NASA Technical Memorandum 100980

Species Biology And Potential For Controlling Four Exotic Plants (Ammophila Arenaria, Carpobrotus Edulis, Cortaderia Jubata, And Gasoul Crystallinum) On Vandenberg Air Force Base, California

October, 1987

(NASA-TM-100980) SPECIES BIOLOGY AND POTENTIAL FOR CONTROLLING FOUR EXOTIC PLANTS (AMMOPHILA ARENARIA, CARPOBROTUS EDULIS, CORTADERIA JUBATA AND GASOUL CRYSTALLINUM) ON VANDENBERG AIR FORCE BASE, CALIFORNIA

N88-18148

Unclas

G3/51 0124769

National Aeronautics and Space Administration

NASA Technical Memorandum 100980

Species Biology And Potential For Controlling Four Exotic Plants (Ammophila Arenaria, Carpobrotus Edulis, Cortaderia Jubata, And Gasoul Crystallinum) On Vandenberg Air Force Base, California

Paul A. Schmalzer, PH.D.
C. Ross Hinkle, PH.D

The Bionetics Corporation
Kennedy Space Center, Florida

October 1987

National Aeronautics and
Space Administration

John F. Kennedy Space Center

Table of Contents

Abstract

Invasive exotic plants can displace native flora and modify community and ecosystem structure and function. *Ammophila arenaria*, *Carpobrotus edulis*, *Cortaderia jubata*, and *Gasoul crystallinum* are invasive plants present on Vandenberg Air Force Base, California designated for study by the Environmental Task Force because of the perceived threat they represent to the native flora.

Ammophila arenaria was planted on Vandenberg for dune stabilization in the Purisima Point area, dominates the dunes there, and excludes native plants. *A. arenaria* is native to Europe but has been widely planted for dune stabilization; it is extremely well adapted to dune habitats. Few insect pests and no known plant diseases affect *A. arenaria*. Several herbicides and treatment with salt offer some potential to control the plant, but techniques are not well developed.

Carpobrotus edulis, a perennial mat-forming succulent native to South Africa, was planted on Vandenberg as an ornamental and along roadsides for erosion control. It has spread into native communities, particularly coastal dune scrub and chaparral. Seeds are animal-dispersed. Fire stimulates seed germination and appears to encourage the spread of the plant. *C. edulis* is attacked by two scale insects and several fungal diseases. A biological control program is unlikely because of its extensive use as an ornamental. Sensitivity to different herbicides is unknown, and there is insufficient information available to design a complete control program. Removal of the plant by hand from high priority sites or recent burns is a possibility, but the effectiveness of this would have to be determined.

Cortaderia jubata, a grass native to South America, was introduced into California as an ornamental and has escaped in the coastal region. It is established primarily in disturbed areas but is spreading into undisturbed native vegetation. *C. jubata* produces large numbers of wind-dispersed seeds. Control techniques are best developed in New Zealand where grazing and herbicides are used. No potential for biological control other than grazing is known.

Gasoul crystallinum, an annual, prostrate herb native to South Africa, occurs along the coastal bluffs and adjacent grassland areas on Vandenberg. It does not appear to be as serious a problem as the three previous taxa, but it does have the potential to expand in coastal areas. *Gasoul* accumulates salt while growing; leaching of salt on death of the plant limits establishment of other species. Herbicides are used to control *Gasoul* in cereal crops in South Australia but would have to be tested for use in coastal vegetation. Removal of the plant by hand before it releases seed or leaches salt is a potential control.

Many other introduced species occur on Vandenberg. The one with the most potential to affect native vegetation is *Conicosia pugioniformis*, a succulent perennial, that invades disturbed sites and burned areas and establishes dense mats that exclude native plants. *Erechtites glomerata* and *Ehrharta calycina* also pose problems.

List of Tables

Page

Acknowledgments

This project was conducted under the direction of Dr. Albert M. Koller, Jr., Chief, Programs and Planning Office and Dr. William M. Knott, III, Biological Sciences Officer, Life Sciences Research Office, The Biomedical Operations and Research Office, John F. Kennedy Space Center (KSC) under NASA Contract NAS10-10285. This study was conducted for the Environmental Task Force at Vandenberg Air Force Base.

P.N. Johnson, Botany Division, New Zealand Department of Scientific and Industrial Research, Leslie Friedman, California Field Office, The Nature Conservancy, Andrea Pickart, Lanphere-Christensen Dunes Preserve, and Charles Bruce, Oregon Department of Fish and Wildlife, provided information on *Ammophila arenaria*. Carla D'Antonio, Department of Biological Sciences, University of California, Santa Barbara, and Paul H. Zedler, Biology Department, San Diego State University, provided information on *Carpobrotus edulis*. Ruth L. Gadgil and J.A. Zabkiewicz, New Zealand Forest Research Institute, provided information on *Cortaderia jubata*. P.M. Kloot, South Australian Department of Agriculture, provided information on *Gasoul crystallinum*. Resa Reddick, The Bionetics Corporation, conducted the DIALOG literature searches. Diana Hickson, The Bionetics Corporation, Carla D'Antonio, University of California, Santa Barbara, Steve Junak, Santa Barbara Botanical Garden, and Michael McElligott and Richard Nichols, Vandenberg Environmental Task Force, reviewed earlier drafts of this paper.

Introduction

Introduced (exotic) plants that have naturalized are a major component of the California flora. Introductions began with the Spanish settlement in the 18th century and have continued to the present (Raven 1977). Munz and Keck (1968) list 975 introduced species as naturalized; Raven (1977) believes that not all of these plants would persist without human interference and gives an estimate of 654 introduced taxa, 13% of the total flora. Mooney et al. (1986) note that disturbance in California has been greatest in the coastal regions and in the Central Valley and that introduced taxa tend to form a larger part of the flora in these areas. For example, 36% of the flora of Santa Barbara County is introduced but only 6% of the flora of the White Mountains (Mooney et al. 1986).

Some native communities in California have been almost completely replaced by exotic plants. For example, introduced grasses dominate 10 million ha of annual grassland and oak savanna in place of native grasses (Heady 1977, Jackson 1985). Dunes and beaches also appear to be prone to invasion. Communities with closed tree canopies, in contrast, have had fewer invasions. Frequency of invasion also appears to decrease with elevation (Mooney et al. 1986).

Escaped exotics in California are a heterogeneous group of plants. Three categories of introductions are generally recognized: plants introduced accidentally through agricultural practices, plants introduced for ornamentals or for soil stabilization or erosion control, and plants introduced for food crops (McClintock 1985). Exotics also differ in ability to spread and invade new areas. McClintock (1985) recognized three groups: 1) benign weeds that remain in urban areas and do not cause significant problems, 2) minor weeds that spread beyond urban areas but remain in disturbed situations such as old home sites, fields, and pastures, and 3) major weeds that spread aggressively beyond disturbed urban areas and invade undisturbed native vegetation. The third group is clearly the most significant. Pemberton (1985) terms these "ecological weeds" and notes they have the potential to damage the habitat for California's native flora and may influence community processes and characteristics including succession, production, diversity, and mineral cycling; (see also Vitousek [1986]).

Once established, major weeds can be difficult to control (McClintock 1985). The California Department of Parks and Recreation allocated nearly one-fifth of its Resource Management Program Budget in 1984 to removal of exotic species and restoration of natural ecosystems (Hillyard 1985). Biological control is a viable option for some but not all weeds (Pemberton 1985).

The present study examines the species biology and potential for controlling four invasive exotic plants (*Ammophila arenaria, Carpobrotus edulis, Cortaderia jubata, Gasoul crystallinum*) considered weed problems on Vandenberg Air Force Base (VAFB), California. Species of concern were specified by the Environmental Task Force on Vandenberg. This study reviews available literature on these four plants and provides recommendations towards a control program, where possible, or towards further study where there is insufficient information to recommend control measures. In addition, comments are included about other exotic species of concern noted during field work on related projects or suggested by other biologists.

Computerized literature searches were conducted using the DIALOG system (Lockheed Dialog Information Retrieval Service 1979) and relevant databases including those in biological and agricultural sciences, government publications (National Technical Information Service), and doctoral dissertations (Dissertation Abstracts). Relevant publications were obtained and reviewed. Where active research programs on any of these species could be identified, researchers were contacted for recent or unpublished information. A record of these communications is provided in the report appendix.

Ammophila arenaria

Species Biology

Ammophila arenaria (L.) Link (Poaceae: Agrostideae) is an erect, perennial, rhizomatous grass with tough, involute blades and pale, dense spike-like panicles (Hitchcock and Chase 1950). Common names include European beachgrass and marram. It is native to coastal sand dunes of Europe from 63°N to 30°N latitude. Two varieties are distinguished in Europe; *Ammophila arenaria* var. *arenaria* occurs along the North Sea, Baltic, and Atlantic coasts south to central Portugal, and *A. arenaria* var. *arundinacea* occurs from central Portugal along the Mediterranean and Black Sea coasts (Huiskes 1979a) including Egypt (Ayyad 1973). The related taxon, *Ammophila breviligulata* Fernald, is native to eastern North America occurring on sand dunes from North Carolina north to Newfoundland and around the Great Lakes (Hitchcock and Chase 1950). *A. breviligulata* may be regarded as a subspecies of *A. arenaria* (Huiskes 1979a).

Ammophila arenaria is a sand-binding grass and has been planted extensively for sand dune stabilization both in and out of its native range. In Britain, *Ammophila* has been used for coastal dune stabilization since the 16th century (Ranwell 1959) and is the major species used today for that purpose (Hewett 1970, Hobbs et al. 1983, Pizzey 1975). Coastal dunes have been planted with *Ammophila* in northern Europe since the Middle Ages (Wiedemann 1987). *Ammophila* has also been planted on inland dunes in Germany and the Netherlands (Huiskes 1979a). In the Mediterranean region, *Ammophila* is used to fix dunes in Israel (Tsuriel 1974). *Ammophila arenaria* has been planted extensively in New Zealand to stabilize dunes for forestry operations (Gadgil 1971, 1979) and other purposes (Johnson 1982). In the Falkland Islands, *Ammophila* was used to stabilize drifting sand in coastal areas (McAdam 1980).

Both *Ammophila arenaria* and *A. breviligulata* have been planted in coastal areas of the United States for dune stabilization (Whitfield and Brown 1948). *A. arenaria* was planted around San Francisco as early as 1869 (Wiedemann 1984). On the coast of Oregon and Washington, *A. arenaria* was used in major dune stabilization projects around Coos Bay in 1910 (Wiedemann 1984), on the Clatsop plain at the mouth of the Columbia River between 1935 and 1948 (Schwendiman 1977, Whitfield and Brown 1948, Wiedemann 1984), and at the mouth of the Siuslaw and Siltcoos Rivers between 1948 and 1963 (Wiedemann 1984). Since the 1960s, it has not been planted extensively on public lands but has been used for commercial developments (Wiedemann 1984). *Ammophila breviligulata* was planted in an extensive dune stabilization project between 1936 and 1940 along the Outer Banks of North Carolina (Dolan et al. 1973, Godfrey and Godfrey 1974).

In several areas of the world, *Ammophila arenaria* has naturalized and spread extensively from sites where it was planted, often displacing native dune flora and fauna. Johnson (1982) reported that *Ammophila* had spread in the eastern and southwestern sections of South Island, New Zealand, displacing native dune flora, and that it is considered among the exotic species most threatening to native vegetation. *A. arenaria* dominates most beaches (Barbour et al. 1976) and foredunes (Barbour and Johnson 1977, Wiedemann 1984) in northern California, Oregon, and Washington. From San Francisco north, *Ammophila* is considered escaped and fully naturalized; it occurs south to San Diego, where planted, but does not aggressively spread in that region (Barbour and Johnson 1977).

Where established on the Pacific coast, *Ammophila arenaria* has caused a radical transformation of beach and dune flora, fauna, and topography (Pavlik 1983a). To understand the transformation, the native beach and dune vegetation on the Pacific coast must be understood. "Beach" is used for the sandy substrate between mean tide and the foredune or furthest reach of storm waves while "dune" refers to the foredunes inland to stabilized substrate (Barbour and Johnson 1977). North of Pt. Reyes (38°N), beaches are characterized by *Ammophila arenaria*, *Elymus mollis*, *Ambrosia chamissonis*, and *Cakile maritima*. Between Pt. Reyes and Morro Bay (38°-35°30'N), *Ambrosia*, *Cakile*, and *Carpobrotus aequilaterus* are dominant, but the two grasses still occur. South of Morro Bay, *Ammophila* and *Elymus* occur only where planted, *Cakile*, *Ambrosia*, *Carpobrotus*, and *Abronia* spp. are the characteristic beach taxa (Barbour and Johnson 1977). Most beaches north of 38°N are now dominated by *Ammophila arenaria*; species diversity on these beaches is half that of beaches dominated by other taxa (Barbour et al. 1976). Biomass is generally low on California beaches, but greater biomass occurs where *Ammophila* or *Carpobrotus aequilaterus* dominates (Barbour and Robichaux 1976).

The transformation of foredunes has been dramatic. In California south of Monterey, vegetation of natural foredunes consisted of a number of perennial herbs with woody taproots such as *Ambrosia chamissonis* and *Abronia* spp. (Barbour and Johnson 1977). North of Monterey and into Oregon and Washington, *Elymus mollis* occurred often with *Abronia latifolia* (Barbour and Johnson 1977, Wiedemann 1984). Dune systems produced by this vegetation consisted of low foredunes and rose gradually inland (Barbour and Johnson 1977). Sand hummocks (mounds) formed around native plant species adapted to sand burial (Wiedemann 1984). *Ammophila arenaria* has greater sand-binding abilities than the native species. Hummocks formed by it tend to coalesce into a single steep foredune ridge parallel to the beach (Barbour and Johnson 1977, Wiedemann 1984) changing the topography of the dunes (Cooper 1967). *Ammophila* has displaced native dune flora by rapid growth and dense cover (Wiedemann 1984), excluding native dune species, reducing open habitat, and reducing species richness (Barbour and Johnson 1977). *A.arenaria* stands at Pt. Reyes had three times the biomass of *Elymus mollis* stands and two to three times the biomass of perennial dune communities (Pavlik 1983a).

