REINTRODUCING THE ENDANGERED PINK SAND-VERBENA TO PACIFIC COAST BEACHES: DIRECT SEEDING AND OUT-PLANTING

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Abstract: Reintroduction is one option for recovery of endangered species. However, few published examples are available that document the success of reintroductions, especially in an experimental setting. Pink sand-verbena (*Abronia umbellata* ssp. *breviflora*) is an endangered plant of Pacific Coast beaches and dunes that is threatened, in part, by an invasive grass (*Ammophila arenaria*). Observations of its basic life-history have been conducted, as well as a series of experiments to compare direct seeding and transplantation as methods for establishing new populations. Both techniques show promise, and various lines of evidence suggest that successful reintroduction may depend on establishing a dynamic, persistent seed bank in the sand at restoration sites.

INTRODUCTION

Making the Case for Reintroduction. Plant conservationists generally agree that the most effective way to protect rare species is to maintain and foster surviving wild populations and their habitats. Current laws protect populations of endangered plants *in situ*, at least on public lands. Creating new populations to compensate for losses caused by development or habitat alteration is controversial (Berg 1996) because it forces us to choose between existing natural populations and artificial replacements. Further, the success of mitigation projects is often uncertain (Howald 1996). But there are some species for which introduction back into former habitat or into new sites may be appropriate, even urgent (Kaye *et al.* 1998), and re-introduction may represent an important conservation tool for their viability and recovery (e.g., Falk *et al.* 1996; Caplow 2004) even outside of a mitigation context. Plants that are extinct from the wild are obvious candidates, and so too are endangered species that occur in only a few remaining locations or have suffered dramatic declines in population numbers. In addition, rare species experiencing population losses on private lands, where they are not legally protected, may especially benefit from population establishment on public lands. There is a growing awareness among plant conservation biologists that reintroduction is a worthwhile measure in some situations, yet the methods of reintroduction are largely untried and experimental. Establishing new populations or enhancing existing ones (often called augmentation), by seeding or adding new plants, is an area of research where elements of ecology and horticulture meet (e.g., Guerrant & Pavlik 1997).

Guidelines for reintroduction projects have been developed, but these tend to deal with general issues such as appropriateness of reintroduction, site selection, protection against genetic problems, damage to other rare species, and loss of irreplaceable propagation stock (e.g., Kaye 1992; Falk *et al.* 1996). Of course, this generality is due to necessity, since very little information is available on how to establish a self-sustaining population. What is more, plants and habitats vary in their needs and limitations, and there is no single recipe for reintroduction. The tools required, including propagation techniques and site selection criteria, must be developed on a species by species basis. Although reintroduction is underway for some plant species, the field is in its infancy. In a bibliography of 600 published accounts and grey literature on plant reintroduction and restoration, only about 10% were detailed reintroduction case histories (Kaye, Kirkland & Testa 1999). Descriptions of effective procedures for rare plant propagation and establishment in the field are crucial for advancing the practice of species re-establishment.

Many sand-verbenas (*Abronia* spp.) are rare and prone to extinction, a characteristic that led Wilson (1972) to call them "disappearing species." Their conservation may rely on restoration of habitat and re-establishment of populations, which in turn, requires information on the behavior of natural populations (Pavlik 1996). Pink sand-verbena (*A. umbellata* ssp. *breviflora*) is a rare member of the four-o'clock family (Nyctaginaceae) indigenous to the Pacific Coast of North America from British

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Columbia to northern California. Due to the invasion and subsequent stabilization of foredune systems by European beachgrass (*Ammophila arenaria*) (Wiedemann 1984; Rittenhouse 1994) and disturbance by off road vehicles, pink sand-verbena is now restricted to 3 to 5 (depending on the year) wild populations on the southern Oregon coast and perhaps a dozen in California (Kaye 1995a), where statewide assessments have not been updated recently. The species is thought to be extirpated from Washington and British Columbia (Gamon *et al.* 1986), despite a recent sighting on Vancouver Island in 2000, which apparently persisted only one year (Douglas 2000).

The introduction of European beachgrass has resulted in the loss of a low, hummocky, discontinuous foredune, which once characterized beaches throughout the range of pink sand-verbena, especially in Oregon and northward, and provided habitat for many native plants and animals. This topographic feature has been widely replaced by a high, steep, primary foredune dominated by a thick growth of European beachgrass (Pickart & Sawyer 1998), which has changed the nature of beach habitats in northwestern North America and led to the decline in many beach species.

