United States Department of the Interior

BUREAU OF LAND MANAGEMENT
Arcata Field Office
1695 Heindon Road
Arcata, CA 95521
www.ca.blm.gov/arcata

July 24, 2017

In Reply Refer To:
1600(P) CA330

Planning Commission
Humboldt County Clerk of the Board
825 5th Street, Room 111
Eureka, CA 955019

Dear Planning Commissioners:

The Bureau of Land Management (BLM) is pleased to provide the Humboldt County Planning Commission (commission) with supporting information relative to BLM's application for a Conditional Use Permit (CUP) for non-native vegetation removal at Table Bluff County Park (APN 308-041-002 PR/B zone. The CUP application is scheduled for the Planning Commission meeting on August 3, 2017.

1) The BLM has successfully managed the Mike Thompson Wildlife Area, South Spit Humboldt Bay (South Spit), including the Table Bluff County Park (TBCP), for the past 15 years. In collaboration with the County and State agencies, BLM has improved and maintained infrastructure, provided diverse recreational opportunities for visitors and enhanced plant and animal habitat in accordance with the goals and objectives of the Humboldt Beach and Dunes Management Plan (1995), South Spit Management Plan (1997), and the South Spit Interim (Final) Management Plan (SSIFMP) (2002). Collaboration between BLM and the County for management of South Spit was initiated in the late 1990s with leadership from former County Supervisor Jimmy Smith.

2) The southern portion (2.74 acres) of the Public Recreation-zoned parcel within TBCP, situated south of the vehicle access corridor, is currently dominated by European beachgrass. The northern portion (4.3 acres) of this parcel, situated north of the vehicle access corridor, had the majority of its European beachgrass removed between 2003 and 2005 using California Conservation Corps hand crews.

3) Ocean Day is a highly popular coastal educational event for up to 1,000 grade-school students that has occurred annually at the South Spit since 2005. Participating students gain a deeper appreciation of the marine and coastal environment while having the opportunity to engage in the physical activity of removing European beachgrass as part of a comprehensive program to enhance native plant recovery at the South Spit. This activity has occurred on TBCP, within the southern portion of the Public Recreation Zone, from 2010-2015. In April 2016, the BLM was informed by the County to apply for a CUP to continue this activity in response to concern that the Public Recreation Zoning does not include this activity as principally permitted. BLM submitted the permit

application paperwork in May 2016. The activity has continued to occur on property situated south of TBCP in 2016 and 2017 while the CUP permit application is pending.

4) As called for in the management plans, removal of European beach grass and recovery of native plant communities has been a primary focus of dune restoration actions. The California Coastal Commission has concurred with BLM's Consistency Determination (CD-052-02) that addresses the removal of European beachgrass at the South Spit.

5) Maintenance of restored native dune mat and foredune grassland plant communities requires repeated, small-scale, manual treatments on an infrequent basis. Brief, occasional resprout sweeps have occurred on the northern portion of the Public Recreation-zoned parcel since 2005 to maintain its enhanced condition. In April 2016, the BLM was informed by the County to apply for a CUP to continue this activity in response to a concern that the Public Recreation Zoning doesn't include invasive, non-native beachgrass removal as principally permitted. (This activity is principally permitted on the Natural Resource-zoned parcel to the north.) BLM submitted the permit application paperwork in May 2016. There has been no native plant community maintenance work on the northern portion of the parcel since fall of 2015 while the CUP permit application is pending. The CUP seeks approval and consistency with Public Recreation Zoning to conduct on-going native plant community maintenance through occasional manual hand-pulling.

6) In addition to an existing Law Enforcement MOU between BLM and Humboldt County; the BLM and Humboldt County staff (Public Works) are working together to develop a MOU to articulate cooperative management of TBCP which has been ongoing since 2002.

7) BLM has heard concerns about potential adverse impacts of European beachgrass removal at the South Spit including activities during Ocean Day. The BLM would like to address those concerns below.

    a. In a Technical Memorandum dated January 6, 2017, in accordance with the Federal Emergency Management Agency's (FEMA's) Guidance for Implementing 44 CFR 60.3(e)(7), the BLM concluded that hand-pulling small patches of invading non-native vegetation as proposed in the Conditional Use Permit application, will not increase potential flood damages. County staff have concurred with this finding.

    b. The BLM has not observed or received any data or evidence to suggest that wetlands or other coastal resources have been impacted by European beachgrass removal associated with Ocean Day or with previously conducted restoration work at the South Spit.

    c. The South Spit road that lies to the east of the restoration area provides a hard substrate upon which to measure sand mobility following dune restoration. With over 15 years of road maintenance experience, the BLM has not observed sand accumulation or movement across the road, and therefore does not foresee impeded public access associated with native plant community maintenance activities.

d. The width of the beach and dunes in the project area is increasing, not decreasing. Preliminary shoreline movement figures provided to BLM by USFWS and developed by Kelsey McDonald and GHD, show the North Spit shoreline width decreasing, while the South Spit to Table Bluff shoreline width is increasing during the timeframe of 1939-2016.

   This work is part of the ongoing Sea-Level Rise Coastal Resilience, Vulnerability and Adaptation Project on Humboldt Bay, California (awarded through the California Coastal Conservancy Climate Ready Grant Program) that is a collaborative, interagency project, with USFWS as the lead, and the Friends of the Dunes as the fiscal sponsor.

e. Dune restoration work affects dune shape but not dune height, according to high-resolution, 2010, Digital Elevation Models completed by Kelsey McDonald (2015) that examined slope, elevation, and profiles of restored foredunes in comparison with invaded foredunes on the North Spit of Humboldt Bay. Restored and invaded areas showed no significant difference in height. However, restored and invaded foredunes varied in shape, with invaded dunes having a steeper aspect with a more flat, plateau-like top, and restored areas were more gently sloping with round peaks.

   Further, preliminary transect data (enclosed figures) for Transects T60 and T61 show seasonal variations at the upper wave slope and incipient foredune area compared with the relatively stable dune crests. The transects extend from just west of the road, and continue ocean-ward along the beach.

f. The primary goals and objectives of the South Spit Interim Management Plan (SSIMP) were to manage for protection and enhancement of threatened and endangered plant and animal species and their habitats; as well as to eradicate invasive, non-native vegetation, including European beachgrass, iceplant, yellow bush lupine, and others.

   Action 14 called for restoring native dune mat (aka dune scrub) habitat "by manual removal of invasive, non-native vegetation; as funding permits, a minimum of two acres of habitat shall be freed from invasive weed competition under this plan."

   While the original horizon of the interim plan was to be three years, the USFWS requested a minimum number of acres to be restored for purposes of computing estimated biological effects to beach layia in balancing restoration activities, contrasted to further invasive species encroachment on the rest of the spit. It was always the intent to exceed two acres of native plant community recovery. Adopting the interim plan as the final plan was consistent with ongoing native plant recovery progress and was based on public input. The SSIFMP includes provisions for adaptive management, and revisited consultation with USFWS. The BLM has consulted with USFWS with respect to ongoing adaptive, restoration and endangered species recovery activities in 2002, 2003-2008, and 2014.

We appreciate the opportunity to provide information, answer questions and discuss this matter further with the Planning Commission. We would be happy to host a field a trip to the South Spit to review this work. If you need additional information, or if you have any questions, please do not hesitate to contact Chris Heppe at (707) 825-2351, or email cheppe@blm.gov.

Sincerely,

Molly Brown
Field Manager

Attachments:

1. Technical Memorandum in Support of Proposed Conditional Use Permit and Flood Hazard Evaluation of Proposed Conditional Use Permit for South Spit Vegetation Removal. (12pp).

2. Figure: Preliminary Shoreline Movement of North Jetty, 1939-2016.
3. Figure: Preliminary Shoreline Movement of South Jetty, 1939-2016
4. Figure: Preliminary Shoreline Movement South Spit to Table Bluff, 1939-2016

5. Figure: Location of Topographical transects in project area.
6. Figure: Transect T60: in Table Bluff County Park Natural Resource zone – restored area – managed under SSIFMP.
7. Figure: Transect T61: in restored area managed under SSIFMP.
8. Differences in the Morphology of Restored and Invaded Foredunes, Humboldt Bay, California. Kelsey McDonald, USFWS, Humboldt Bay National Wildlife Refuge, Arcata CA 95521. January 2015.

United States Department of the Interior

BUREAU OF LAND MANAGEMENT
Arcata Field Office
1695 Heindon Road
Arcata, CA 95521
www.ca.blm.gov/arcata

January 27, 2017

In Reply Refer To:
1150(CA330)

Memorandum

To: Todd Sobolik, Chief Building Official, County of Humboldt

From: Molly Brown, Field Manager, Arcata Field Office (Acting)

Subject: Technical Memorandum in Support of Proposed Conditional Use Permit

The Bureau of Land Management (BLM) Arcata Field Office is providing the attached technical memorandum in support of a proposed conditional use permit for vegetation management actions on a county-owned parcel near the Mike Thompson Wildlife Area, South Spit Humboldt Bay (application # 10548). This memorandum is prepared in accordance with Federal Emergency Management Agency (FEMA) guidelines. The attached memorandum describes these FEMA guidelines, our methods and conclusions regarding the proposed conditional use permit. If you have any questions I may be reached at 707-825-2309.

Enclosure

Flood Hazard Evaluation of Proposed Conditional Use Permit for South Spit Vegetation Removal. (12 pp)

ATTACHMENT 1

Technical Memorandum

From: Sam Flanagan, Geologist,
Eric Antrim, P.E., Civil Engineer C-74282
Bureau of Land Management, Arcata, California

Subject: Flood Hazard Evaluation of Proposed Conditional Use Permit for South Spit vegetation removal. County Parcel # APN 308-041-002.

25 January 2017

Introduction

This memorandum outlines our analysis of potential changes to flood hazard associated with a proposed conditional use permit for non-native vegetation removal within portions of a County-owned parcel at the southern end of the South Spit, Humboldt Bay. This memorandum has been prepared in accordance with the Federal Emergency Management Agency's (FEMA's) Guidance for Implementing 44 CFR 60.3(e)(7) (dated November 1, 2010) to analyze whether the proposed action will increase potential flood damage.