The subsequent changes in the dune plant community affect animal communities. Slobodchikoff and Doyen (1977) found that the diversity of sand burrowing arthropods was greatly reduced in *Ammophila*-dominated dunes compared to dunes with native plant species. Small increases in *Ammophila* cover (up to 20%) produced large declines in the number of arthropods. Arthropod communities in *Ammophila*-dominated dunes had fewer species and fewer rare species than native dunes. Slobodchikoff and Doyen (1977) suggested that the dense root mat produced by *Ammophila* restricted movement of burrowing organisms; also, *Ammophila* has its growing material above the sand, out of the reach of substate dwellers, in contrast to the sprawling native vegetation. Pitts and Barbour (1979) found that deer mice (*Peromyscus maniculatus*) were most frequently trapped in *Ammophila*-dominated areas of beach and dune probably due to the greater cover, shade, more stable substrate, and decreased temperature fluctuations provided. However, *Ammophila* also reduced plant species richness, including food plants used by *Peromyscus*. Reduction of dry, open areas in dunes by *Ammophila* growth reduces the nesting habitat for snowy plovers; without control measures these birds may be eliminated from the Oregon coast

(Charles Bruce, Oregon Department of Fish and Wildlife, personal communication).

Where *Ammophila breviligulata* has been used for dune stabilization on the eastern coast of the United States, unintended effects have also occurred. Dune stabilization on the barrier islands of North Carolina produced a continuous, steep barrier dune in place of the lower, discontinuous dunes. This resulted in narrower beaches, increased turbulence and erosion, and changes in dune vegetation (Dolan et al. 1973, Godfrey and Godfrey 1974).

Ammophila arenaria has numerous structural and physiological features that make it a very successful dune species. It is very tolerant of sand deposition and will survive deposition rates of up to 1 m per year (Huiskes 1979a, Willis et al. 1959). Burial stimulates rapid elongation of stem internodes; rhizome and root production tend to stabilize the mobile sand (Huiskes 1979a). Development of the plant canopy alters wind flow by increasing surface roughness (Ranwell 1972), causing sand deposition to occur behind the plant, resulting in both vertical and horizontal growth of the dune (Chapman 1976, Goldsmith 1971, Hesp 1981, Willis et al. 1959). *Ammophila* reestablishes leaf density more rapidly after burial than associated species (Huiskes 1980). It forms both vertical and horizontal rhizomes (Grieg-Smith 1961). Pavlik (1983 b, c) showed that *Ammophila* formed more vertical rhizomes and a spatial pattern of densely aggregated tillers while *Elymus mollis* (native to the Pacific coast) formed more horizontal rhizomes with more dispersed tillers. This "shoot-oriented" development of *Ammophila* allowed it to develop greater photosynthetic capacity than *Elymus*. The high concentration of tillers also modifies the microenvironment for other dune taxa (Pavlik, 1983 b,c).

Ammophila arenaria tolerates a wide range of soil chemical properties. In Britain, soil pH in *Ammophila* stands varies between pH 5 and pH 9; $CaCO_3$

content varies between 0.037% and 58.6%. Growth is slightly more vigorous under alkaline conditions (Huiskes 1979a). Dune soils are typically deficient in nitrogen (N), phosphorus (P), and potassium (K). Fertilization with N or with N, P, and K in greenhouse tests improved growth (Willis 1965). In field tests, Huiskes (1980) found a fertilization response only where there were few associated species. Nitrogen fixation by bacteria associated with the rhizosphere of *Ammophila arenaria* has been detected in British dunes (Abdel Wahab 1975, Abdel Wahab and Wareing 1980) but not in California (Pavlik 1983a). Nitrogen use efficiency of *Ammophila* is greater than that of *Elymus* (Pavlik 1983a). Nicolson and Johnston (1979) found the vesicular-arbuscular (VA) mycorrhizal fungi, *Glomus fasciculatus,* present in roots of *Ammophila arenaria* in dunes in Scotland. Rates of infection generally increased from active to stable dunes. *Ammophila* growth was stimulated by the fungi. Mycorrhiza could be important to mineral nutrition of *Ammophila* in nutrient deficient sands and may also contribute to sand stabilization. *Ammophila* does not grow in saline soils but only in those containing <1% sea salt (Huiskes 1979a). *Ammophila* is tolerant of salt spray.

Ammophila arenaria inhabits dune soils that are typically well drained and have low water holding capacity. Root systems of *Ammophila* extend to 1 - 2 m and sometimes deeper. In some sites (e.g., Cape Cod [Goldsmith 1973], Oregon [Pavlik 1985]), roots reach the water table. In Britain, *Ammophila* is considered very tolerant of drought and high temperatures (Huiskes 1979a). Pavlik (1984, 1985) found that *Ammophila* and *Elymus* have different responses to water stress and that *Ammophila* may be more drought-sensitive than *Elymus.* Purer (1936) found that leaves of *Ammophila* were usually partially unrolled in northern California and Oregon but always rolled in southern California where conditions were more xeric. DeJong (1979) found that beach taxa were subject to greater water stress in southern California (Malibu) compared to a northern California site (Bogeda).

Reproduction of *Ammophila arenaria* is primarily vegetative, by clonal spreading (Huiskes 1979a); rhizomes washed out of dunes by storms and deposited elsewhere can sprout and establish in new sites (Ranwell 1972, Wiedemann 1984). Flowering occurs most often in active rather than stabilized dunes (Grieg-Smith 1961, Huiskes 1979a). Viable seed are produced and dispersion is primarily by wind (Huiskes 1979a). Germination occurs only in the surface layer of the soil; 1 cm of sand covering seeds reduces germination by 50% (Huiskes 1979a). Most seedlings die from desiccation, burial, or erosion (Huiskes 1977). However, seedlings can survive to maturity in dune slacks where the soil remains damp (Grieg-Smith 1961, Huiskes 1977). Laing (1958) found that seedling establishment by *Ammophila breviligulata* was rare and occurred only on moist sites.

Once established, *Ammophila arenaria* can persist vegetatively for long periods; tufts of *Ammophila* in some fixed dunes are thought to be derived from plants that established when the dunes were active, perhaps hundreds of years ago. Gray (1985) showed that *Ammophila arenaria* had high phenotypic plasticity and that plants from the foredunes were more variable than those of mature (fixed) dunes; there was no evidence of fixed genetic polymorphism. Laing (1965) found no genetic differences between populations of *Ammophila breviligulata* on aggrading and stable dunes.

Numerous studies in both the native range of *Ammophila arenaria* (e.g. Huiskes and Harper 1979, Ranwell 1960, Wallen 1980, Willis et al. 1959) and where it has been introduced (Wiedemann 1984) have shown that the grass declines in vigor with dune stabilization. *Ammophila breviligulata* behaves similarly (Eldred and Maun 1982). This decline has been termed the

"*Ammophila* problem" (Marshall 1965, Gray 1985). The decline includes a decrease in tiller and live leaf density (Huiskes 1980, Huiskes and Harper 1979), decrease in frequency of flowering (Huiskes and Harper 1979), decrease in maximum green leaf area (Wallen 1980), and decrease in yearly production of above and below ground biomass (Wallen 1980). Several explanations for this phenomena have been suggested including competition from other plant species for water and/or nutrients (Huiskes 1980), aging of the root system in the absence of sand accretion (Hope-Simpson and Jeffries 1966, Marshall 1965), and a change in the balance of assimilating and non-assimilating tissue (Wallen 1980). *Ammophila* can be rejuvenated by sand accretion (Hope-Simpson and Jeffries 1966, Huiskes 1980, Willis 1965) and in some cases fertilization (Huiskes 1980, Willis 1965).

One mammal and several insects are known to feed on *Ammophila arenaria*. Young shoots of *Ammophila* are sometimes grazed by rabbits but are not preferred food (Huiskes 1979a). Pavlik (1983c) found that *Ammophila* was not grazed by deer but *Elymus* was. Small mammals, birds, and insects eat seeds of *Ammophila* (Huiskes 1979a). Eleven insects are reported to feed on *Ammophila arenaria* but also other grasses (Huiskes 1979a). *Meromyza pratorum* (Diptera: Chloropidae) feeds only on *Ammophila arenaria* in Britain, France, and the Netherlands but attacks wheat in Italy and Russia (Huiskes 1979b). The insect completes one generation per year. Eggs are laid in July on plant leaves; young larvae penetrate into the main or axillary shoot buds and develop for about a year. The effect on *Ammophila* is that the youngest emerging leaf on the tiller dies while the rest remain green, but production of new leaves from that tiller ceases. Up to 40% of the tillers were affected in a fixed dune slack, 5 to 20% in younger dune stages, and 20 to 30% in other older dune stages; however, the overall density of tillers was not decreased.

Ammophila arenaria appeared to be sufficiently plastic to compensate for the mortality (Huiskes 1979b). A lepidopteran larva attacks *Ammophila breviligulata* but has little impact on the population (Laing 1958). A scale insect, *Eriococcus carolinae*, attacks *A. breviligulata* on the Atlantic coast from North Carolina to Newfoundland causing slight to severe damage (Campbell and Fuzzy 1972 in Wiedemann 1987).

No plant diseases of *Ammophila arenaria* are known. No known host-specific fungi attack it; most fungi found on *Ammophila arenaria* are saprophytes or weak parasites on senescing plant parts (Huiskes 1979a). However, the southern range of the other species, *Ammophila breviligulata,* on the Atlantic coast is said to be limited by insects and diseases (Dolan et al. 1973). A fungal disease, *Marasmius* blight, has attacked *A. breviligulata* in the Outer Banks of North Carolina (Lucas et al. 1971 in Wiedemann 1987).

Ammophila is sensitive to trampling damage produced by recreational use of beach and dune areas (Boorman and Fuller 1977, Hygaard and Liddle 1981, Page et al. 1985). Even trampling by gulls can destroy *Ammophila* tussocks (Ranwell 1972). Vehicular traffic (ORV or "off-road vehicle") can destroy *Ammophila* as well as other dune vegetation (Wiedemann 1987).

Status on Vandenberg Air Force Base

Ammophila arenaria was planted on Vandenberg as part of an erosion control program carried out between 1953 and 1960 in the Purisima Point area. Previous construction had destabilized active and arrested dunes in this area and wind-blown sand had become a problem for launch facilities (Peters and Sciandrone 1964). Cooper (1967) noted damage to dunes in the Purisima Point area by military activities. The purpose of planting *Ammophila* was to create an artificial foredune to cut off sand from moving inland. Two parallel lines of snow fences were erected, and six months later (February 1960) *Ammophila* was planted between them; 350 ac of active dunes were treated. These plantings were successful, and a foredune was created (Peters and Sciandrone 1964). *Ammophila* still dominates these areas forming dense stands and excluding most native taxa (personal observation). It is not clear whether *Ammophila* has expanded beyond the area in which it was planted. Examination of aerial photography from 1972 and 1978 suggests that *Ammophila* may have filled in between the rows where it was planted, but no major extension of the *Ammophila* zone could be seen (Diana Hickson, personal communication). *Ammophila arenaria* also occurs on dunes in the Surf area on Vandenberg where there is public access to the beach (Diana Hickson, personal communication), on the north side of the mouth of the Santa Ynez River (Carla D'Antonio, personal communication), on foredunes between Surf and Honda Point, and at other scattered localities (Richard Nichols, personal communication). Origin of these other populations is not known. It is not clear if they were planted or spread from planted populations. The *Ammophila* population around Surf does not appear to be spreading (Carla D'Antonio, personal communication). Monitoring of *Ammophila* populations is required to determine their long term status (e.g., stable, invasive, declining).

Methods of Control

Published studies on control or eradication of *Ammophila arenaria* are not available. Preliminary or unpublished information from three control programs have been obtained.

Fiordland National Park, New Zealand, has had a control program for *Ammophila arenaria* and other exotics, particularly gorse (*Cystisus scopiarius*) and broom (*Ulex europaeus*), in effect since 1980. Herbicides are the primary means used for controlling these exotics. *Ammophila* is sprayed with Valpa L at concentrations of 1 L Valpa L to 10 L water for hand operated Knapsack spray units or 2 L Valpa L to 10 L water for a motorized Knapsack spray unit. Roundup (glyphosate) has been successful in some dune systems. Tordon 2G Prills and Tordon 520 DS are used on gorse and broom. These treatments are considered successful (P.N. Johnson, Botany Division, New Zealand Department of Scientific and Industrial Research, personal communication). This control program followed the preparation of a report documenting the threat *Ammophila*, *Cystisus*, and *Ulex* posed to the native dune flora (P.N. Johnson 1979, Vegetation of Fiordland beaches, unpublished).

The Nature Conservancy conducted a two year study of control techniques for *Ammophila* at the Lanphere-Christensen Dunes Preserve in Arcata, California. Techniques compared were burning, mowing, digging up the rhizomes, herbicide (Roundup), sand removal, and application of sea water and rock salt (Van Hook 1985). The most effective technique in preliminary results was digging up the grass 10 cm below the surface at intervals of one week during February to June, one month during July to August, and three months during November to January (The Nature Conservancy, undated, Draft Element Stewardship Abstract-*Ammophila arenaria*). This removal campaign was extremely labor-intensive and depended on volunteer help (Van Hook 1985). Although this technique did control the grass it did not eliminate it, and if digging were to stop *Ammophila* reinvasion is considered likely (Andrea Pickart, Lanphere-Christensen Dunes Preserve, personal communication). Application of rock salt in a complete but single layer to the surface occupied by an *Ammophila* stand followed by digging up the weakened grass six months later gave some encouraging results in preliminary trials (The Nature Conservancy, undated). Future research on the effectiveness of salt application is planned

(Andrea Pickart, personal communication). Experiments conducted in 1985 and 1986 showed that application of Roundup when *Ammophila* was in the flowering stage was effective but not when applied at other times; more tests are planned (Andrea Pickart, personal communication).

The Oregon Department of Fish and Wildlife has conducted some trials of herbicides for controlling *Ammophila* at the Oregon Dunes National Recreation Area. Roundup caused top-kill of some *Ammophila* plants that later recovered. Dowpon (dalapon) killed *Ammophila* in a treatment in 1982 but not in 1983 when rain occurred after application (Charles Bruce, Oregon Department of Fish and Wildlife, personal communication).

There is little prospect for biological control of *Ammophila arenaria*. No plant diseases or pests that eliminate the grass are known from its native range. Effects of the fungal disease of *A. breviligulata* (*Marasmius*) on *A. arenaria* are not known. *Marasmius* is known to cause diseases in other grasses, and its introduction to try to control *Ammophila arenaria* may not be appropriate (Wiedemann 1987). No biological control programs for grasses have been developed (Pemberton 1985).

Mechanical removal (repeated digging of the rhizomes) requires great effort and is likely to be applicable only to small areas. Treatment with salt may be useful in some instances. In the high rainfall areas in the Pacific Northwest, salt would leach quickly from the soil (Wiedemann 1987). In the Mediterranean climate region of California, salt might persist in the soil longer. It is not known how long elevated salt levels must be maintained to kill the grass rhizomes (Wiedemann 1987).

