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Distribution and Effects of *Ammophila breviligulata* Fern. (American beachgrass) on the Foredunes of the Washington Coast

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ABSTRACT

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Since the turn of the century, the foredunes on the west coast of North America have become dominated by *Ammophila arenaria* due to extensive sand stabilization plantings. *Ammophila breviligulata* was planted less extensively than *A. arenaria*. However, *A. breviligulata* has come to singularly dominate the foredunes of Washington in the southern half of the state and its range extends north along the entire coast. By comparing the distribution of current *A. breviligulata* and *A. arenaria* communities with historic shorelines, it was found that this invasion occurred in the last 50 years and the locus of the invasion was determined. A comparison of foredunes dominated by *A. breviligulata* with existing *A. arenaria* foredunes shows that this colonization has had minimal impact on the species diversity of the dunes, but it has resulted in a lowering of the mean height of the foredune crests.

ADDITIONAL INDEX WORDS: Ammophila arenaria, *dune morphology, introduced species, coastal plant communities.*

INTRODUCTION

Ammophila breviligulata Fern. (American beachgrass) is native to the East Coast and Great Lakes Region of North America (BALDWIN and MAUN, 1983; GLEASON and CRONQUIST, 1963; OLSON, 1958a,b; HITCHCOCK, 1950; COWLES, 1899), and it has been intensively studied within this native range (MAUN and BAYE, 1989). It is a pioneer species adapted to dynamic coastal dune systems where it is, typically, the major dune building plant species present (DISRAELI, 1984; DUNLOP and CROW, 1985). It rapidly becomes senescent when dune areas stabilize and is then rapidly replaced by other species (DISRAELI, 1984; VAN DER VALK, 1975; ELDRED and MAUN, 1982).

Ammophila arenaria (L.) Link (European beachgrass or marram grass) is a native of Europe similar to *A. breviligulata* in its adaptations to the coastal dune ecosystems. *A. arenaria* has been widely planted on the west coast of North America for dune stabilization since the early 1900's. It has become naturalized along nearly the entire coastline (BARBOUR and MAJOR, 1988; HITCHCOCK *et al.*, 1969; HITCHCOCK, 1950) and is a dominant feature in the coastal ecosystem, replacing many of the native communities in the foredune habitat (PAVLIK, 1983).

Because of the overwhelming success of the *A. arenaria* plantings, there has been little use of *A. breviligulata* for dune stabilization on the west coast. Accordingly, very little information on the status of *A. breviligulata* on the west coast of North America is available. A review of this literature and the collection history leads to the conclusion that *A. breviligulata* exists on the west coast only as persistent remnant populations (MAUN and BAYE, 1989; BARBOUR *et al.*, 1975; BARBOUR *et al.*, 1976).

The only sizable planting of *A. breviligulata* that has been recorded was a part of the Warrenton Dunes Stabilization project on the Clatsop Peninsula in Oregon near the mouth of the Columbia River. The Soil Conservation Service undertook this project in 1935; and up to that time, it was one of the largest dune stabilization projects in the western United States. A nursery was established at Warrenton, Oregon, and 1,214 ha were progressively stabilized with a variety of species including *A. breviligulata* (SCHWENDIMAN, 1977). *A. breviligulata* from this nursery was also

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planted at the south end of the Long Beach Peninsula at Ilwaco (Figures 1, 2).

At present, the densest populations of *A. breviligulata* are located between the mouth of the Columbia River and Westport, 75 km to the north. In this area, *A. breviligulata* is almost singularly dominant on the foredune, the first dune landward of the beach. The dominance of *A. breviligulata* decreases beyond these boundaries to the north and south. This distribution pattern indicates that the Clatsop and Ilwaco plantings were the likely source of the naturalized populations of *A. breviligulata* now found on the Washington and Oregon coastal dunes.

The primary dispersal mechanism of *A. breviligulata* is through waterborne rhizome fragments (MAUN, 1984), and the dominant current on the southern Washington coast is the northward longshore current (PHIPPS, 1990). If the source of the *A. breviligulata* invasion was the Clatsop and Ilwaco plantings, the longshore current would have rapidly spread rhizome fragments along the accreting shoreline of the Long Beach Peninsula allowing *A. breviligulata* to colonize the beach and replace *A. arenaria* as the dominant dune forming species.

If this scenario were the case, it should be possible to locate the transition from one *Ammophila* species to the other. Since both species have extremely low vegetative and sexual reproductive rates in stabilized dune areas (OLSON, 1958a), it is unlikely that there would have been significant invasion by either population in the highly stable backdune areas. WILLIS (1963) found that even fertilization could not stimulate senescent *Ammophila* populations to the point of expansion.

If there is no invasion in the backdune areas and the transition zone is stable, then the border between the two communities actually represents the location of the historic shoreline or foredune crest when *A. breviligulata* replaced *A. arenaria* as the foredune's dominant grass.