The primary goal of this paper is to summarize research from various reports on the life history of pink sand-verbena and methods for its reintroduction to restored dunes and natural beaches on the Pacific Coast. Below I present the results of studies conducted in Oregon from 1992 through 2001.

Background and Life History

Status. Pink sand-verbena (Fig. 1) is listed by the Oregon Department of Agriculture as endangered [OAR 603-73-070 (1)] because of its steady decline in geographic range and the significant threats posed to a very small number of extant populations. The Washington Department of Natural Resources (1997) lists pink sand-verbena as Extirpated, and the California Native Plant Society (2001) considers it to be "Rare, Threatened or Endangered in California and Elsewhere" (List 1B). It is currently considered a Species of Concern by the U.S. Fish and Wildlife Service (Oregon Natural Heritage Program 2001). In Canada, the species is on the British Columbia Red List, indicating that it is extremely rare (British Columbia Conservation Data Centre 2001).

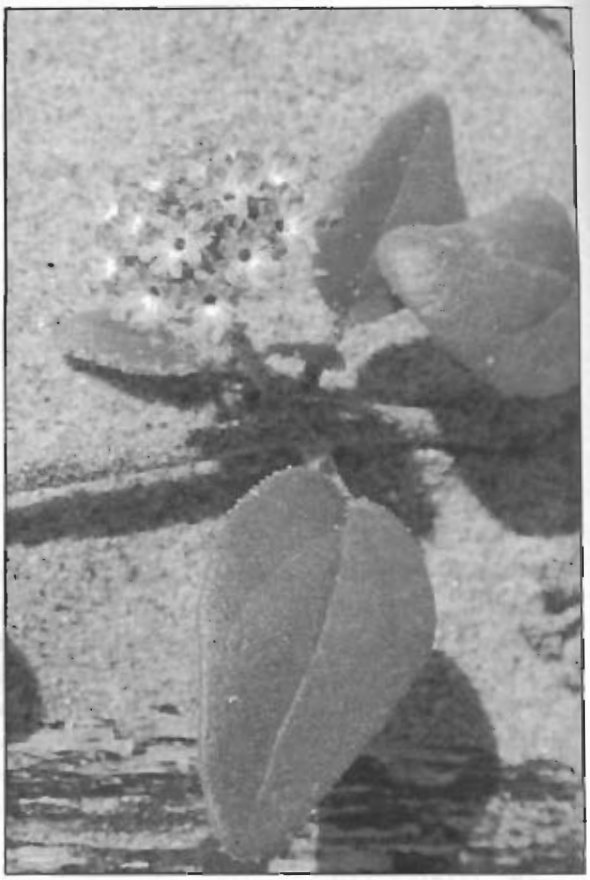

Figure 1. Pink sand-verbena (*Abronia umbellata* ssp. *breviflora*). Photo by Tom Kaye

Reproduction and Life-span. Pink sand-verbena has a predominantly annual life cycle, and individuals reproduce by seed only. The plants are tap-rooted and do not root adventitiously from the stems. It has deep pink to purple flowers borne in clusters of 12 to 20 in the leaf axils. Each flower produces a single-seeded fruit (achene), which is broadly 3- to 5-winged, presumably to promote dispersal (Wilson 1976). Most individuals observed in demographic studies of tagged plants conducted at Port Orford and Otter Point, Oregon, behaved as annuals, flowering and dying in their first year of growth (Kaye 1999b; Kaye *et al.* 1999). However, a small percentage of individuals at Port Orford grew and flowered for two years, and transplanted individuals on dredged sand at that site had a high probability of living for two seasons. At Otter Point, where a typical wild population occurs on a beach, all individuals lived for only one season. The difference between these two populations is that the Port Orford habitat is partially protected from winter storms, while Otter Point is exposed to the full strength of

extreme climatic conditions experienced by coastal beaches. Therefore, although pink sand-verbena is typically annual, it appears to be capable of growing for more than one year if protected conditions are available without too much competition from associated vegetation. This variability in life-span probably accounts for conflicting reports in floras as to whether the species is annual or perennial (e.g., Hitchcock *et al.* 1964; Hickman 1993).