Herbicides will probably be required for any widespread program of eradication or control of *Ammophila* such as that carried out in Fiordland National Park in New Zealand. Detailed procedures for a successful treatment program in California have not been established. Several chemicals (Roundup, Dowpon, Valpa L) have been used in different places with varying success rates. Time of application, dosage rates, and post-application conditions may influence plant response. Further research is needed to determine effective treatment programs.

Recommendations

Ammophila arenaria is well established on Vandenberg in areas where it was planted in 1960. Without treatment it will continue to dominate these areas indefinitely. It is not clear from existing information whether *Ammophila* has spread from these planted areas or is spreading today. Vandenberg is well south of the areas where *Ammophila* is generally considered invasive. It is important to know if *Ammophila* is actively spreading in designing a control program. Is it necessary to eliminate *Ammophila*? If it is actively invading native dune vegetation, elimination would be more important than if it only maintains itself in existing areas. Monitoring is required to determine whether existing populations are spreading. *Ammophila* does occupy potential least tern and snowy plover habitat.

Techniques for controlling or eradicating *Ammophila* are not well developed. If a control program is implemented, it should begin as a small-scale experimental program to develop methods appropriate for this region of California. Exchanges of information should be maintained with groups involved in controlling *Ammophila* in northern California, Oregon, and New Zealand to take advantage of the experience these groups have.

Removal of *Ammophila* from the foredunes will create the possibility of sand movement inland. Native species will have to be established on dunes to reduce erosion if *Ammophila* is eradicated. In contrast to the well developed techniques for dune stabilization with *Ammophila*, there is limited information on reestablishing native dune species. Cowan (1975) reported on a project at Asilomar State Beach in California where heavy recreational use had destabilized the dunes, resulting in inland dune migration. After controlling vehicular and foot traffic and contouring the sand by bulldozing , the site was hydromulched with annual and perennial rye grass. Irrigation and fertilization were needed to establish cover. After cover was established and irrigation ceased, the introduced grasses died, and seeds or cuttings of native plants were planted. The intensity of treatment at this site related to its size and the severity of the problem. Small areas (7 m^2) of *Ammophila* eradicated by salt treatment and digging at the Lanphere-Christensen Dunes Preserve were invaded by native species without planting (The Nature Conservancy, undated). Dunes formed by native plants differ from those formed by *Ammophila;* there will be changes in dune topography and sand distribution if *Ammophila* is eliminated. Changes in dune vegetation in the Point Purisima area would probably have to be made gradually to avoid possible effects on facilities.

Carpobrotus edulis

Species Biology

Carpobrotus edulis (L.) Bolus is a perennial, mat-forming herb with succulent, 3-angled leaves and showy yellow to pink or even white flowers (Munz 1974, Smith 1976, Carla D'Antonio, personal communication). Common names include Hottentot fig and ice plant. Synonyms include *Mesembryanthemum edulis* L. (Munz 1974); some authorities spell the species epithet "edule" rather than "edulis" (Munz and Keck 1968). *Carpobrotus* is included in the Aizoaceae family by most authorities (Lawrence 1951, Cronquist 1981) or in the Mesembryanthemaceae if the Aizoaceae is subdivided.

Carpobrotus edulis is native to South Africa, but it has been planted extensively as an ornamental in Mediterranean Europe, Canary Islands, Germany, Chile, Argentina, and Australia (Washburn and Frankie 1985). In Australia, *Carpobrotus edulis* has naturalized in coastal areas (Collins and Scott 1982). *C. edulis* has been planted extensively in California. The California Department of Transportation (CALTRANS) maintains over 6000 ac of *Carpobrotus edulis* along highways and there is an equal acreage estimated to occur on private and other lands (Washburn and Frankie 1985). *C. edulis* is considered a hardy, low maintenance ground cover, except for its susceptibility to freezing injury, and is easily propagated and established (MacDonald et al. 1984).

Carpobrotus aequilaterus (Haw.) N.E. Br. (*Mesembryanthemum aequilaterus* Haw., *Carpobrotus chilensis* [Mol.] N.E. Br., *Mesembryanthemum chilensis* Mol.) also occurs in California on sand dunes and bluffs along the coast (Munz and Keck 1968). It is sometimes considered native (Moran 1950, Munz 1974, Smith 1976), but others consider it introduced (Barbour and Johnson 1977, Carla D'Antonio, personal communication). *C. aequilaterus* ranges from lower California to Oregon and also Chile. Hybrids between the two species occur (*Carpobrotus edulis* [L.] Bolus X *C. aequilaterus* [Haw.] N.E. Br.) (Ferren et al. 1984) and are reported to be common on many areas of the base (Carla D'Antonio, personal communication).

Although cultivated extensively, *Carpobrotus edulis* has also become a weed problem. On coastal strand and dunes, it has often spread and crowded out native plants (McClintock 1985). *C. edulis* has invaded disturbed areas in maritime chaparral in the Monterey Bay region (Griffin 1978); Smith (1976) stated that it was "...becoming serious competition to the native flora on arrested beach dunes, adjacent ocean bluffs, and sandy mesas about Vandenberg Air Force Base, Pt. Conception, and other localities" (in Santa Barbara County).

Despite the widespread use of *Carpobrotus edulis* as an ornamental and the threat it poses to native flora in some areas, there is little published information on its species biology and ecology. Carla D'Antonio (Department of Biological Sciences, University of California, Santa Barbara) is currently studying *Carpobrotus edulis* on Vandenberg. She has found that animals are important in distributing seeds of *C. edulis* and that seed germination is greatly enhanced by passing through the digestive system of rabbits and moderately enhanced by passage through deer. Heating from fire enhances germination of seeds that have not been ingested by rabbits but decreases germination of those that have. Localized soil disturbances from animals may be important in establishment in stabilized communities although they do not appear to be important for establishment in dunes. The initial invasion by *Carpobrotus* is slow, but then growth is rapid and can overtop shrub and other seedlings. Mats of *Carpobrotus* become up to 50 cm thick and decay of the litter is slow. Matted shrubs can sometimes be found under *Carpobrotus edulis* (Carla D'Antonio, personal communication). *C. edulis* will grow up onto established shrubs and slow their growth (D'Antonio 1987); it will also grow on shrubs killed by fire (personal observation). Reproductive potential of *C. edulis* is very high. Zedler and Scheid (1987) estimate a seed production of over 5.3 million/ha for a site in Burton Mesa chaparral and found 7000 seedlings/ha in a recent burn, 70% of which were still present 3 years after the fire.

Carpobrotus edulis is freeze-sensitive (MacDonald et al. 1984). Water stress also affects *Carpobrotus* growth (MacDonald et al. 1983, 1984). *C. edulis* on Vandenberg undergoes water stress at some times during the year and appears to compete with *Ericameria ericoides* and other shrubs for water in some locations (Carla D'Antonio 1987 and personal communication). Soil nitrogen levels limit *Carpobrotus edulis* growth along highways (MacDonald et al. 1983). *Carpobrotus edulis* is capable of crassulacean acid metabolism (CAM) (von Willert et al. 1977); some plants on Vandenberg Air Force Base use CAM (Carla D'Antonio, personal communication). CAM may confer some advantages in water-limited, nitrogen-limited, or saline environments. (See section on *Gasoul crystallinum* for details on this photosynthetic pathway.)

Recently, interactions between fire and *Carpobrotus edulis* have been observed. Seedlings of *C. edulis* established in a 1982 prescribed burn in Burton Mesa chaparral on Vandenberg (Jacks et al. 1984); by 1985, *C. edulis* was a dominant in this stand (Zedler and Scheid 1987). *C. edulis* has been found in nearly all areas of recently burned Burton Mesa chaparral on Vandenberg (Hickson 1987b).

Mortality of *Carpobrotus* along highways in the 1970s and 1980s due to scale insects or plant pathogens led CALTRANS to fund research on these topics (MacDonald et al. 1983, Tassan et al. 1982, Washburn and Frankie 1985). Costs of replacing the 6000 ac of *Carpobrotus* along state highways was estimated at $20 million (Tassan et al. 1982). These topics are reviewed below since they could represent possible biological controls for *C. edulis.*

Scale Insects. Scale insects that attack *Carpobrotus edulis* may have been introduced in California as early as 1949, but the first confirmed outbreak occurred in Napa, California in 1971; the species in this outbreak was *Pulvinariella mesembryanthemi* (Homoptera: Coccidae) (Washburn and Frankie 1985). The first outbreak was controlled by spraying with malathion (Koller 1978). In 1973, a second related species, *Pulvinaria delottoi,* was collected in Berkeley, California (Gill 1979). Both species originated in South

Africa. *P. mesembryanthemi* reappeared in 1973; between then and 1984 it spread to 24 counties in California (Washburn and Frankie 1984). *P. delottoi* spread more slowly and was present in only 7 counties in 1984 (Washburn and Frankie 1985). Dispersal of the scale insects is primarily by wind dissemination of the crawler (1st instar) phase; crawlers can survive 4 days in dry air and twice as long in moist air (Washburn and Frankie 1981). Dispersal by vertebrates also occurs.

Both species of scale insects have similar (and fairly complex) life cycles. The first instar or crawler phase emerges from eggs within the ovisac; after a sufficient number emerge the ovisac splits open and the crawlers disperse. Crawlers are negatively geotaxic and positively phototaxic; so they accumulate at the tips of the plants where they may be blown off by the wind. After dispersal, crawlers settle on feeding sites. *P. mesembryanthemi* tends to settle on younger leaves than *P. delottoi.* Failure to settle on a suitable feeding spot is a major cause of mortality; mortality, excluding parasitism, is concentrated in the crawler stage. Crawlers insert a feeding stylet into the leaf vascular tissue. Scale insects go through three immature instars before molting to the adult stage. In *P. mesembryanthemi,* the sex ratio is >300 female:1 male; in *P. delottoi,* males have not been found in the field. Both species reproduce by parthenogenesis. Fourth instar females develop ovisacs, white, fibrous, waxy structures, into which 350 to 800 eggs are deposited. Eventually the body of the scale insect shrivels and becomes part of the ovisac (Washburn and Frankie 1985).

P. mesembryanthemi completes two generations per year in central California but three per year in southern California; *P. delottoi* completes only one generation per year in its current range in California. Temperature affects survivorship; more crawlers survive at 20.5 to 27.0°C but ovisacs are larger and more crawlers are produced per ovisac at lower temperatures. High temperatures and low humidity cause mortality in *P. mesembryanthemi* (Washburn and Frankie 1985).

In South Africa, both scale insects live on host plants in the Aizoaceae; their primary host is *Carpobrotus edulis.* In California, *P. mesembryanthemii* occurs on *Carpobrotus* spp. and *Lampranthus* spp. *P. delottoi* is known from *Carpobrotus* spp., and ornamental *Sedum* and *Lampranthus*; it has colonized one native species of *Dudleya* in Monterey County. Feeding trials showed that *P. mesembryanthemi* could successfully complete its life cycle on 29 of 48 species and hybrids in the Aizoaceae tested; *Carpobrotus aequilateris* was the only possibly native species tested and it was a suitable host. *P. delottoi* was successfully reared on *C. edulis* and *C. aequilateris* (Washburn and Frankie 1985).

Mortality of *Carpobrotus* heavily infested by scale insects is presumably related to loss of nutrients, but the physiology of the infested plant has apparently not been studied. Carla D'Antonio (personal communication) suggests that scale insects might also transmit fungal spores since plants with scales are also frequently attached by fungi.

CALTRANS funded a research project to develop biological controls for the scale insects to reduce damage to *Carpobrotus* plantings along highways. Natural enemies of scale insects were located in South Africa and introduced into California. Two small parasitic wasps, *Metaphycus funicularis* and *Metaphycus stramineus* (Hymenoptera), have been successfully established in northern and southern California. Both deposit eggs on scale insects; the larvae feed inside the scale and kill it before it reaches maturity. These wasps complete their life cycles in 2 to 3 weeks, much faster than the scale insects. A solitary wasp, *Encyrtus saliens,* is also established in two northern California localities. Two other wasps, *Coccophagus cowperi* and a *Metaphycus* sp., were introduced but have not been recovered in the field (Tassan et al. 1982).

A predatory lady beetle, *Exochomus flavipes* (Coccinellidae), is established in northern California; it is a voracious feeder on scale insects. Another beetle, *Hyperaspis senegalensis hottentotta,* feeds preferentially on scale eggs but also on scale insects; it is considered tenuously established in northern California. Where parasites have been established, substantial reductions in *P. mesembryanthemi* and significant but less dramatic reductions in *P. delottoi* occurred 18 to 24 months after the parasites were established. As the range of the scale insects has increased, CALTRANS has released their natural enemies in the new areas. Mortality of *Carpobrotus* has been negligible where parasites have been successfully established (Tassan et al. 1982). Scale insects are also attacked by the native *Coccophagus lycimnia* and the previously established *Metaphycus helvolus* and *Rhizobellius ventralis* (Washburn et al. 1983).

Pathogens. In 1980, decline and death of *Carpobrotus* along roadsides in the absence of insect pests was reported in several areas in California (MacDonald et al. 1983, 1984). Plant pathogens were associated with some of these areas of decline.

Root rots occurred in several sites where poor drainage and excessive rainfall or irrigation produced prolonged periods of soil saturation. Plants turned light green to yellow, leaves wilted, lower stems and crowns turned brown, and roots showed decay and sloughing of cortical tissue. Two fungi were isolated, *Phytophthora crypotogea* and *Phthium aphanidermatum.* Both of these species would invade stem tissue when inoculated into healthy stems, but *Phthium aphanidermatum* was more aggressive causing a soft rot of succulent tissue. When *C. edulis* was planted in infected media, *Phytophthora crypotogea* caused severe decay of roots and lower stems; decay caused by *Phthium aphanidermatum* was less severe. For either fungus, decay was minor unless the plants were periodically flooded (MacDonald et al. 1983, 1984).

A vascular wilt has been observed in a few isolated areas. Affected plants turned dull gray-green, exhibited chlorosis as leaves shriveled, and turned brown and desiccated. In these stands, 50% to 75% of the plants were severely wilted or dead. The fungus, *Verticillium dahliae*, was isolated from infected plants. Inoculated into stems, the fungus produced localized areas of chlorosis and wilt, but when inoculated into roots, symptoms were widespread and death occurred in some plants in 8 to 12 weeks. *Verticillium dahliae* is not specific to *Carpobrotus* but will also cause wilt in other plants including cotton, tomatoes, and okra (MacDonald et al. 1983, 1984). Reasons for the isolated incidence of the wilt are not known.

