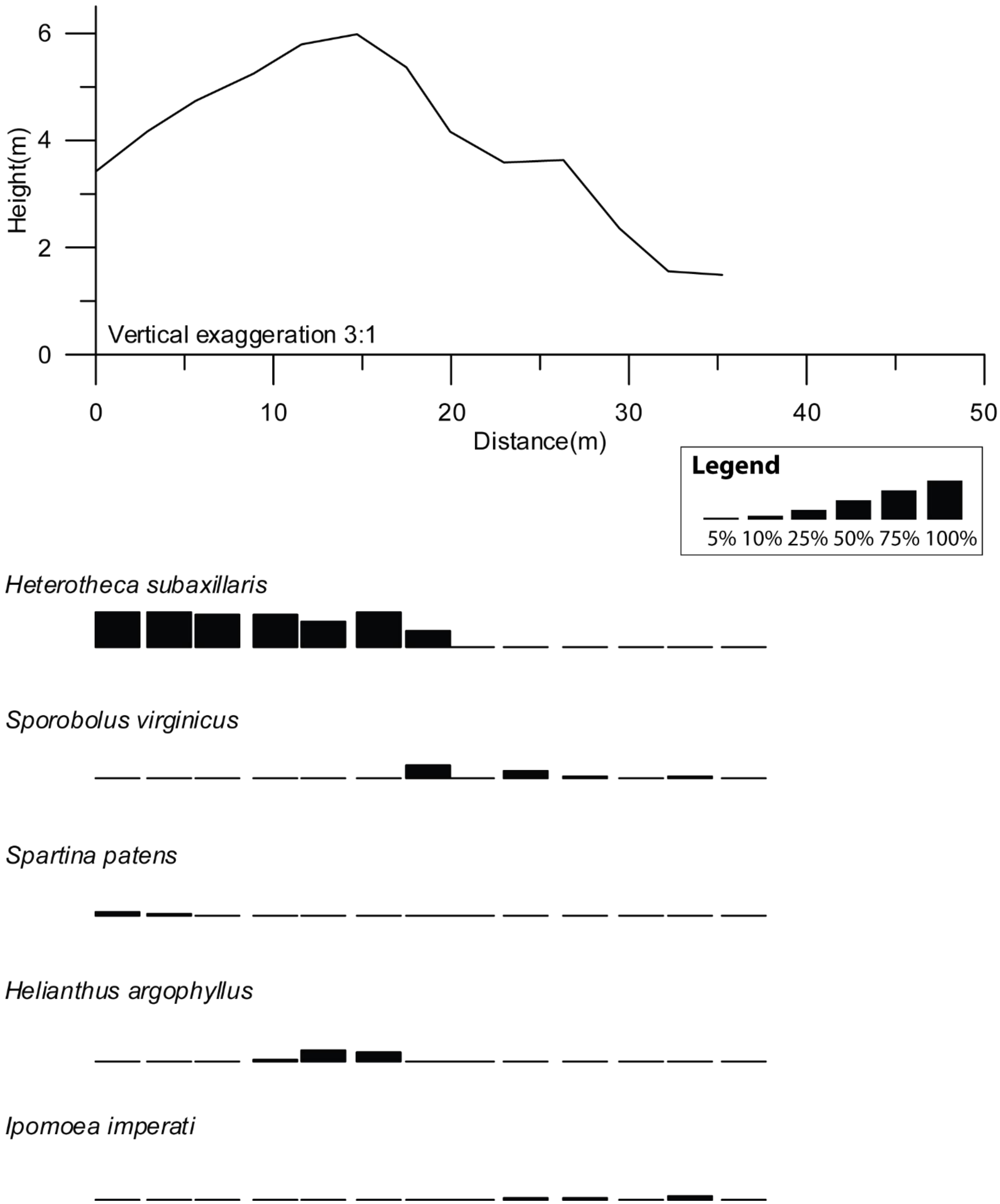
F. Vegetation Transect Data- July 2015 Survey

[Continued on next page]