Several other *Abronia* species are described as being both annual or perennial, or biennial and perennial. Perennation of *A. angustifolia*, for example, is possible only when individuals occur in highly favorable locations, such as protected micro-sites with high moisture availability (Royce & Cunningham 1982). Such flexibility can improve the ability of pink sand-verbena to persist at a given site or disperse seeds to new locations, since individuals that live for more than one season may be very large, produce thousands of fruits, and contribute a large proportion of a population's annual seed production (Kaye *et al.* 1999).

Population Dynamics. Because pink sand-verbena populations typically occur on beaches in Oregon and northern California at or below the zone of driftwood accumulation, they tend to be obliterated each winter by storms that reshape the shore. The taxon may occur on foredunes at the southern edge of its range in California (Tillet 1967). Each spring, populations on beaches reestablish from seeds that persist in the sand or that are washed into the site from another location. These processes may make a metapopulation approach to pink sand-verbena's range-wide conservation appropriate (e.g., McEachern *et al.* 1994), but much more information on the dynamics of seed movement in this species will be needed.

Because of the highly stochastic nature of its habitat, population sizes of pink sand-verbena are variable from one year to the next. Long-term monitoring of a wild population at Otter Point has documented this type of annual variation (Kaye 2001), which is consistent with the changes in population sizes of this species noticed at other locations (Kaye *et al.* 1999). At Otter Point between 1992 and 2001, the population peaked in 1997 at over 175 plants, only to fall to zero individuals in 2000, then rebound to three plants the following year (Fig. 2). At some sites, such as Ona Beach, Oregon, only one or a few plants have been observed, and only in one year. At others, such as Cape Blanco, Oregon, several years may pass between observations of individuals (Kaye 2001). Long distance dispersal of seeds by ocean currents to and from suitable habitat (metapopulation dynamics) and exchange of seed between a long-lived, persistent seed bank and the above-ground population, are significant processes in the dynamics of pink sand-verbena populations.

Population Genetics. Populations of pink sand-verbena appear to have a high degree of genetic similarity to one another. Published reports by McGlaughlin *et al.* (2002) and McGlaughlin (1999) found that all 14 sampled populations in southern Oregon and California had a genetic identity of greater than 92%. There was some geographic pattern to the observed genetic variability, especially in the Humboldt Bay area, and genetic distance and geographic distance were positively correlated. However, there was great similarity between all populations, and some widely-separated populations were more similar to one another than some closer populations. This pattern may reflect metapopulation dynamics in the species in the form of occasional long-distance dispersal events of seeds from a source population to available habitat many miles away, as well as more frequent short-distance dispersal. Overall, there was no evidence of significant genetic differentiation among populations ($F=0.0196$) of pink sand-verbena (McGlaughlin 1999). Most populations observed were moderately genetically diverse, with heterozygosity ranging from 0.102-0.261 (0.377-0.441 for polymorphic loci only and corrected for dominant data) (McGlaughlin 1999).