Wilts confined to one or more branches of plants of *Carpobrotus edulis,* where the other branches were normal, occurred in some localities. Foliage on these branches turned dull gray-green and then olive as it shriveled. Orange-discolored tissue from beneath the surface of the plant yielded a fungus, *Phomapsis* sp. Inoculated into stems, this fungus produced the same wilt observed in the field (MacDonald et al. 1983, 1984).

Additional fungi isolated from diseased branches of *Carpobrotus* included *Fusarium* spp., *Macrophomina* sp., and *Pestolotia* sp. Pathogenicity of these fungi could not be established in greenhouse tests (MacDonald et al. 1983, 1984). Tests for mycoplasmas, spiroplasmas, rickettisia, viruses, and nematodes were all negative (MacDonald et al. 1983).

In most cases, no pathogen could be associated with decline in *Carpobrotus.* Nitrogen deficiency due to inadequate fertilization appeared to be the cause in some areas, while water stress was the apparent cause in others (MacDonald et al. 1983).

Status on Vandenberg Air Force Base

Carpobrotus edulis is well established on Vandenberg; it was planted as an ornamental in the cantonment area and for erosion control along roadsides and probably other sites. Aerial photography suggests that it was planted in the firing ranges when they were abandoned (Carla D'Antonio, personal communication). From these sites, it has spread into native communities including coastal dune scrub, coastal sage scrub, grassland, and chaparral. As noted earlier, fire stimulates *Carpobrotus* seed germination and appears to favor the invasion of *Carpobrotus* into Burton Mesa chaparral, at least where there is a seed source near the burn. *Carpobrotus aequilaterus* occurs on Vandenberg in mixed communities on active dunes; however, it does not establish dense stands that exclude other species. Hybrids also occur on Vandenberg but are generally less aggressive in invading sites than *C. edulis* (Carla D'Antonio, personal communication).

Methods of Control

There apparently has been no comprehensive survey of herbicide effects on *Carpobrotus edulis.* Broad spectrum herbicides would probably kill *Carpobrotus* but might also injure adjacent vegetation; they might be useful where *Carpobrotus* is in pure stands. Chlorflurenol, a morphactin, has been used to reduce growth of *Carpobrotus* and control encroachment on roadways and fences (Hield and Hemstreet 1974).

The pathogens that attack *Carpobrotus* are not specific to it. Root rots are effective only with periodic flooding. Branch wilts affect only portions of plants.

Verticillium wilt caused considerable damage to the stands infected but has only infected a few stands. Using it in a biological control program could be difficult since it also attacks commercial crops.

There is some potential that scale insects could be used in a biological control program (Washburn and Frankie 1985). However, the successful introduction of parasites of the scale insects may reduce or eliminate this prospect. Pemberton (1985) suggested that a natural enemy that would attack *C. edulis* but not *C. aequilaterus* might be located in South Africa, (assuming *C. aequilaterus* was native); however a biological control project was unlikely given the widespread use of *C. edulis* in landscaping. Since CALTRANS appears committed to maintaining *C. edulis* along highways, it would probably be difficult to get a biological control program approved. Biological control programs, even when politically feasible, are not always simple or cheap (Pemberton 1985). CALTRANS spent $190,000 between 1978 and 1981 on research on its control program for *Carpobrotus* scale insects (Tasslan et al. 1982).

Recommendations

Carpobrotus edulis is an extremely successful invasive plant on the sandy soils of Vandenberg. There is insufficient information presently available to attempt to outline a complete control program. The current research project by Carla D'Antonio will provide needed information on the plant. The recent finding that fire encourages the spread of *Carpobrotus edulis* (Hickson 1987b, Jacks et al. 1984, Zedler and Scheid 1987) is extremely important. Modification of controlled burning plans to avoid burning areas likely to be invaded by *Carpobrotus* post-burn could help slow its spread. Burton Mesa chaparral is thought to be particularly vulnerable to invasion (Hickson 1987a, b, Zedler and

Scheid 1987). Halting controlled burning in Burton Mesa chaparral until the situation is better understood would be advisable. Research is needed to understand the interactions of fire and exotic plants on the Burton Mesa. The invasion of exotics into Burton Mesa chaparral post-fire was not predicted in the environmental assessment for the wildland fuel management program (Wakimoto et al. 1980). This situation may be unique to maritime chaparral, a poorly understood vegetation type. Zedler and Scheid (1987) suggest that this chaparral is likely to resist invasion better if left unburned as long as possible. If certain areas must be burned because of fuel hazards and proximity to facilities, then it has been suggested that hand weeding the stand the spring after the fire might eliminate seedlings of the exotic plants (Richard Nichols, personal communication). This is certainly a possibility, but the effectiveness of weeding and the effort required need to be determined. Zedler and Scheid (1987) reported about 8000 seedlings per hectare at the 35th Street site post-fire. Monitoring of burns to determine the effectiveness of weeding would need to be conducted on a long term basis. It is possible that *Carpobrotus* or *Conicosia* could establish subsequent to weeding either from seed in the soil or from seed dispersing into the site.

Cortaderia jubata

Species Biology

The genus *Cortaderia* (Poaceae: Festuceae) consists of erect perennial grasses forming large tussocks with inflorescences of large plume-like panicles (Costas-Lippmann 1976). There are 24 taxa in the most recent taxonomic treatment of the genus (Connor and Edgar 1974, Connor 1983). Of these, 19 are native to South America, 4 to New Zealand, and 1 to New Guinea. Two species have been introduced into California (Costas-Lippmann 1976).

Standard manuals (Munz and Keck 1974, Hoover 1970) identify only one taxon, *Cortaderia selloana*, while Smith (1976) following Connor (1971) uses the name *Cortaderia atacamensis* for *C. selloana*. Connor (1973) and Connor and Edgar (1974) now consider the first species to be *Cortaderia selloana* and the second taxon in California to be *Cortaderia jubata*. *Cortaderia selloana* is native to the plains and slopes from southern Argentina to northern Chile and Bolivia. Within its range, *C. selloana* is often associated with wetlands vegetation along river banks and floodplains and also on certain inland sand dunes. At higher elevations, it occurs along mountain streams. *Cortaderia jubata* is distributed from northern Argentina along the Andes of Bolivia, Peru, and Ecuador where it frequently occurs along mountain streams (Costas-Lippmann 1976). Both species are commonly known as pampas grass.

Cortaderia selloana was introduced into California in the 19th century; between about 1874 and 1895 it was cultivated extensively in the Santa Barbara area for its flowering plumes (Costas-Lippmann 1976, Kerbavaz 1985). *C. jubata* was introduced in California as an ornamental; the exact date appears uncertain as it was not originally differentiated from *C. selloana* (Costas-Lippmann 1976). By the 1960s its weedy nature was recognized (Kerbavaz 1985).

Costas-Lippmann (1976) showed that *C. selloana* seldom escapes from cultivation in California. *Cortaderia jubata* is considered a major weed in California (McClintock 1985), since it has spread aggressively beyond disturbed urban areas into native vegetation and since it is difficult to eradicate or control once established. *C. jubata* occupies and holds space on a site making it difficult or impossible for native plants to reestablish (Pemberton 1985). It has spread along road cuts and slides in the Coast Ranges (Costas-Lippmann 1976) and on the Monterey Peninsula (Cowan 1976) where it has established in disturbed maritime chaparral (Griffin 1978). In Humboldt County, *C. jubata* has established on several thousand acres of cut-over redwood forest in sufficient density to choke out redwood seedlings (Kerbavaz 1985). Problems with *Cortaderia* are also reported in Santa Cruz (Libby 1979) and Sonoma (Kiner 1979) counties.

C. jubata is rated as a "C" pest by the California Department of Food and Agriculture indicating that it is sufficiently widespread that no quarantine action or eradication effort is being made except on a local basis (Fuller 1976). Apparently is is considered too widespread to control on a statewide basis.

Cortaderia jubata has established on various soil textures and in soils derived from a wide range of parent materials, including serpentine. Establishment is generally on bare areas of mineral soil or sometimes mineral soil mixed with organic matter. Soil pH in established stands ranges from 4.7 to 8.1, although in most cases it is near 6.0. The spread of *C. jubata* may be limited climatically since it is sensitive to frost and may require summer fog to limit moisture stress, particularly for seedling establishment. *C. selloana* is killed by hard freezes (Powell and Whitcomb 1979).

Cortaderia selloana was introduced into New Zealand around 1880 where it was used for stock fodder, as a shelter plant, and for erosion control. *Cortaderia jubata* was an accidental introduction in New Zealand first identified in 1966 (New Zealand Forest Service 1985). Both have escaped from cultivation and become weed problems, particularly in plantation forestry (Forest Research Institute 1984, Gadgil et al. 1984). *Cortaderia selloana* is currently the more serious weed problem, as it is more widespread; however, *C. jubata* may be more aggressively spreading. Thousands of hectares of forest have been invaded; invasion usually follows clear-cutting and occurs before the development of a closed canopy. Suppression of young trees by *C. selloana* and/or *C. jubata* may make successful forest establishment impossible (Gadgil et al. 1984).

Cortaderia selloana and *C. jubata* both have been introduced into South Africa where they were planted as ornamentals and to stabilize mine dumps. *C. jubata* is spreading invasively in the Witwatersrand region (Robinson 1984). *C. jubata* is also reported to be spreading in Australia (J.A. Zabkiewicz, New Zealand Forest Research Institute, personal communication).

Cortaderia jubata has several characteristics that contribute to its weediness (Costas-Lippmann 1976). The species is strictly apomictic, that is, it produces seeds without fertilization by diploid parthenogenesis and the population consists of female plants only. Therefore, seed set is always 100%. All seeds produced by a single plant will have the same genotype (Costas-Lippmann 1979) and genetic variability in the population is low (Costas-Lippmann and Baker 1980). In contrast, *Cortaderia selloana* consists of two types of plants, female and hermaphrodite, pollination is required for seed formation, and seed set is about 50% (Costas-Lippmann 1976). This breeding system is known as gynodioecism.

Cortaderia jubata requires about 1 year to reach flowering size after establishment and typically flowers every year. *C. selloana* may require longer to reach flowering size and may not flower every year. The number of culms and the culm size of *C. jubata* increase for several years after flowering begins and then may decline; culm size and number are directly related to seed production since seed set is 100% (Costas-Lippmann 1976). One inflorescence may produce 1,000,000 seeds. Seeds of both are wind dispersed. The life span of *C. jubata* is apparently unknown but *C. selloana* clumps have survived for 40 years in botanical gardens (Costas-Lippmann

1976). *Cortaderia jubata* can also reproduce vegetatively by stolons, but this does not appear to occur frequently (Costas-Lippmann 1976).

Seedling establishment appears to be the most critical stage in the life history of *Cortaderia jubata*. Seeds of *C. jubata* have no dormancy and do not require overwintering or heat treatment to germinate (Costas-Lippmann 1976). In germination tests, Costas-Lippmann (1976) found that the greatest percent germination occurred with freshly collected seeds. Germination success declined with dry storage of seeds. Germination was better in the light than in the dark and better at 10°C than at 27°C. With an 8 hour photoperiod and a temperature of 10°C germination occurred within 2 weeks to 3 months of sowing of the seeds. With a 16 hour photoperiod, germination was more rapid. In New Zealand, the germination of *C. jubata* was found to be relatively unaffected over the temperature range of 6 to 30°C and did not require light (J.A. Zabkiewicz, personal communication). In tests with different soils, *C. jubata* and *C. selloana* both germinate in soils of sand, clay, and silt-loam textures and soils derived from serpentine but survive and grow well only in silt-loam soils. In California, however, seedlings of *C. jubata* are found much more frequently than those of *C. selloana* and in a wider range of sites (Costas-Lippmann 1976). Often seedling establishment occurs where seepage keeps the soil moist.

Status on Vandenberg Air Force Base

Material collected on Vandenberg appears to be *Cortaderia jubata* based on the differentiating characteristics given by Costas-Lippmann (1976). This is consistent with its aggressive weedy spread on the base. Major populations of *Cortaderia* occur around the airfield extending from the railroad tracks south along both sides of the runway and in adjacent areas. Populations occur elsewhere on the Burton Mesa and also on South Vandenberg. *Cortaderia* was well established on the Burton Mesa by 1975 (Coulombe and Cooper 1976). Many of the populations of *Cortaderia* on Vandenberg are in disturbed sites where bare mineral soil is available or are in spreading from sites into adjacent vegetation, particularly chaparral, in which there are openings and bare soil. Any activities that remove native vegetation and leave bare soil create an opportunity for invasion by *Cortaderia.* Burning, chaining, or disking chaparral or other vegetation may allow its spread into impacted areas. Once established, *C. jubata* is difficult to eliminate. Its response to fire has not been studied. Gadgil et al. (1984) report that *C. jubata* and *C. selloana* increase fire danger in New Zealand forest plantations due to the build up of dead foliage. A hot fire is required to kill the tussocks from which the grass grows.

Fortunately, *Cortaderia jubata* seeds do not appear to be long-lived. Given their rapid loss of viability, it is unlikely that they maintain seed banks in the soil, although this has not been studied. If *C. jubata* is eliminated from an area before it has flowered for that year, it is unlikely that viable seed will be present from the previous year. (Of course, seed could still disperse by wind into the site from other areas.) If *C. jubata* is eliminated from an area the year before it is scheduled to be burned, this will reduce the risk of invasion.

On Vandenberg, *Cortaderia jubata* appears to flower primarily in late summer and fall. Conditions for germination and seedling establishment probably exist only after the fall and winter rains.

Methods of Control

In New Zealand, several methods of control of *Cortaderia selloana* and *C. jubata* in forestry operations have been attempted. Cutting is reported to be labor intensive and provide only temporary control. Grazing of cattle in forest blocks infested by *Cortaderia* has been successful in controlling the grass but depends on the availability of cattle, fencing, water supply, and supplemental high-protein fodder.

Beef cattle are said to provide good control of pampas grass provided they are introduced early in the forestry rotation and graze the stand three to four times per year. A single grazing per year is ineffective in controlling pampas grass in New Zealand as is grazing by sheep and young cattle. Mature pampas grass is poor forage, but fresh regrowth is twice as nutritious as mature pampas grass (New Zealand Forest Service 1985). Sowing of other pasture plants, particularly nitrogen-fixing species, has been used to provide supplemental fodder and to establish a ground cover in recently cleared stands (Gadgil et al. 1984).

