Predicting and Measuring Climate Change Impacts at a Coastal Dune Site: Progress Report

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Purpose

The goal of this ongoing research program is to provide long-term quantitative measurements of dune morphodynamics and vegetation change at the Lanphere and Ma-le'l Dune Units of Humboldt Bay National Wildlife Refuge, as a basis for modeling response to climate change. This naturally functioning dune system is rich in biodiversity and supports many species and communities that have evolved to survive the stochastic nature of the dune environment, potentially conferring an evolutionary advantage to climate change adaptation. The USFWS approach to climate change calls for managing for change rather than historic or static conditions (NWF 2014). Due to the high degree of uncertainty, this approach necessitates the anticipation of multiple outcomes as a preparation for efficient management course changes (Stein et al. 2014). Such an approach is served by predictive modeling using robust data sets. Over time, we hope to expand the geographic scope of the project to include the North and South Spits of Humboldt Bay, thus enlarging the applicability of the models to the Humboldt Bay region. This report presents the current status of the first phase of the project, funded through the USFWS Inventory and Monitoring Program.

Methods

In January 2012 a total of 14 transects were established parallel with prevailing wind direction along a 3-km stretch of coastline within the Lanphere and Ma-le'l Dunes Units of Humboldt Bay National Wildlife Refuge (Fig. 1). The study design was developed by the Refuge Ecologst in collaboration with Dr. Patrick Hesp, a geomorphologist now with Flinders University, Australia, and Dr. Conor Shea, a hydrologist/geomorphologist and engineer with the USFWS Region Coastal Program at Humboldt Bay. Transect length ranged from 156-276 m. Three permanent benchmarks were placed at topographic high points behind foredune crests, and their locations were documented with RTK GPS. Measurements used a datum of NAVD 1988. Topographic stations were positioned at 1-m intervals beginning with the zero point at the eastern end of each transect.

Transects were located along the shoreline subjectively to encompass variation in distance alongshore, dominant vegetation, geomorphology, and management history (Fig. 1). Two transects were placed at the north end of the site, in a new acquisition that has never received management (Bair *Ammophila* transects). Eight transects were placed in what was originally the Lanphere Dunes Unit, which was restored between 1992 and 1997 primarily through the removal of European beachgrass (*Ammophila arenaria*) (Pickart 2013). Two of these transects were placed where the native dune grass *Elymus mollis* was dominant along the foredune crest and stoss slope (Lanphere *Elymus* transects), and two where native dune mat vegetation (with no or minor *Elymus*) was dominant (Lanphere Non-*Elymus* transects). Two transects were placed in active blowouts (Lanphere Blowout transects), and were angled to follow the axis of the blowout at least as far as the foredune crest. The two southernmost Lanphere transects were located in an area that was incorporated into the newer Ma-le'l Dunes Unit and they have been named accordingly. These two transects (Ma-le'l Transgressive transects) were placed along a stretch of shoreline that underwent significant foredune erosion and mobilization in the early late 1990s, resulting in a 160-m-wide transgressive dune sheet. The remaining four transects in the Ma-le'l Unit were located in areas analogous to the Lanphere *Elymus* and Non-*Elymus* transects (Ma-le'l *Elymus* Non-*Elymus* transects). Monitoring was

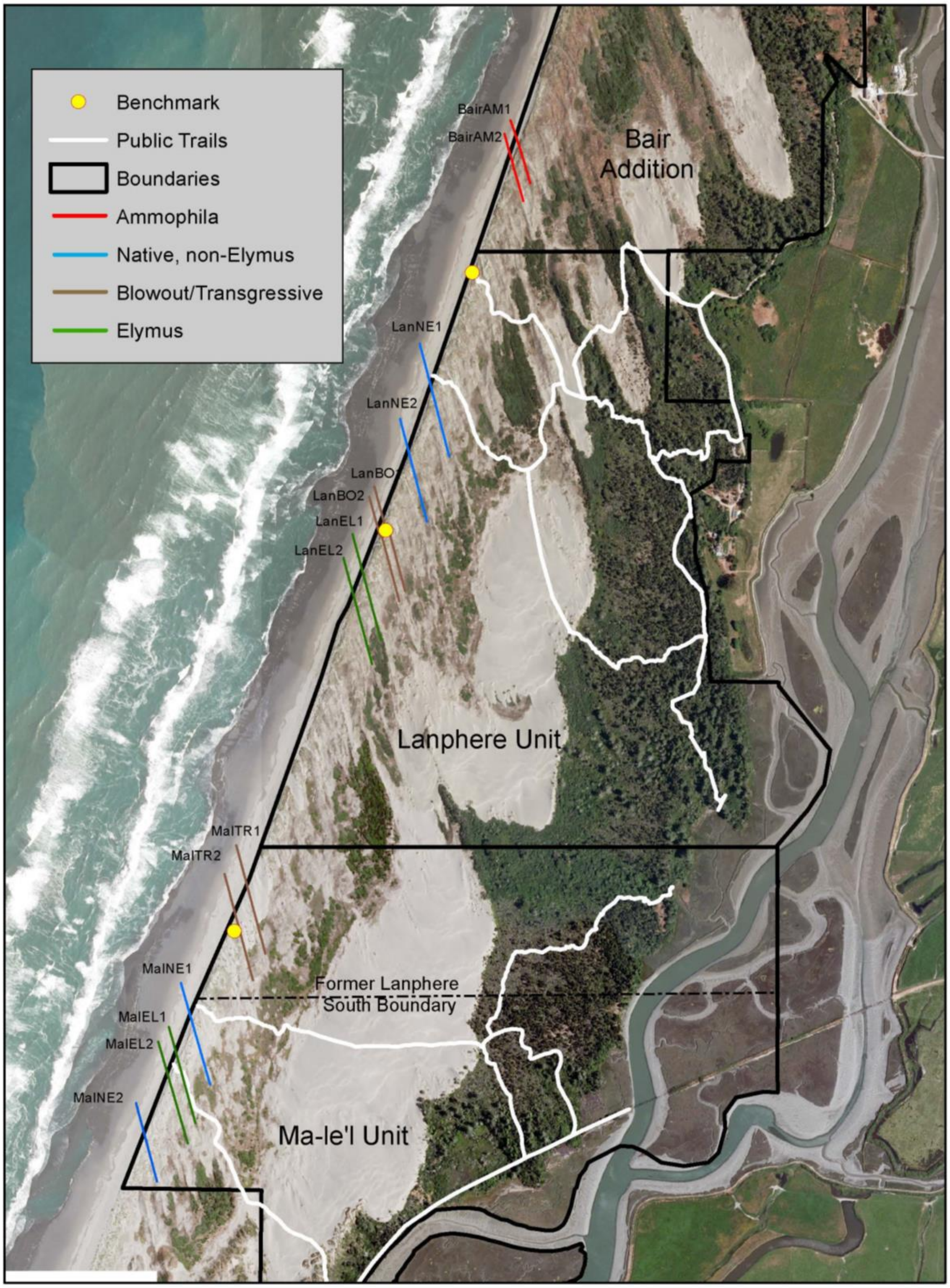

Figure 1. Location of transects on the Lanphere and Ma-le'l Dunes Units, Humboldt Bay National Wildlife Refuge.

carried out at intervals of approximately 6 months, to capture peak seasonal variation (approximately January and July) for the years 2012, 2013 and 2014.

An ATV was used to transport GPS and sampling equipment between transect locations. RTK rover units provided by the USFWS Coastal Program at Humboldt Bay were used to navigate to each station record elevation (Fig. 2). The western end of each transect was chosen based on accessibility, logistics and safety during the first monitoring interval in January 2012 at approximately MHHW (2.0 m NAVD 1988). In summer 2014 endpoints were extended west to maintain endpoints at this elevation following significant deposition. Topographic measurements were collected primarily by Dr. Conor Shea and Refuge Botanist Laurel Goldsmith. Dr. Shea downloaded data into Excel spreadsheets and created plots for each set of elevation observations at each transect.