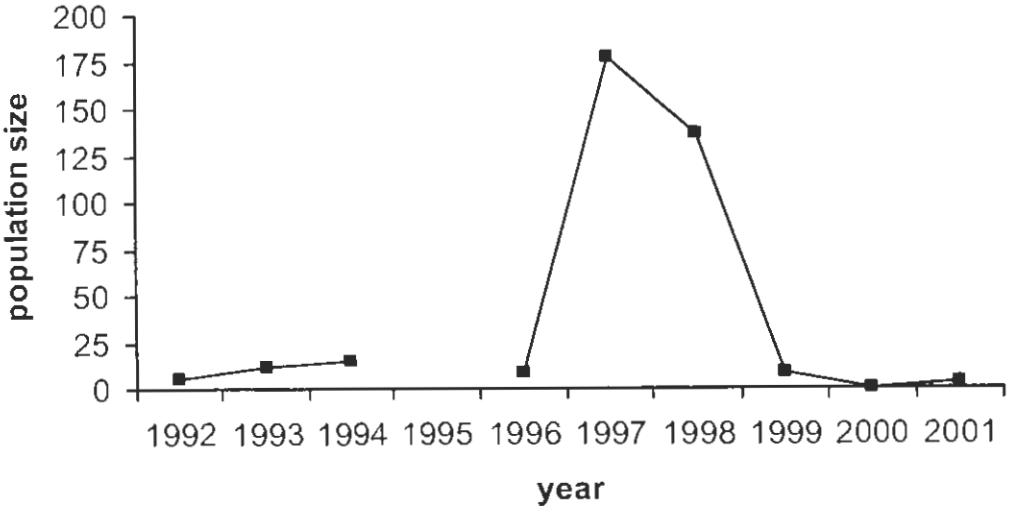

Figure 2. Population trends of pink sand-verbena at Otter Point, a population on the Oregon coast, illustrating the variability of wild population sizes through time. This population declined to zero in 2000, but recovered to three plants in 2001. Data were not available for 1995.

Reintroduction Methods and Results

Sowing seeds directly on beaches and out-planting greenhouse-grown stock both appear to be options for pink sand-verbena population re-establishment and augmentation. Transplanting and seeding experiments have documented the potential strengths (and weaknesses) of each of these techniques for short-term population establishment.

Transplanting. An out-planting experiment conducted in 1995 examined the survival and growth of plants on 10 beaches on the Oregon coast, and evaluated the importance of fertilizing transplants (Kaye 1995b). Potted plants were grown in a heated greenhouse following seed germination procedures outlined in Kaye (1999a). A total of 12 to 72 plants were out-planted to each location, and half were randomly assigned an application of slow-release fertilizer (14-14-14). On average, 45% of the transplants survived from May to August. Fertilizer had only a weak effect on transplant survival (42% survival without fertilizer, 51% with fertilizer), but it substantially and significantly increased plant size, and more than doubled reproduction (avg. flowering increased from 13 to 29 inflorescences per plant).

Continued out-planting efforts on beaches since that time have adopted the use of fertilizer as standard procedure and documented a similar overall survival rate of 47% (Kaye 2001). Environmental factors that appear to affect survival of transplants at any given site include the amount of wind blown sand that buries or excavates the plants, moisture availability in the sand at the time of transplanting, and the abundance or proximity of competing vegetation, especially European beachgrass.

Depending on these conditions, results to date suggest that it is possible to establish pink sand-verbena plants on natural beaches and in restored dune habitat, at least in the short-term. In 2001, for example, transplants at Tahkenitch Creek, Oregon, did relatively well (76% survival of 50 plants), especially those near the shore and those that did not show evidence of intense wind (Kaye 2001). In contrast, transplants at Siltcoos Creek, Oregon were clearly damaged by wind that excavated their root systems, and they had relatively low survival (16% of 45 plants).

Since most pink sand-verbena plants on beaches are short-lived (annual), the viability of out-plant-reintroduced populations hinges on recruitment of new individuals from seed produced by the transplants, or the planting of additional transplants. So far, offspring from transplants have been relatively uncommon (possibly due to inadequate seed production to produce a functional seed bank), except after transplanting in 1997 at Siltcoos Creek, which produced abundant plants the following year (but not the year after that) (Kaye 2000).

Seeding. Population models suggest that planting small transplants will produce more vigorous populations than sowing an equal number of seeds (Guerrant 1996). However, seeds are much easier to sow than plants are to propagate and out-plant, so larger numbers of pink sand-verbena seeds than plants can be used in direct-seeding, possibly outweighing any transplant advantage.

Seeding experiments (broadcasting 5000 seeds onto beaches and foredunes) at 13 sites on the Oregon Coast in 1995 (Kaye 1998) resulted in establishment of at least one plant at six locations. However, the establishment rate was so low, on average 0.07%, that this work was followed up with seedings of 50,000 seeds. Seeds in all attempts were collected from large numbers of individuals (>20) in a population at Port Orford, Oregon; this site has been the largest natural population in Oregon for several years and has produced ample seeds to sustain this level of harvest (<5% of the population's seed output) with little risk to the local population. Efforts with this larger number of seeds produced an average of 299 plants per site (0.61% establishment rate), and at least some plants in 18 of 19 attempts between 1997 and 2001 (Fig. 3, Kaye 2001).