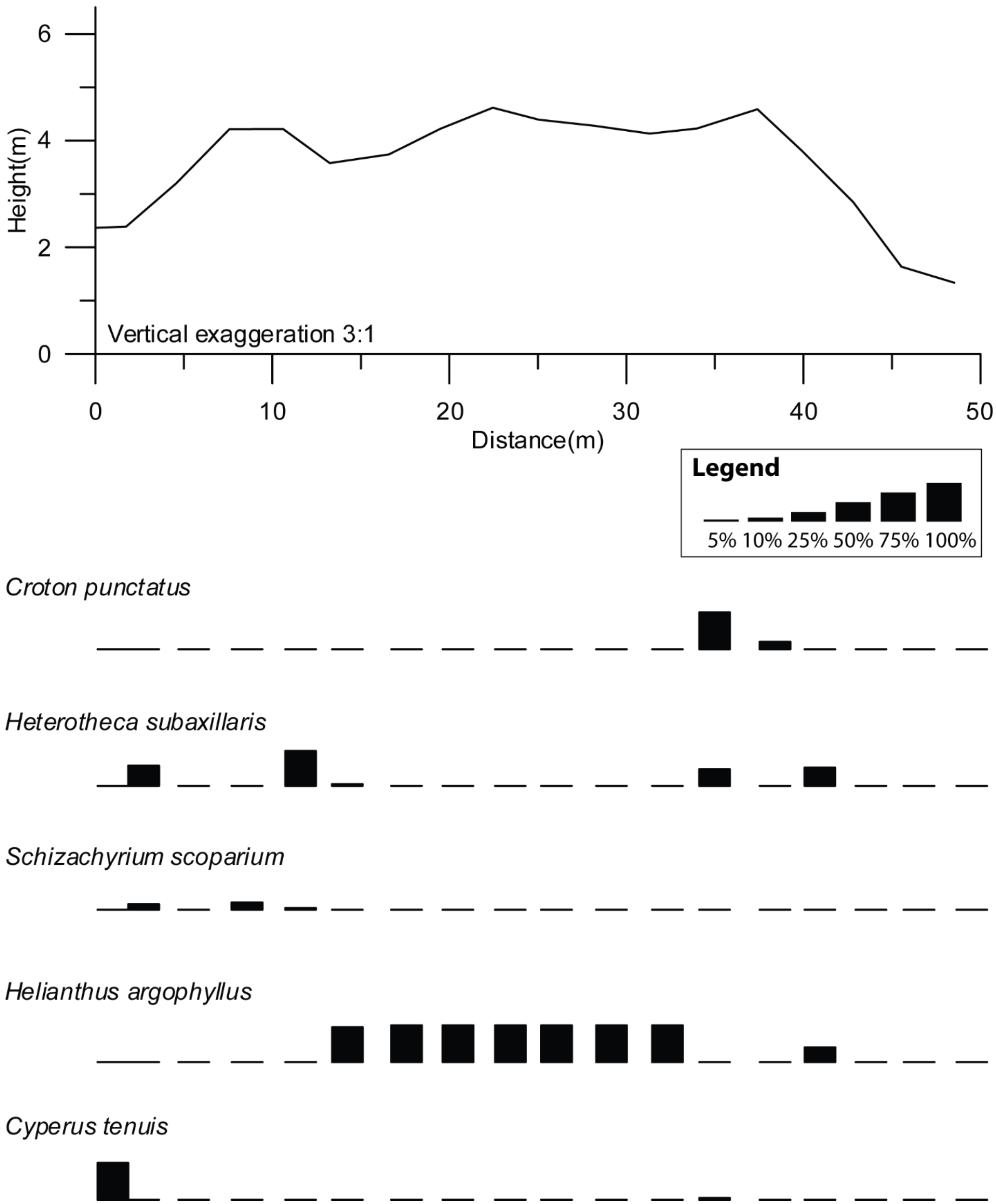
MUI01 - Profile A - July 2014

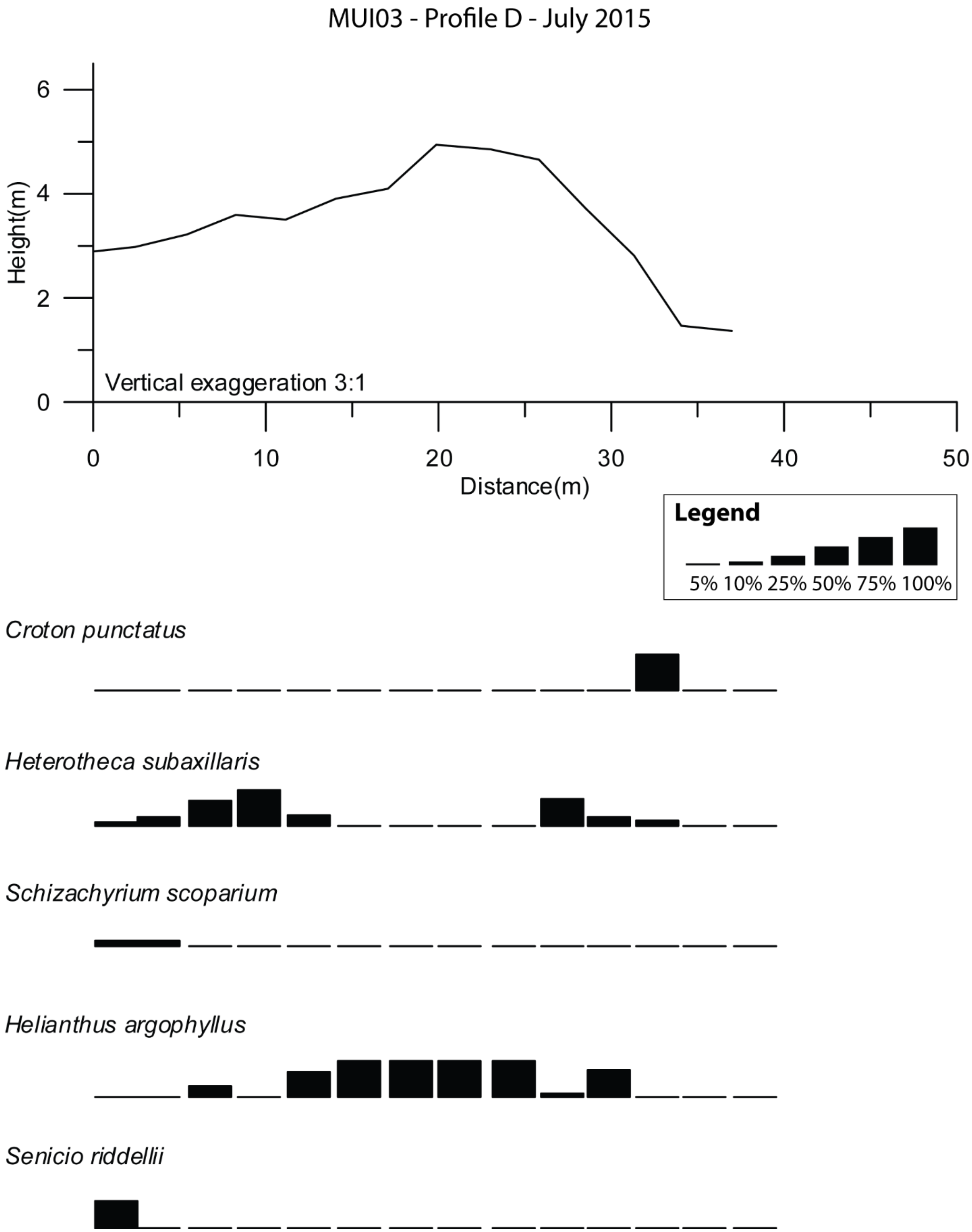


MUI01 - Profile B - July 2014



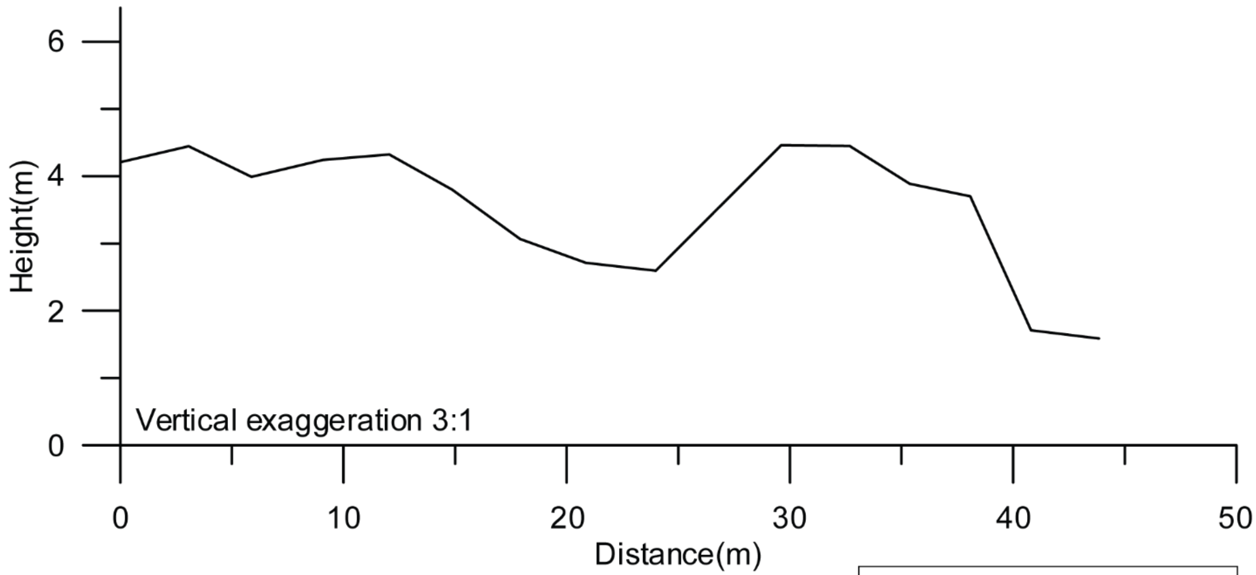
MUI03 - Profile C - July 2015

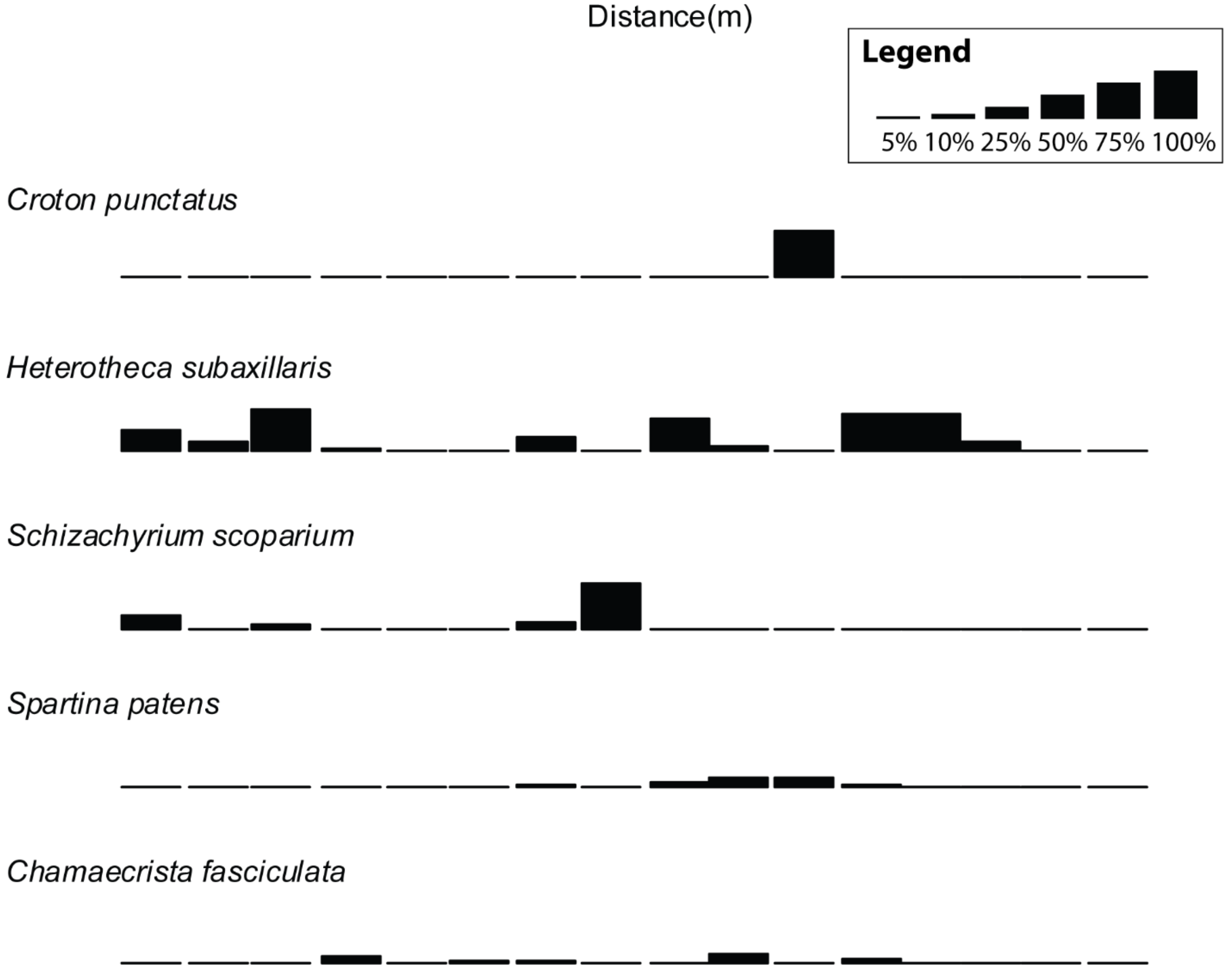