Background

The Federal Emergency Management Agency (FEMA) develops and maintains Flood Hazard Information for the National Flood Insurance Program. Management criteria for flood-prone areas are provided in 44 CFR 60.3 and have been incorporated by Humboldt County in Chapter 5 (Flood Damage Prevention) of Title III, Division 3 of the Humboldt County Code. This technical memo reviews a proposed conditional use permit for County-owned parcel #APN 308-041-002 at the southern boundary of the Mike Thompson Wildlife Area, South Spit Humboldt Bay (Figures 1 and 2). The proposed action would occur on sand dunes which are partially situated within an area designated as a coastal high hazard area (Zone VE) on FEMA's preliminary Flood Insurance Rate Map (FIRM) dated October 27, 2015. Within this zone, 44 CFR 60.3(e)(7) and Humboldt County Code §335-7(e) prohibit man-made alterations of sand dunes and mangrove stands which would increase potential flood damages.

Guidance provided by FEMA (FEMA 2010) indicates the burden of proof is on the permit applicant to demonstrate, utilizing a qualified coastal engineer or coastal geologist with experience in coastal processes, that the proposed alteration of the sand dune does not result in any increase in flood damages. The guidance states that communities (*i.e.*, County) may issue a permit for an alteration of a dune if the evidence indicates that the alteration will not increase flood damages.

Our purpose here is to (a) describe the proposed action, and (b) provide a framework for assessing the risk of flood damage, and (c) evaluate the proposed action under this framework.

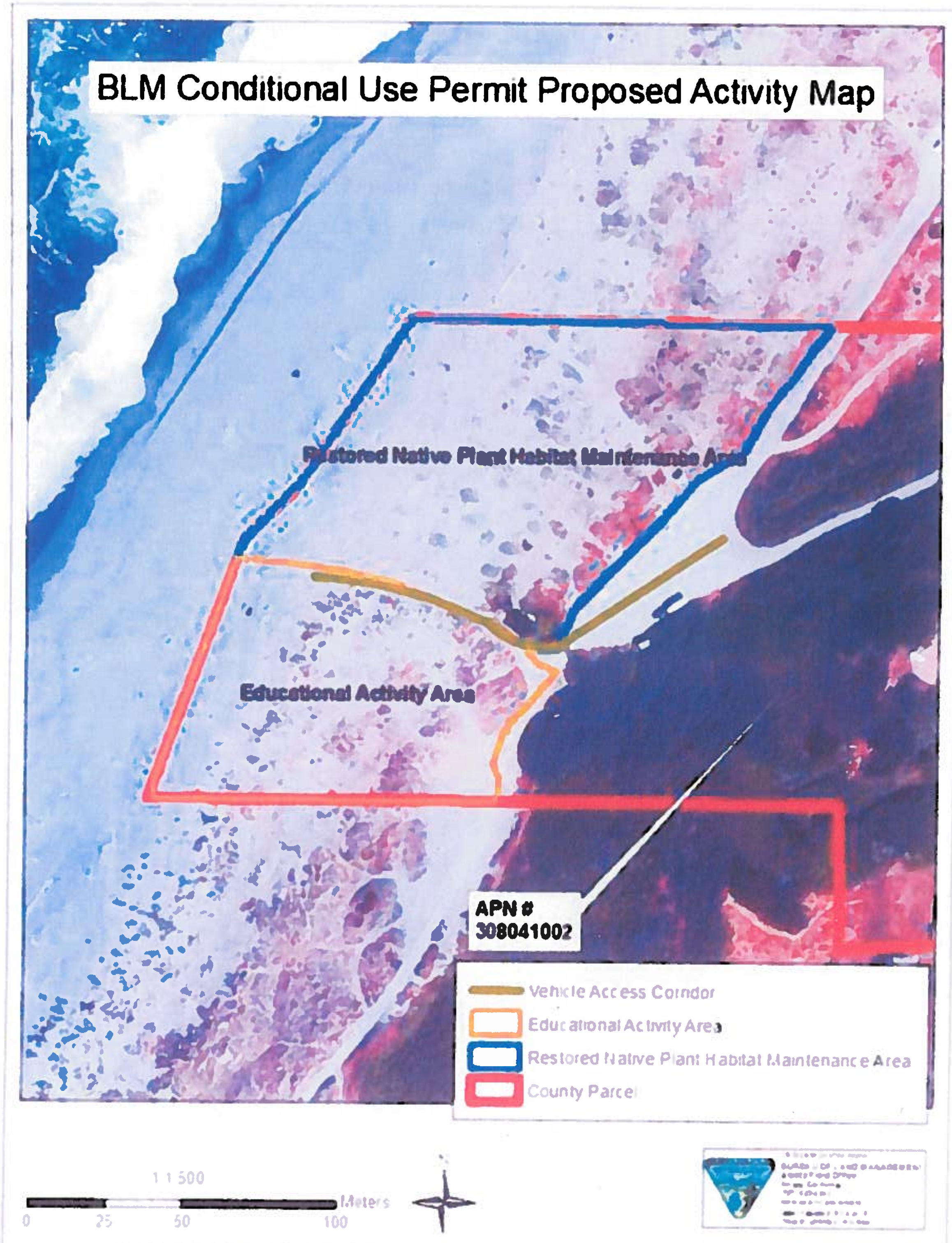

Figure 1. Location of County parcel at foot of Table Bluff.

Figure 2. Oblique view of proposed action area showing treatment dunes and BLM maintained day use area to rear of dunes at the base of Table Bluff. Copyright © 2002-2015 Kenneth & Gabrielle Adelman, California Coastal Records Project, www.californiacoastline.org

Proposed Action

The proposed action is described in detail in the Conditional Use Permit application prepared by the Bureau of Land Management. Elements of the proposed action relative to the assessment of any potential increased flood damages are considered here. The proposed action is intended to maintain the native dune vegetation by periodically removing invading, non-native vegetation. The target species for this effort is European beachgrass (*Ammophila arenaria).* However, during removal efforts, other non-native species that have invaded the area may be incidentally removed. This includes small patches of invasive iceplant (*Carpobrotus edulis*), or individuals of yellow bush lupine *(Lupinus arboreus)*. Previous work indicates that native vegetation rapidly recolonizes areas where non-native vegetation is removed (BLM 2014). We note that revegetation with native plants is a requirement in the FEMA guidance for implementing 44 CFR 60.3(e)(7).

Removal of vegetation will occur by hand pulling and the use of hand tools. The frequency of removal on the subject parcel will generally occur on an annual basis. On the southern portion of the parcel, south of the vehicle access corridor, removal would occur as part of an elementary school education event. Incidental removal may also occur across the northern portion of the parcel using other hand crews. Removal efforts avoid pulling of native vegetation such that the area of disturbance is likely to be scattered across a mosaic of native vegetation.

Framework for evaluating the potential of the proposed action to increase flood damages

To evaluate the effects of the proposed action relative to guidance for implementing 44 CFR 60.3(e)(7) we consider: (1) the existence of nearby structures and human developments potentially at risk of flood damage; (2) the function of the treatment area dunes in providing flood protection to these features; and (3) the potential for dune alteration as a result of the proposed treatment. To evaluate the effects of the proposed action on increased flood damages, we consider all three of these factors in our determination. Consideration of all three factors provides multiple lines of evidence for an informed, risk-based decision process. We elaborate on these three factors below and in Figure 3:

(1) Structures at Risk of Flood Damage. 44 CFR 60.3(e) is focused on new construction, existing structures, manufactured homes and recreational vehicle storage sites. Therefore, our assessment ranks the presence of these potentially flood prone structures as either:

- absent
- resilient to flooding, or
- at risk of damage from flooding

(2) Dune functions influencing flood damage. To describe and evaluate the function of the proposed treatment area in providing protection from flooding, we consider the specific landforms where the proposed action will occur and any offsite effects where applicable. Since this effort focuses on the coastal dune environment, we broadly consider the active wave slope, the foredune complex, intra-dune hollows and back dunes, where they exist. Each of these landforms interacts with and modifies the potential for ocean-driven flooding, dune overwash and erosion. For example, the foredunes may not provide any flood protection to areas behind the dune complex, but rather the higher

backdunes would control this. Our assessment considers the topography of the area and rates these landforms as either:

- not providing any flooding protection in light of the structures at risk, or
- providing some level of flood buffering or modification.

(3) Expected landform changes. The third area of consideration is the potential for alteration of these dune forms as a result of the proposed action. We consider empirical evidence from the local area to guide our assessment of potential changes to the physical dune environment. We rate these changes as either:

- negligible,
- change is expected but no loss of flood function (e.g. loss of dune height or continuity), or
- a degradation of the feature is anticipated such that increased flooding frequency can be expected.

FEMA guidance indicates that activities should not negatively impact natural processes. Thus we consider the role of natural processes, principally sand transport through the dunes as an integral part of our analysis.