In the past, several herbicides have been used to control *Cortaderia* in forest plantations. Hexazinone (Velpar) applied at 6 kg/ha by aerial spraying was used frequently. However, hexazinone causes damage to trees and eliminates lupine regrowth on sandy soils. In sand dune forests, weed wiping using glyphosate (Roundup) in 12% solution and Knapsack spot treatments with 0.72% solutions of glyphosate are reported to be reasonably effective. Spot applications of other herbicides, including 2-4D plus paraquat, dalapon plus amitrole, and dalapon alone had variable success (Gadgil et al. 1984) and are no longer recommended (J.A. Zabkiewicz, personal communication).

Herbicide treatments currently recommended in New Zealand are given in Table 1. Besides hexazinone (Velpar) and glyphosate (Roundup), a recent herbicide more selective for grass is haloxyfopmethyl (Dow Chemical Company, marketed as Gallant in New Zealand) (J.A. Zabkiewicz, personal communication). The New Zealand Forest Research Institute has developed

Table 1. Current chemical control options for *Cortaderia jubata* used in New Zealand forestry operations (New Zealand Forest Service 1985).

Degree of Infestation	Before or After Planting	Method of Application	Size of Plants	Recommended Treatments
Light (widely scattered individuals)	Before	Knapsack pump	All (mixed sizes)	B, G
		Brushgun-and-hose (roadside cleanup)	"	C, J
		Helicopter spot treatment of inaccessible individuals	Large (only)	D, H
	After	Weedwiper	Small (less than 50 cm tall)	A
		Knapsack pump	"	B, F
		Spotgun	Medium (up to 20 cm diameter at base)	E
		Knapsack pump	"	E
		Knapsack pump	Large	B, G
Medium to heavy	Before	Broadcast aerial	All (mixed sizes)	D, I
	After	Weedwiper	Small (in planting lines)	A
		Knapsack pump	"	F
		Knapsack pump	Medium	B, G
		Knapsack pump	Large (off-line clumps)	B, G
		Broadcast aerial	All (mixed sizes)	I

<u>Treatments</u>

A. Roundup 1 l + water 2 l, wipe both ways.
B. Roundup 1 l + water 50 l, barely wet foliage.
C. Roundup 1 l + water 100 l, spray to wet but not to run off.
D. Roundup 12 l + water 188 l, apply at 200 l/ha.
E. Velpar-90 25 g/litre of water, apply to foliage and soil at 12 ml/clump (0.5m^2).
F. Velpar-90 25 g/litre of water, apply to foliage and soil at 16 ml/m^2 (=4 kg/ha).
G. Velpar-90 25 g/litre of water, apply to foliage and soil at 24 ml/m^2 (=6 kg/ha).
H. Velpar-90 6 kg + water 300 l, apply at 150 ml/5 m^2 (=300 l/ha).
I. Velpar-90 6 kg + water 300 l, apply at 300 l/ha.
J. Velpar-90 6 kg + water 2000 l, apply to foliage and soil at 200 ml/m^2.

<u>Notes</u>

1. Roundup is foliage-active only and rates depend largely on foliage area. Good coverage is necessary.
2. Velpar-L (liquid) can be used in place of Velpar-90, but the rates must be adjusted. Multiply the g or kg amounts above by 3.6 to get the equivalent amounts of Velpar-L in ml or l.
3. Velpar is mainly root-absorbed, and rates are related to ground area.
4. Velpar is selective for radiata pine but can cause tree damage on light, low-organic matter soils, especially in warmer weather. Minimizing foliar contact in the case of hand treatments can minimize risk.

application methods for using these herbicides including helicopter methods for spraying single clumps (Table 1).

Native species of *Cortaderia* in New Zealand are not a major weed problem but control has been needed on some sites. Aerial spraying of herbicides with crushing, burning, and grazing has been successful. In a pilot study, Rowe and O'Connor (1975) found that tetrapion at 6 and 12 kg/ha eliminated *Cortaderia fulvida* that was initially 20 to 40 cm in height within 7 months; plants that were initially 40 to 100 cm high were eliminated within 13 months by tetrapion at 9 and 12 kg/ha. Tetrapion also kills rhizomatous grasses including species of *Pennisetum*, *Agropyron*, *Cynodon*, and *Agrostis* (Rowe and O'Connor 1975).

No reports of biological control of *Cortaderia* other than by grazing are known. No specific insect pests or plant diseases have been identified. Biological control programs for weedy grasses have yet to be developed (Pemberton 1985).

Some control or eradication programs for *Cortaderia jubata* have been conducted in California. Cowan (1976) reported that small clumps could be dug out with a little effort. For large clumps, however, the entire root crown must be removed with a pick. Clumps can be killed by removing the foliage and pouring two gallons of diesel fuel on each crown without igniting. On the Monterey peninsula, spraying with amino triazole is said to have "fairly good" success in controlling *C. jubata* (Cowan 1976). The California Department of Transportation is removing *C. jubata* along state highways on the central coast (Fremontia 12 [4]: 19).

Recommendations

Given the status of *Cortaderia* on Vandenberg, only some control measures appear feasible. *Cortaderia* occurs on many sites that are too steep for mowing or are occupied in part by other vegetation, particularly chaparral. The large tussock growth form of *Cortaderia* may make difficult the use of equipment. While mowing, if timed correctly, could be used to reduce seed production of *Cortaderia*, it would not eliminate the grass. Removal of *Cortaderia* by hand digging would be possible but extremely labor-intensive and therefore probably prohibitively expensive. Grazing may be useful on some sites where *Cortaderia* occurs in existing pastures. Many *Cortaderia* sites are probably inappropriate for grazing. The effects of fire on *Cortaderia* have not been evaluated. It is unlikely that fire would be effective in eliminating the grass.

Herbicide treatment would appear to be required to control *Cortaderia* on Vandenberg. Several chemicals have been used in New Zealand, but Gadgil et al. (1984) stated that there was a need for a cheaper, selective herbicide. New Zealand researchers have achieved effective control of *Cortaderia* with hexazinone and glyphosate and have developed methods for applying these herbicides to the plant. Federal and state pesticide regulations and impacts on other vegetation would also have to be considered before beginning a herbicide treatment program. Widespread application of hexazinone is probably inappropriate on the sandy soils of the Burton Mesa where *Cortaderia* has frequently established since hexazinone is reported to damage other vegetation on sandy soils (Gadgil et al. 1984). Spot treatment of individual clumps of grass rather than widespread application of herbicide should be implemented.

Considerable expertise exists in the New Zealand Forest Research Institute on the control of *Cortaderia* (J.A. Zabkiewicz, personal communication). Consultation with them could be extremely useful in designing a control program.

If it is not currently feasible to eradicate *Cortaderia* on Vandenberg, steps could be taken to prevent or reduce its continued spread. *Cortaderia* frequently establishes on disturbed sites; therefore, disturbance of vegetation and soil should be minimized. Significant populations of *Cortaderia* occur along roadsides and cable routes, around gravel pits, and in other disturbed sites. If removal of native vegetation is necessary, revegetation should be accomplished before *Cortaderia* has a chance to establish in these sites. If planned sufficiently in advance, it would be possible to eliminate *Cortaderia* from the vicinity of a project before construction and thus reduce the seed source for new establishment.

Similarly, controlled burning of areas with *Cortaderia* should not be carried out until the grass is eliminated from the vicinity. This would reduce the seed source. Burning increases the bare ground in an area and may create a potential for *Cortaderia* to establish.

Gasoul crystallinum

Species Biology

Gasoul crystallinum (L.) Rotm. is an annual, succulent, prostrate herb; the surface of the plant is covered with saccate, unicellular trichomes filled with a water solution giving rise to the common name "crystalline ice plant" (Vivrette and Muller 1977). Synonyms include *Mesembryanthemum crystallinum* L. and *Crytophytum crystallinum* N.E.Br. (Munz 1974). *Gasoul* is included in the

Aizoaceae family by most authorities (Lawrence 1951, Cronquist 1981) or in the Mesembryanthemaceae if the Aizoaceae is subdivided.

Gasoul crystallinum (hereafter designated *Gasoul* unless otherwise noted) is native to the west coast of southern Africa. It was introduced long ago into the eastern Mediterranean (Kloot 1983) where it naturalized (Winter et al. 1978). In South Australia, *Gasoul* was introduced in 1851, escaped by 1879, and has since spread (Kloot 1983). *Gasoul* was widespread in California by the 1890s (Moran 1950). Its current range is from Monterey, California, south into Baja California, including most of the California Channel islands (Vivrette and Muller 1977). *Gasoul* was present on the Channel islands between San Miguel and Natividad with the exception of Anacapa and San Nicolas by 1900 (Philbrick 1972). It is also found on the west coast of Chile.

Sites occupied by *Gasoul* in California are typically along the upper edge of the coastal bluffs. With some disturbance, however, *Gasoul* will invade other sites, including road cuts and railroad banks along the central coast of California, campsites and trails in coastal San Diego County, and agricultural fields in the coastal plain of Baja California (Vivrette and Muller 1977). In California, *Gasoul* occurs near the coast; this is also the case in Israel (Winter et al. 1978). However, in South Australia, *Gasoul* occurs well inland where it has become a weed problem in cereal crops and pastures (Kloot 1983). Expansion of *Gasoul* on Santa Barbara Island (Philbrick 1972) followed overgrazing by rabbits; invasion on Guadalupe Island followed goat grazing (Vivrette and Muller 1977). On Santa Barbara Island, *Gasoul* came to dominate much of the island when it was denuded by rabbit grazing in the 1950s; it replaced native species including *Coreopsis*, *Suaeda*, *Dudleya*, and *Calystegia* (Philbrick 1972).

In California, *Gasoul* germinates with the first rains in the fall and with subsequent rains or heavy fogs. Vegetative growth continues until spring. Flowering occurs from March to June and fruiting from June to August. The plant gradually dries from the base upward. Most plants die in the summer. Dried plants remain in place several years and decompose slowly. Mature fruits open with rain or fog, release seed, and then close up as they dry; this process repeats with subsequent rains, until the fruit ruptures (Vivrette and Muller 1977). The life cycle in Israel is similar (Winter et al. 1978).

When soil moisture is high, *Gasoul* grows by standard C_3 photosynthesis. As soil moisture declines in the dry season, the plant switches to another photosynthetic pathway, crassulacean acid metabolism (CAM) (Winter et al. 1978, Bloom and Troughton 1979). This "inducible CAM metabolism" can be triggered by other mechanisms that increase water stress including growth in cooled nutrient solutions that reduce water absorption by plants (Winter 1974), highly saline conditions produced by several salts (Winter 1974, Heun et al. 1981), decreased water potential (von Willert 1975), and closure of the stomates produced by ouabain (Van Zyl et al. 1974). It is generally thought that water stress and not salinity per se is responsible for the switch to CAM metabolism (Osmond et al. 1982).

Crassulacean acid metabolism is a variant of standard photosynthesis in which the stomates of the plant open primarily at night allowing carbon dioxide to be fixed as malic acid and then converted to carbohydrates by standard photosynthesis in the day. CAM achieves superior water economy since the stomates are only open at night when temperatures and water potential differences are lower (Osmond et al. 1982). CAM is also more efficient in its requirements for nitrogen and may confer some advantages in nitrogen deficient sites. These advantages of CAM are offset by limits to carbon fixation imposed by limits on the storage of malic acid at night (Osmond et al. 1982). CAM occurs in about 20 families of vascular plants. Some plants, particularly stem succulents, employ CAM throughout their life cycle; others, including many leaf succulents, switch to CAM under water stress (Osmond et al. 1982). Preferred habitats for CAM plants are semi-arid regions with seasonal rainfall, coastal fog deserts, and perhaps epiphytic habitats in tropical rain forests (Osmond et al. 1982). CAM is widespread in the Mesembryanthemaceae and is often associated with halophilism (von Willert et al. 1977). CAM conveys an advantage to *Gasoul* in that it allows productivity to continue into the dry season (Bloom and Troughton 1979, Osmond et al. 1982) when the annual grasses die back.

Vivrette and Muller (1977) describe the process by which *Gasoul* invaded a site near Surf on Vandenberg. The site was a coastal grassland with scattered shrubs of *Haplopappus squarrosus* and *Coreopsis gigantea* in a matrix of annual grasses. *Gasoul* was initially associated with ground squirrel mounds. Within three years, it expanded in area occupied three-fold into the annual grassland. *Gasoul* expanded in the wet winters of 1970-71 and 1972-73, but in the dry winter of 1971-72 plants were smaller and mainly within the confines of older plants.

Fewer seedlings of annual grassland species established under *Gasoul* than under the adjacent annual grassland. Of the annual grassland species that established, fewer survived and flowered under *Gasoul*. The reduction in grassland species was greatest under newly dried *Gasoul*. In contrast, more seedlings of *Gasoul* established and survived under old *Gasoul*. *Gasoul* germinated in the grassland but seldom survived; however, it both germinated and survived under old *Gasoul* (Vivrette and Muller 1977). Bloom and

Troughton (1979) showed that *Gasoul* grew poorly under low light conditions and could be shaded out by annual grasses.

Once established, *Gasoul* develops a deeper root system than the annual grasses with a tap root extending to 60 cm and secondary roots below 20 cm. Roots of spring-flowering grassland species are concentrated within the top 20 cm of soil (Vivrette and Muller 1977).

Vivrette and Muller (1977) found that trichomes on *Gasoul* accumulate salt (NaCl) as the plant grew. Concentrations increased from 500 mosmol during vegetative growth, to 1000 mosmol at flowering, to 1400-1750 mosmol at fruiting. Leachate from newly dried *Gasoul* was 400 mosmol while that from one-year-old plants was 35 mosmol. Salt was leached by rain and by fog drip. Soil accumulations of salt were greatest under newly dried plants and declined with subsequent rains. Salt was more quickly leached from sandy soils than from clay soils. The leachate from dried *Gasoul* inhibited germination and growth of grassland species. The inhibition was greatest from material from newly dried *Gasoul* and was caused by salt in the leachate.

Kloot (1983) showed that *Gasoul* accumulated salt when grown in non-saline as well as saline soils and in inland areas not receiving salt spray. Salt leached from dead plants reduced the establishment and growth of *Medicago.*

Vivrette and Muller (1977) found that salt levels in the soil of 150 mosmol reduced the growth of *Festuca* and *Bromus*, but *Gasoul* could grow at 250 mosmol. Some grasses would germinate at salinities to 400 mosmol but would not grow. Salt released from the dead plants of *Gasoul* creates conditions that favor the establishment of *Gasoul* seedlings and limit the establishment of annual grassland plants. Vivrette and Muller (1977) termed this osmotic interference to differentiate it from allelopathy where organic compounds released from plants inhibit other species. The invasion of *Gasoul* may be cyclical. Wet years favor larger animal populations that, in turn, cause greater disturbance by burrowing, digging, grazing, etc., favoring greater establishment of *Gasoul* in the subsequent year. Release of salts retards the invasion of grassland species into areas occupied by *Gasoul*. Heavy rains early in the season would leach salts, particularly from sandy soil, and reduce or eliminate the advantage to *Gasoul* (Vivrette and Muller 1977).