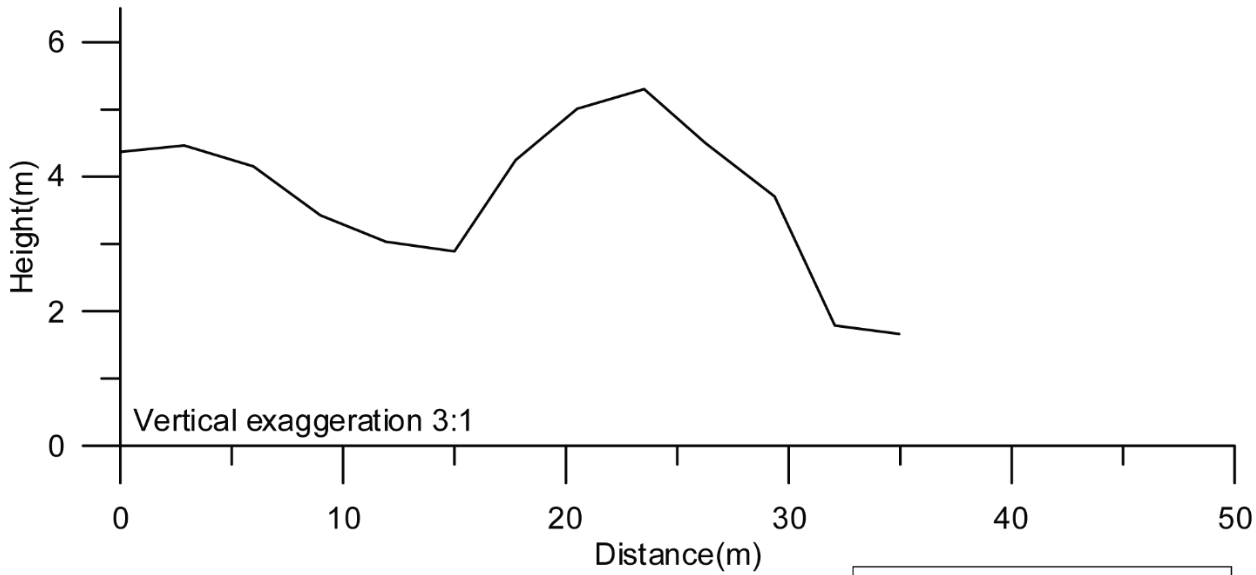
MUI03 - Profile D - July 2015
Height(m)
6
4
2
0
Vertical exaggeration 3:1
0
10
20
30
40
50
Distance(m)
Legend
5% 10% 25% 50% 75% 100%
Croton punctatus
Heterotheca subaxillaris
Schizachyrium scoparium
Helianthus argophyllus
Senicio riddellii