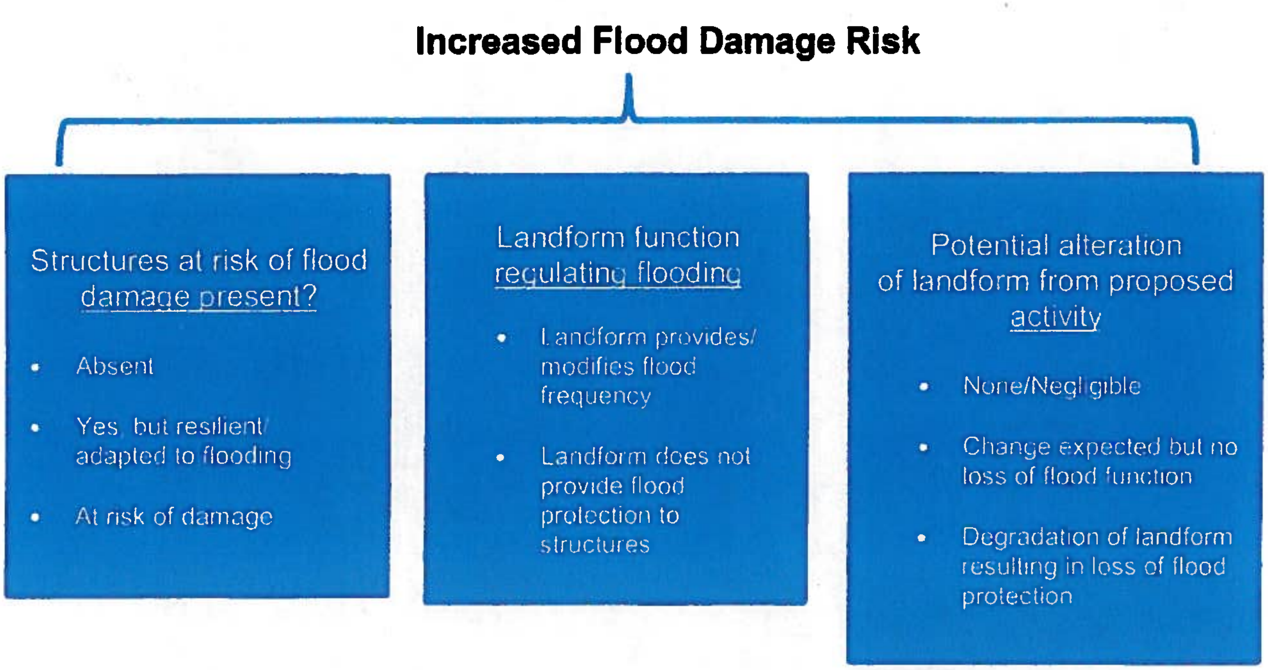

Figure 3. Our framework for evaluating the risk of flood damage from the proposed action considers the developments potentially at risk, and the role of topography in influencing potential flooding.

Evaluation of the Proposed Action

Given the framework described above, below is our discussion and evaluation of the proposed action as it relates to potential flood damage.

(1) Structures at Risk.

We assessed the area for any potential structures at risk of flood damage from activities on the subject parcel. Flooding in the proposed action area could occur from waves overtopping sand dunes during large storm events and tsunamis. The access road to the South Spit area (South Jetty Road) traverses that northeast corner of the parcel (Figure 1). At the access road switchback is a day use area maintained by the BLM, consisting of a gravel parking area and vault toilet. A four wheel drive route traverses the southern portion of the parcel over the active sand dunes, connecting the parking area and waveslope. South Jetty Road, the gravel parking area, and the vault toilet are all situated outside the VE zone shown on the October 27, 2015 preliminary FIRM (Figure 4). A portion of the vehicle access corridor is situated inside the VE zone.

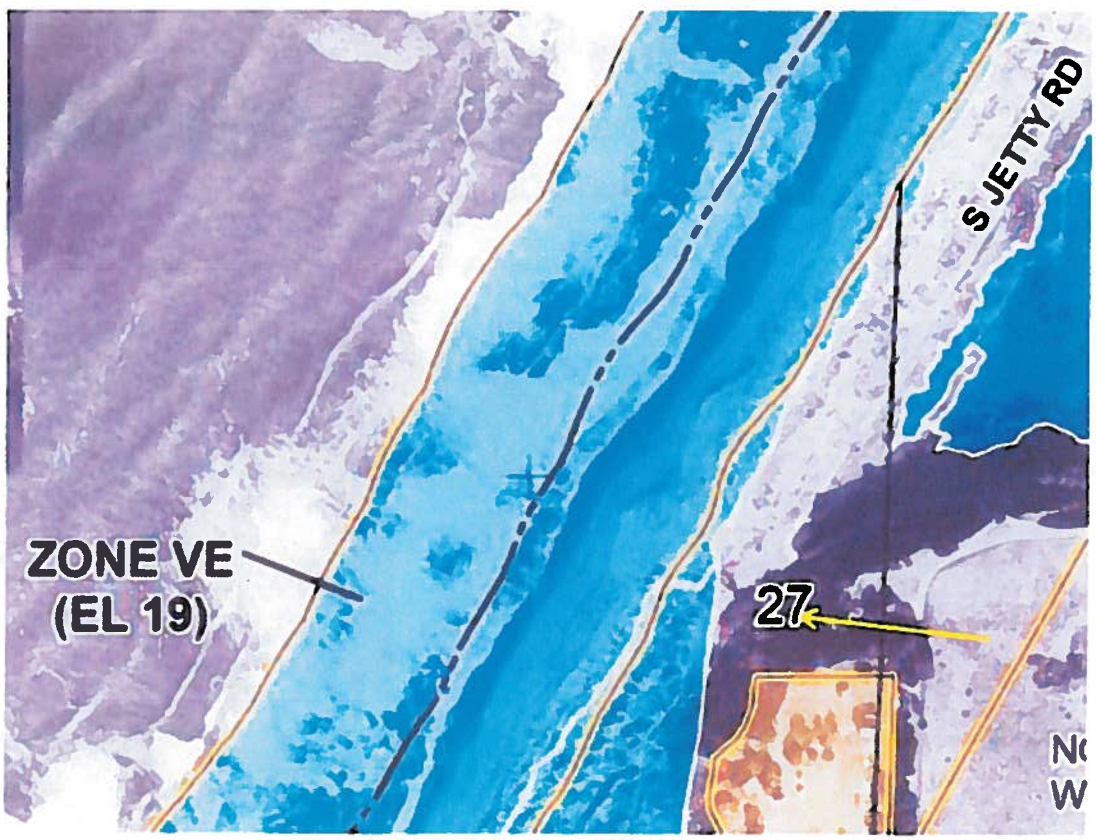

Figure 4. FEMA Flood Insurance Rate Map, Humboldt County, California, October 27, 2015. Zone VE extends up the waveslope to the first set of foredunes. Yellow arrow indicates location of day use area.

Past flooding of these areas has occurred as evidenced by scattered large driftwood pieces around the parcel. Historic aerial photos from 1939 document washover events in this location at a time when the South Spit was significantly narrower (Figure 5). However, we consider the developments in these areas to be more resilient to flooding under current conditions given that the spit is now wider, more vegetated and has more complex topography. If flooding were to occur, the developments are expected to be resilient in that they are flat surfaces not positioned in an erosive environment. Much of the erosive energy would dissipate through the dunes, spreading out across the area and quickly infiltrating. This is evidenced by the lack of erosion evidence along the base of Table Bluff where the facilities are located.

Figure 5. Aerial photo from 1939 of proposed project area showing washover events and narrower dunes.

(2) Landform functions influencing flood damage.

The proposed activities would occur on the upper edge of the waveslope, across the foredunes and into the low elevation back dunes above the Zone VE elevation (Figures 1 and 4). These features provide a mechanism for wave energy dissipation due to their elevation and complex topography. Our evaluation of the site indicates that large wave events appear to be an integral process to the form and function of these dunes. Any minor, or localized, changes that might occur here would not appreciably affect flooding of any areas of concern given the width and complexity of the dune field. We discuss potential changes to the dunes below.

(3) Expected landform changes.

The magnitude of vegetation removal in the proposed action is not expected to alter the shape of the dunes. For our evaluation, we are principally concerned with both the height and shape of the foredunes as a factor influencing wave overtopping and energy dissipation. Because the proposed action is only targeting small patches of invading vegetation, leaving the native vegetation community largely intact, we do not expect any appreciable changes in foredune morphology. We note that the scattered pattern of vegetation along the foredunes may be allowing wind transport of sand to more interior dunes and maintaining these features. Thus, we speculate that in the absence of the vegetation removal, which currently prevents re-establishment of *Ammophila,* this sand transport may diminish as European Beachgrass re-invades the foredune complex and gradual diminishment of these interior dunes might occur. In this case, a loss of important dune maintaining processes would occur. Maintaining the dynamic dune environment, particularly in areas where human developments are minimal, such as the assessment area described here, are critical for adapting to rising sea levels (see discussion below). We note that work done along the Lanphere and Ma-le'l dunes west of Arcata suggests that wholesale differences in the vegetation community do not correlate with significant differences in dune heights (McDonald 2015). This work suggests that removal of smaller patches of vegetation, as proposed, is not likely to result in appreciable changes to the dune forms.

Sea Level Rise Considerations.

Sea level rise is an increasing threat to coastal environments. The issue is particularly acute along Humboldt Bay where ongoing land subsidence is accelerating sea level rise up to 2-3 times greater than anywhere else in California (Cascadia GeoSciences 2013). Coastal dunes provide an important buffer between the ocean and low lying inland areas. The FEMA guidance cited here prohibits alterations of dunes that would increase flooding risk and impact natural processes. These natural processes result in dunes that are ever evolving in response to a variety of factors including local tectonics, climatic fluctuations, sediment supply, vegetation, wind patterns and human development (Wiedemann 1984). Dunes are not static, nor fixed, landscape features. The ability of dunes to adapt to changing sea levels is a well-documented natural process (*e.g.*, NRC 2012, Davis 1992, Crooks 2004). Generally, with rising sea levels, the shoreline migrates inland (retrograding shoreline) and the dunes respond by moving inland (transgressive dunes). However, the site-specific responses that accompany this are difficult to predict, and the process is not necessarily linear. For example, photo evidence suggests the dunes in the vicinity of the proposed action have widened over the past decades, most likely in response to increased sediment supply. Foredune erosion (and subsequent ramping) is one process by which foredunes translate (Davidson-Arnott 2010). Thus, we emphasize that maintaining a resilient dune system with intact natural processes and native vegetation, per FEMA guidance, are key components to accommodating sea level rise.

Conclusions

We conclude that hand pulling small patches of invading non-native vegetation will not increase potential flood damages. First, the magnitude of vegetation pulling is minor, leaving the existing native vegetation community largely intact. Any changes in dune shapes due to vegetation removal are likely to be negligible, and would not rise to a level where flooding risk is increased. Rather, it is more likely that removal of dense, sand-trapping non-native vegetation will benefit flood protection and resilience by enhancing inland sand transport and dune formation. Overall, the dunes provide some level of energy dissipation to large overtopping waves that have occurred in the past. The limited human developments near the site appear to be generally resistant to some level of periodic flooding and are intended as recreational facilities (not occupied structures). Except for a portion of the vehicle access corridor, all of the developments at the site are situated outside the designated coastal high hazard area shown on the October 27, 2015 preliminary FIRM. Therefore, the potential for increased flood damages from the proposed action appears negligible.