The timing of the introduction of *A. breviligulata* was determined by comparing the *A. breviligulata/A. arenaria* transition zone to the location of historic foredunes as determined from a chronological sequence of aerial photos. The southern portion of the Washington coast is characterized by a broad band of sand beach and dunes as far north as the Copalis River (47° 08′ 00″ N Lat). These dunes are examples of the parallel dune system described by WIEDEMANN (1984) as typical of prograding shorelines in this area. North of this point the rocky headlands are close to the beach and prevent any major dune formation (Figures 1 and 2).

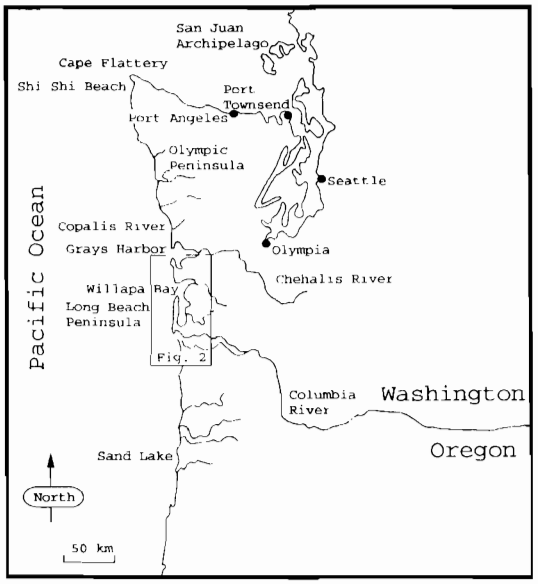

Figure 1. Map of the area surveyed for the distribution of *Ammophila breviligulata* and *Ammophila arenaria*. The location of Figure 2 is shown as an inset.

The objectives of this research were threefold: to determine the source, location, and time period of the major introductions of the exotic species *A. breviligulata*; to establish the current range and habit of *A. breviligulata* on the Washington Coast; and to determine if the *A. breviligulata* and *A. arenaria* foredunes differ significantly in structure or plant species diversity.

METHODS

Study Sites

The quantitative fieldwork for the determination of the source and timing of the introduction of *A. breviligulata* and the characterization of the current *Ammophila* dunes took place on the foredunes of the Washington Coast from North Head near the state's southern border at the mouth of the Columbia River (46° 17′ 30″ N Lat) north to Westport (46° 52′ 30″ N Lat). In addition, the distribution of *A. breviligulata* was surveyed along the western and northern coastlines of Washington as far east as Port Angeles and the north half

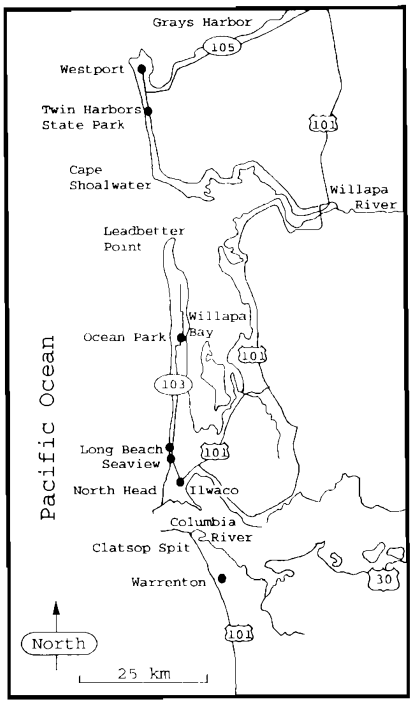

Figure 2. Map of the Long Beach Peninsula, and the site of the quantitative dune morphology and population studies.

of the coast of Oregon as far south as Sand Lake (Figures 1 and 2).

The Introduction of *A. breviligulata*

The localization of the *A. breviligulata/A. arenaria* transition zone on the Long Beach Peninsula at 17 transects was mapped onto a 1:12,000 scale aerial photograph series taken on 31 July 1988, one month prior to the time the measurements were taken. Initially, 21 transect locations were chosen at one mile intervals beginning at the Seaview beach access and running north to Leadbetter Point, however, four locations were eliminated due to human disturbances in the backdune area.

The historic foredune position was determined using a series of historic aerial photos (1949, 1964, 1970, 1974, and 1982). The location of the foredune for each of these years was determined at each transect and mapped onto the 1988 photo series. It was then possible to measure the distance to the east or west that each historic dune lay from the *A. breviligulata/A. arenaria* transition zone (Figure 3).

Field Sampling

The quantitative fieldwork on dune shape and vegetative characteristics was completed between July and October of 1988. A second series of 34 transects, 19 on the Long Beach Peninsula and 15 between Cape Shoalwater at the north edge of the mouth of Willapa Bay and Westport, were selected randomly. In addition, several transects were established on the specific dunes where *A. arenaria* was dominant. None of these transects coincided with those used for the historic shoreline study.