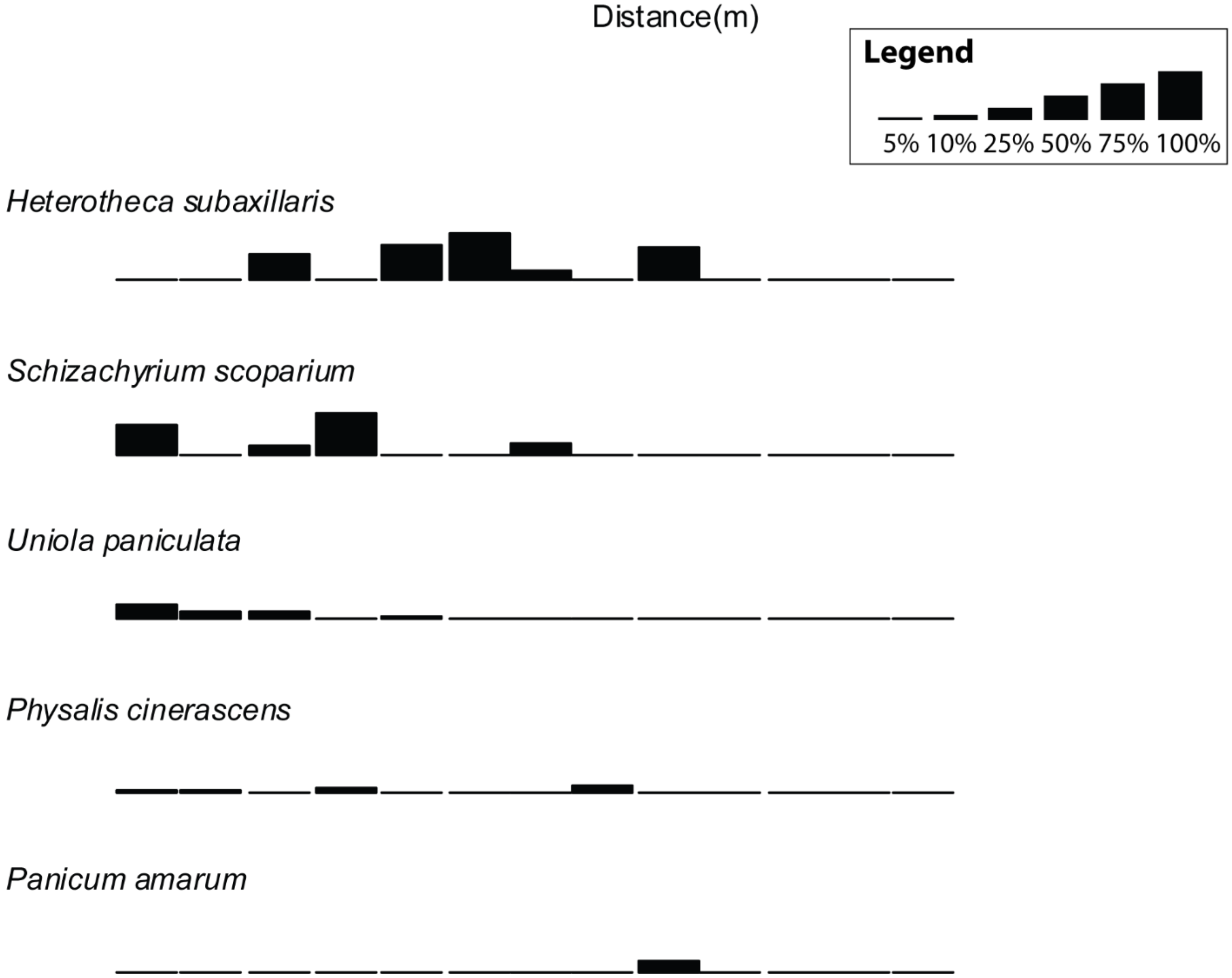
MUI06 - Profile E - July 2015

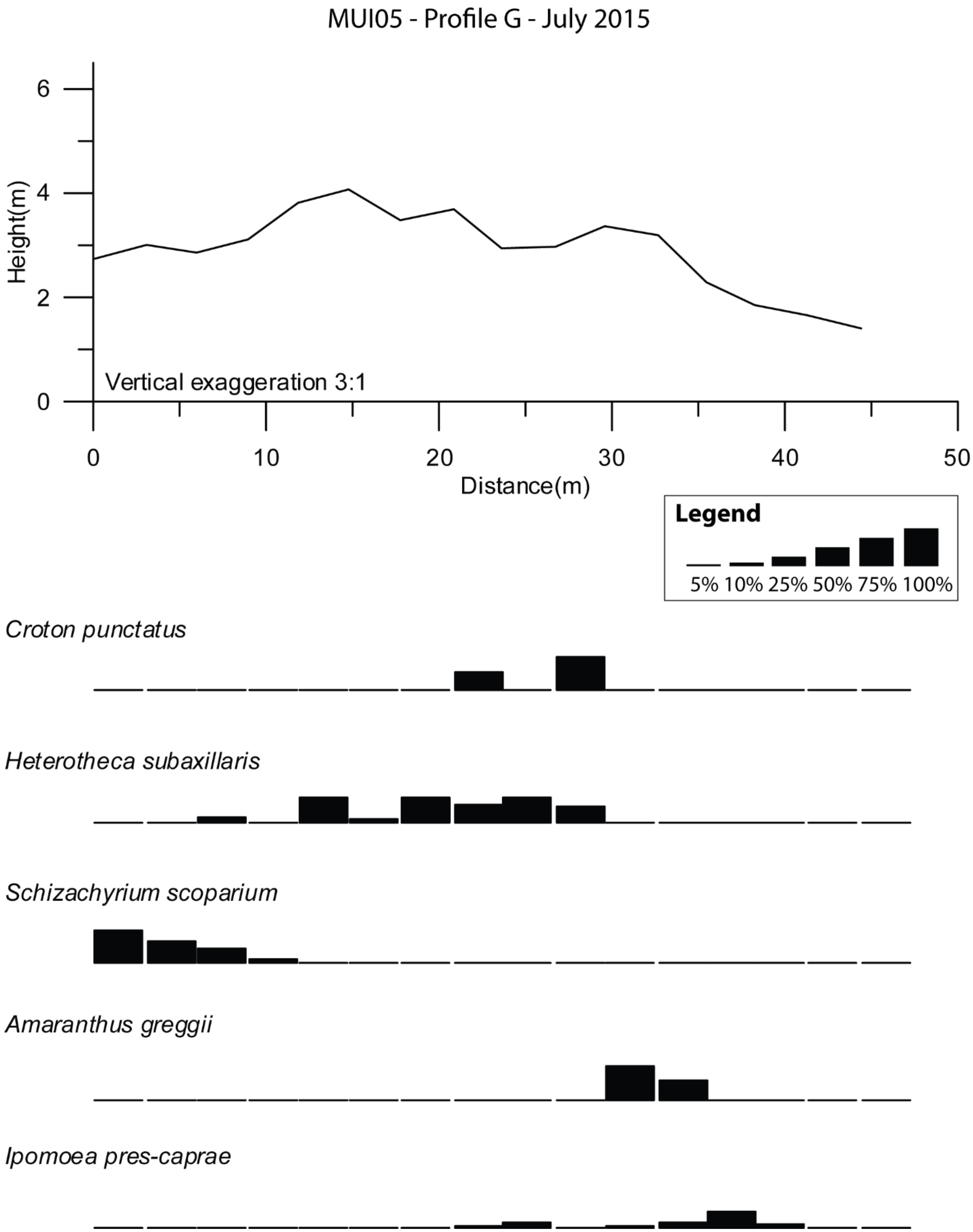


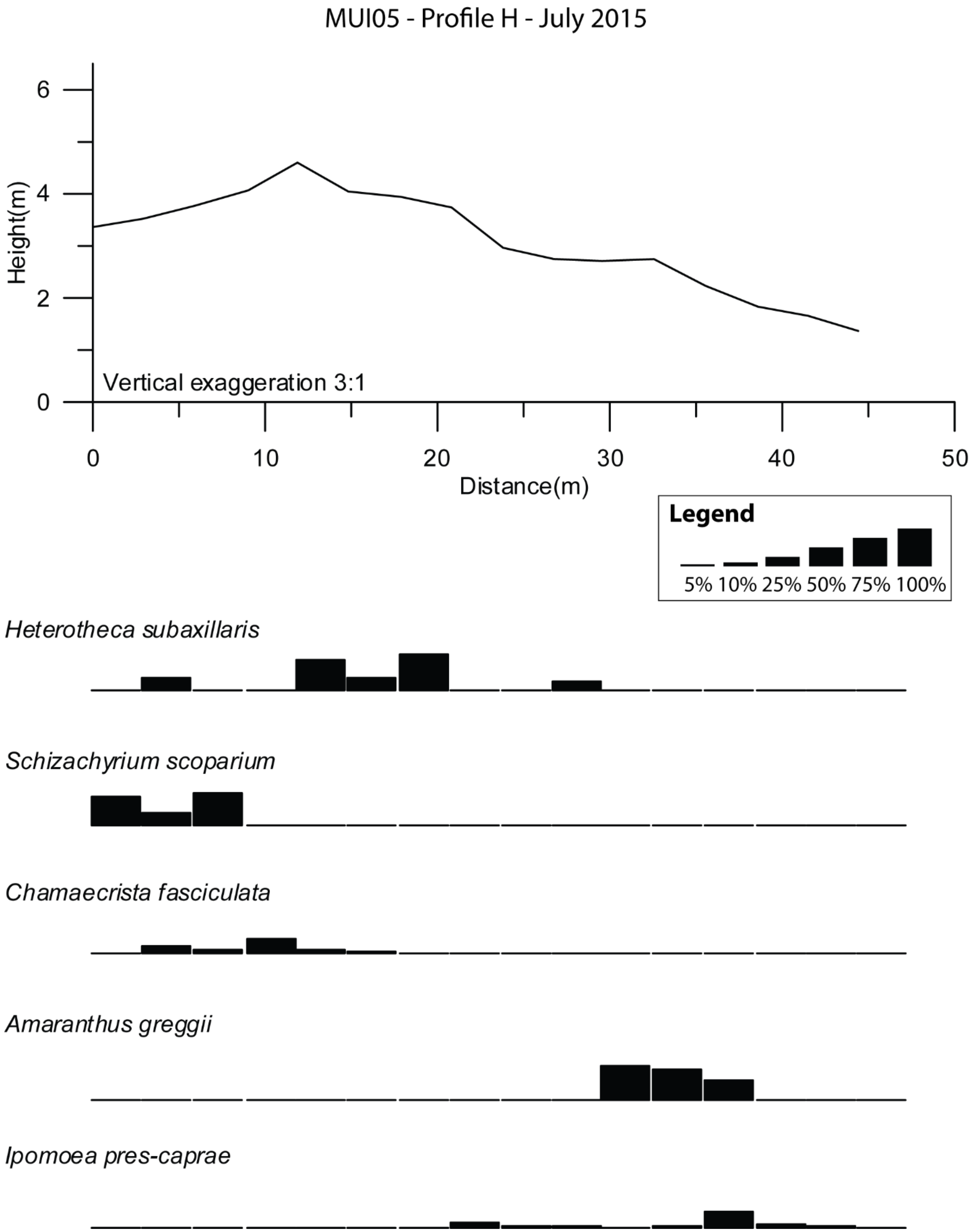


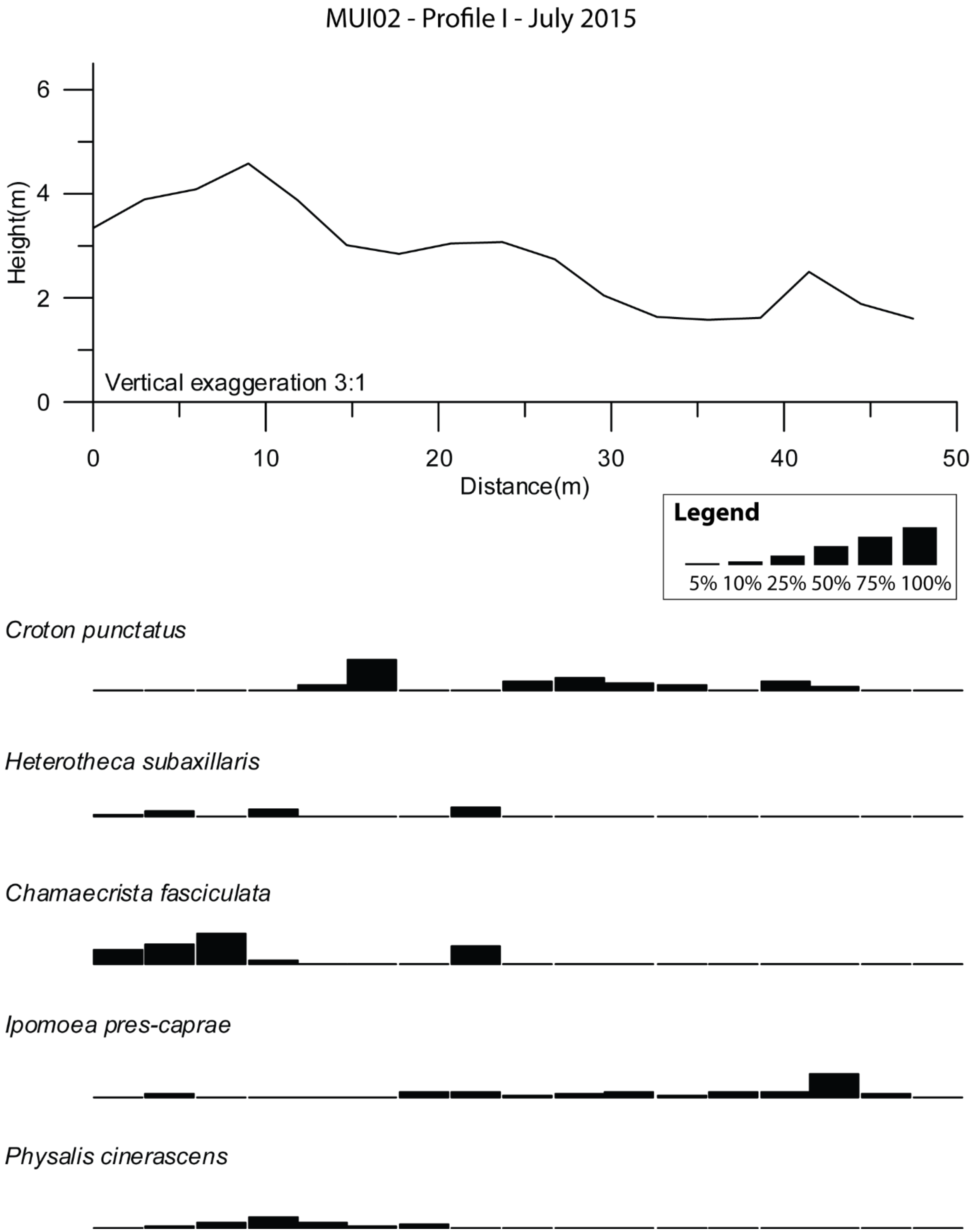
MUI06 - Profile F - July 2015



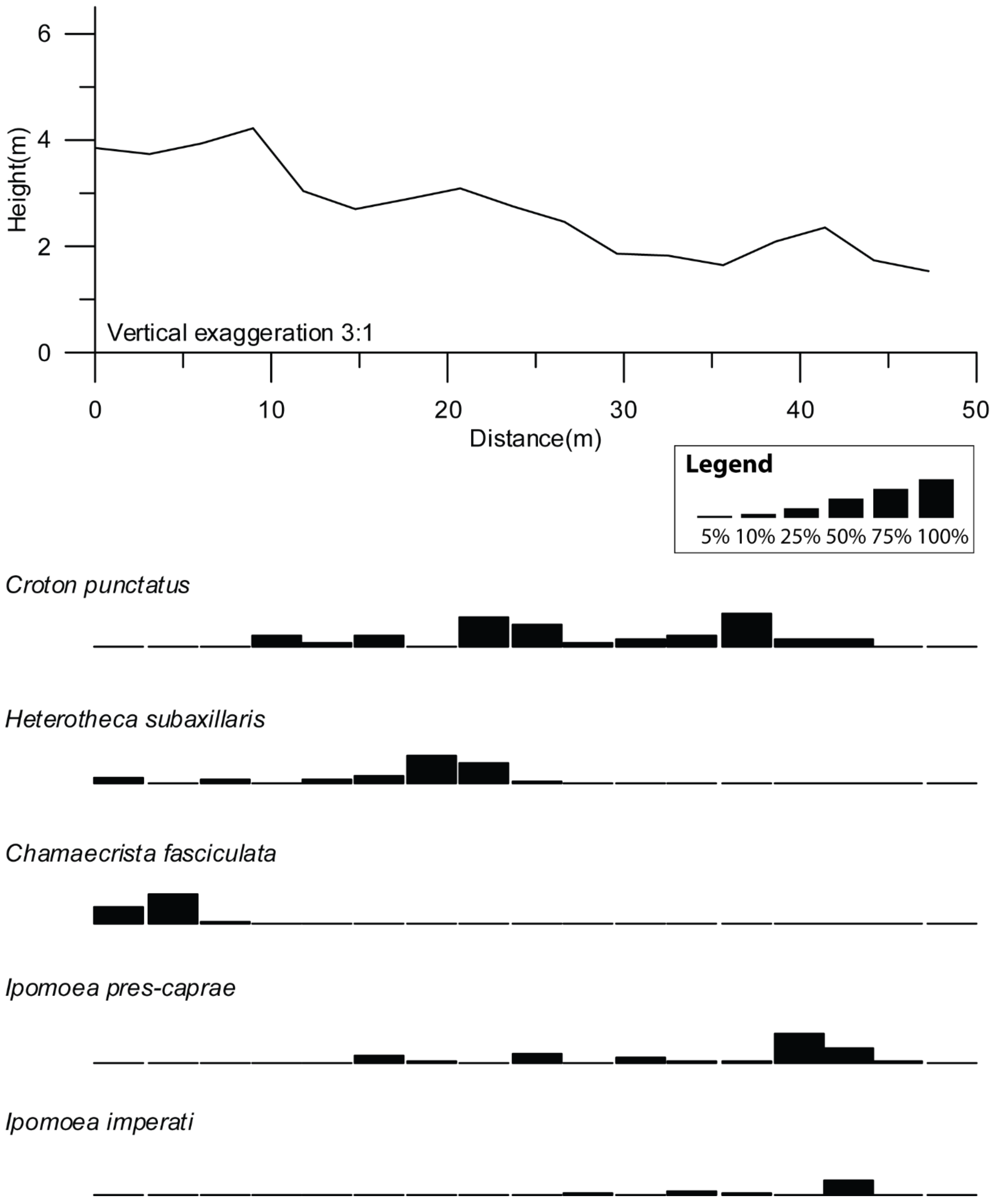


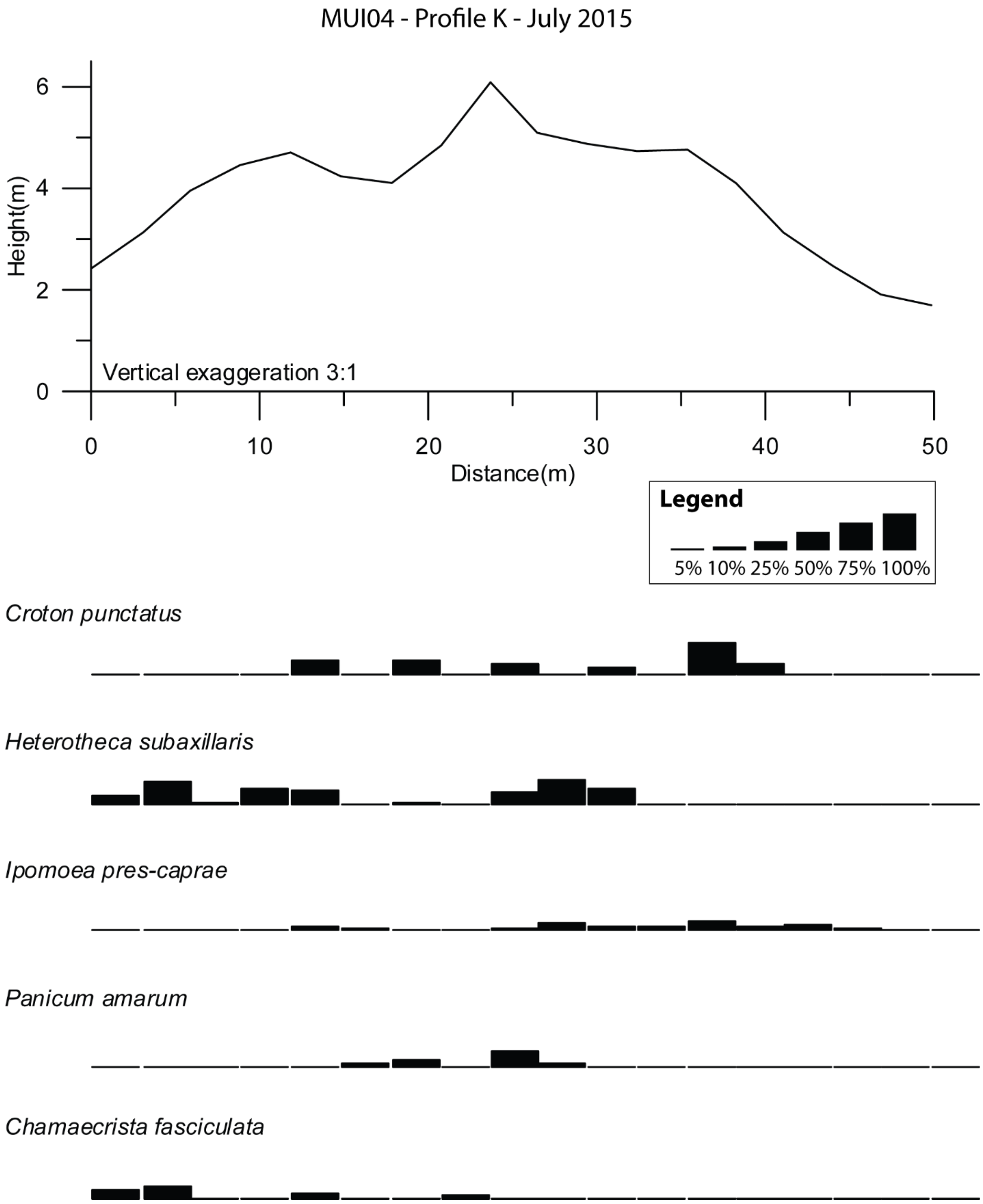

MUI05 - Profile G - July 2015
Height(m)
6
4
2
0
Vertical exaggeration 3:1
0
10
20
30
40
50
Distance(m)
Legend
5% 10% 25% 50% 75% 100%
Croton punctatus
Heterotheca subaxillaris
Schizachyrium scoparium
Amaranthus greggii
Ipomoea pres-caprae


MUI05 - Profile H - July 2015
6
4
2
0
Height(m)
Vertical exaggeration 3:1
0
10
20
30
40
50
Distance(m)
Legend
5% 10% 25% 50% 75% 100%
Heterotheca subaxillaris
Schizachyrium scoparium
Chamaecrista fasciculata
Amaranthus greggii
Ipomoea pres-caprae


MUI02 - Profile I - July 2015
Height(m)
6
4
2
0
Vertical exaggeration 3:1
0
10
20
30
40
50
Distance(m)
Legend
5% 10% 25% 50% 75% 100%
Croton punctatus
Heterotheca subaxillaris
Chamaecrista fasciculata
Ipomoea pres-caprae
Physalis cinerascens