Citations

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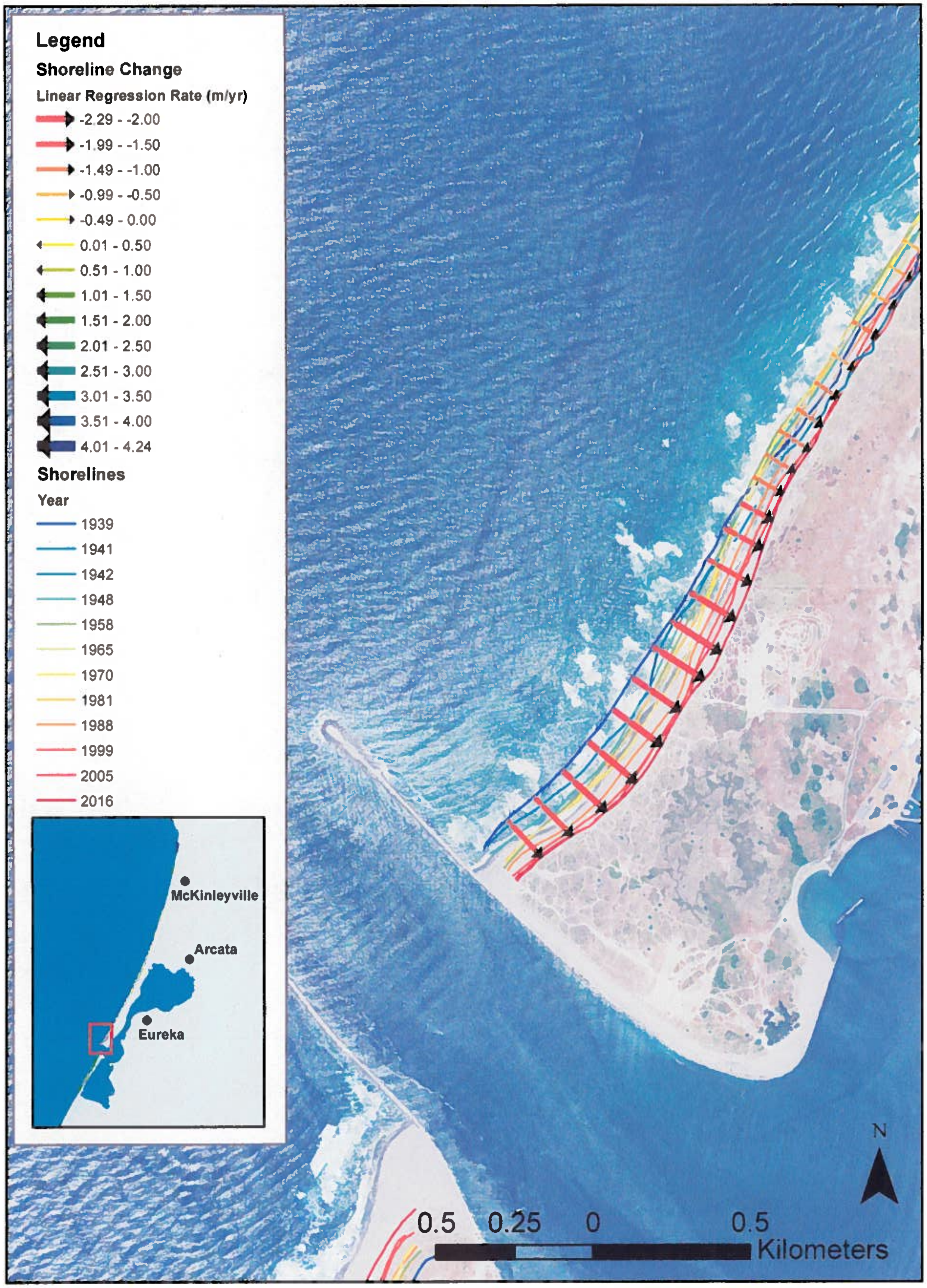
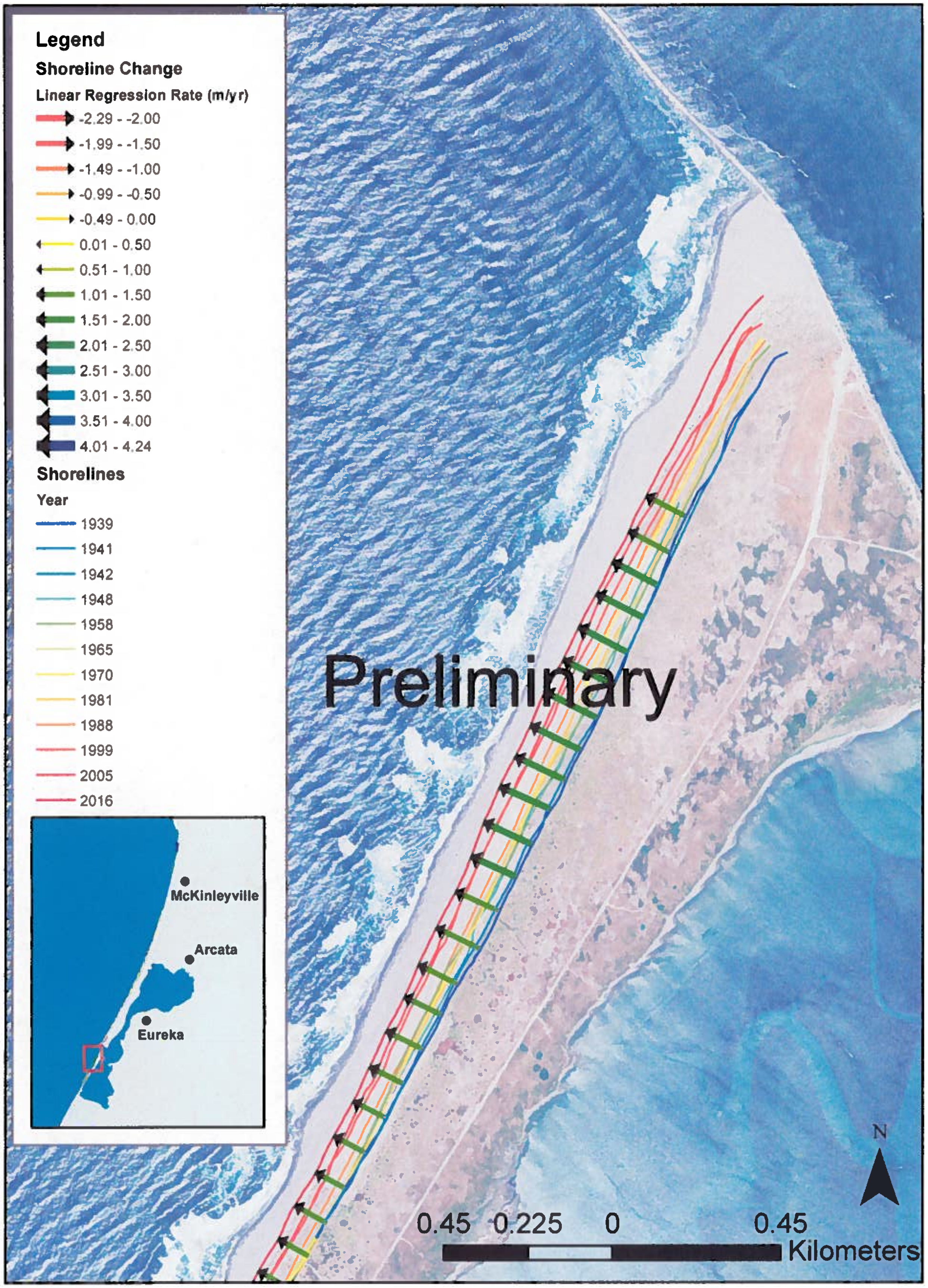
Shoreline Movement North Jetty1939-2016