Unfortunately, most of these seeding attempts have failed to produce self-perpetuating populations. One notable exception is the now-thriving population at North Spit near Coos Bay, Oregon. This site is relatively unique among the directly seeded sites in that the habitat is completely protected from catastrophic ocean waves associated with winter storms. The reintroduction site is located in the interior of the spit, in an area formerly dominated by European beachgrass that was cleared of this invasive species in an effort to restore habitat for the western snowy plover and pink sand-verbena (Kaye 1998; Pickart & Sawyer 1998). The site was seeded in 1997 in five plots (10,000 seeds per plot) with various residual infestations of invasive plants, predominantly European beachgrass, ranging from <5% to >80% cover. The abundance of beachgrass and other weedy plants had a negative impact on the growth and reproduction of pink sand-verbena; the establishment of the species was highly negatively correlated with the abundance of invasive weeds (Fig. 4), showing a clear connection between the success of a rare species and the destruction of an invasive exotic.

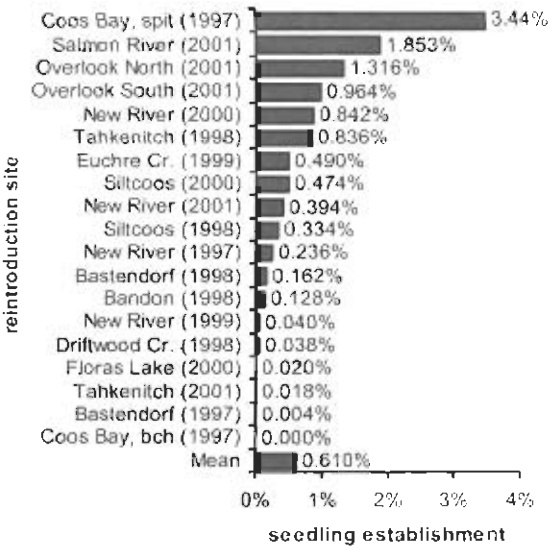

Figure 3. Plant establishment rates within one year of seed-sowing on beaches and restored dunes. Bar length and the value to the right indicate the percentage of seeds establishing as vegetative or reproductive plants. The year of seed sowing is indicated in parentheses after each location name. At New River in 1999, the seeding area was partially destroyed prior to observation, so the value presented may be an underestimate of the actual number of plants established there. A total of 50,000 seeds were sown at each site (from Kaye 2001).

In 1997, the Coos Bay population numbered about 1700 plants, then climbed to over 4100 plants in 1998. Since that time, the population has increased to the point that it is now the largest population of pink sand-verbena in the world, topping 45,000 flowering individuals in 2001 (Fig. 5). It also successfully captured the genetic diversity and heterozygosity of the source population (Port Orford) from which the seeds to create it were collected (McGlaughlin *et al.* 2002). The habitat has been disced each year in the winter to further control European beachgrass and keep other competing vegetation from invading the open sandy habitat, and this continued management is likely the main reason the population has done so well.

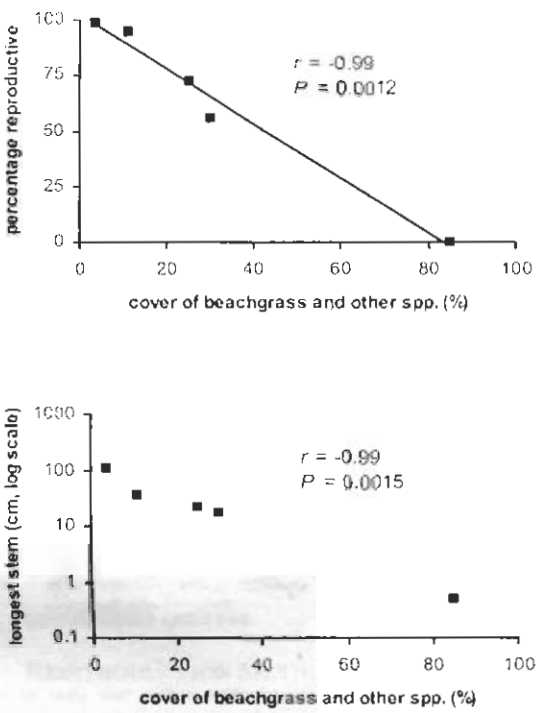

Figure 4. Competing vegetation (mostly European beachgrass) versus pink sand-verbena longest stem (bottom) and percentage reproductive (top) in five plots submitted to different levels of beachgrass control, then seeded with sand-verbena at Coos Bay (from Kaye 1998).