The foredune profile was mapped by measuring the height at 5 m intervals (survey stations) along a 50–75 m transect (depending on foredune width) running perpendicular to the foredune. This profile was used to calculate the slope, length, and height of the west face of the foredune. The transect started at the lower limit of the vegetation. This point was given an arbitrary elevation of zero m. The dune crest height was measured independently, if it did not coincide with one of the survey stations. In addition, the following data were collected at these survey stations within a 20 by 50 cm rectangular quadrat placed perpendicular to the transect line and centered on each survey stake: (a) the total number shoots of each species of *Ammophila* in the quadrat; (b) The width of the second lowest live leaf at a point 2 cm distal from the ligule on the culm nearest the southeast corner of the quadrat; (c) the number of *Ammophila* inflorescences in the quadrat; and (d) the % cover (using the 1–10 Domin Cover Class scale) within the quadrat of all plant species, vegetative litter, and bare ground.

A. breviligulata and *A. arenaria* generally occurred in discrete stands, and were readily distinguishable in the field on the basis of ligule length, inflorescence morphology, phenology, and foliar characteristics (SEABLOOM, 1991). Specimens of both species from a number of representative locations in Washington and Oregon were deposited in the University of Washington Herbarium, Seattle, Washington.

Because the transect profiles varied widely, each transect was divided into four habitat zones to facilitate comparative analysis (Figure 4). This zonal approach permits the comparison of the distinct environments present on each foredune by correcting for the specific profile of each foredune. The beach (Zone I) extends from the seaward line of vegetation east to the seaward toe of the dune; the windward slope (Zone II) extends from this