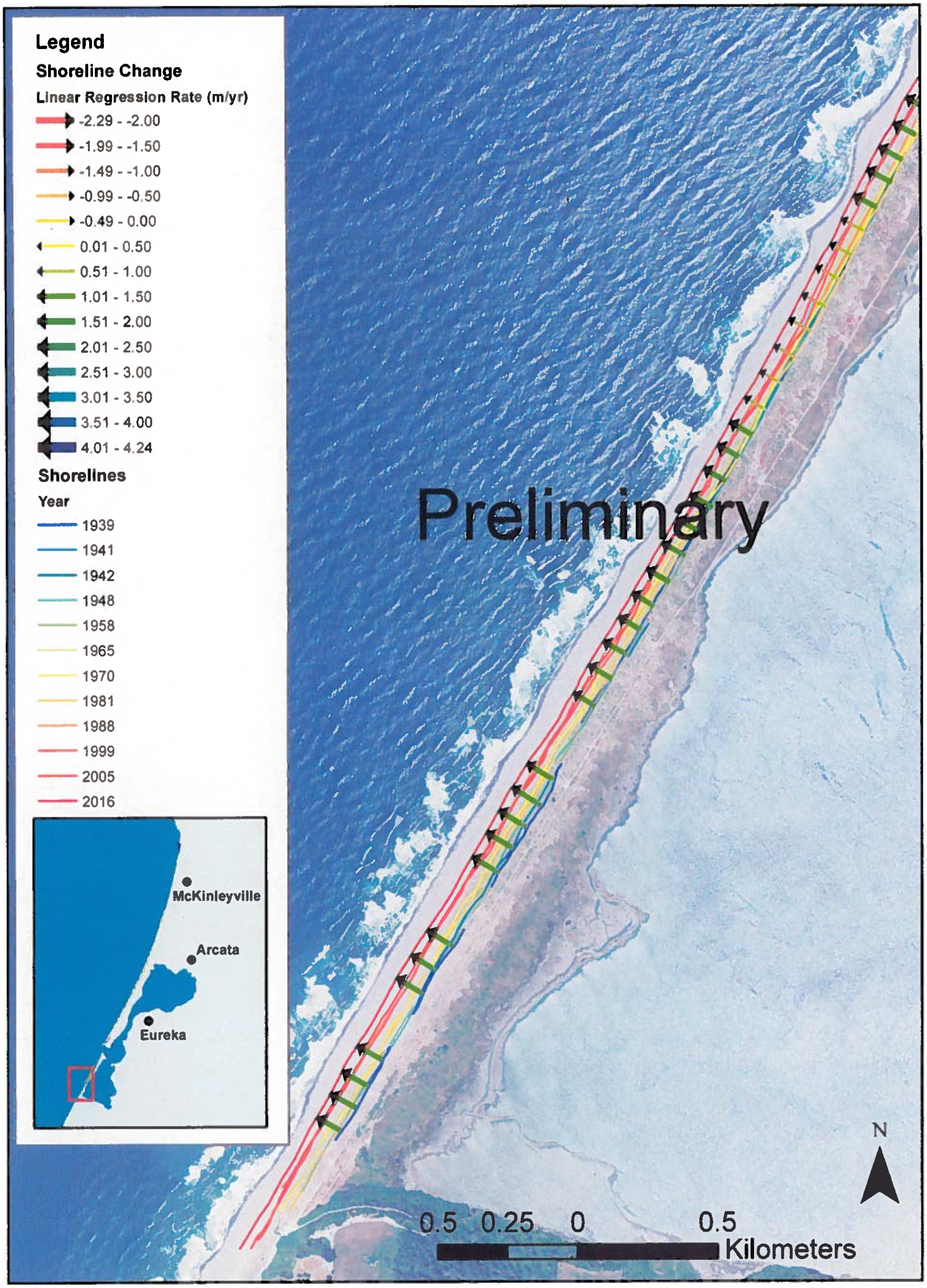
ATTACHMENT 2

Shoreline Movement South Jetty 1939-2016



ATTACHMENT 3

Shoreline Movement South Spit to Table Bluff 1939-2016



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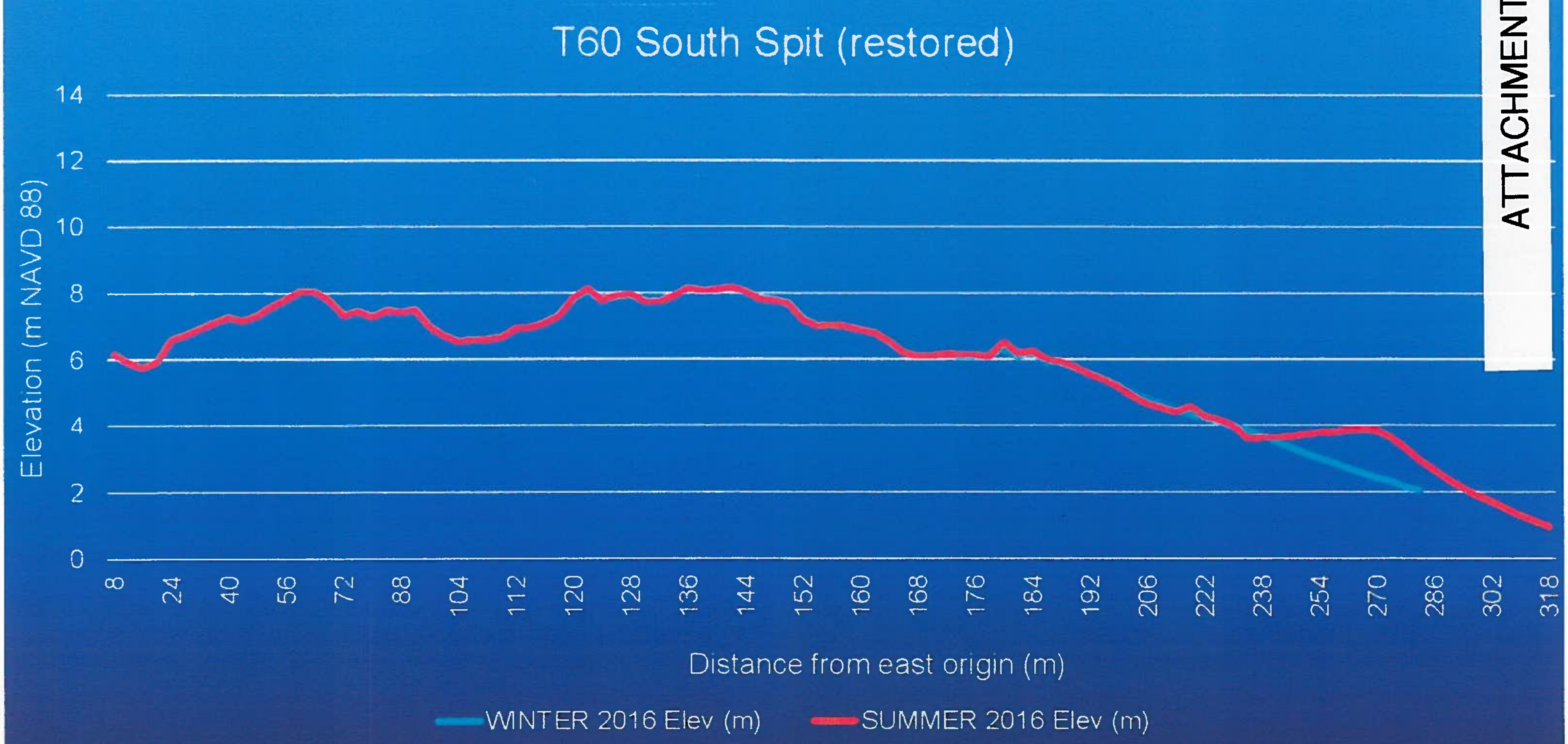

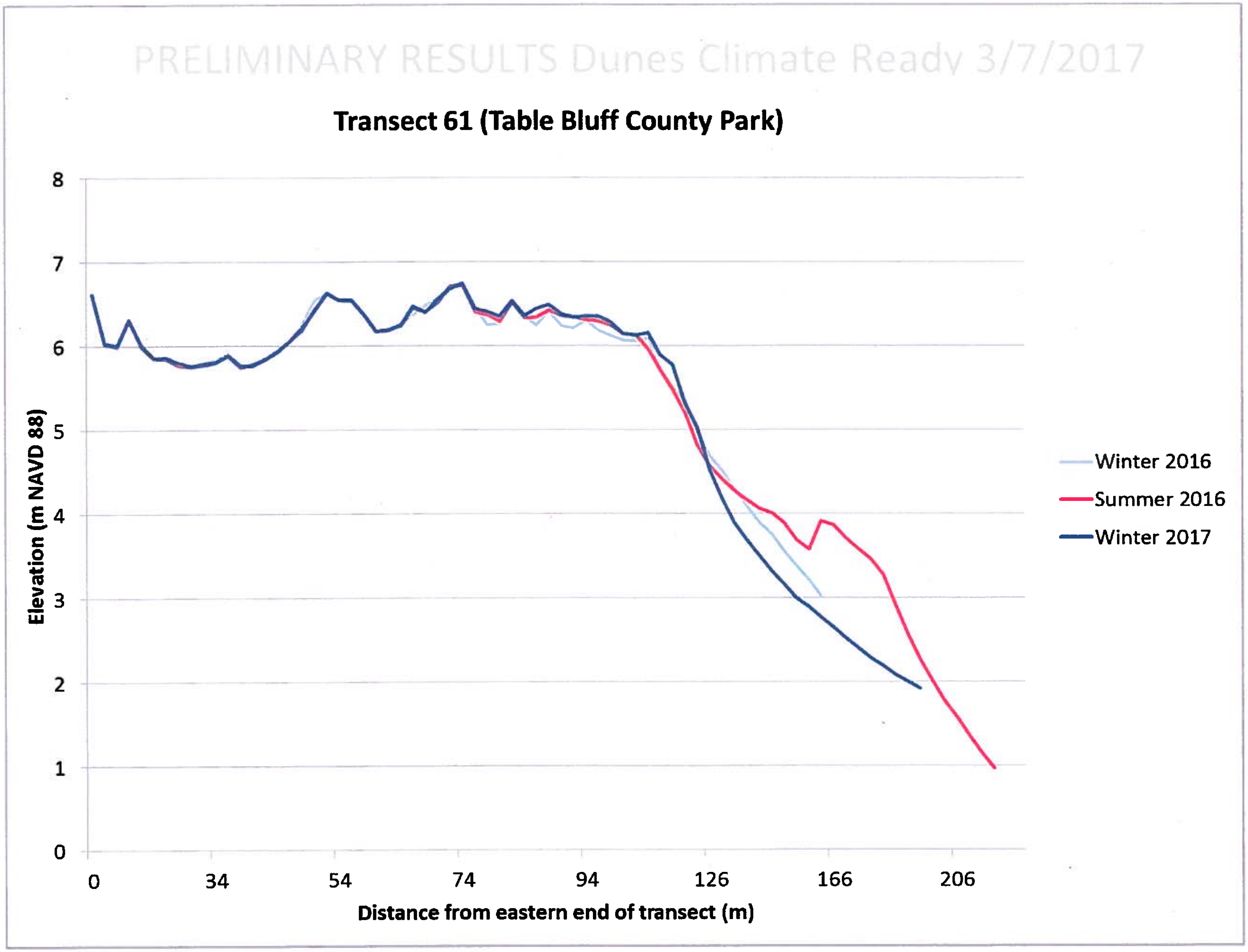

ATTACHMENT 7

Differences in the Morphology of Restored and Invaded Foredunes

Humboldt Bay, California

Invaded area of North of Lanphere Dunes (photo credit: Kelsey McDonald)

Restored area of Lanphere Dunes (photo credit: Laurel Goldsmith)

Kelsey McDonald
U.S. Fish and Wildlife Service
Humboldt Bay National Wildlife Refuge
Arcata, CA 95521

January, 2015

ATTACHMENT 8

Abstract

This study used remotely sensed data from a high-resolution (1 m^2) 2010 Digital Elevation Model (DEM) to model the slopes, elevations, and profiles of restored foredunes in comparison with invaded foredunes on the North Spit of Humboldt Bay. Restoration in the study area took place over the last 25 years, and these areas now primarily support native dunegrass (*Elymus mollis* Trin.) and other native dune species. The invaded areas are dominated by non-native European beachgrass (*Ammophila arenaria* L.). Despite recently voiced concerns that restoration might be permanently lowering the foredune, restored and invaded areas showed no significant difference in height ($p=0.748$). However, restored and invaded foredunes did show a significant difference in slope ($p<<0.001$) and slightly different profile shapes; invaded dunes were steeper with a more flat, plateau-like top, and restored areas were more gently sloping with rounded peaks. Dune heights increased from the southern end of the study area to the north, regardless of restoration status, indicating that other factors affect dune heights in the study area. The availability of only one high-resolution DEM limits these observations to a point-in-time characterization, and the applicability of the models is limited to the study area.