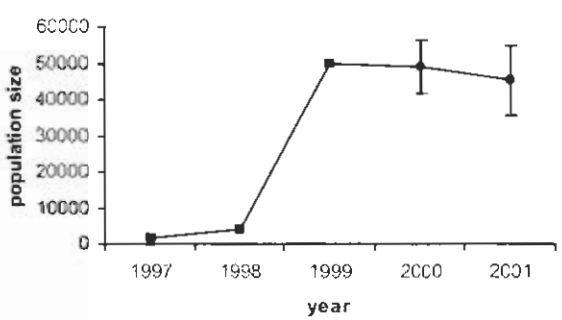

Figure 5. Population trends at the Coos Bay North Spit reintroduction site. The area was seeded in January 1997 with 50,000 seeds from a population at Port Orford, Oregon. Population size estimates for 1997-99 (squares) are complete censuses of all plants in the population, while those from 2000-01 (circles) are estimates of reproductive plants only based on a random sample. The error bars for 2000-01 values represent 95% confidence intervals.

The Importance of a Seed Bank

Long-term persistence of pink sand-verbena at sites on the Oregon coast may depend on the development and maintenance of a long-lived persistent seed bank. Results from germination tests with seeds of various ages (stored in paper sacks at room temperature) show that seeds of this species can remain viable for long periods of time (Kaye 2001). Loss of viability over time appears to be very slow. On average, seeds appear to decline in viability by about 3.6% per year. One seed lot stored for ten years retained over 90% viability. Although environmental conditions of seeds stored in paper sacks are not the same as those buried in sand in a wild state, these results are consistent with the hypothesis that pink sand-verbena seeds are capable of persisting in the sand for extended periods of time.

Furthermore, the appearance of some populations of pink sand-verbena long distances from natural populations but adjacent to historic sites, such as at Tenmile Creek in 1995 and Vancouver Island in 2000 (after nearly 60 years of absence), suggest that some populations may establish from seed many years after their presence as adult plants.

And finally, the stochastic behavior of the natural population at Otter Point, which resulted in a decline to zero plants in 2000, followed by the emergence of three plants in 2001, also suggests that the species can re-colonize sites from a local seed bank. Taken together, these lines of evidence provide strong support for the notion that pink sand-verbena is capable of maintaining a persistent seed bank, and that buried seeds may play an important role in the population dynamics of this species and should be fostered in reintroduction attempts. An alternative (and not mutually exclusive) explanation for some of these observations is that seeds dispersed long-distances to the beaches where plants reappeared. Long-distance dispersal may indeed occur in this species (and hopefully does!), but given the current low numbers of populations, this explanation seems less likely than the presence of buried viable seeds. At this point, more information is needed on seed bank dynamics to predict the minimum number of reproductive plants and period of years they must be present to produce sufficient seeds for lasting population viability.

The Role of Disturbance

Although pink sand-verbena appears capable of colonizing disturbed habitats like beaches and dunes in which European beachgrass has been removed, it does not appear able to persist in these habitats without continued disturbance. In a study at Port Orford, Oregon (Kaye 1999b) on sand deposits of 0, 3, and 6 years in age, the abundance of pink sand-verbena was related to time since sand disturbance or deposition (the sand deposits were dredged from the adjacent harbor and placed on the foredune to smother European beachgrass). Randomly sampled plots were used to document the abundance of pink sand-verbena, all other associated species (15 plots per substrate age), and major soil macronutrients (nitrogen [nitrate, NO3 and ammonium, NH4)] phosphorus [P], potassium [K]) (10 samples per substrate age), and pH across this chronosequence.

Total vegetative cover increased with time since disturbance from 13% on fresh (3 month old) sand to 22% on 3-yr old sand and nearly 30% on 6-yr old substrate. European beachgrass in particular increased from no presence on fresh sand to 5.7% cover after six years. Pink sand-verbena, on the other hand, tended to decline in abundance with substrate age. Average cover was 4.1% on fresh sand and 8.1% on 3-yr sand, but only 0.2% on the oldest material. Large plants (>0.5-cm) were not detected in the plots on the oldest substrate, but were present at 2.7 and 2.5 plants m^{-2} on the 3-yr old and fresh material, respectively. Small plants (<0.5-cm) and seedlings were infrequently encountered on the 6-yr old material (5.7 plants m^{-2}), very abundant on the 3-yr old sand (167.5 plants m^{-2}), and absent from the fresh substrate.