Vegetation plots were placed at 4-m intervals from the eastern end of the transect to the zone of greater sand movement (or, for *Ammophila*-dominated foredunes, at the boundary of the *Ammophila* zone), and at 2-m intervals thereafter until the end of the vegetation zone was reached. Because vegetation sampling requires more time, pin flags were placed to mark all vegetation plots at the time of topographic monitoring. The pin flags were removed as vegetation plots were completed. At each vegetation plot, a 1-m^2 PVC quadrat was placed with the pin flag at its center point. Quadrats had wire grids at 1-dm spacing. Vegetation sampling consisted of a hybrid method of point intercept and quadrat sampling (Fig. 3). A pin flag was placed at each intersection of the grid (n=100 per quadrat), and all species that were intercepted at that point were recorded (one record per species, even if multiple intercepts occurred). This method provides an estimation of the proportion of cover by each species (and open sand, indicated by no intercepts at a point) that is much more accurate than ocular estimation. Vegetation in this zone of the dunes is low-growing, and structure was more coarsely measured by recording the tallest individual in each of the four quadrants of the quadrat. The vegetation field crew varied, with consistent participation by Laurel Goldsmith, Desiree Davenport, Britney Newby, Ashley Dickinson and Kelsey McDonald. The core crew was trained prior to the start of the project by Andrea Pickart. Data were collected on paper data sheets and later transcribed into an Excel spreadsheet, primarily by I&M technician Kelsey McDonald but with assistance from refuge staff.

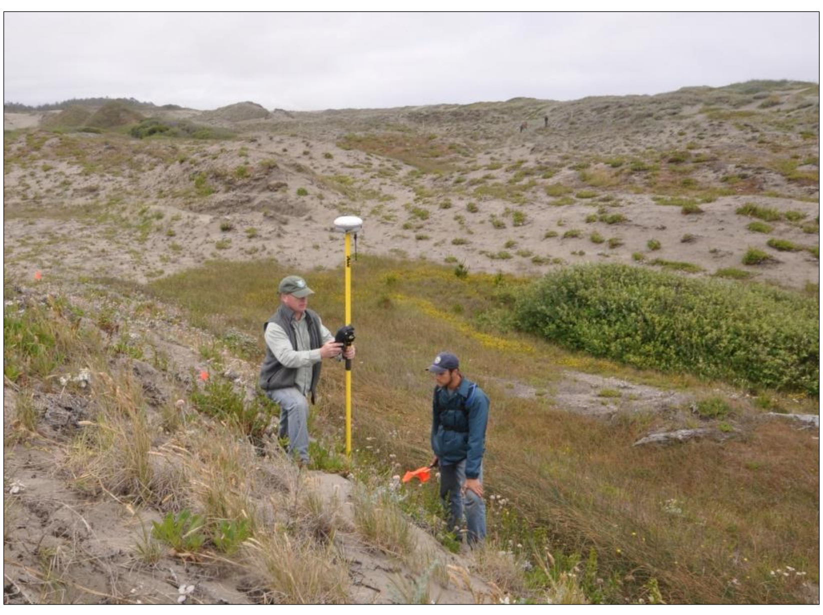

Figure 2. The RTK rover is used to navigate to a pre-loaded location; labeled flags are inserted at points that will also receive vegetation sampling.

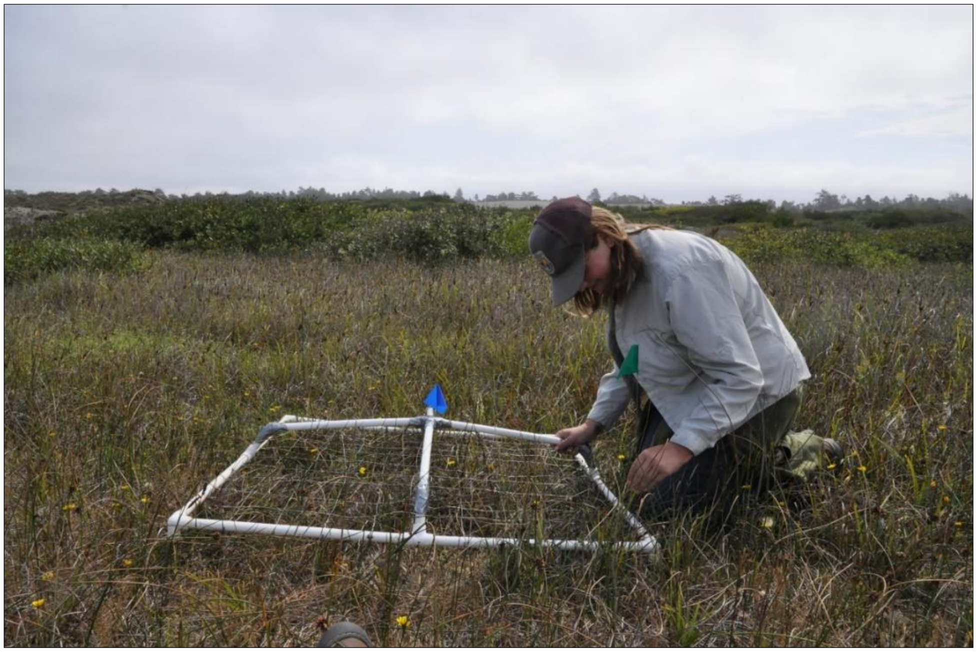

Figure 3. A pin is inserted at each intersection of the gridded quadrat and each species intersected by the pin is recorded.

Photopoints were taken along shoreward portion of each transect beginning in summer 2013 (several transects have photopoints going back to winter 2013). Photopoints were located at intervals from the shoreward end of the transect successively over and just beyond the foredune crest. Photographs were taken from a southern vantage point within 1-4 m of the transect. Location of photopoints was recorded with a GeoXT. Photographs were catalogued and archived. All photopoints were taken by Britney Newby and Andrea Pickart.

Results and Discussion

A quantitative analysis of volumetric change and sediment budget is planned prior to presentation of data at the California Native Plant Society Conservation Conference in January 2015. This progress report presents topographic profiles and photographs as well as a qualitative description of observed trends. Results are presented by site (Bair, Lanphere, Ma-le'l). All profiles and photographs depict the shoreline from the south with the ocean on the left.

LANPHERE

Over the two year period, all Lanphere transects showed net accretion in summer profiles on the backshore, and four of the six profiles developed an incipient foredune in front of the established foredune, colonized primarily by *Elymus*. The incipient foredune was absent only in the two Non-*Elymus* transects (Figs. 4 and 5), one of which still lacks a significant *Elymus* component on the backshore (Fig. 4). The absence of an incipient foredune in the two Non-*Elymus* transects is consistent with the ability of *Elymus* to trap sand more sand and at lower backshore elevations than other native species (Pavlik 1983). The two Non-*Elymus* transects experienced accretion along the stoss slope of the foredune, as well as on or beyond the foredune crest. In contrast, both of the *Elymus* transects (Figs. 6 and 7) as well as the blowout transects (Figs. 8 and 9) developed an incipient foredune up to 1 m higher than the backshore. Although the *Elymus* transects showed some accretion on the stoss slope of the established foredune, there was no deposition at or beyond the crest. The presence of an incipient foredune has been shown to reduce sand transport to established foredunes, and denser vegetation at the toe of the stoss slope results in less transport upslope under certain wind conditions (Hesp 2002, Davidson-Arnott and Law 1990).

The two blowout transects had steeper slopes than other profiles (Figs. 8-9). Although both blowouts were active in winter 2011/2012 when transects were established, by summer 2014 both had well developed incipient foredunes and one of the two became colonized with *Elymus* along its shoreward axis. Both blowouts experienced sediment accumulation rather than scouring along the stoss slope of the foredune trough, and only one showed deposition at the crest. On high wind-energy coastlines, an incipient foredune can close the throat of a blowout while the depositional lobe or parabolic dune continues to increase (Hesp 2002). Because the two blowout transects do not accurately follow the axis of their depositional lobes past the foredune crest, these features have been ground-mapped with a GeoXT to determine future changes.

Both the *Elymus* and Non-*Elymus* Lanphere transects experienced scarping on the backshore following the winter 2012 survey. One profile (Non-*Elymus* transect 1) still exhibited a sharply scarped backshore by the summer survey, and in all four transects the backshore had not recovered its pre-scarping elevation by summer. The two blowout transects showed little difference in elevation of the backshore between the winter and summer 2012 surveys. These two transects were located adjacent to each other, and this difference was a reflection of the localized nature of the erosional event. In winter 2012/2013 another, larger scarping event occurred prior to the winter survey. Transects located alongshore from *Elymus* Transect 1 to Blowout Transect 2 were affected, but not those to the north or south. The 2013 scarping event caused vertical cliffing of more than 1 m and in places exceeding 1.5 m, but by summer 2013 the backshore had infilled. There were no major erosional events in winter 2013-14.