Gasoul is grazed by mice and rabbits but only when other plants are not available (Philbrick 1972, Vivrette and Muller 1977).

Status on Vandenberg Air Force Base

Gasoul occurs primarily along the coastal bluffs and in the adjacent annual grassland on Vandenberg (Vivrette and Muller 1977). It occasionally occurs on other sites such as roadsides and in the saltmarsh along the Santa Ynez River (personal observation). *Gasoul* does not appear to be as invasive on Vandenberg as *Carpobrotus* or *Cortaderia* and has not come to dominate extensive areas the way it did on Santa Barbara Island (Philbrick 1972). Vivrette and Muller (1977) demonstrated that *Gasoul* does have the capability to expand rapidly in coastal areas.

Methods of Control

There is limited information on controlling *Gasoul*. No insect pests or plant diseases have been reported; thus, there are no known prospects for biological control. *Gasoul* is grazed by mice and rabbits but only when other food is not available. Extensive animal activity tends to create openings for new establishment. *Gasoul* is tolerant of phenoxy-herbicides (Kloot 1983). Methods for controlling *Gasoul* in cereal crops in South Australia have been developed (P.M. Kloot, South Australian Department of Agriculture, personal communication). A number of herbicides are used depending on the stage of the crop (Table 2). It should be noted that these herbicide recommendations are for use in grain crops (e.g., barley) and not in natural communities invaded by the plant. Kloot (1983) points out that it is not enough to kill *Gasoul* since salt leaching from dead plants will limit other plant species' establishment. Therefore, it is also necessary to remove the plant residues which then become a disposal problem. Kloot (1983) recommends using early post-emergence herbicides in grain crops to remove direct competition and stop salt accumulation as early as possible. Use of herbicides in mixed communities containing native species and *Gasoul* would have to be evaluated before it was adopted as a management strategy.

Gasoul does depend on disturbance to become established and requires bare ground for successful invasion. Erosion of the coastal cliffs is a natural occurrence and can be expected to provide a continuing source of potential sites for *Gasoul* establishment. However, other disturbance to areas where *Gasoul* populations occur could be limited to reduce the number of potential sites for *Gasoul* establishment. Possible strategies include limiting construction activity, where possible, in the coastal areas and insuring that construction sites are promptly revegetated to eliminate potential sites for *Gasoul* establishment. Range management in the coastal zone should take into account potential interactions of grazing with Gasoul establishment; management should reduce direct soil disturbance from over-grazing and maintain taller grass. This could have two benefits; one is reducing the soil disturbance from cattle that may create openings for *Gasoul* establishment; the second is that taller grass would be less favorable to ground squirrels, whose mounds are known to be establishment sites for *Gasoul*.

Table 2. Herbicides used to control *Gasoul crystallinum* in cereal crops in South Australia (Plant Protection Agronomists 1986).

Herbicide	Crop Stage	Application Rate	Remarks
GLEAN 750g/kg chlorsulfuron	Pre-Sowing	15g	Do not use on soils above pH 8.5. Only use 20g on heavy soil, or light soils where pH<7.0. Apply prior to planting or in conjunction with seeding. Do not apply to ridged or cloddy soils. Use low profile 10 cm combine point and light harrows at sowing. Can tank mix with Avadex BW®. Use the higher rate if a high weed population is expected and on soil pH less than 7.0. WARNING: Clean equipment as per label.
SENCORT 560g/kg methabenzthiazuron 140g/kg metribuzin	Early Post-Emergent	750g	Works best when applied to moist soil surface. Do not apply later than 6 weeks after seeding. Sow at 5-7 cm. Do not spray if rain is likely within 12 hours.
TRIBUNIL 700g/kg methabenzthiazuron	Early Post-Emergent	850g	Do not spray if rain is likely within 12 hours. Use lower rates within 3 weeks of seeding and higher rates within 3-5 weeks of seeding. Should not be used on spring-sown barley as severe yellowing may occur.
GLEAN 750g/kg chlorsulfuron	Early Post-Emergent	15g*	Do not use on soils with pH above 8.5. Needs addition of wetting agent (see label). Apply to young actively growing weeds. For ryegrass apply not later than 3 leaf stage. *Barley*- On light soils (sands and sandy loams) of pH 7.0-8.5, use delay until start of tillering. WARNING: Clean equipment as per label.
DIURON POWDERS 800g/kg	Early Post-Emergent	500g	Do not use on very sandy soils, or soils liable to drift. Do not apply to dew covered crops. Sow at 5 cm (especially oats). Use 50 mesh filters or coarser and have good tank agitation. Variety *Galleon* - Do not exceed 850g.
DIURON LIQUIDS 500g/L	Early Post-Emergent	850mL**	Do not use on very light sandy soils, or soils liable to drift. Do not apply to dew covered crops. Sow at 5 cm (especially oats). Have good tank agitation. Variety *Galleon* - Do not exceed 1.3L.

Table 2. (continued)

Herbicide	Crop Stage	Application Rate	Remarks
MECOBAN 640 600g/L MCPP 40g/L dicamba	Crop Tillering	2.0L	Do not use on late sown barley. If season conditions are unusually dry, or season is late, seek advice on timing. Do not spray if rain is likely within 4 hours.
BROMOXYNIL/ DICAMBA/ MCPA MIXTURES 200g/L MCPA ester 140g/L bromoxynil 40g/L dicamba	Crop Tillering	1.0L*	Do not spray when crop is under stress. Do not spray if rain is likely within 3 hours. Rate depends on weed stage (see label).
DICAMBA/MCPA MIXTURES 300-340g/L MCPA exceed 80g/L bromoxynil	Crop Tillering	1.0L	Do not use on late sown barley. If seasonal conditions are unusually dry, or season is late, seek advice on timing. Do not spray if rain is threatening. Do not 1.0L/ha for barley. Older weeds may require higher rates (see label).
DICAMBA 200g/L	Crop Tillering	550mL***	Do not exceed maximum recommended rate. If 2, 4-D or MCPA is added, remarks in dicamba MCPA mixture column apply. Do not spray if rain is threatening. Rates can vary according to crop growth stage, weed problem and weed stage (see label).
2,4-D AMINE 500g/L	Crop Tillering	1.4L	Do not spray if rain is threatening. Safer for crop spraying than 2,4-D ester.

* **Rate suggested based on limited trials.**

** **500mLof 500g/L diuron per ha plus 350mL of 500g/L amine MCPA per ha will control *Gasoul.***

*** **Add 500mL of 500g/L amine MCPA per ha to dicamba to control *Gasoul.***

Note: After 6 leaf stage, DICAMBA/MCPA mixture is recommended.

If there are sites of particular concern in the coastal zone that are threatened by *Gasoul* invasion, a possible course of action would be to remove *Gasoul* plants from the area by hand while they are still green and before they have released seed. While this would be labor intensive, it would avoid unintended effects of herbicide use. This process would probably have to be repeated for several years since *Gasoul* seed does persist in the soil (Carla D'Antonio, personal communication).

Recommendations

There is no one simple method for controlling *Gasoul* on Vandenberg. Herbicides used in Australia to control it in cereal crops would have to be evaluated for their use in mixed species communities on Vandenberg. Certain herbicides might be appropriate for use on pure stands of *Gasoul*, if such areas could be identified.

Limiting disturbance in the coastal zone would be useful in reducing potential sites for *Gasoul* invasion. This could be accomplished by limiting construction, requiring prompt revegetation, and appropriate range management.

For high priority sites, removal of *Gasoul* by hand while it is still green and has not released seed or begun leaching salt could be an effective control.

Other Exotic Species of Concern

There are many introduced taxa in the flora of Vandenberg. Some occur only in disturbed habitats and show little propensity to invade undisturbed vegetation. Others are so completely naturalized that it would not be feasible to control or eradicate them. However, several taxa that field observations or information from others suggest may be of concern are discussed below.

Conicosia pugioniformis (L.) N.E. Br. (*Herrea elongata* [Haw.] L. Bolus, *Conicosia elongata* Schwant., *Mesembryanthemum elongatum* Haw., *Mesembryanthemum pugioniforme* DC.) is a decumbent, perennial, succulent herb in the Aizoaceae family related to *Carpobrotus* and *Gasoul* (Munz 1974, Smith 1976). *Conicosia* was introduced from South Africa and is becoming naturalized from Santa Barbara County north (Munz 1974). Smith (1976) gave its range in Santa Barbara County as "...scattered on sandy slopes about coastal sage scrub from Canada Honda Creek to Surf, Burton Mesa, northwest of Lompoc, and Oso Flaco Lake area to dunes south of Oceano." It is widespread on Vandenberg (Carla D'Antonio, personal communication). *Conicosia* frequently invades Burton Mesa chaparral following fire (Hickson 1987 a, b); it may also require at least minor soil disturbance (Hickson 1987b). Since it is wind-dispersed rather than animal-dispersed it may invade sites where there is no adjacent seed source. *Conicosia* is also invading revegetation sites along the Union Oil pipeline (Carla D'Antonio, personal communication). It produces dense mats of vegetation which exclude native plants. It forms a large, fleshy taproot that is difficult to pull up and from which it can sprout (Carla D'Antonio, personal communication). Thus, *Conicosia* may displace native species after either fire or mechanical disturbance. It is not affected by scale insects (Washburn and Frankie 1985).

Ehrharta calycina J.E. Smith (veldt grass) (Poaceae: Phlarideae) is an erect, perennial grass native to South Africa (Hitchcock and Chase 1950). It was introduced as a drought resistant species for non-irrigated range lands (Hitchcock and Chase 1950). On Vandenberg, it was planted for erosion control (Peters and Sciandrone 1964) and probably also for range improvement (Richard Nichols, personal communication). *Ehrharta* appears to be well established in the area planted for erosion control, along roadsides, and on fire breaks. It also invades coastal dune scrub and chaparral on Vandenberg (personal observation). *Ehrharta* is invading many areas along the Unocal pipeling right of way (Carla D'Antonio, personal communication). Smith (1976) indicates that it "...should never be sowed on potential parkland or in areas where the native flora is to be preserved...." Dense stands of *Ehrharta* contain little native vegetation (Carla D'Antonio, personal communication).

Erechtites glomerata (Poir.) DC. (*Erechtites arguta* [A. Rich] DC.) (Asteraceae) is an annual or short-lived perennial weed of Australasian origin (Munz and Keck 1968, Smith 1976). It was observed in several locations on Vandenberg during this study including a mesic slope on serpentine on South Vandenberg, a roadside along Arguello Boulevard at Santa Ynez Ridge Road, and around Punchbowl Lake. *Erechtites glomerata* is well established on San Miguel Island. The National Park Service began an eradicaction program in 1985 (Steve Junak, Santa Barbara Botanical Garden, personal communication). The plant is very aggressive and does not appear to require disturbance for establishment. It appears to form a substantial seed bank and eradication efforts so far have been unsuccessful (Carla D'Antonio, personal communication). The species has the potential to become a problem on Vandenberg.

Acacia longifolia (Andrews) Willd. (Fabaceae) (golden wattle) is a shrub to small tree native to Australia (Munz 1974, Smith 1976). Smith (1976) states that it was planted on arrested dunes north of Canada Honda Creek for dune stabilization and has now naturalized. *Acacia* species have developed into weed problems elsewhere in California (Libby 1979) and are among the species targeted for removal from state parks (Hillyard 1985). It is not presently clear whether *A. longifolia* represents a significant management problem on Vandenberg.

Eucalyptus globulus Labill. (Myrtaceae) (blue gum) is an Australian tree commonly planted in the coastal region of Santa Barbara County (Smith 1976). Seedlings occur about the plantings and can mature into trees (Smith 1976). Negative impacts on the native flora occur when they spread from plantings; spreading appears to be limited on Vandenberg.. *Eucalyptus* excludes most other plants due to the characteristics of the litter produced (Boyd 1985) and allelopathic effects (Smith 1976). *Eucalyptus* is also a fire hazard because of the high flammability of the litter. However, the trees also provide roosts for birds and Monarch butterflies (Smith 1976). Since *Eucalyptus* blooms in the winter, it provides a food source not previously available and is thought to be responsible for the overwintering of several birds previously thought to leave the state at that time (Lehman 1982). Therefore, the elimination of *Eucalyptus* basewide is not recommended. If they represent a threat to a particular sensitive plant habitat, then control should be in that area only.

General Characteristics of Invasive Species on Vandenberg

Baker (1986) lists seven generalizations regarding successful invasive plants. These are:

1. The climate of the source and reception area must be similar.
2. Life forms of the vegetation should be similiar.
3. Soils should not be significantly different.
4. The invader should have a generalized pollination system (wind, generalized insect, or self-pollination).
5. There should be a seed dispersal system appropriate not only to bring the immigrant to the new area but to disperse it within the new habitat.
6. The breeding system is important; it should allow seed reproduction while providing for genetic recombination.

7. Vegetative reproduction helps in the invasion of communities where very few of the native species reproduce frequently by seed.

Several of the successful invasive species on Vandenberg including *Carpobrotus edulis*, *Conicosia pugioniformis*, *Gasoul crystallinum*, and *Ehrharta calycina* originate from South Africa where there are regions with Mediterranean climate, sclerophyllous shrublands (fynbos), and acidic sandy soils of low nutrient status (Kruger 1977, Stock and Lewis 1986). *Ammophila arenaria* occurs in various climates in its native range (Huiskes 1979a). On the Pacific coast, it spreads aggressively in the northern part of its range where rainfall is greater and water stress is less. Sand dunes are similar substrates for plant growth throughout the world. The climate in the Andes where *Cortaderia jubata* originates is not a Mediterranean climate like that of central California. *C. jubata* frequently occurs along streamsides in the Andes; in California its establishment appears limited by moisture availability.

None of the significant invasive species on Vandenberg have specialized pollination systems. *Ammophila* and *Ehrharta* are wind pollinated; *Cortaderia* is apomictic. *Carpobrotus*, *Conicosia,* and *Gasoul* appear to have generalized insect pollinators (personal observation); they may also be self-fertile.