Introduction

The Lanphere and Ma-le'l Dunes Units of Humboldt Bay National Wildlife Refuge contain the best remaining example of the native coastal dune ecosystem that once occurred between Monterey, California and Coos Bay, Oregon (Cooper 1967, Buell et al. 1995). European beach grass (*Ammophila arenaria*), which was widely introduced to stabilize sand, has invaded the coastal dune ecosystem and supplanted native vegetation, including native dunegrass (*Elymus mollis*) (Pickart and Sawyer 1998, Buell et al. 1995). Few scattered native dunegrass communities remain in California, Oregon and Washington (Pickart and Sawyer 1998). Several restoration projects along sections of the North Spit of Humboldt Bay have removed *A. arenaria* from the foredunes over the last few decades, and native vegetation has recovered in much of the restored area.

Vegetation plays a critical role in dune formation and impacts dune morphology. Foredunes, defined as dune ridges adjacent and parallel to the shore, are created by aeolian sand deposition within vegetation (Hesp 2002). Tall, dense vegetation like *A. arenaria* tends to capture more sand and form high, peaked dunes (Hesp 2002, Zarnetske et al. 2012). Native *E. mollis* grows to a similar height (or slightly taller) compared to invasive *A. arenaria*, but it grows less densely, with total vegetation cover typically ranging from 25%-75%, compared to *A. arenaria* cover ranging up to 100% (Hacker 2011, Pickart and Sawyer 1998). *Elymus mollis* foredunes often support higher species diversity, presumably due to their more open growth pattern. The more open habit of *E. mollis* is believed to allow more sand transport from the beach over the crest of the foredune and into the diverse dune mat community found there (Pickart 2008). In Oregon and Washington, *A. arenaria* has been observed to create a continuous high foredune ridge where previously a lower or no foredune existed (Wiedemann and Pickart 1996, Buell et al. 1995, Zarnetske et al. 2012). Prior to invasion, native foredunes in the Pacific Northwest were reportedly low and gently sloping (Pickart and Sawyer 1998). The low density and growth habit of *E. mollis* has led to predictions that the biophysical feedback of native *E. mollis* cover would produce a low, gently sloping dune compared to *A. arenaria* (Zarnetske et al.

2012); however, the native portion of the Lanphere Dunes that was never dominated by *A. arenaria* currently contains a high continuous foredune similar to the structure commonly attributed to *A. arenaria* invasion (Pickart and Sawyer 1998).

Over the past 5 years, some members of the public have expressed concerns that the *Ammophila* eradication process could be destabilizing and lowering the foredune near the community of Manila on the North Spit (Walters 2011). Immediately following eradication of *A. arenaria* from the invaded portion of Lanphere Dunes, the slope and elevation of the foredunes was observed to decrease (Pickart 2014), but the foredunes have accumulated sand as native species including *E. mollis* have recolonized the area. The steeper seaward slope of invaded foredunes compared to native dunes has been commonly observed, but their comparative morphology has not previously been systematically measured. To address this information gap, this study was designed to characterize foredunes by restoration status along a 10 km stretch of the North Spit of Humboldt Bay that contains both native and invaded foredunes (Figure 1).

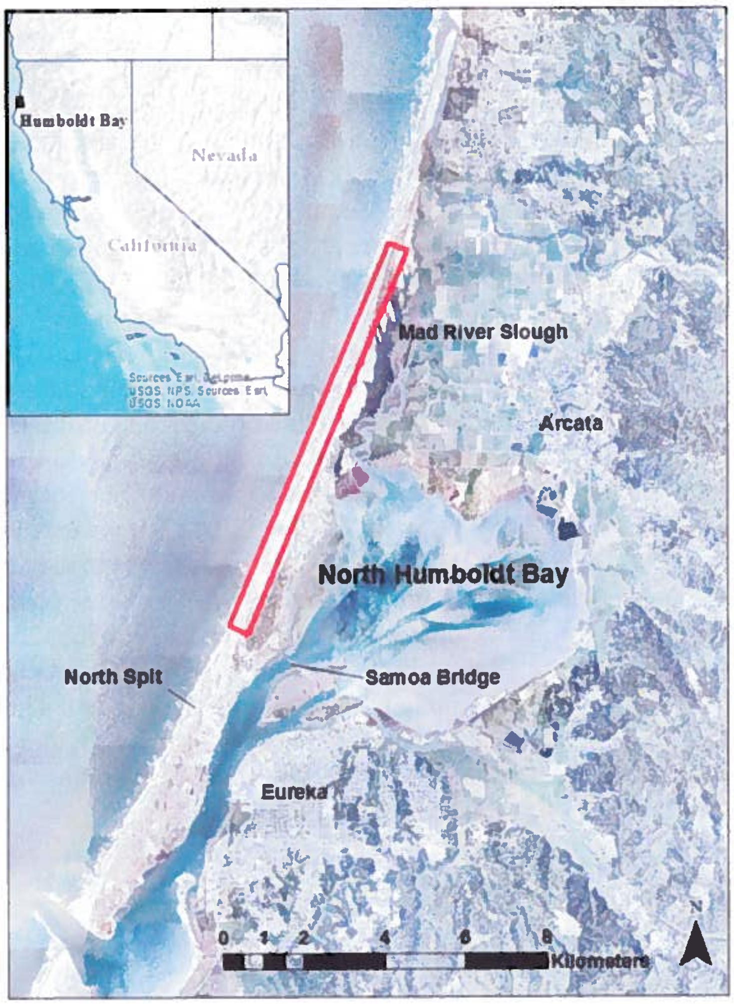

Figure 1. The study area covered the dune system that stretches 10 km from the beginning of the Mad River Slough to the Samoa Bridge on the north spit of Humboldt Bay.

Purpose of the Study

The purpose of this study was to determine the relative heights, slopes, and profile shapes of restored and invaded foredunes. Interpolation of elevation data has been widely used to create individual dune profile transects or show volumetric change over time (Andrews 2002). In this study, interpolation of elevation data from digital transects was used to model the overall shape of the foredunes and extract slopes and maximum heights for data analysis. Because the invasive European beachgrass *A. arenaria* has anecdotally been observed to create a higher, steeper stabilized foredune, the invaded foredunes were hypothesized to be both higher and steeper than restored foredunes vegetated by native species, including *E. mollis*. Determining the differences in the physical structure of these foredunes can shed light on the effects of restoration on dune processes and inform future management decisions.

Study Area and Management History

The study area is owned and/or managed by several different entities, including the U.S. Fish and Wildlife Service (FWS), the Bureau of Land Management (BLM), Friends of the Dunes (a 501(c)3 non-profit), Manila Community Services District, and private landowners (Figure 2). Restoration status varies by management unit (Figure 2). *Ammophila arenaria* is still highly abundant in dense, monospecific stands in a recently acquired FWS parcel north of Lanphere Dunes, as well as in an adjacent, privately owned parcel to the north. U.S. Fish and Wildlife Service eradicated *A. arenaria* from 1.4 km of foredune in the Lanphere Dunes between 1992 and 1997, and then eradicated *A. arenaria* and replanted native *E. mollis* on the Male'l Dunes between 2005 and 2011. The Bureau of Land Management (BLM) eradicated *A. arenaria* and replanted *E. mollis* on their northern property from 1994-2004, and on their southern property from 2003-2008 (BLM). The area to the south of BLM, owned by Friends of the Dunes, is highly invaded. Friends of the Dunes began restoration on the back of the foredunes at the north end of this area in 2008. Restoration on the foredune of the Manila Community Services District parcel took place from 1992-2000 (Miller 1997, Walter, pers. comm. 2014). However, maintenance of this restoration was halted after a 2008 lawsuit (Walters 2011), and in the intervening time, invasive *A. arenaria* reestablished itself along much of the foredune (personal obs. 2014). It is unknown exactly how much of the foredune had been reinvaded as of 2010, but aerial photography from 2010 appears to show a primarily native plant dominated foredune. The southern-most portion of the study area is privately owned and highly invaded. The presence of interspersed stretches of restored and invaded foredunes in the study area provides an opportunity to compare the physical structures of foredunes dominated by invasive *A. arenaria* with restored foredunes dominated by native species including *E. mollis*.

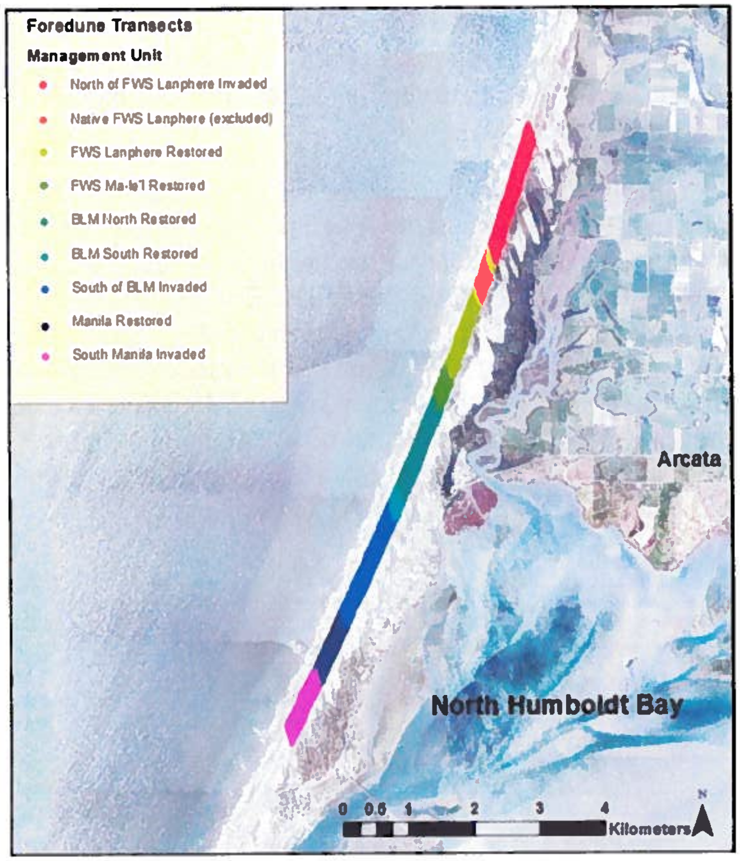

Figure 2. The study area on the North Spit of Humboldt Bay contains several different management units owned by the U.S. Fish and Wildlife Service (FWS), the Bureau of Land Management (BLM), Friends of the Dunes, Manila Community Services District, and private landowners. The unrestored native area of Lanphere was excluded from analysis.