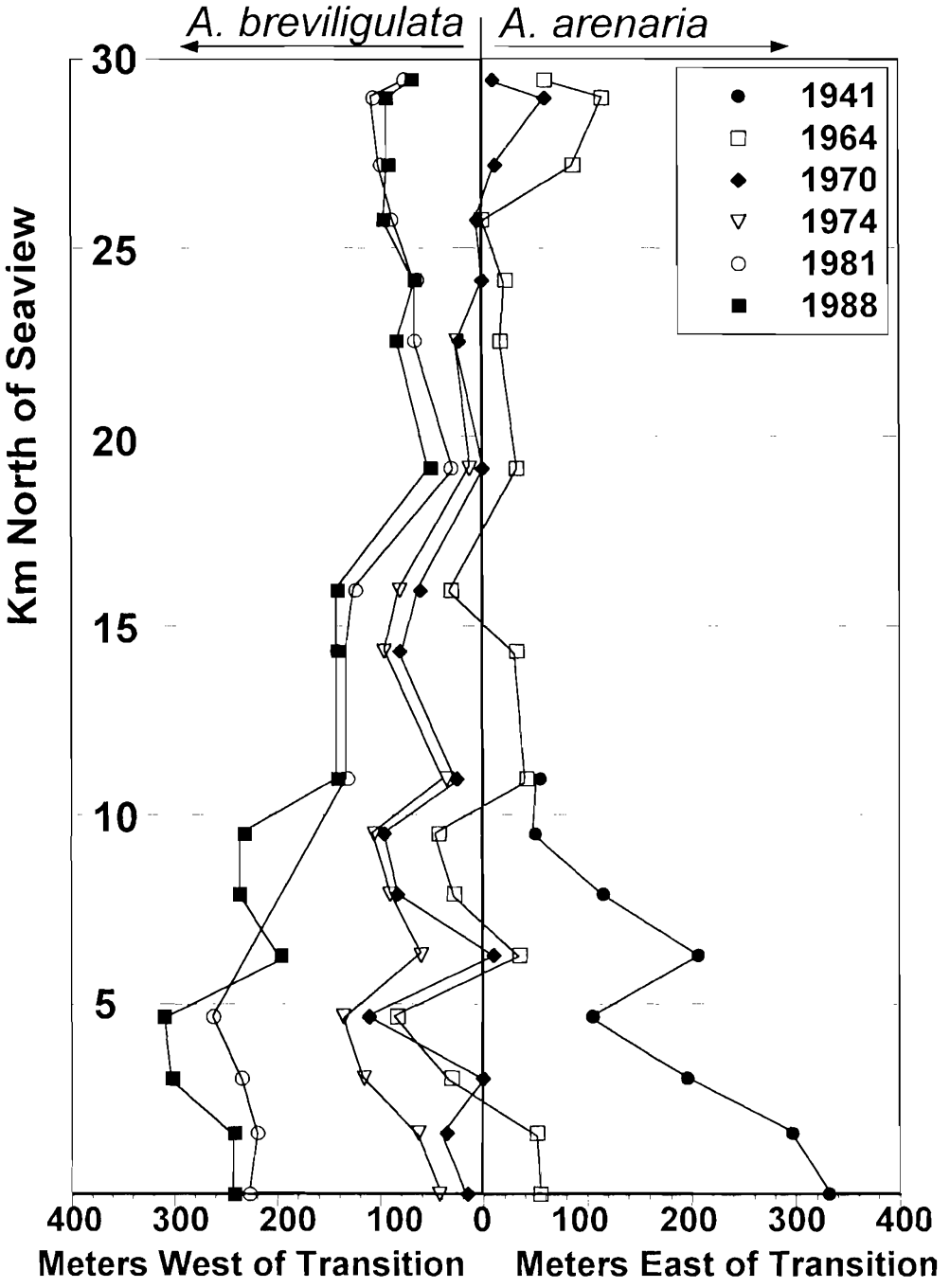

Figure 3. Location of the transition between the *Ammophila breviligulata* and *Ammophila arenaria* communities in relation to the locations of six historic foredunes on the Long Beach Peninsula.

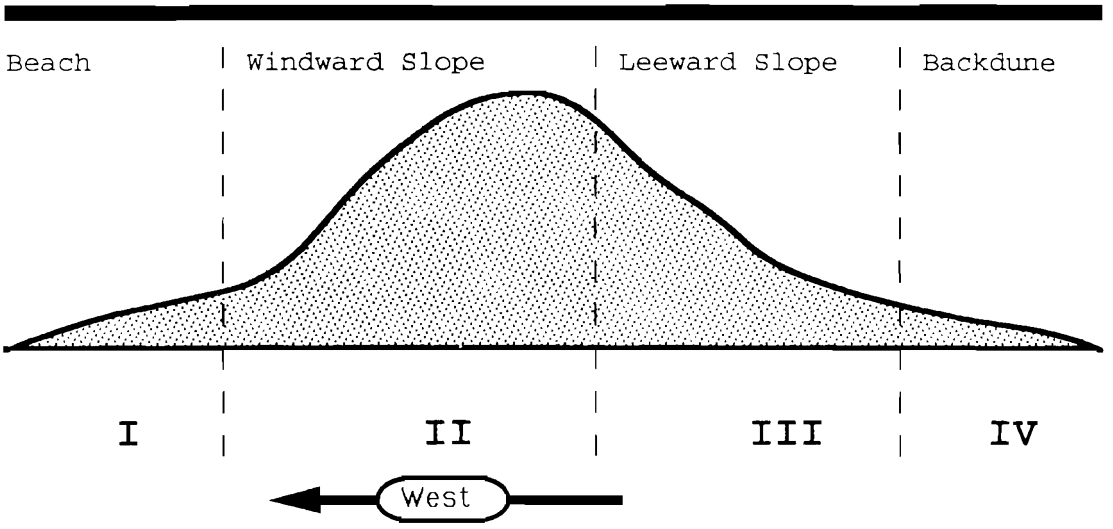

Figure 4. Four Zones of the coastal foredune.

point to just past the crest of the foredune; The leeward slope (Zone III) extends from the limit of high sand accretion just past the foredune crest to the landward toe of the dune; and the backdune (Zone IV) includes all of the area east this point.

The vegetative and dune profile data were compared between dune zones using an ANOVA followed by a Fisher's Test for Least Significant Differences to locate the sources of the detected variance. An ANOVA was also used to compare *A. breviligulata* and *A. arenaria* populations. The Simpson and Shannon indices were used to compare species diversity between dune zones and *Ammophila* communities (BROWER and ZAR, 1977).

RESULTS

The Introduction of *A. breviligulata*

In 0.76 of the transects, the transition between *A. breviligulata* and *A. arenaria* dominated stands occurred between the location of the 1964 and the 1974 or the 1970 and 1974 shorelines. In all but one transect, the transition zone was bounded by the 1941 and the 1974 shorelines. This one variation occurred because there was no information available prior to 1964 at that location (Figure 3).

Current Range and Habit of *A. breviligulata*

Within its current range on the west coast, *A. breviligulata* occupies two distinct habitats. First, it is the dominant vegetation on the foredunes in the quantitative study area which ranges from North Head at the southern end of the Long Beach Peninsula to Westport, where it is present in nearly monospecific stands in Zones II, III, and IV (Figures 1 and 5). On the dune systems north of Westport both species of *Ammophila* alternate as the dominant foredune species. The only sizable unmixed *A. arenaria* foredune community located in Washington was at Twin Harbors State Park south of Westport where five acres was planted in 1981 as part of a cooperative project between the Soil Conservation Service and the Washington Parks and Recreation Commission. This population now covers about 3 km of coastline.