BAIR

Both Bair *Ammophila* transects depict a steeper, more peaked foredune than the native Lanphere foredunes (Figs. 10-11). The *Ammophila* foredunes are newer and prograded shoreward from older, relict foredunes that still support native vegetation (USFWS unpubl. data). The native foredune on the Lanphere site has a similar history of progradation, but the boundary between the new and relict foredune is less distinct than on Bair. The Bair *Ammophila* foredune profiles are also lower in elevation, both approximately 11 m NAVD 1988, compared with 12-13 m for the Lanphere profiles. The incipient foredune is either lacking or indistinct on the *Ammophila* profiles, and the backshore has been colonized primarily by relatively sparse *Cakile* spp. rather than *Elymus* or *Ammophila*. The *Ammophila* profiles both exhibit accretion on the backshore and low to mid stoss slope, but sediment is not accumulating at or behind the crest. The dense *Ammphila* cover may be preventing significant transport under the wind regimes encountered thus far in the study. The *Ammophila* transects were north of the localized erosional event that occurred in winter 2012/13. There has been no significant erosion of the backshore on these profiles during the course of the study. In fact, the backshore showed little seasonal variation during the two years of the study, with the exception of a significant elevation increase between summer 2013 and winter 2014 that could have occurred in late summer.

MA-LE'L

The Ma-le'l profiles, with the exception of Transgressive transects 1 and 2, are all located in areas that underwent restoration through the removal of invasive *Ammophila* from 2005-2006 (Pickart 2013). Prior to restoration, two distinctive foredune ridges, one active and one relict, were present. *Ammophila* had built the shoreward foredune and dominated the vegetation almost to the exclusion of other species, whereas the relict foredune had been invaded while some native species were present. In winter 2006/07 a major scarping event eroded back the active foredune before significant recolonization had occurred. Between 2009 and 2011, *Elymus* was planted over much of the foredune and subsequently increased in cover and density. The two Non-*Elymus* transects were located in areas lacking *Elymus* when the study began, but in the subsequent two years, *Elymus* colonized the stoss slope of Non-*Elymus* transect 1 (Fig. 12).

All four of the transects on the more recently restored Ma-le'l site were lower in elevation than the Lanphere profiles, ranging in elevation from 10.3 to 11.0 m NAVD 1988. Three of the four (all but Non-*Elymus* transect 2) developed an incipient foredune by summer 2014 up to 1 m above the backshore (Figs. 12-15). Non-*Elymus* transect 2, which lacked the incipient foredune, was different in character than the other profiles (Fig. 13). It had the lowest vegetation cover on the stoss slope at the start of the study, and was characterized by a lower shoreward and a higher rear crest. The lower crest is a remnant of the *Ammophila*-built outer foredune ridge. During the two years of the study, this ridge eroded in height and width, with a concomitant deposition on the stoss face of the second ridge. Non-*Elymus* profile 1 also exhibited displacement of sediment, but from the upper stoss face over the crest, which maintained its elevation, forming two slipfaces behind the crest that have migrated inland. The stoss slope of this transect below the crest has maintained the same profile over the two-year period. Both *Elymus* profiles exhibited little change in their stoss slopes, and both developed an incipient foredune (Figs. 14-15). *Elymus* transect 2 increased in elevation 0.3 m at the crest, which also shifted shorewards (Fig. 15). These observations suggest that *Elymus* exhibited a stabilizing influence on the established foredune similar to that seen in the Lanphere transects.

The transgressive dune profiles are located in an area that was largely unvegetated until colonized by *Ammophila* in the 1970s. *Ammophila* was removed in phases between 1992 and 1997, and native recolonization occurred (Pickart 2013). Between 1998 and 2000 this area was severely scarped during the 1997/98 El Niño and 1998/99 La Niña winters, and over the next 5 years the foredune along this 160-m long stretch eroded to a Stage 5 foredune as defined by Hesp (2002), initiating a transgressive sand sheet. By 2009 the dune sheet had begun differentiating into two distinct lobes which appear to be transitioning into parabolic dunes. In 2011, *Elymus* was planted along the base of the sand sheet, aligned with the unaffected foredune to the north and south. The profiles have tracked the development of this transgressive dune as well as the initiation of a new Stage 1 incipient foredune. Transgressive transect 1 is located in the northern lobe and Transgressive transect 2 in the southern lobe. The northern lobe is fed from a much broader stretch of beach, and the profile of this transect is the lowest (9 m NAVD 1988) of all the profiles in the study area, having lost approximately 1 m in the past two years. However, transgressive profile 2, while lower than the other Lanphere profiles, is also higher than all of the

Ma-le'l transects (12 m NGVD 1988), and has maintained this elevation since the start of the study. Both profiles have exhibited a landward translation, although transect 2, with its high point anchored by vegetation, has become more concave on its shoreward side and migrated less than transect 1, although collapse of the peak may be imminent given the amount of erosion at its base. Both profiles have experienced significant deposition on the backshore, and the development of an incipient foredune. The incipient foredune in transect 1 (the lower of the two profiles) has a higher incipient foredune (7.5 m NGVD 1988), than transect 2 (6.75 m NGVD 1988). As the windward slope of these dunes has lowered, the surface has become much more topographically heterogeneous, and vegetation is steadily increasing.

The Ma-le'l transects did not exhibit as much loss of elevation between winter and summer 2012 as the Lanphere transects, and were not subject to the large scarping event of winter 2013. This portion of the Study Area appears to have ultimately formed slightly higher incipient foredunes, with a possible correlation between these processes.

OVERALL TRENDS

Results to date have revealed some distinctive trends in foredune morphology and dynamics. *Ammophila*-dominated foredunes were steeper and more peaked than *Elymus*-dominated foredunes. Restored foredunes with the greatest time since restoration were higher than both *Ammophila*-dominated and more recently restored foredunes. The relatively low height of the Ma-le'l foredunes, but not that of the *Ammophila* foredunes, may be partly attributed to a north-south elevational gradient. Incipient foredunes did not develop in front of *Ammophila*-dominated foredunes, which trapped sediment on their stoss slopes before it reached the crest. In contrast, *Elymus*-dominated foredunes stored sand both in an incipient foredune as well as on the stoss slope of the established foredune. The native dune mat foredunes (lacking both native and non-native dune-building grasses) allowed the most sand to reach or travel past the foredune crest (excluding blowout/transgressive transects). Both blowouts were inactive (no scouring on the stoss slope) due to the development of a frontal, sand-trapping (*Elymus*-dominated) incipient foredune. Overall, the Ma-le'l site, which was much more recently restored, was characterized by a lower foredune and more dynamic processes than the Lanphere site. During the two year period of this study, there were no major erosional events. The upper beach was locally scarped before or after the first and second winter monitoring intervals, which may have affected the height and/or volume of the developing incipient foredunes in those locations.

FUTURE DIRECTIONS

Monitoring of the profiles will continue an additional two years with funding from USFWS. In summer 2014, additional transects are planned for property to the south owned by the Bureau of Land Management with assistance from that agency. As the geographic scope of the project expands, transects will be less intensively monitored so that the study remains cost effective. The new transects will likely be monitored annually rather than semi-annually, and vegetation monitoring will be simplified. Expansion of the Study Area is important because there is significant alongshore variation in foredune morphology along the North Spit which may reflect underlying gradients such as sediment supply or tectonic variations (downfaulting vs. uplifting blocks). Ultimately, the goal is to include the South Spit as well, a much narrower and more low-lying feature than the North Spit. Given the role of these two spits in protecting the estuary and adjacent development and infrastructure, the need for reliable models predicting their response to sea level rise cannot be overstated. The dune profiles being monitored provide us with a wide range of foredune morphologies and vegetation characteristics, which will ultimately allow us to much more robustly model dune and vegetation response to sea level rise.