Methods

A 1 m resolution 2010 Digital Elevation Model (DEM) from the 2009-2011 CA Coastal Conservancy Coastal Lidar Project provided elevation and slope data for this study. The "slope tool" in ArcMap 10.1 (ESRI 2012) generated a 1 m slope raster from the 2010 DEM. The study area was restricted to the northern portion of the spit where both restored and invaded foredunes occur, and where encroaching development and consequent impacts on natural processes are limited (Figure 2). In order to address the impact of restoration on dune structure, the relatively undisturbed section of native foredunes on the north end of Lanphere Dunes Unit was excluded from the analysis of restored and invaded foredunes. A 20 m buffer excluded the transition area between management units. The restored and invaded stretches are evenly distributed from north to south within the study area, with no significant correlation between dominant vegetation and northings ($r<<0.001$, $p=0.906$). The study area was confined to the foredune area from a 6 m elevation contour along the beach to 70 m southeast along transects parallel with prevailing wind. The inland edge of the study area (70 m southeast along the transects, which corresponds to approximately 40 m from the 6 m contour) was chosen because this is the typical area occupied by foredune grasses *A. arenaria* and *E. mollis*, as shown by previous GPS mapping of the extent of *E. mollis* and *A. arenaria* between Manila and the Bair parcel of Lanphere Dunes Unit (McDonald 2014, unpublished data).

A smoothed 6 m elevation contour line along the shore of the North Spit served as a baseline approximating the seaward edge of the foredune. The "create random points" tool distributed 844 points along the 6 m contour within the limits of study area between UTM y-coordinates 4520600 and 4529550 (from near the Samoa Bridge north to the north end of the Mad River Slough), excluding the unrestored native area and 20 m buffers between management areas. These points served as the start of 844 digital profile transects roughly parallel to the prevailing north-northwest winds. Each transect consisted of 49 points located 1 m apart in the x-direction (a diagonal distance of 3.85 m) for a total of 41,356 points (Figure 3). 421 transects were located in the invaded areas, and 423 transects were located in the restored areas. Elevations and slopes were extracted from the DEM and slope rasters in ArcMap at each point.

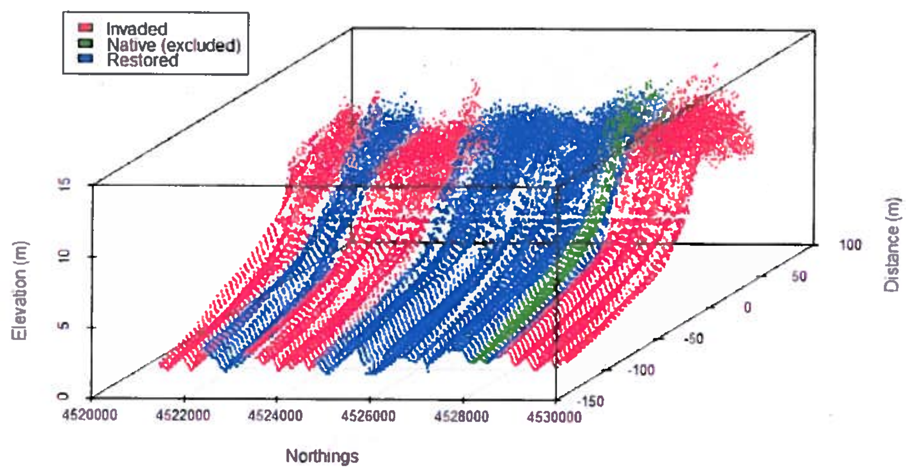

Figure 3. Random profile transects showing elevations extracted from the DEM, plotted from south to north colored according to restoration status. Positive distances are indicated for meters inland southeast along the transect from a 6 m elevation contour at the base of the foredune, and negative distances approach the ocean as they increase in magnitude.

The maximum heights and the mean seaward slopes of foredune transects in invaded and restored areas were compared using oneway tests, t-tests and boxplots in R statistical software (2013). Generalized Additive Models (GAMs) were created to depict the typical profile for restored versus invaded dunes. Mean seaward slopes of each transect were calculated between the 6 m contour baseline and 25 m southeast along the transect towards the foredune peak. Because the ArcMap slope tool calculates slope based on the elevations of the surrounding cells, the slope analysis used means from every other transect to eliminate the possibility of using slope data calculated from overlapping areas. Restored and invaded profile models were cross-validated by subsetting 50% of the transects (Wood 2011, Graham 2014).

Results

Oneway tests on the means (not assuming equal variances) of the maximum transect heights showed that the heights of invaded and restored foredunes are not significantly different (p=0.748) (Table 1). However, dunes dominated by invasive *A. arenaria* had significantly steeper mean slopes (p<< 0.001) from the base of the foredune (at the 6 m contour) to the area where the dune peak begins to level out (25 m back along the transects) according to a t-test (Table 1, Figure 4).

Table 1. Oneway tests and t-tests on the means showed that maximum elevations of restored and invaded foredunes were not significantly different, but the slope of invaded dunes was significantly higher than the slope of restored dunes.

	Invaded mean /median		Restored mean /median		P-value	Outcome
Max Height (m)	10.78	10.65	10.75	10.77	0.748	Not significantly different
Slope (percent rise)	16.54	16.68	13.94	14.28	<<0.001***	Significantly different

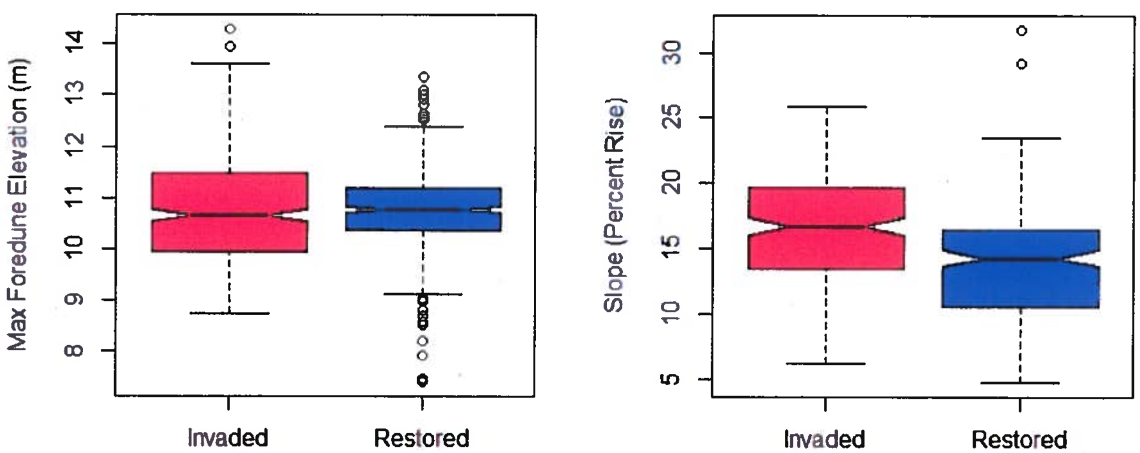

Figure 4. Maximum foredune elevations (m) were not significantly different (left), but invaded primary foredunes had significantly steeper slopes (right).

Modeling foredune transects in native and invaded areas in R with GAMs showed the typical foredune profile shapes of restored and invaded areas (Fig. 5) The foredune model extends approximately 70 m back along transects from the baseline at the 6 m shoreline contour (distance 0 m). Model residuals were normally distributed for the foredune area. Despite a wide variation between transects, models had a high level of precision because of the large number of transects (n=844), and showed a slight difference in the typical shapes of restored and invaded dunes (Figures 5-6). Restoration status was a highly significant predictor of profile shape (p<<0.001). Cross-validating the GAM profile models by repeatedly subsetting 50% of the transects for training and 50 percent for testing demonstrated low model sensitivity by generating models that were consistent with the overall GAMs.

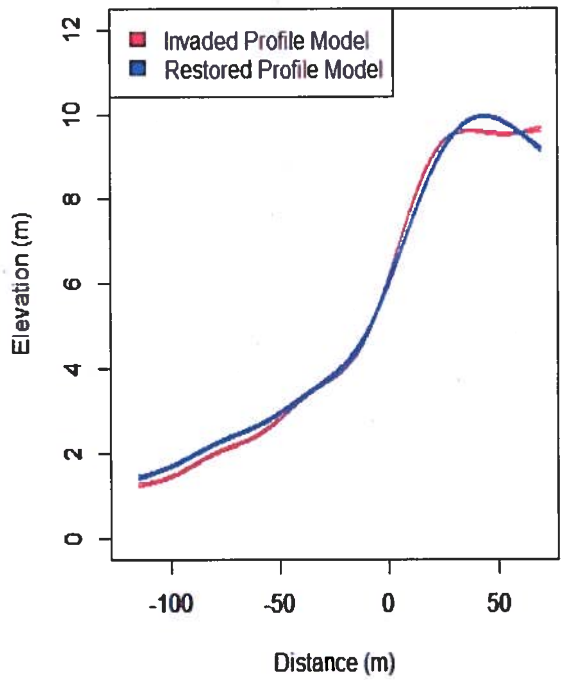

Figure 5. GAMs for foredune profiles in invaded and restored areas plotted with 95% confidence intervals showed different shapes for invaded and native foredunes, with a rounded peak in native foredunes and plateau-like shape in invaded foredunes.