The second niche *A. breviligulata* occupies is the area between the shoreward toe of the foredune and the lower limit of vegetation (Zone I). In this area, it creates hummocks, usually less than 2 m in diameter, along with a number of native hummock forming species, including *Ambrosia chamissonis* (silver bursage), *Cakile edentula* (American searocket), and *Abronia latifolia* (yellow sand-verbena).

In this more marginal habitat, *A. breviligulata* can be found along the entire Washington coast as far north as Shi Shi Beach and south to Sand Lake in Oregon, although its frequency decreases markedly at the northern and southern limits of this range. *A. breviligulata* can also be found scattered on sand bars and spits in Willapa Bay and Grays Harbor, although this habitat is dominated by the native *Elymus mollis* (American dunegrass) (Figure 1).

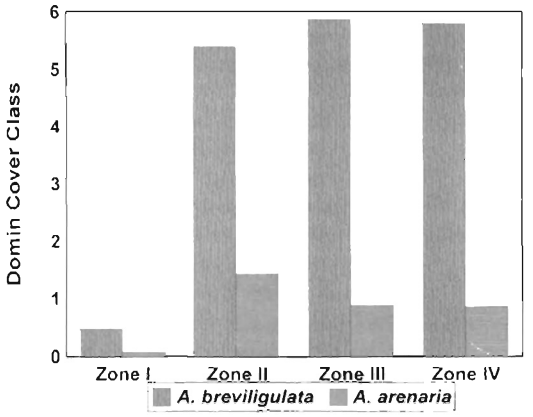

Figure 5. Comparison of the dominance of *Ammophila breviligulata* and *Ammophila arenaria* in each of the four Dune Zones as indicated by their respective cover of live plants averaged over the entire population of samples.

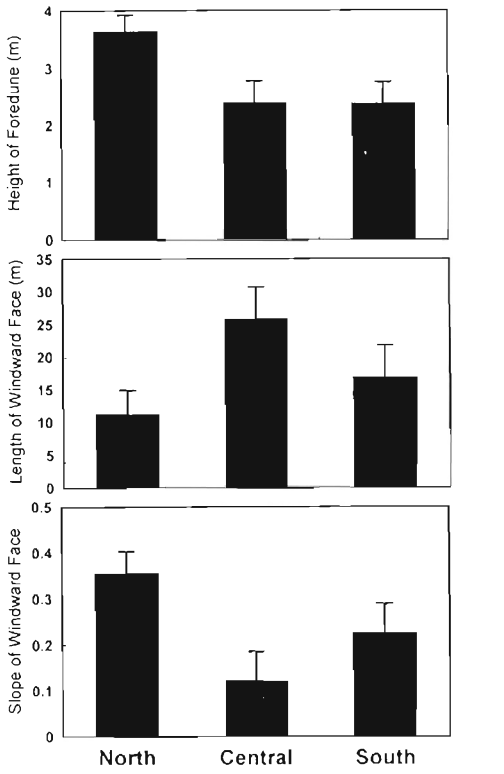

Figure 6. Comparison of the mean height, slope, and length of the west face of the foredunes in the three Geographic Units on the Long Beach Peninsula.

Neither species of *Ammophila* was located along the northern edge of the Olympic Peninsula, but *A. breviligulata* is present at Port Townsend and both *A. breviligulata* and *A. arenaria* are present in the San Juan Archipelago (Figure 1).

Field observations of the *A. breviligulata* population on the Long Beach Peninsula distinguished three distinct geographic units on the basis of dune shape and vegetative characteristics. The South Unit extends from North Head to Long Beach and is characterized by a low foredune with minimally developed beach plant communities characterized by *Cakile edentula*. The Central Unit extends from Long Beach, north to Ocean Park and has a low *A. breviligulata* foredune somewhat similar to the southern Unit; however, Zone I in this Unit has a well developed vegetative community dominated by *Ambrosia chamissonis* with *Cakile edentula* and *Abronia latifolia* as associated species. The North Unit extends from Ocean Park north to Leadbetter Point and has a steep foredune of *A. breviligulata* with little or no beach vegetation (Figure 2).

An ANOVA comparison of these three geographic units showed that their foredunes differed significantly in height of the crest, length of the windward face, and slope of the windward face. In all three parameters, the only equivalency was between the height of the dunes in the South and Central Units (Figure 6). The species diversity of the plant communities in these three Units was not found to be significantly different (Figure 7).

The percent cover of live *A. breviligulata* plants and vegetative litter increases markedly from the beach to the dune, but remains constant on the entire foredune (Figure 8A,F). Stem density reaches its maximum on the seaward slope of the dune in Zone II (Figure 8B) and flowering occurs almost entirely in Zone I (Figure 8C). Leaf width also appears to be an indicator of the vigor of the individual plants since it diminishes steadily with increasing distance from the beach. The width remains equivalent in Zones I and II but drops consecutively in Zone III and again in Zone IV (Figure 8D). The presence of bare ground in the transects drops as the cover value of *A. breviligulata* increases and the individual vigor of the plants is declining (Figure 8E).