Ammophila (Huiskes 1979a),*Cortaderia* (Costas-Lippmann 1976), *Conicosia* (Hickson 1987a), and probably *Ehrharta* are wind-dispersed. *Carpobrotus* is animal-dispersed (Carla D'Antonio, personal communication). Seeds of *Gasoul* fall mainly under the parent plant but do disperse into adjacent areas via the wind. Seed production by *Cortaderia* (Costas-Lippmann 1976), *Carpobrotus* (Zedler and Scheid 1987), and *Conicosia* (personal observation) appears to be particularly high. *Cortaderia* is strictly apomictic (Costas-Lippmann 1976) with no genetic recombination but is a successful invasive plant. It does have some limitations in that it is climatically restricted to coastal areas and does not invade closed grassland; these may be related to its lack of variability (Baker 1986). *Ammophila* seldom establishes from seed; whether it does so at all on Vandenberg is not known.

Vegetative reproduction is the main mode of reproduction in *Ammophila* and is important in *Carpobrotus.*

Several of these invasive plants have features that limit native species from reestablishing. *Gasoul* creates saline soil beneath it that limits germination and survival of grassland species. *Ammophila, Carpobrotus*, and *Conicosia* maintain dense stands that prevent seedlings of other plants from establishing. *Cortaderia* clumps also dominate areas where established even if openings are present between clumps.

Thus, several of the important invasive species on Vandenberg have many of the general traits of successful invasive plants.

Conclusions and Recommendations

1. *Ammophila arenaria* is well established on Vandenberg where it was planted for dune stabilization, and it precludes the reestablishment of native dune flora in these areas. It is not clear from current information whether *Ammophila* is expanding into undisturbed dunes. Techniques for controlling or eliminating *Ammophila* are not well developed; several herbicides and possibly treatment with salt have some potential. Before a control program is initiated, it should be determined if *Ammophila* is spreading from the original plantings. A control program, if initiated, should begin as an experimental program to determine effective techniques. It will be important to reestablish native dune flora as *Ammophila* is eliminated to prevent dune erosion.

2. *Carpobrotus edulis* is well established on Vandenberg along roadsides and in disturbed areas; it has spread into coastal dune scrub, coastal sage scrub, grassland, and chaparral communities. Fire encourages the spread of *Carpobrotus*. Pathogens and scale insects exist that attack *C. edulis*, but the potential for a biological control program is low because of the extensive use of *Carpobrotus* in landscaping. Effectiveness of herbicides in controlling *Carpobrotus* is not established. Currently, there is insufficient information to design a complete control program. Prescribed burning programs, particularly in the Burton Mesa chaparral, should be modified to avoid burning areas where *Carpobrotus* is established and fire will be likely to encourage its spread. If fuel hazards and proximity to facilities require that areas be burned, post-fire weeding should be attempted to reduce the populations of exotic plants to reduce the populations of exotic plants on the site. Monitoring will be required to determine the effectiveness of weeding on a long term basis. Research is needed to understand the interactions of fire with *Carpobrotus* and other exotics.

3. *Cortaderia jubata* occurs along roadsides and powerlines and in other sites where natural vegetation and soil have been mechanically disturbed. From these sites *Cortaderia* has spread into native vegetation, particularly chaparral, where there are openings and bare soil. Seedling establishment requires mineral soil and moist conditions. Techniques for controlling *Cortaderia* are best developed in New Zealand where it is a major pest in forestry operations. Grazing is effective under some conditions in controlling *Cortaderia*. Roundup (glyphosate) and Velpar (hexazinone) are the herbicides most effective against *Cortaderia*, but hexazinone may damage other vegetation on sandy soils. Eradication of *Cortaderia* on Vandenberg would require herbicides use, probably by spot treatment of individual clumps.

Consultation with New Zealand researchers would be valuable in designing a control program. The spread of *Cortaderia* might be limited by reducing disturbance to vegetation and soil and eliminating *Cortaderia* from the vicinity of construction sites before soil disturbances. Prescribed burning may also increase the potential for *Cortaderia* to spread; *Cortaderia* should be eliminated from areas to be burned in advance of the fire to reduce seed dispersal into these sites.

4. *Gasoul crystallinum* occurs primarily along coastal bluffs and adjacent annual grasslands on Vandenberg. *Gasoul* does not appear to be as invasive as the other three taxa but does have the capacity to expand into coastal grassland areas. *Gasoul* requires soil disturbance for initial establishment. It excludes other species by osmotic interference; salt accumulates in the living plant and leaches after it dies creating soil salinities in which competing species cannot survive. Several herbicides are used to control *Gasoul* in cereal crops in South Australia, but their suitability for use in natural communities has not been determined. In any control program, dead plant material of *Gasoul* would have to be removed from the site to prevent salt accumulation in the soil. Limiting soil disturbance from construction and grazing in the coastal zone could be useful in limiting the spread of *Gasoul.* Removing *Gasoul* by hand while the plant is still green and has not released seeds or leached salts could be an effective control for high priority sites.

5. *Conicosia pugioniformis* appears to be the most significant additional exotic plant on Vandenberg not covered in the literature review. It is invading disturbed areas, coastal dune areas, coastal dune scrub, coastal sage scrub, and chaparral. Both fire and soil disturbance encourage its establishment. As a wind-dispersed species it may become a significant threat to the native flora. *Ehrharta calycina*, once planted for erosion control, also invades disturbed sites

and some native vegetation and should not be planted in the future. *Erechtites glomerata* has become a significant weed problem on San Miguel Island. It occurs on Vandenberg and has the potential to become a more serious problem.

Literature Cited

Abdel Wahab, A.M. 1975. Nitrogen fixation by *Bacillus* strains isolated from the rhizosphere of *Ammophila arenaria*. Plant and Soil 42: 703-708.

Abdel Wahab, A.M. and P.F. Wareing. 1980. Nitrogenase activity associated with the rhizosphere of *Ammophila arenaria* L. and effect of inoculation of seedlings with *Azotobacter*. New Phytologist 84: 711-721.

Ayyad, M.A. 1973. Vegetation and environment of the western Mediterranean coastal land of Egypt. Journal of Ecology 61: 509-523.

Baker, H.G. 1986. Patterns of plant invasion in North America. Pp. 44-57. In: H.A. Mooney and J.A. Drake (eds.). Ecology of biological invasions of North America and Hawaii. Springer-Verlag. New York.

Barbour, M.G. and A.F. Johnson. 1977. Beach and dune. Pp. 223-261. In: M.G. Barbour and J. Major (eds.). Terrestrial vegetation of California. John Wiley & Sons, New York.

Barbour, M.G., T.M. DeJong, and A.F. Johnson. 1976. Synecology of beach vegetation along the Pacific coast of the United States of America: a first approximation. Journal of Biogeography 3: 55-69.

Barbour, M.G. and R.H. Robinchaux. 1976. Beach phytomass along the California coast. Bulletin of the Torrey Botanical Club 103: 16-20.

Bloom, A.J. and J.H. Troughton. 1979. High productivity and photosynthetic flexibility in a CAM plant. Oecologia (Berlin) 38: 35-43.

Boorman, L.A. and R.M. Fuller. 1977. Studies on the impact of paths on the dune vegetation at Winterton, Norfolk, England. Biological Conservation 12: 203-216.

Boyd, D. 1985. Eucalyptus. Fremontia 12 (4): 19-20.

Campbell, W.V. and C.A. Fuzy. 1972. Survey of the scale insect effect on American beachgrass. Shore and Beach 40: 18-19.

Chapman, V.J. 1976. Coastal vegetation (second edition). Pergamon Press. New York. 292 pp.

Collins, L. and J.K. Scott. 1982. Interaction of ants, predators, and the scale insect, *Pulvinariella mesembryanthemi*, on *Carpobrotus edulis*, an exotic plant naturalized in Western Australia. Australian Entomological Magazine 8(5): 73-78.

Connor, H.E. 1971. A naturalized *Cortaderia* in California. Madrono 21: 39-40.

Connor, H.E. 1973. Breeding systems in *Cortaderia* (Gramineae). Evolution 27: 663-678.

Connor, H.E. 1983. Names and types in *Cortaderia* Stapf (Gramineae) II. Taxon 32: 633-634.

Connor, H.E. and E. Edgar. 1974. Names and types in *Cortaderia* Stapf (Gramineae). Taxon 23: 595-605.

Cooper, W.S. 1967. Coastal dunes of California. Geological Society of America Memoir 104. Denver, Colorado. 131pp.

Costas-Lippmann, M.A. 1976. Ecology and reproductive biology of the genus *Cortaderia* in California. Ph.D. Dissertation. University of California, Berkeley. 365pp.

Costas-Lippmann, M. 1979. Embryogeny of *Cortaderia selloana* and *C. jubata* (Gramineae). Botanical Gazette 140: 393-397.

Costas-Lippmann, M. and I. Baker. 1980. Isozyme variability in *Cortaderia selloana* and isozyme constancy in *C. jubata* (Poaceae). Madrono 27: 186-187.

Coulombe, H.N. and C.F. Cooper. 1976. Ecological assessment of Vandenberg Air Force Base, California. Vol. I. Evaluation and recommendations. AFCEC TR-76-15. Air Force Civil Engineering Center. Tyndall Air Force Base, Florida. 187pp.

Cowan, B.D. 1975. Protecting and restoring native dune plants. Fremontia 3(2) 3-7.

Cowan, B.D. 1976. The menace of pampas grass. Fremontia (July): 14-16.

Cronquist, A. 1981. An integrated system of classification of flowering plants. Columbia University Press. New York. 1262pp.

D'Antonio, C.M. 1987. Interference and preemption in three coastal plant assemblages. Bulletin of the Ecological Society of America 68: 289.

DeJong, T.M. 1979. Water and salinity relations of California beach species. Journal of Ecology 67: 647-663.

Dolan, R., and P.J. Godfrey, and W.E. Odum. 1973. Man's impact on the barrier islands of North Carolina. American Scientist 61: 152-162.

Eldred, R.A. and M.A. Maun. 1982. A multivariate approach to the problem of the decline in vigour of *Ammophila*. Canadian Journal of Botany 60: 1371-1380.

Ferren, W.R., Jr., H.C. Forbes, D.A. Roberts, and D.M. Smith. 1984. The botanical resources of La Purisima Mission State Historic Park, Santa

Barbara County, California. Publication No. 3. The Herbarium, Department of Biological Sciences, University of California, Santa Barbara. 159pp.

Forest Research Institute. 1984. Pampas-recognition of a new forest weed problem. What's New in Forest Research No. 128. Forest Research Institute, Rotorua, New Zealand.

Fuller, T.C. 1976. Its (pampas grass) history as a weed. Fremontia (July): 16.

Gadgil, R.L. 1971. The nutritional role of *Lupinus arboreus* in coastal sand dune forestry. I. The potential influence of undamaged lupin plants on nitrogen uptake by *Pinus radiata*. Plant and Soil 34: 357-367.

Gadgil, R.L. 1979. The nutritional role of *Lupinus arboreus* in coastal sand dune forestry. IV. Nitrogen distribution in the ecosystem for the first 5 years after tree planting. New Zealand Journal of Forestry Science 9: 324-336.

Gadgil, R.L., A.L. Knowles, and J.A. Zabkiewisz. 1984. Pampas - A new forest weed problem. Pp. 187-190. In: Proceedings 37th New Zealand Weed and Pest Control Conference.

Gill, R.J. 1979. A new species of *Pulvinaria* Targioni-Tozzetti (Homoptera: Coccidae) attacking iceplant in California. Pan-Pacific Entomologist 55: 241-250.

Godfrey, PJ. and M.M. Godfrey. 1974. An ecological approach to dune management in the National Recreation Areas of the United States East Coast. International Journal of Biometeorology 18: 101-110.

Goldsmith, V. 1973. Internal geometry and origin of vegetated coastal sand dunes. Journal of Sedimentary Petrology 43: 1128-1142.

Gray, A.J. 1985. Adaptation in perennial coastal plants - with particular reference to heritable variation in *Puccinellia maritima* and *Ammophila arenaria*. Vegetation 61: 179-188.

Greig-Smith, P. 1961. Data on pattern within plant communities. II. *Ammophila arenaria* (L.) Link. Journal of Ecology 49: 703-708.

Griffin, J.R. 1978. Maritime chaparral and endemic shrubs of the Monterey Bay region, California. Madrono 25: 65-81.

Heady, H.F. 1977. Valley grassland. Pp. 491-514. In: M.G. Barbour and J. Major (eds.). Terrestrial vegetation of California. John Wiley & Sons, New York.

Hesp, P.A. 1981. The formation of shadow dunes. Journal of Sedimentary Petrology 51: 101-111.

Heun, A.M., J. Gorham, U. Luttge, and R.G. WynJones. 1981. Changes of water-relation characteristics and levels of organic cytoplasmic solutes during salinity induced transition of *Mesembryanthemum crystallinum* from C_3-photosynthesis to crassulacean acid metabolism. Oecologia (Berlin) 50: 66-72.

Hewett, D.G. 1970. The colonization of sand dunes after stabilization with marrum grass (*Ammophila arenaria*). Journal of Ecology 58: 653-668.

Hickson, D.E. 1987a. The role of fire and soil in the dynamics of Burton Mesa chaparral, Santa Barbara County, California. M.A. Thesis. University of California, Santa Barbara. 83pp.

Hickson, D.E. 1987b. History of wildland fires on Vandenberg Air Force Base, California. Draft NASA Technical Memorandum. (In preparation.)

Hield, H. and S. Hemstreet. 1974. Border growth control of iceplant with chlorflurenol sprays. Hortscience 9: 473-474.

Hillyard, D.S. 1985. Weed management in California's state park system. Fremontia 13(2): 18-19.

Hitchcock, A.S. and A. Chase. 1950. Manual of the grasses of the United States (second edition). U.S.D.A. Miscellaneous Publication No. 200. Washington, D.C. 1051pp.

Hobbs, R.J., C.H. Gimingham, and W.T. Band. 1983. The effects of planting technique on the growth of *Ammophila arenaria* (L.) Link and *Lymus arenarius* (L.) Hochst. Journal of Applied Ecology 20: 659-672.

Hoover, R.F. 1970. The vascular plants of San Luis Obispo County, California. University of California Press, Berkeley. 350pp.

Hope-Simpson, J.F. and R.L. Jefferies. 1966. Observations relating to vigour and debility in marram grass (*Ammophila arenaria* (L.) Link). Journal of Ecology 54: 271-274.

Huiskes, A.H.L. 1977. The natural establishment of *Ammophila arenaria* from seed. Oikos 29: 133-136.

Huiskes, A.H.L. 1979a. Biological flora of the British Isles: *Ammophila arenaria* (L.) Link. Journal of Ecology 67: 363-382.

Huiskes, A.H.L. 1979b. Damage to marram grass *Ammophila arenaria* by larvae of *Meromyza pratorum* (Diptera). Holarctic Ecology 2: 182-185.