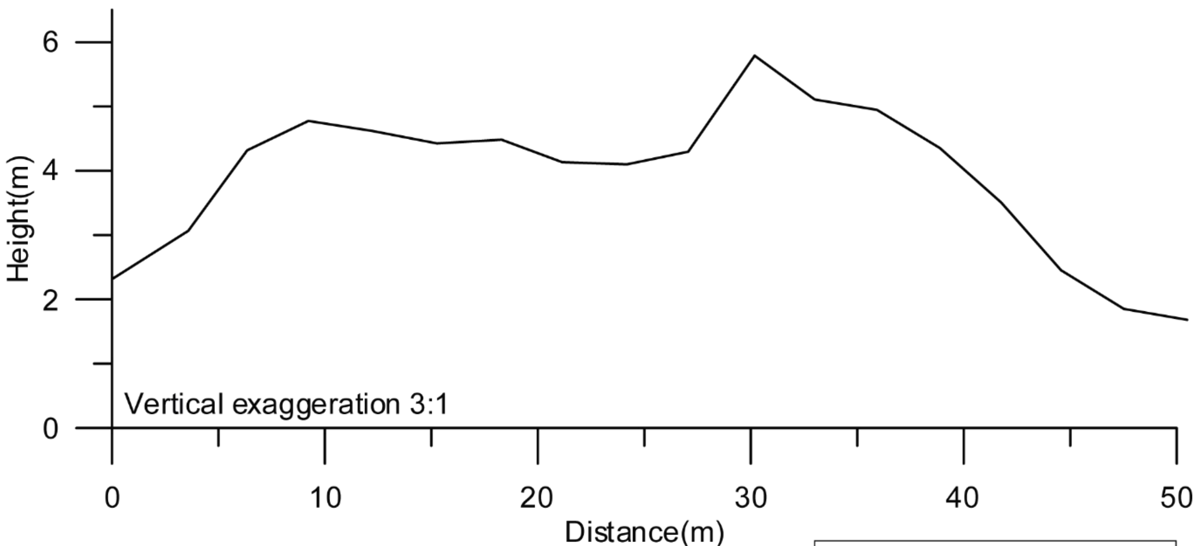
MUI02 - Profile J - July 2015

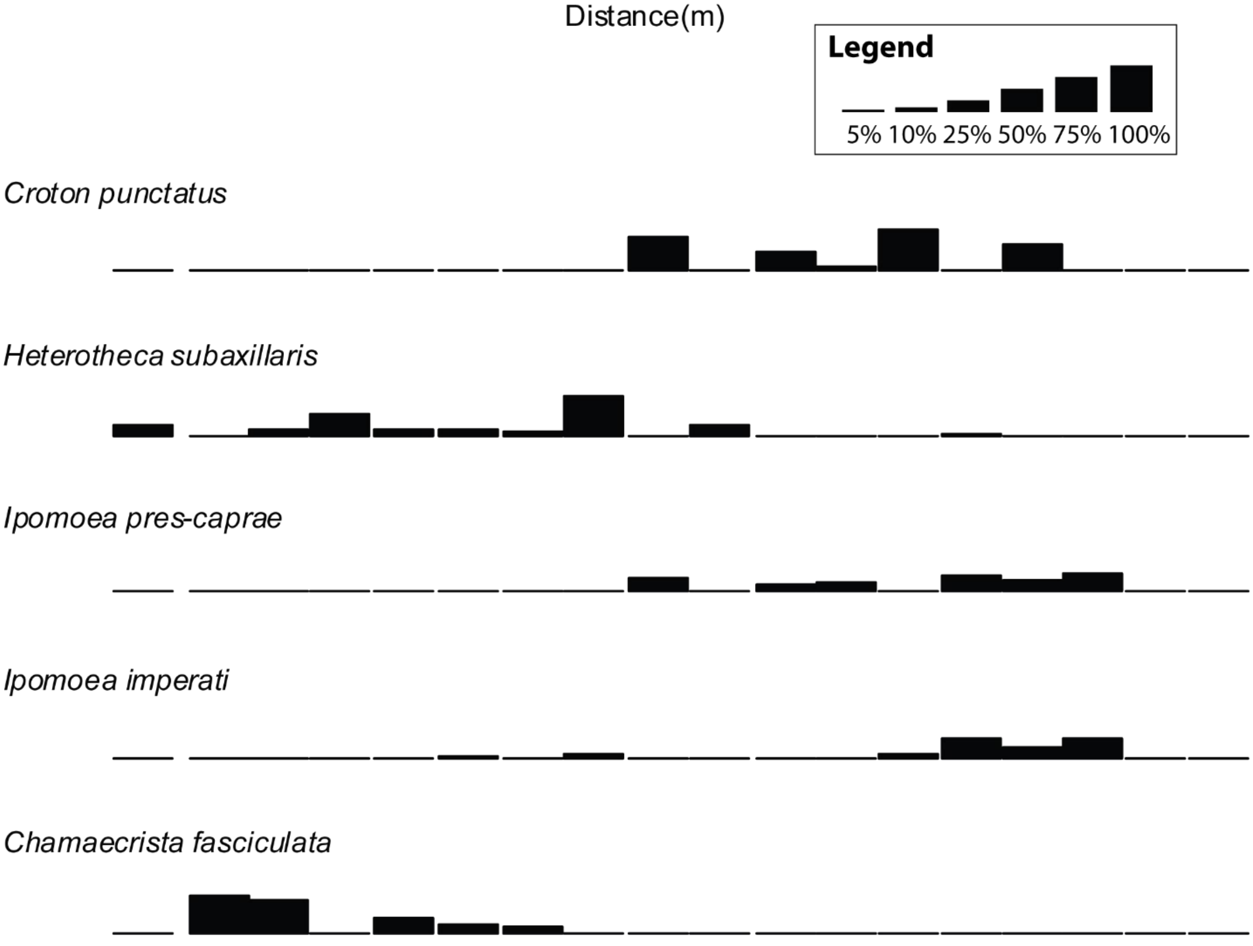


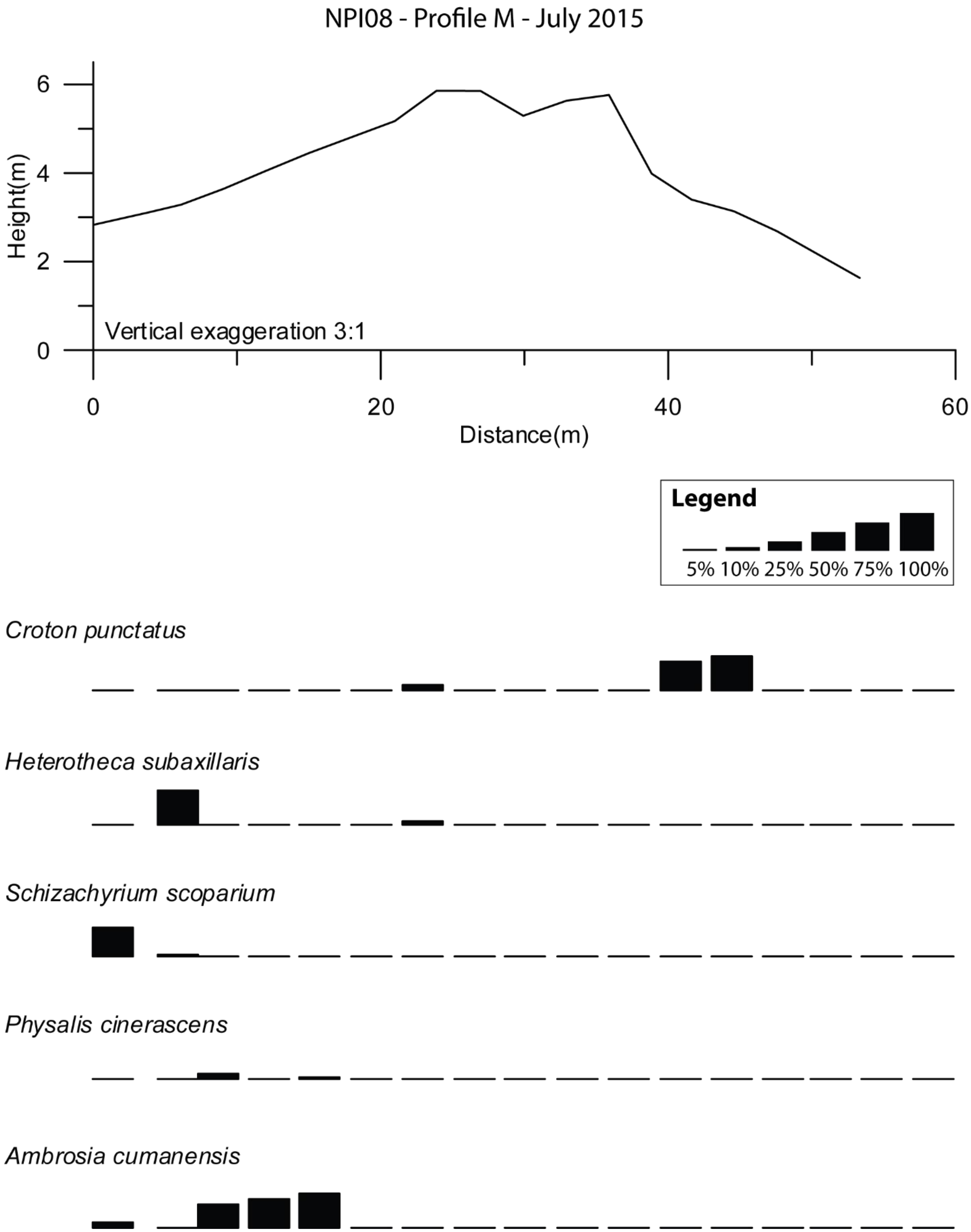


MUI04 - Profile K - July 2015
Height(m)
6
4
2
0
Vertical exaggeration 3:1
0
10
20
30
40
50
Distance(m)
Legend
5% 10% 25% 50% 75% 100%
Croton punctatus
Heterotheca subaxillaris
Ipomoea pres-caprae
Panicum amarum
Chamaecrista fasciculata

MUI04 - Profile L - July 2015






NPI08 - Profile M - July 2015
Height(m)
6
4
2
0
Vertical exaggeration 3:1
0
20
40
60
Distance(m)
Legend
5% 10% 25% 50% 75% 100%
Croton punctatus
Heterotheca subaxillaris
Schizachyrium scoparium
Physalis cinerascens
Ambrosia cumanensis

NPI08 - Profile N - July 2015