This decrease in the vigor of the *Ammophila* stands was paralleled by an increase in species

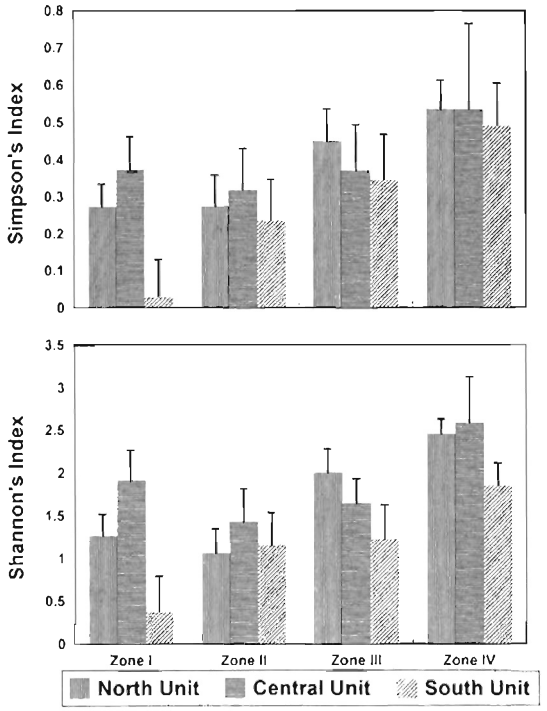

Figure 7. Comparison of the Simpson and Shannon Species Diversity Indices of each of the four Dune Zones between the three Geographic Units on the Long Beach Peninsula.

diversity in the stable backdune areas as compared to the high depositional environment of Zones I and II (Figure 9).

Comparison of *A. breviligulata* and *A. arenaria* Foredunes

A comparison of the foredune communities dominated by *A. breviligulata* versus those dominated by *A. arenaria* showed equivalent species diversity indices in all the Zones except Zone II (Figure 10). In this Zone, *A. arenaria* foredune communities have a slightly higher species diversity than the *A. breviligulata* dominated foredunes. Both the Simpson and the Shannon indices show this difference at the same confidence level.

The overall stem density between the *Ammophila* species was compared over the entire set of samples. All of the samples with density values of zero were excluded from this comparison. This was done in order to compare mean stem density within a stand rather than the importance of the species in the study area as a whole. The stem density was significantly ($P = 0.012$) greater for *A. arenaria* (203 stems/m^2) than for *A. breviligulata* (79 stems/m^2).

Comparing the means of the three dune shape parameters for the entire population of foredunes showed that the population of *A. arenaria* dunes, which had a mean elevation of 4.52 m, were significantly taller than the *A. breviligulata* dune which had an overall mean of 2.82 m. However, while the *A. breviligulata* dunes were only 67% as long as the *A. arenaria* dunes, the ANOVA failed to detect a difference between the two populations ($P = 0.147$). The slope of the windward face of the dunes associated with both species of *Ammophila* was nearly identical and there was no difference detected in the ANOVA (Table 1).

DISCUSSION AND CONCLUSIONS

The current locus of *A. breviligulata* on the west coast supports the conclusion that the colonization source was the Clatsop and Ilwaco plantings which began in 1935. This conclusion is in accord with the timing of the colonization of the Long Beach Peninsula foredunes as determined by examining the distribution of *A. breviligulata* and *A. arenaria* in relation to the location of historic shorelines. These findings indicate that *A. breviligulata* replaced *A. arenaria* as the primary foredune colonizing species between 1941 and 1974, and it is most likely that the majority of the colonization occurred in the ten year period from 1964 to 1974 (Figure 3).

The maximum stem density in Washington populations (Figure 8B) occurs in a similar successional stage and within the range of values given for stands along Lake Michigan, which range from 110 to 150 stems/m^2 and the cover values of 50 to 59% (KRAJNYK and MAUN, 1981; OLSON, 1958a). However, flowering occurs almost entirely in Zone I in Washington (Figure 8C) while on Lake Erie flowering reaches its peak in the adolescent growth phase when stem density is the highest (KRAJNYK and MAUN, 1981). This is equivalent to Zone II where the flowering rates were low for the Washington populations (Figure 8C).