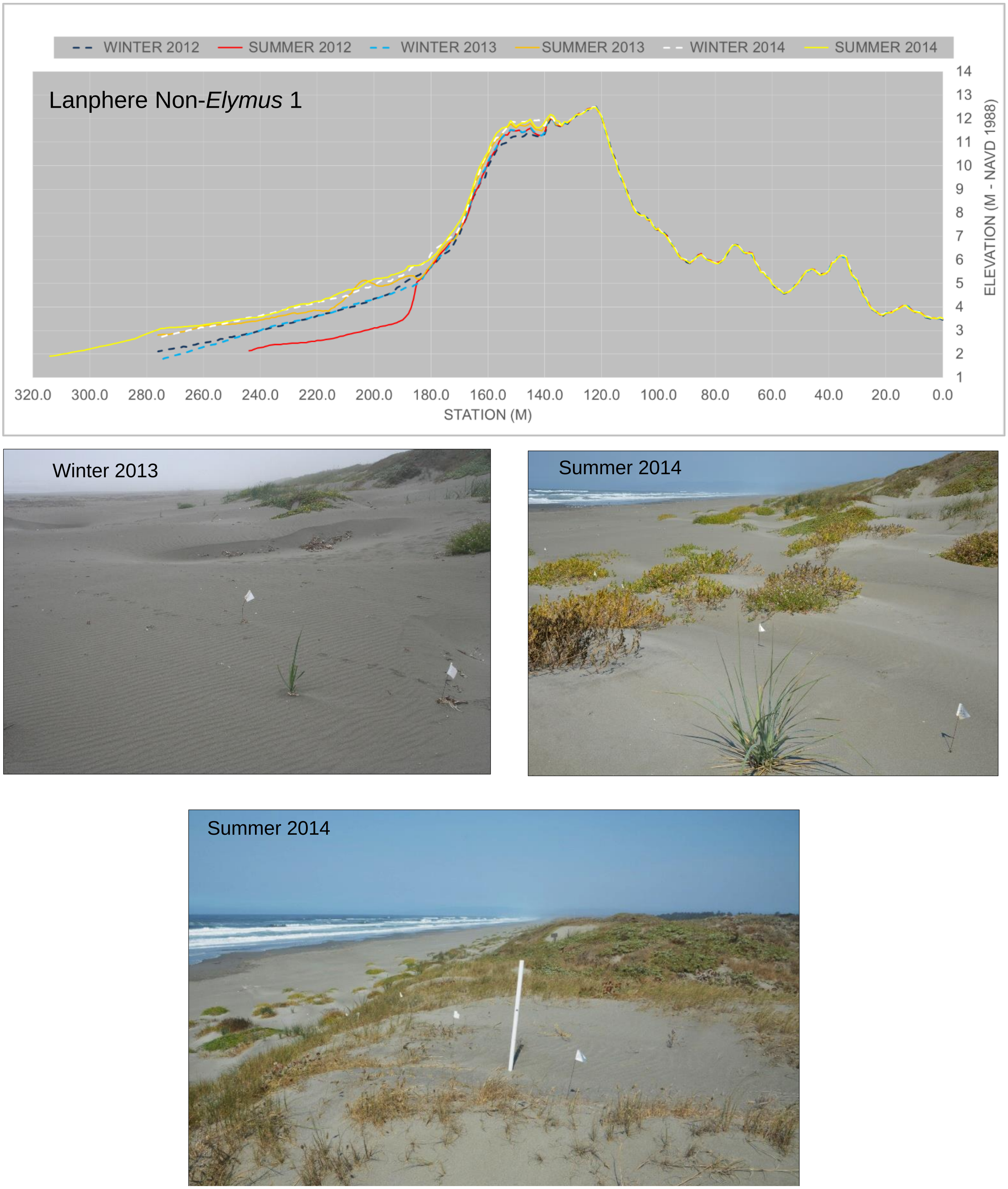

Figure 4. Lanphere Non-*Elymus* transect 1 profiles (top); photopoints of westernmost vegetation in Summer 2013 and 2014 (middle), and overall shape of foredune in 2014 (bottom).

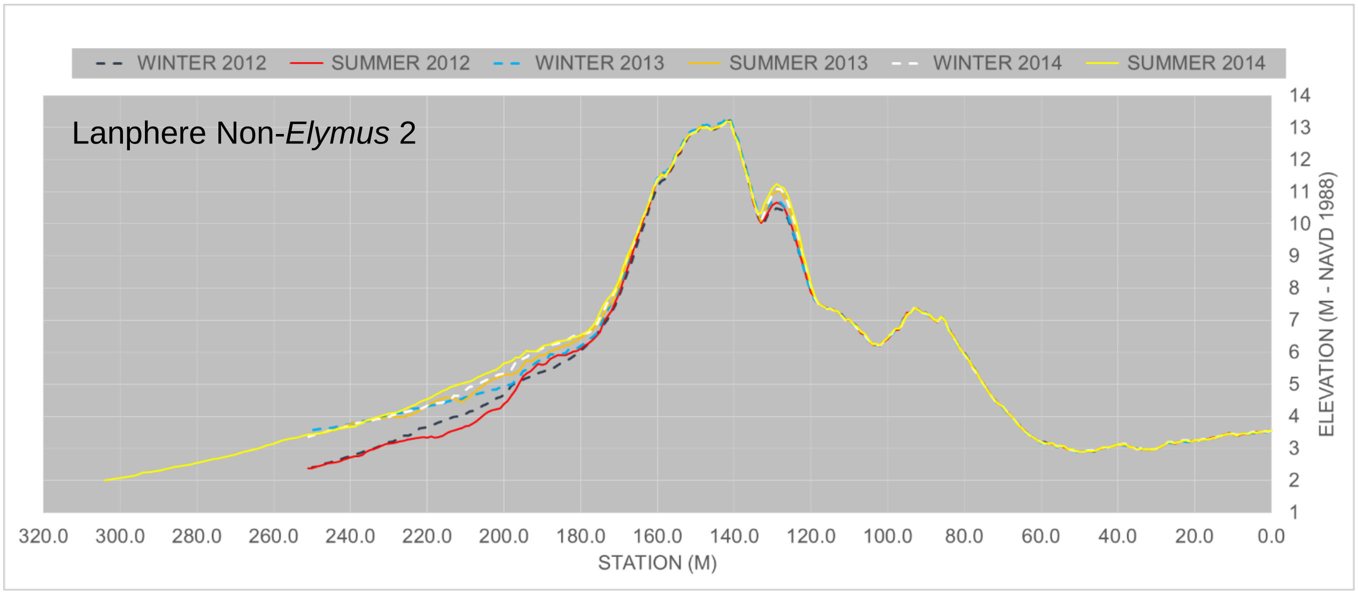

Figure 5. Lanphere Non-*Elymus* transect 2 profiles (top); photopoints of westernmost vegetation in Summer 2013 and 2014 (middle), and overall shape of foredune in 2014 (bottom).

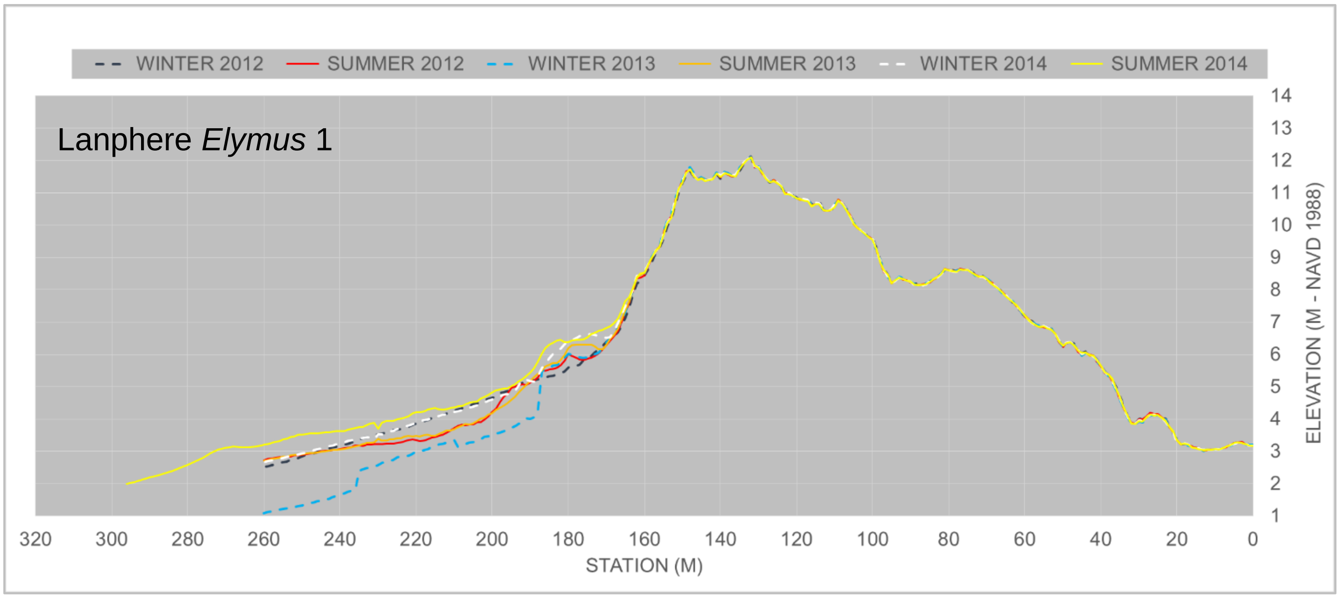

Figure 6. Lanphere *Elymus* transect 1 profiles (top); photopoints of westernmost vegetation in Summer 2013 and 2014 (middle), and overall shape of foredune and incipient foredune in 2014 (bottom).