Substrate age had a significant effect on some macronutrients but not others. For example, nitrogen in the form of ammonium (NH4) increased significantly with substrate age from an average of about 10 ppm on freshly disturbed sand to 30 ppm on 6 yr old substrate, but nitrate (NO3) was nearly undetectable and showed no trend. In contrast, average potassium (K) concentrations dropped from about 110 ppm in fresh sand to 40 to 60 ppm in older sands. Phosphorus remained at very low concentrations (<6 ppm) in all substrates. Acidity (pH) declined significantly in the oldest substrates, but probably not meaningfully because average pH levels were all between 8.3 and 8.8, a relatively narrow range. These results lead to the hypothesis that pink sand-verbena may do well on freshly disturbed or deposited substrates because of a lack of competition and availability of nutrients like phosphorus, but as time passes, competition from other plants (including European beachgrass) and leaching or uptake of some nutrients leads to poor plant performance (Kaye 1999b).

Implications for Conservation & Recovery

One lesson learned from all of these seeding and out-planting experiments is that pink sand-verbena establishes only on beaches in Oregon, not on foredunes, most likely because much of the available foredune habitat is occupied by European beachgrass. Seeding attempts in 1995 involved spreading of seeds on the beaches and grassy foredunes, but plants emerged only on the beaches – never on the dunes. This is consistent with past observations of the species in California in which pink sand-verbena was noted as occupying beaches and rarely foredunes, except at the southern end of its range (e.g., Tillet 1967; Imper 1987; Kaye pers. obs.).

The reasons for all of the successes and failures of past reintroduction attempts are not completely known but may be related to habitat quality, continued presence of European beachgrass, and susceptibility to the scouring effects of winter storms. For example, the presence of competing vegetation, especially in foredune habitats, may result in small plants that produce few or no seeds. Also, winter storms on the Oregon coast can have dramatic effects on beaches, removing large amounts of sand and even established foredunes. Any plants or recently deposited seeds on a beach could be removed from the site and carried away by ocean currents. For example, a seeding attempt with 50,000 seeds at Floras Lake, Oregon in 2000 resulted in only 10 plants, but the beach at this site has coarse sand, a short shelf, and steep slope – factors that make the beach erode more quickly during winter storms (Komar 1997). Also, some recent winters in Oregon have been characterized by frequent and intense winter storms. If milder winters had been experienced, more population carryover after seeding attempts in 1997 to 2000 might have occurred.

The habitat at the Coos Bay North Spit, however, is protected from these winter storms because it is in the interior of the sand spit. This protection allows all seeds produced from the pink sand-verbena plants

to remain on site, maximizing their chances of establishing seedlings the following year. Further, repeated mechanical disturbance during fall and winter months each year has kept competing plant species from revegetating the site and has probably been crucial to the successful population growth of pink sand-verbena at this site. Finally, studies at Port Orford and Gold Beach, Oregon, on dredged sand confirm that competing vegetation is a major factor affecting establishment and survival of pink sand-verbena (Kaye 1999b).

Many coastal *Abronia* species do not compete well in stable sandy areas, occurring instead in ecologically dynamic habitats (Purer 1936; Couch 1941) and acting as pioneer species (Johnson 1985). Dredged sand placed on top of foredune vegetation offers an excellent substrate for short-term plant growth and reproduction, but unless it is disturbed frequently to remove competing vegetation, pink sand-verbena may ultimately decline (Kaye 1999b).

Results to date support the hypothesis that pink sand-verbena populations require frequent disturbance, either by humans or nature, to maintain suitable habitat, but that this disturbance must be balanced by re-colonization from a persistent seed bank (or dispersal from off site) to be successful. Sowing seeds or transplanting greenhouse-grown individuals on beaches may be effective methods for reintroducing pink sand-verbena. Sites with high summer winds should be avoided, however, because the plants appear intolerant of heavy burial during the growing season. Repeated reintroduction attempts (by seed or out-planting) may be necessary to establish a viable population with a dynamic, persistent seed bank.

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