While the overall % cover of *A. breviligulata* shows a marked increase from the beach to the dune, the cover values remain relatively constant on the foredune proper in Zones II, III, and IV (Figure 8A). However, the vigor of the individual

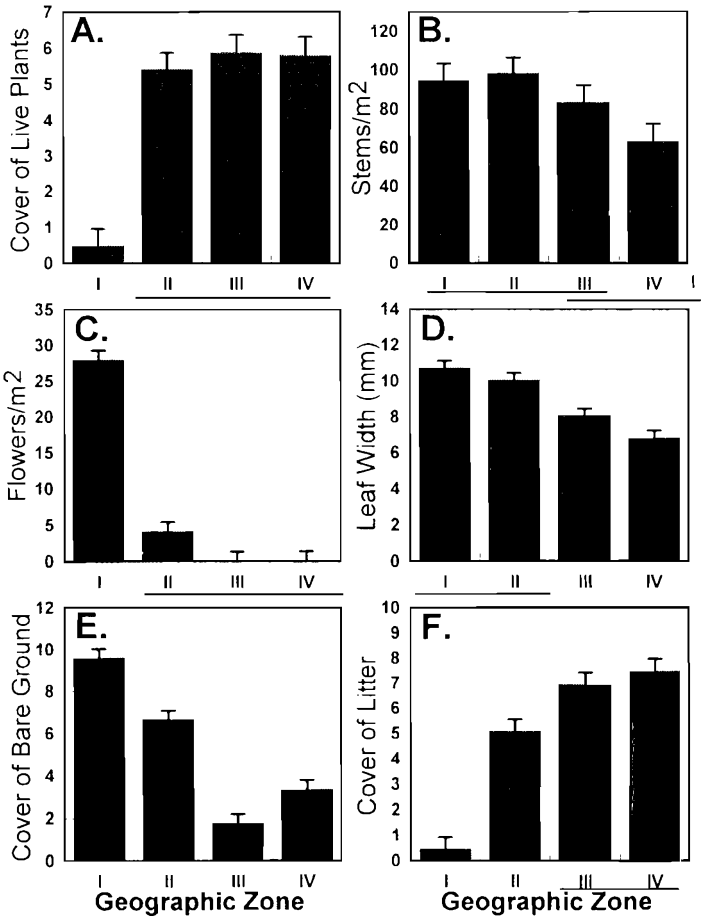

Figure 8. Comparison of six indicators of *Ammophila breviligulata* population vigor between each of the four Dune Zones throughout the entire set of transects. Total cover of live plants, stem density, flower shoot density, leaf width, cover of bare ground, and cover of litter are shown as graphs A–F respectively. Underlined Dune Zones are equivalent at $\alpha = 0.05$.

plants diminishes as indicated by decreasing leaf width and depressed vegetative and sexual reproduction (Figure 8B,C,D). *A. breviligulata* maintains a constant high cover value as the dune matures by replacing stands comprised of highly vigorous and reproductive individuals with scattered senescent plants interspersed in dense mats of litter (Figure 8E and F).

This is typical of East Coast populations where stands in areas with heavy deposition have high individual vigor with patchy distribution, and those populations in stable or erosional areas have a more even distribution of less vigorous plants (DISRAELI, 1984).

Thus, the overall ecology of *A. breviligulata* on the west coast in its range as an exotic resembles that within its native range, with its vigor highly dependent on sand deposition and with this dependence manifesting itself in a series of successional changes reflecting a gradual decline in the reproductive vigor of the stand and its constituent individual plants. This decline allows other species to invade the senescing *Ammophila* community, increasing the species diversity (Figure 9). This successional pattern of the west coast populations of *A. breviligulata* is analogous to the growth phases described in the Great Lakes Region (ELDRED and MAUN, 1982; KRAJNYK and

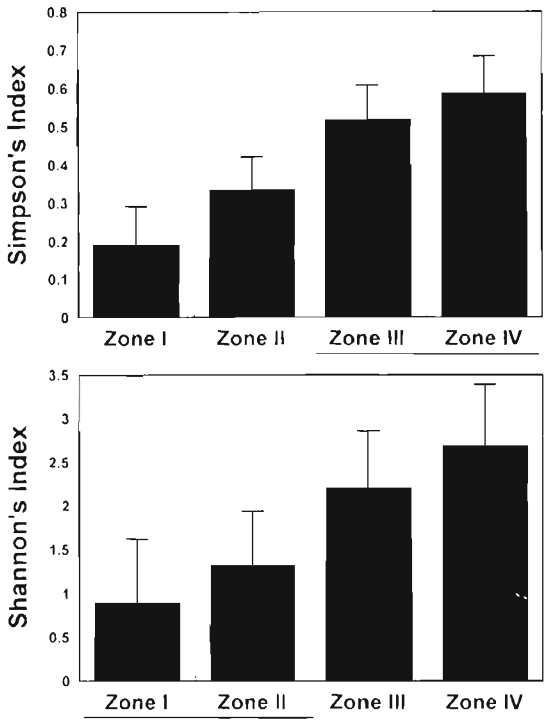

Figure 9. Comparison of the mean Simpson and Shannon Species Diversity Indices of each of the four Dune Zones over the total population of samples. Underlined Dune Zones are equivalent at $\alpha = 0.05$.