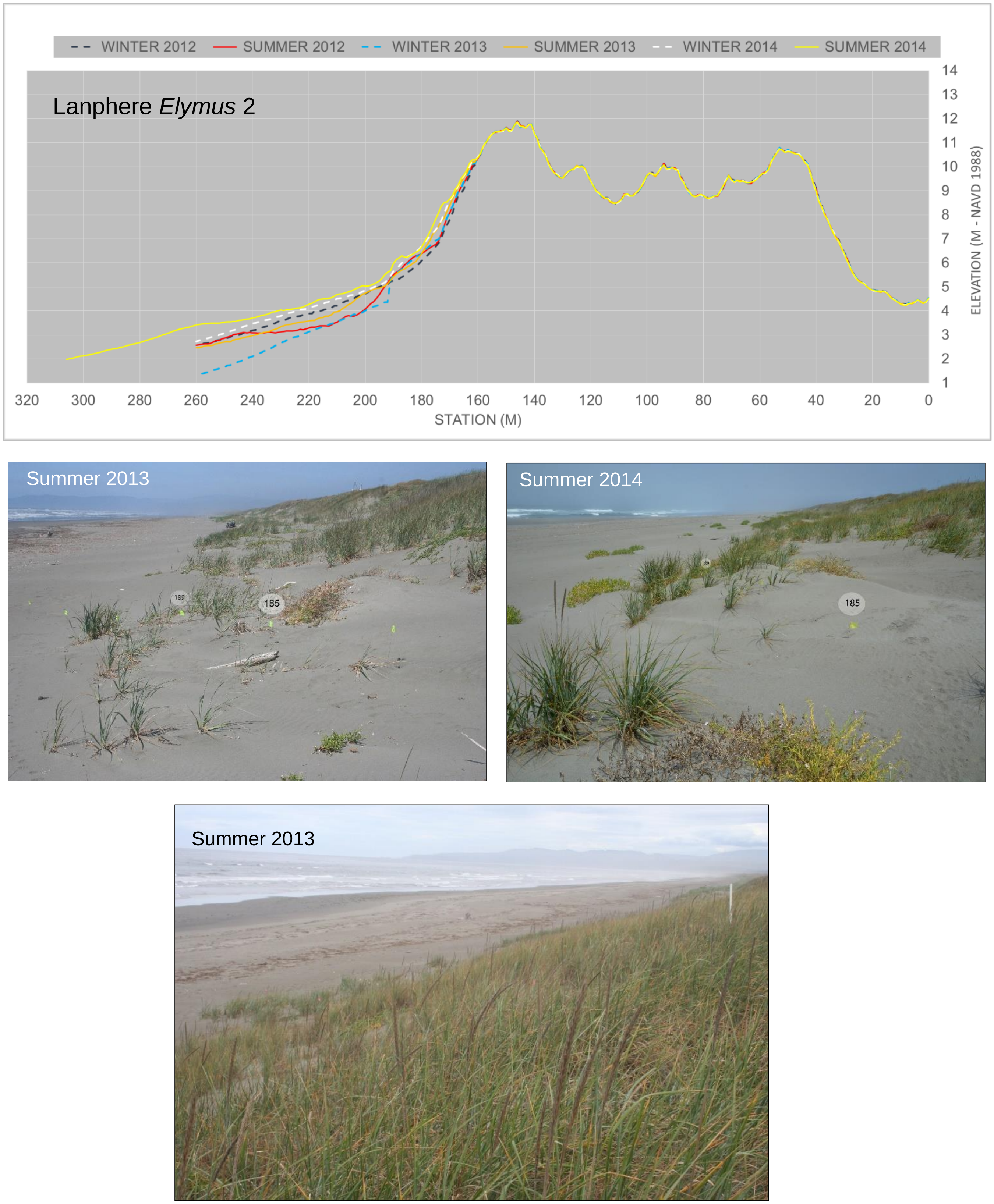

Figure 7. Lanphere *Elymus* transect 2 profiles (top); photopoints of westernmost vegetation in Summer 2013 and 2014 (middle), and overall shape of foredune and incipient foredune in 2013 (bottom).

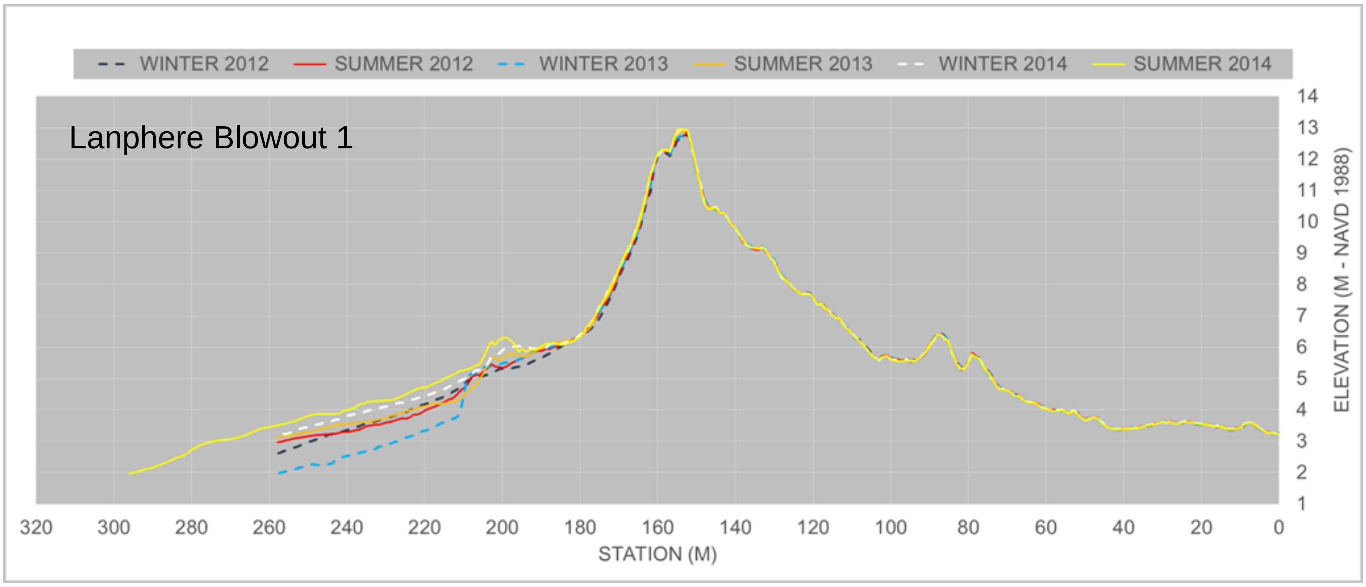

Figure 8. Lanphere Blowout transect 1 profiles (top); photopoints of westernmost vegetation in Summer 2013 and 2014 (middle), and overall shape of foredune and incipient foredune in 2014 (bottom).