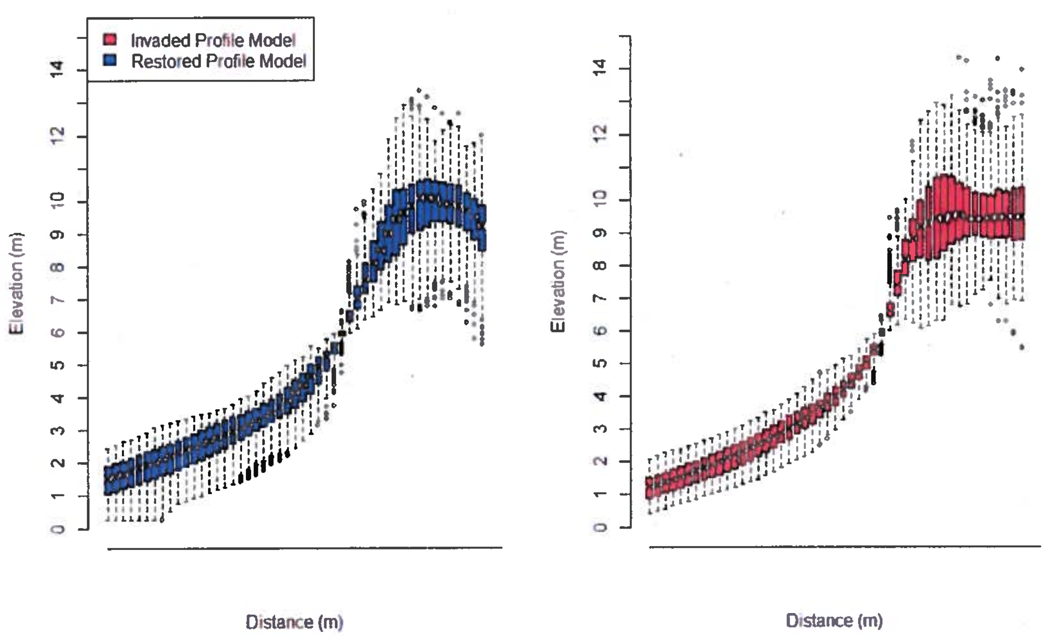

Figure 6. Boxplots around median profile elevations for restored (left) and invaded dunes (right) show a wide variation in profile shape, but most data points are tightly clustered.

Northings were the best predictor of dune heights, according to a linear model (r^2=0.24; p<<0.001), and and dune heights showed no significant correlation with restoration status (p= 0.876) (Figure 7). The isolated patch of undisturbed native dunes that was excluded from the analysis of restored and invaded foredunes was significantly higher than the restored and invaded dunes in the study area, according to a linear model controlling for the linear latitudinal elevation gradient (p<<0.001). The roughly sinusoidal GAM based on northings showed a complex repeating pattern of spatial autocorrelation in foredune elevation (Figure 7).

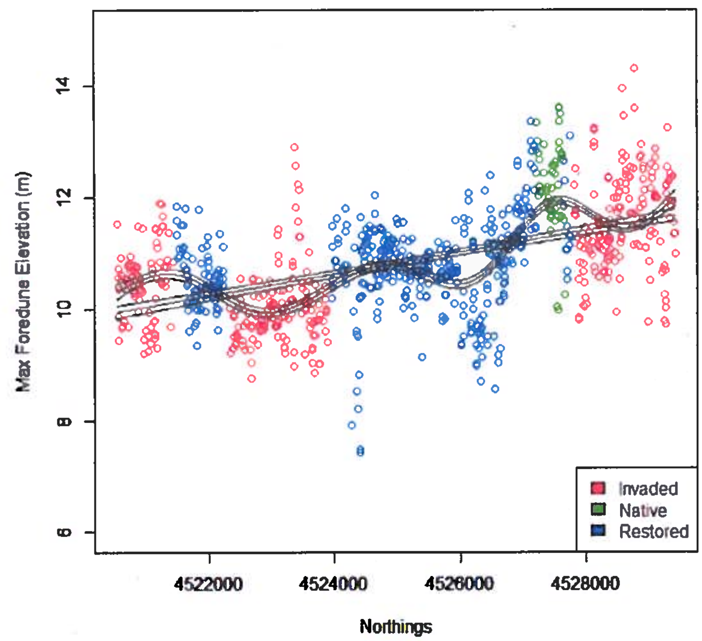

Figure 7. The maximum foredune elevations were linearly correlated with northings (r^2=0.24; p<<0.001) with higher foredunes to the north, and had no linear relationship to restoration (p= 0.876). The undulating GAM showed a more complex pattern based on northings. 95% confidence intervals are shown on both the linear model and the GAM.

Discussion

Although statistical testing and models supported the hypothesis that foredunes invaded by *A. arenaria* in the study area are steeper (p<<0.001), they did not support the hypothesis that they are taller than restored foredunes in the study area (p=0.748). The removal of *A. arenaria* did not result in foredunes that are significantly different in height from the surrounding invaded foredunes. The initial erosion and lowering of the dunes after restoration was photodocumented (Pickart 2014); however, they appear to have regrown to an equivalent height as of 2010. The restoration process did not completely remove the foredune structure built up by *A. arenaria*, so this study cannot address the question of the relative capacity of *E. mollis* and *A. arenaria* to build foredunes where they did not previously exist. The relatively undisturbed native section of Lanphere Dunes was excluded from analyses addressing the differences between restored and invaded areas. The excluded undisturbed native area was significantly higher than the restored and invaded foredunes according to a linear model controlling for the latitudinal elevation gradient (p<<0.001), but this site is unreplicated and the effect of vegetation is confounded by abiotic effects. This small native area provides insufficient evidence to determine relative dune-building capacity of *A. arenaria* and *E. mollis*; however, it shows that native plants can build relatively high dunes in certain circumstances.

The invaded dunes are not significantly taller overall, but their significantly steeper slope might be contributing to the misperception that they are higher than the more gradually sloping native dunes. *Ammophila arenaria*'s dense growth pattern and thick web of rhizomes might allow the foredunes to build up at a steeper angle. In contrast, native *E. mollis* might be allowing sand to move farther from the base of the foredune so that dunes build up gradually to a similar height with a peak further back from the shore. Although dune shapes vary widely, it is common to see invaded dunes in the study area with closely set double peaks of similar heights that would make the averaged shape of the dune plateau-like (personal obs. 2014). Native dunes in the study area often have a single, rounded primary foredune peak (personal obs. 2014). These shapes are reflected in the profile models, which are significantly affected by restoration status (p<<0.001) (Figures 5-6).

The increase in foredune height from south to north points to geological processes or historical events as the main causes of differing dune heights in the study area. The latitudinal gradient in elevation might reflect differing rates of sedimentation or the higher rates of subsidence on the southern end of Humboldt Bay (Williams et al. 2013). The undulating pattern in maximum dune heights over the study area might reflect natural patterns of sediment accumulation and erosion, or other abiotic factors (Figure 7). The morphology of foredunes depends on sand supply, vegetation cover and species composition, the rate of aeolian sand accretion and erosion, waves and wind forces, storm erosion, dune scarping and overwash processes, long term accretion or erosion of the beach, sea level, and the extent of human impact (Hesp 2002). A wide variety of stochastic events could be affecting the variation in foredune heights and shapes.

Although restored and invaded transects were evenly distributed from north to south to eliminate covariance with the linear elevation gradient (r<<0.001, p=0.906), location and restoration status are inherently confounded in this study. Models reflect the typical shapes, heights, and slopes within the study area at the time of LiDAR (Light Detection and Ranging) data collection. *Ammophila arenaria*'s dense growth might be the primary cause of the steep slope in invaded areas, but scarping and other circumstantial events might also be contributing to the differing shapes seen among native and invaded areas. Dunes continuously build, erode, and sometimes wash away over time, and the heights and profile shapes seen in this report might reflect the stages of the dunes' development in 2010 as well as any influence of geological processes, management history, or vegetation.

The use of elevation data from a DEM created from airborne LiDAR represents a source of error; however, the resolution of the 2009 - 2011 CA Coastal Conservancy Coastal Lidar Project: Hydro-flattened Bare Earth DEM is suitable for the scale of this study (Andrews 2002). The metadata for the DEM reported 50 cm horizontal root mean square error (rmse) and 9 cm vertical rmse, with at least 95% of the positions having an error less than or equal to 18 cm when compared to GPS survey grade points in generally flat, non-vegetated areas (CA Coastal

Conservancy 2012). The vegetation on the dunes could be negatively affecting the vertical accuracy of the model, especially where the vegetation density is particularly high and LiDAR might not be able to penetrate to the earth. This source of error would be more likely to overestimate the height of invaded dunes because they tend to be more densely vegetated. The max height and slope data are dependent upon the designated limits of the study area. The profile model shapes are dependent upon the placing of the baseline at the 6 m elevation contour, which approximates the elevation of the beginning of the foredunes. Profile model shapes could shift with different baseline designations. The profile models seen in this report are specific to the study area and the year the elevation data was collected (2010), and they are not intended to be extrapolated beyond these bounds.

Conclusion

The availability of remotely sensed high-resolution elevation data provided a way to conduct the extensive sampling needed to create models of a large, complex dune system. Creating randomly-spaced digital transects using GIS can be a powerful tool for topographical modeling. Manually collecting data with highly accurate RTK (Real Time Kinematic) GPS units to plot individual profile transects can provide valuable, precise information about change over time on individual transects. However, these methods are far more labor intensive and prohibitively costly for modeling on the scale of this study. Foredunes exist at a larger scale than humans can easily perceive from the ground, and their complex shapes and variability make them difficult to generalize. Creating models based on the vast data available from the remotely sensed DEM showed the overall shapes of restored and invaded foredunes within the study area in 2010, and demonstrated that they are not significantly different in height. The finding that restoration status is not a significant predictor of dune height is valuable for informing management decisions, especially in light of concerns voiced from community members that removing *A. arenaria* might be permanently lowering the height of the dunes. Additional high resolution LiDAR data is needed to verify the trend of these patterns over time, and to show how the dunes change over time, particularly after restoration. Expanding this study to other areas with invaded and restored or native foredunes could determine whether the results of this site study are typical for dunes vegetated by invasive *A. arenaria* and native *E. mollis*.

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