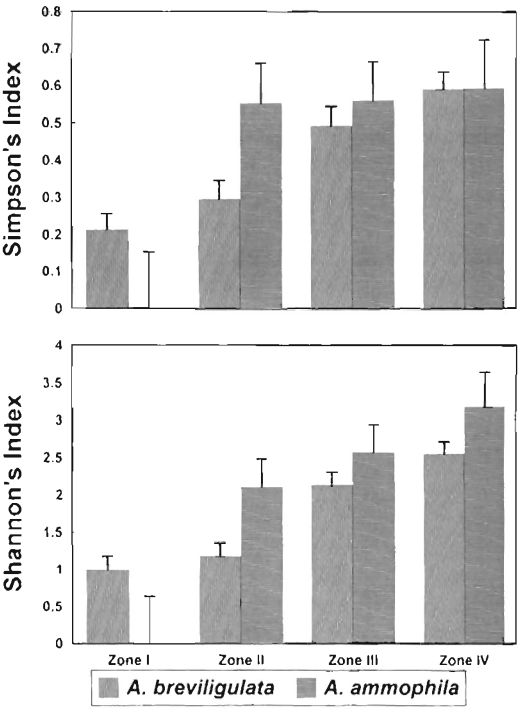

Figure 10. Comparison of the mean Simpson and Shannon Species Diversity Indices for the *Ammophila breviligulata* and *Ammophila arenaria* populations in each of the four Dune Zones over the total population of samples. Underlined Dune Zones are equivalent at $\alpha = 0.05$.

MAUN, 1981), and in North Carolina (VAN DER VALK, 1975) with the exception of the location of the highest rates of sexual reproduction.

It is likely that the replacement of *A. arenaria* by *A. breviligulata* in the role of foredune colonizer had little effect on the overall species diversity. The only significant difference between the *A. breviligulata* population and the *A. arenaria* population was in Zone II where both the diversity indices showed that *A. arenaria* had a slightly higher diversity. It is likely that this is a result of the prevalence of the *A. arenaria/Lathyrus japonicus* (maritime pea) association in this zone. *L. japonicus* is one of the few plant species which can maintain a moderately high cover value in *Ammophila* dominated dunes, and it is not as common in the *A. breviligulata* dominated dunes as it is in those dominated by *A. arenaria*.

Although there was little difference in species diversity between the foredunes of the two *Ammophila* species, the shape of the foredune associated with each species was significantly different. The difference total crest height was the only measure of dune shape which this study was able to detect. However, the mean lengths of the windward face of the two populations appear to be quite different, and it is likely that the failure to discern a difference in the length of the windward face represents a Type 1 error due to the limited availability of *A. arenaria* foredunes in the study site (n = 6) (Table 1).

The greater height of the *A. arenaria* dunes is probably attributable to two factors. First, it has a higher sand trapping potential created by a higher stem density than *A. breviligulata*; and, secondly, its leaves are more persistent in the winter due to their more erect growth and tighter inrolling. The highest levels of sand movement occur as a result of high winter winds (WIEDEMANN, 1984), and the more persistent leaves of *A. arenaria* allows them to continue entrapping sand during this period when potential deposition is

Table 1. *Comparison of the means of three dune characters of* Ammophila breviligulata *and* Ammophila arenaria *foredunes.*

Parameter	*Ammophila breviligulata*	*Ammophila arenaria*	Significant at a = 0.01
Crest height	2.817 m	4.516 m	Yes
Distance to crest	15.637 m	23.330 m	No
Slope (height:length)	0.261	0.259	No

the highest. *A. breviligulata*'s leaves tend to die back and become flattened into mats early in the winter where they are quickly buried by sand deposition.

MANAGEMENT IMPLICATIONS

The conservation of native plant communities is not affected differentially by either species to a degree which would warrant use in management strategies. Both species of *Ammophila* depress species diversity to a very high degree and are a serious threat to the existence of diverse native plant communities. However, the species' effects on dune shape do have management implications.

The difference in the shapes of the *Ammophila* dunes affects structural and esthetic characters of the foredune. The lower *A. breviligulata* dune may be more susceptible to breaching during storm or flood events. If this is true, then the introduction of *A. breviligulata* may have placed the coastal communities of southern Washington at a higher risk to flood or erosion damage. Conversely, local residents may appreciate more visual access to the beach when their houses are located behind an *A. breviligulata* dune. This may result in a lowered incidence of illegal dune grading which immediately increases the risk of a damaging flood event, and causes a funnelling of wind which can cause weathering on neighboring structures. It may be that an unbreached *A. breviligulata* dune may provide a better balance between protecting coastal communities and allowing visual access to the beach than a tall dune which is regularly breached by illegal grading.

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