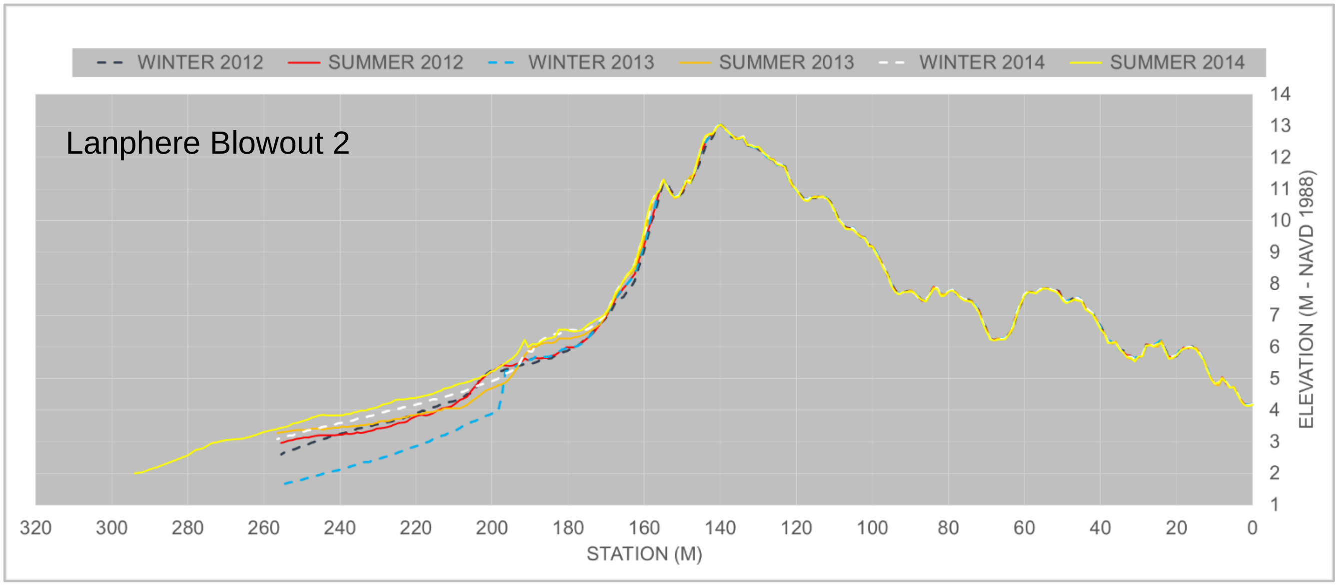

Figure 9. Lanphere Blowout transect 2 profiles (top); photopoints of westernmost vegetation in Summer 2013 and 2014 (middle), and overall shape of foredune and incipient foredune in 2014 (bottom).

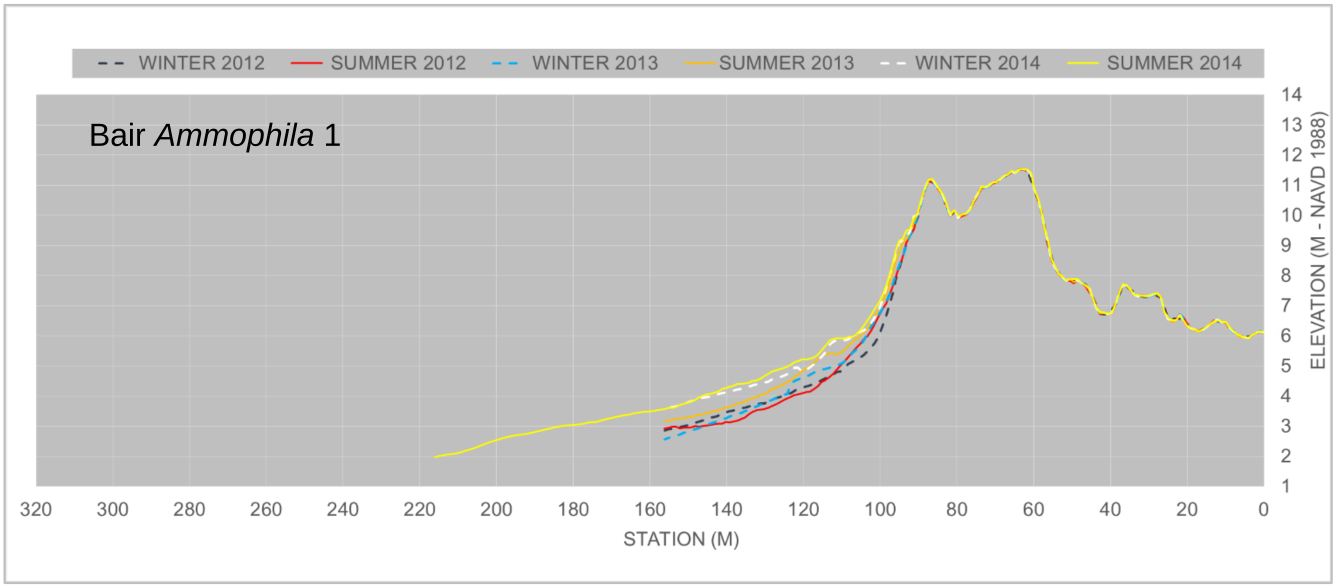

Figure 10. Bair *Ammophila* transect 1 profiles (top); photopoints of westernmost vegetation in Summer 2013 and 2014 (middle), and overall shape of foredune and incipient foredune in 2014 (bottom).

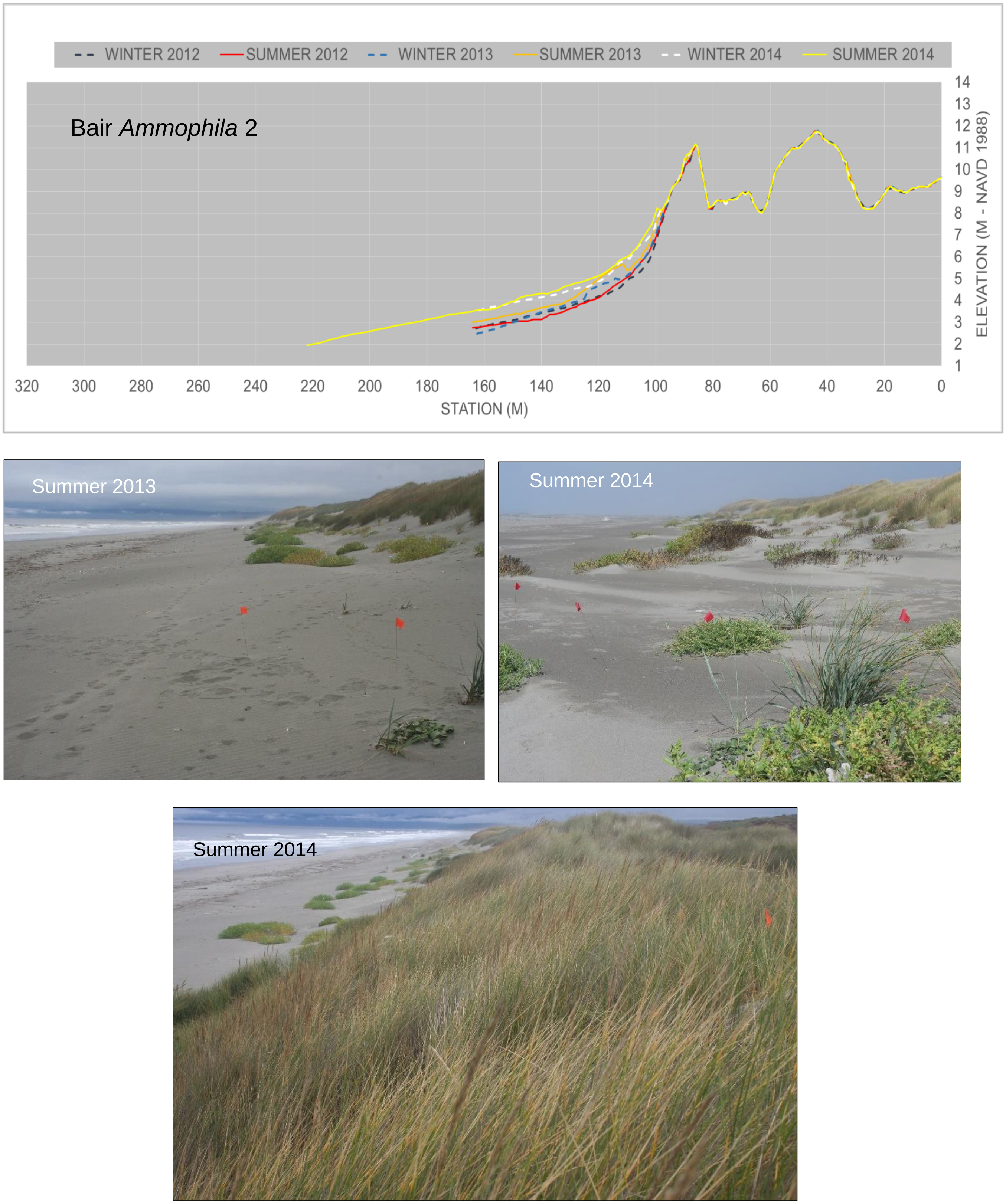

Figure 11. Bair *Ammophila* transect 2 profiles (top); photopoints of westernmost vegetation in Summer 2013 and 2014 (middle), and overall shape of foredune and incipient foredune in 2014 (bottom).

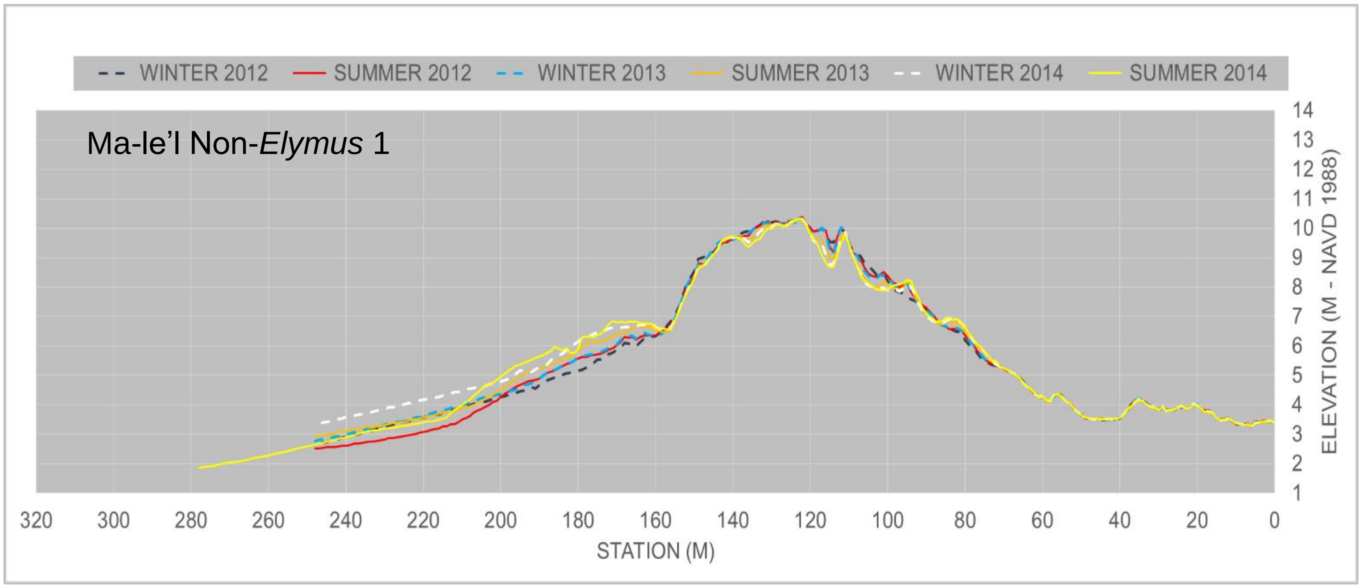

Figure 12. Ma-le'l Non-*Elymus* transect 1 profiles (top); photopoints of westernmost vegetation in Summer 2013 and 2014 (middle), and overall shape of foredune and incipient foredune in 2014 (bottom).

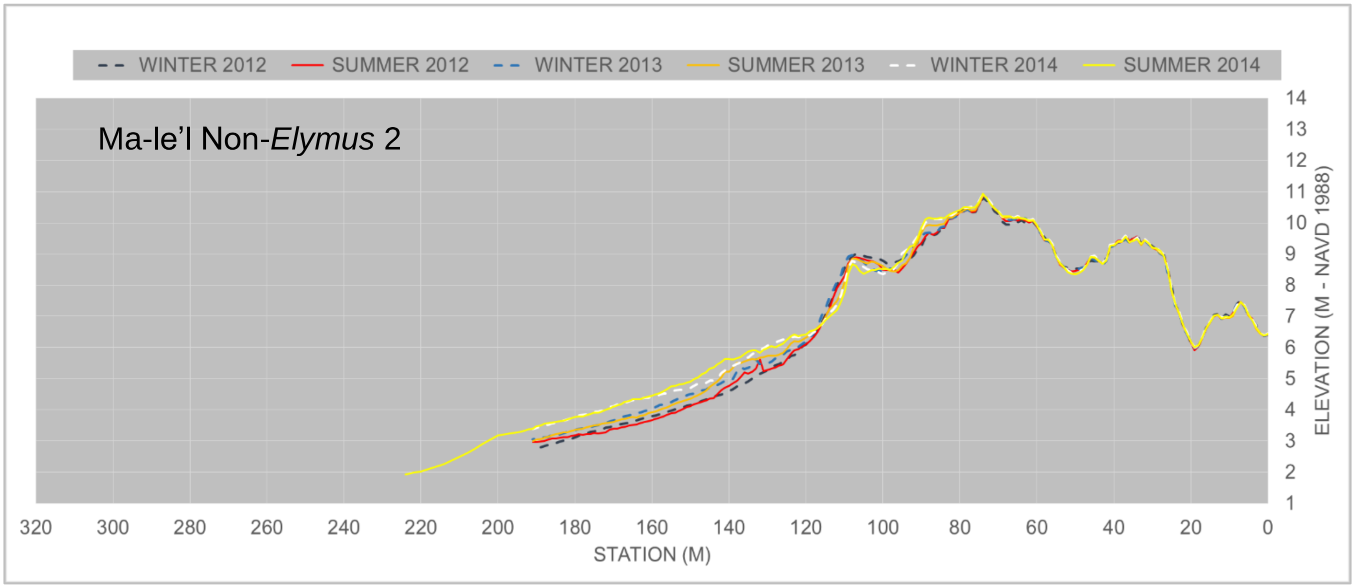

Figure 13. Ma-le'l Non-*Elymus* transect 2 profiles (top); photopoints of westernmost vegetation in Summer 2013 and 2014 (middle), and overall shape of foredune and incipient foredune in 2014 (bottom).

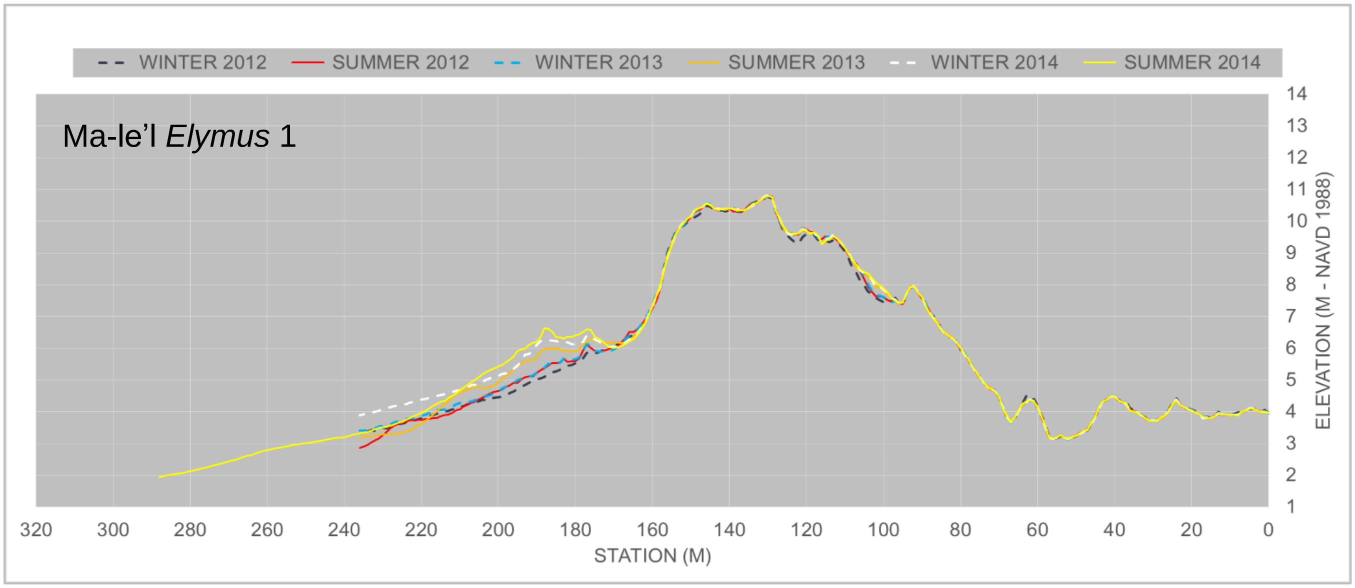

Figure 14. Ma-le'l *Elymus* transect 1 profiles (top); photopoints of westernmost vegetation in Summer 2013 and 2014 (middle), and overall shape of foredune and incipient foredune in 2014 (bottom).

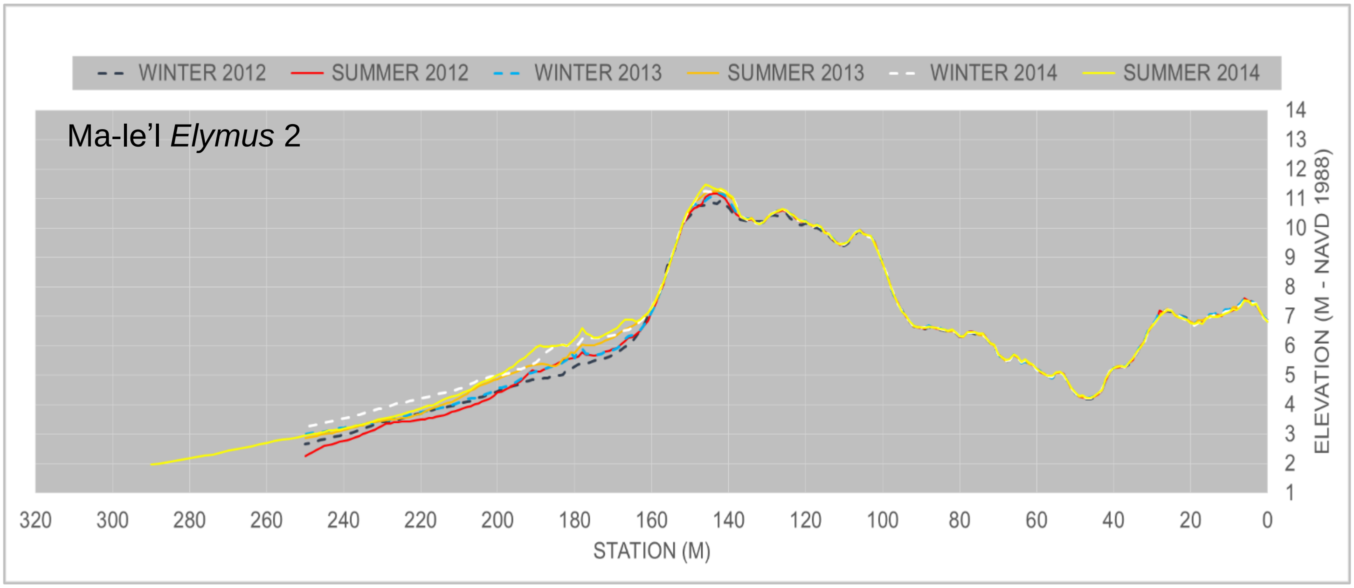

Figure 15. Ma-le'l *Elymus* transect 2 profiles (top); photopoints of westernmost vegetation in Summer 2013 and 2014 (middle), and overall shape of foredune and incipient foredune in 2014 (bottom).

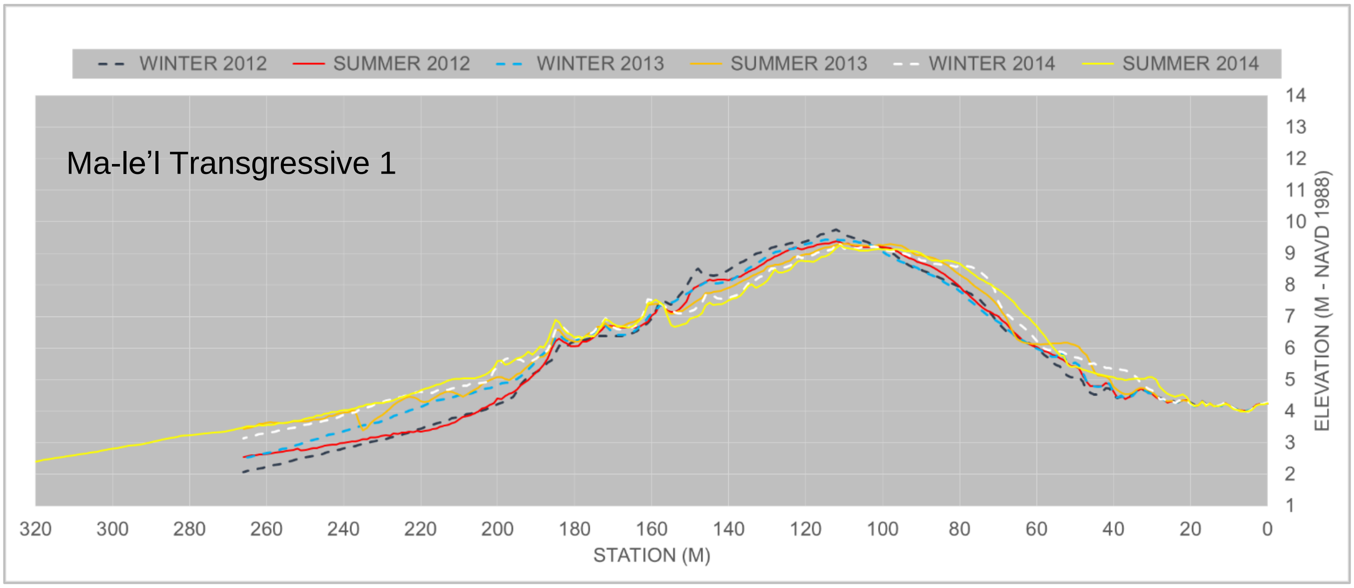

Figure 16. Ma-le'l Transgressive transect 1 profiles (top); photopoints of westernmost vegetation in Summer 2013 and 2014 (middle), and overall shape of foredune and incipient foredune in 2014 (bottom).

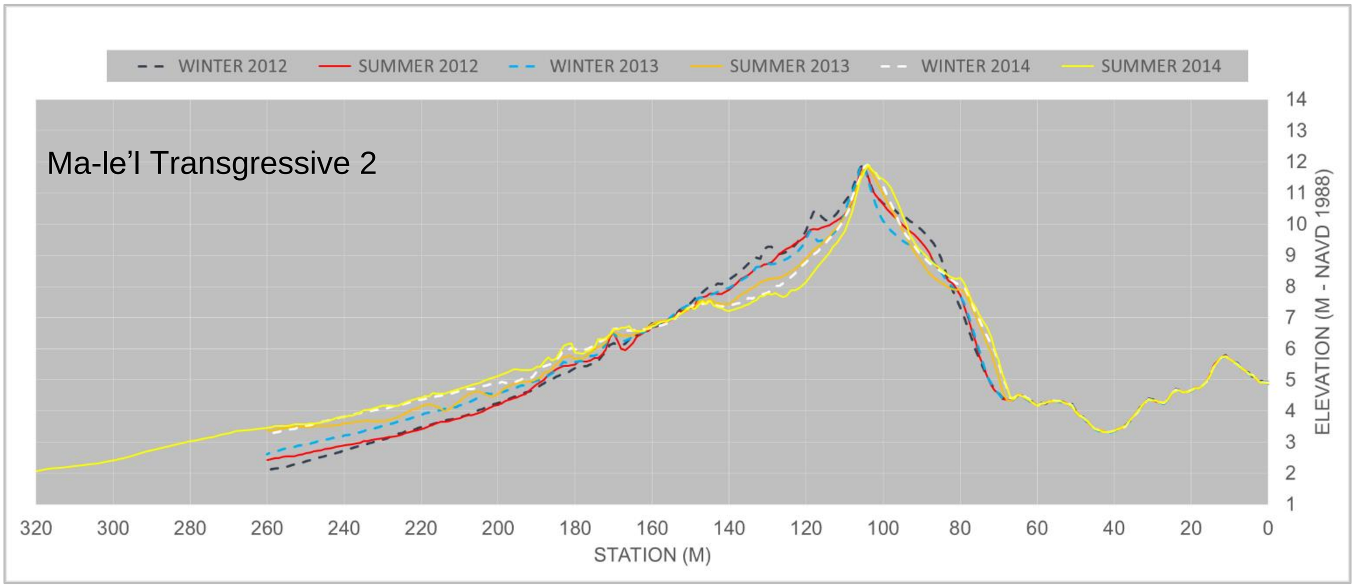

Figure 17. Ma-le'l Transgressive transect 2 profiles (top); photopoints of westernmost vegetation in Summer 2013 and 2014 (middle), and overall shape of foredune and incipient foredune in 2014 (bottom).

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