Huiskes, A.H. L. 1980. The effects of habitat perturbation on leaf populations of *Ammophila arenaria* (L.) Link. Acta Botanica Neerlandica 29: 443-450.

Huiskes, A.H.L. and J.L. Harper. 1979. The demography of leaves and tillers of *Ammophila arenaria* in a dune sere. Oecologia Plantarum 14: 435-446.

Hylgaard, T. and M.J. Liddle. 1981. The effect of human trampling on a sand dune ecosystem dominated by *Empetrum nigrum.* Journal of Applied Ecology 18: 559-569.

Jacks, P., C. Scheidlinger, and P.H. Zedler. 1984. Response of *Eriodictyon capitatum* to prescribed fire on Vandenberg AFB, California. Report to U.S. Dept. of the Interior, Fish and Wildlife Service. Contract No. 11310-0263-81. 39pp.

Jackson, J.E. 1985. Ecological origins of California's Mediterranean grasses. Journal of Biogeography 12: 349-361.

Johnson, P.N. 1982. Naturalized plants in southwest South Island, New Zealand. New Zealand Journal of Botany 20: 131-142.

Kerbavaz, J.H. 1985. Pampas grass. Fremontia 12(4): 18-19.

Kiner, N. 1979. Sonoma County problems. Fremontia 6(4): 19.

Kloot, P.M. 1983. The role of common iceplant (*Mesembryanthemum crystallinum*) in the deterioration of medic pastures. Australian Journal of Ecology 8: 301-306.

Koller, C.S. 1978. Iceplant scale. University of California, Berkeley, Cooperative Extension Service Leaflet. p.3.

Kruger, F.J. 1977. Ecology of Cape fynbos in relation to fire. Pp. 230-244. In: H.A. Mooney and C.E. Conrad (technical coordinators). Symposium on the environmental consequence of fire and fuel management in Mediterranean ecosystems. U.S.D.A. Forest Service General Technical Report WO-3. Washington, D.C.

Laing, C.C. 1958. Studies in the ecology of *Ammophila breviligulate.* I. Seedling survival and its relation to population increase and dispersal. Botanical Gazette 119: 208-216.

Laing, C.C. 1965. The ecology of *Ammophila breviligulate.* II. Genetic change as a factor in population decline on stable dunes. American Midland Naturalist 77: 495-500.

Lawrence, G.H.M. 1951. Taxonomy of vascular plants. The MacMillan Company. New York. 823pp.

Lehman, P.E. 1982. The status and distribution of the birds of Santa Barbara County, California. M.A. Thesis. University of California, Santa Barbara. 365pp.

Libby, J. 1979. Acacia and pampas grass in Santa Cruz. Fremontia 6(4): 19-20.

Lockheed Dialog Information Retrieval Service. 1979. Guide to DIALOG searching. LMSC, Inc. Palo Alto, California.

Lucas, L.T., T.B. Warren, W.W. Woodhouse, Jr., and E.D. Seneca. 1971. *Marasmius* blight, a new disease of American beachgrass. Plant Disease Reporter 55: 582-585.

MacDonald, J.D., J.R. Hartman, J.D. Shapiro, and K. Reinke. 1983. Diseases of ice plant along California roadsides. Report FHWA/CA/UCD-83-1. California State Department of Transportation, Sacramento. 35pp.

MacDonald, J.D., J.R. Hartman, and J.D. Shapiro. 1984. Pathogens of ice plant in California. Plant Disease 68: 965-967.

Marshall, J.K. 1965. *Corynephorus canescens* (L.) P. Beauv. as a model for the *Ammophila* problem. Journal of Ecology 53: 447-463.

McAdam, J.H. 1980. Uncontrolled grazing and vegetation removal in the Falkland Islands. Environmental Conservation 7: 201-202.

McClintock, E. 1985. Escaped exotic weeds in California. Fremontia 12(4): 3-6.

Mooney, H.A., S.P. Hamburg, and J.A. Drake. 1986. The invasion of plants and animals into California. Pp. 250-272. In: H.A. Mooney and J.A. Drake (eds.). Ecology of biological invasions of North America and Hawaii. Springer-Verlag. New York.

Moran, R. 1950. *Mesembryanthemum* in California. Madrono 10: 161-163.

Munz, P.A. 1974. A flora of southern California. University of California Press, Berkeley. 1086pp.

Munz, P.A. and D.D. Keck. 1973. A California flora (with supplement by P.A. Munz). University of California Press, Berkeley. 1681 and 224pp.

New Zealand Forest Service. 1985. Pampas grass a weed of plantation forests. New Zealand Forest Service. Wellington.

Nicolson, T.H. and C. Johnston. 1979. Mycorrhizae in the Gramineae. III. *Glomus fasciculatus* as the endophyte of pioneer grasses in a maritime sand dune. Transactions of the British Mycological Society 72: 261-268.

Osmond, C.B., K. Winter, and H. Ziegler. 1982. Functional significance of different pathways of CO_2 fixation in photosynthesis. Pp. 479-547. In: O.L. Lange, P.S. Nobel, C.B. Osmond, and H. Ziegler (eds.). Plant physiological ecology. II. Water relations and carbon assimilation. Springer-Verlag. New York.

Page, R.R., S.G. daVinha, and A.D.Q. Agnew. 1985. The reaction of some sand-dune plant species to experimentally imposed environmental change: a reductionist approach to stability. Vegetation 61: 105-114.

Pavlik, B.M. 1983a. Nutrient and productivity relations of the dune grasses *Ammophila arenaria* and *Elymus mollis*. I. Blade photosynthesis and nitrogen use efficiency in the laboratory and field. Oecologia (Berlin) 57: 227-232.

Pavlik, B.M. 1983b. Nutrient and productivity relations of the dune grasses *Ammophila arenaria* and *Elymus mollis*. II. Growth and patterns of dry matter and nitrogen allocation as influenced by nitrogen supply. Oecologia (Berlin) 57: 233-238.

Pavlik, B.M. 1983c. Nutrient and productivity relations of the dune grasses *Ammophila arenaria* and *Elymus mollis*. III. Spatial aspects of clonal expansion with reference to rhizome growth and the dispersal of buds. Bulletin of the Torrey Botanical Club 110: 271-279.

Pavlik, B.M. 1984. Seasonal changes of the osmotic pressure, symplasmic water content and tissue elasticity in the blades of dune grasses growing in sites along the coast of Oregon. Plant, Cell and Environment 7: 531-539.

Pavlik, B.M. 1985. Water relations of the dune grasses *Ammophila arenaria* and *Elyumus mollis* on the coast of Oregon, USA. Oikos 45: 197-205.

Pemberton, R.W. 1985. Naturalized weeds and the prospects for their biological control in California. Fremontia 13(2): 3-9.

Peters, J. and J. Sciandrone. 1964. Stabilization of sand dunes at Vandenberg Air Force Base. Journal of the Soil Mechanics and Foundations Division, Proceedings of the American Society of Civil Engineers 90: 97-106.

Philbrick, R.N. 1972. The plants of Santa Barbara Island, California. Madrono 21:329-393.

Pitts, W.D. and M.G. Barbour. 1979. The microdistribution and feeding preferences of *Peromyscus manicultus* in the strand at Point Reyes National Seashore, California. American Midland Naturalist 101: 38-48.

Pizzey, J.M. 1975. Assessment of dune stabilization at Camber, Sussex, using air photographs. Biological Conservation 7: 275-288.

Plant Protection Agronomists. 1986. Cereal weed spraying guide. Department of Agriculture, South Australia.

Powell, A. and C.E. Whitcomb. 1979. Factors affecting the survial of pampas grass, *Cortaderia selloana*, in the landscape. Oklahoma Agricultural Experiment Station Research Report. Pp. 12-13. Stillwater, Oklahoma.

Purer, E.A. 1936. Studies of certain coastal sand dune plants of southern California. Ecological Monographs 6: 1-89.

Ranwell, D. 1959. Newborough Warren, Anglesey. I. The dune system and dune slack habitat. Journal of Ecology 47: 571-601.

Ranwell, D. 1960. Newborough Warren, Anglesey. II. Plant associes and succession cycles of the sand dune and dune slack vegetation. Journal of Ecology 48: 117-141.

Ranwell, D.S. 1972. Ecology of salt marshes and sand dunes. Chapman and Hall. London. 258pp.

Raven, P.H. 1977. The California flora. Pp. 109-137. In: M.G. Barbour and J. Major (eds.). Terrestrial vegetation of California. John Wiley & Sons. New York.

Robinson, E.R. 1984. Naturalized species of *Cortaderia* (Poaceae) in southern Africa. South African Journal of Botany 3: 343-346.

Rowe, G.R. and B.P. Connor. 1975. Tetrapion: evaluation for the control of rhizomatous grasses and toetoe. Pp. 173-176. In: Proceedings 28th New Zealand Weed and Pest Control Conference.

Schwendiman, J.L. 1977. Coastal sand dune stabilization in the Pacific Northwest. International Journal of Biometeorology 21: 281-289.

Slobodchikoff, C.N. and J.T. Doyen. 1977. Effects of *Ammophila arenaria* on sand dune arthropod communities. Ecology 58: 1171-1175.

Smith, C.F. 1976. A flora of the Santa Barbara region, California. Santa Barbara Museum of Natural History. Santa Barbara, California. 331pp.

Stock, W. D. and O.A.M. Lewis. 1986. Soil nitrogen and the role of fire as a mineralizing agent in a South African coastal fynbos ecosystem. Journal of Ecology 74: 317-328.

Tassan, R.L., K.S. Hagen, and D.V. Cassidy. 1982. Imported natural enemies established against iceplants scales in California. California Agriculture 36(9/10): 16-17.

Tsuriell, D.E. 1974. Sand dune stabilization in Israel. International Journal of Biometeorology 18:89-93.

Van Hook, S.S. 1985. European beach grass. Fremontia 12(4): 20-21.

van Zyl, J., C.K. Pallaghy, and D.J. Connor. 1974. Some observations on salinity-induced crassulacean acid metabolism in *Mesembryanthemum crystallinum*: effects of ouabain. Australian Journal of Plant Physiology 1: 583-590.

Vitousek, P.M. 1986. Biological invasions and ecosystem properties: can species make a difference? Pp. 163-176. In: H.A. Mooney and J.A. Drake (eds.). Ecology of biological invasions of North America and Hawaii. Springer-Verlag. New York.

Vivrette, N.J. and C.H. Muller. 1977. Mechanism of invasion and dominance of coastal grassland by *Mesembryanthemum crystallinum.* Ecological Monographs 47: 301-318.

von Willert, D.J. 1975. Stomatal control, osmotic potential and the role of inorganic phosphate in the regulation of the crassulacean acid metabolism in *Mesembryanthemum crystallinum.* Plant Science Letters 4: 225-229.

von Willert, D.J., D.A. Thomas, W. Lobin, and E. Curdts. 1977. Ecophysiologic investigations in the family Mesembryanthemaceae: occurrence of CAM and ion content. Oecologia (Berlin) 29: 67-76.

Wakimoto, R.H., P. Veisze, D. Kaplow, R. Elefant, and D. Pitcher. 1980. Environmental analysis report. Wildland fuel management for Vandenberg Air Force Base. University of California Department of Forestry and Fire Staff. Berkeley. 120pp. and appendices.

Wallen, B. 1980. Changes in structure and function of *Ammophila* during primary succession. Oilos 34: 227-238.

Washburn, J.O. and G.W. Frankie. 1981. Dispersal of a scale insect, *Pulvinariella mesembryanthemi* (Homoptera: Coccidae) on iceplant in California. Environmental Entomology 10: 724-727.

Washburn, J.O. and G.W. Frankie. 1985. Biological studies of iceplant scales *Pulvinariella mesembryanthemi* and *Pulvinaria delottoi* (Homoptera: Coccidae) in California. Hilgardia 53(2): 1-27.

Washburn, J.O., R.L. Tassan, K. Grace, E. Bellis, K.S. Hagen, and G.W. Frankie. 1983. Effects of malathion sprays on the ice plant insect system. California Agriculture 37(1/2): 30-32.

Whitfield, C.J. and R.L. Brown. 1948. Grasses that fix sand dunes. U.S. Department of Agriculture Yearbook 1948: 70-74.

Wiedemann, A.M. 1984. The ecology of Pacific Northwest coastal sand dunes: a community profile. U.S. and Wildlife Service FWS/OBS-84/04. 130pp.

Wiedemann, A.M. 1987. The ecology of *Ammophila arenaria* (L.) Link (European beachgrass). Unpublished report prepared for Oregon Department of Fish and Wildlife.

Willis, A.J. 1965. The influence of mineral nutrients on the growth of *Ammophila arenaria*. Journal of Ecology 53: 735-745.

Willis, A.J., B.F. Folkes, J.F. Hope-Simpson, and E.W. Yemm. 1959. Braunton Burrows: the dune system and its vegetation. Part I, Part II. Journal of Ecology 47: 1-24, 249-288.

Winter, K. 1974. Evidence for the significance of crassulacean acid metabolism as an adaptive mechanism to water stress. Plant Science Letters 3: 279-281.

Winter K., U. Luttge, W. Winter, and J.H. Troughton. 1978. Seasonal shift from C_3 photosynthesis to crassulacean acid metabolism in *Mesembryanthemum crystallinum* growing in its natural environment. Oecologia (Berlin) 34: 225-237.

Zedler, P.H. and G.A. Scheid. 1987. Invasibility of chaparral after fire: seedling establishment of *Carpobrotus edulis* and *Salix lasiolepis* in a coastal site in Santa Barbara County, California. Manuscript.

Appendix

Correspondence Relating to Exotic Species

Ammophila arenaria

the bionetics corporation

Biomedical and Environmental Laboratories
Mail Code BIO-2
Kennedy Space Center, Florida 32899
Telephone (305) 853-3281
FTS 253-3281

May 5, 1987
BIO-2-87-262

Dr. P.N. Johnson
Botany Division, DSIR
Private Bag
Dunedin, New Zealand

Dear Dr. Johnson:

We are currently conducting a literature review study of several exotic plants that cause management problems or are threats to native vegetation on Vandenberg Air Force Base in California. One of these species is Ammophila arenaria. This grass was planted for dune stabilization some years ago and now may present a threat to the native dune flora. The base contains some of the best remaining natural dunes in the state and the flora contains a number of rare species. Current management policies protect the dunes from development on the base but the spread of Ammophila may represent a long-term threat.

I have just read your paper (New Zealand J. Bot. 23:131-142. 1982) on naturalized plants in south-west South Island, New Zealand. I found it extremely interesting that Ammophila was a management problem there, displacing native dune flora. You mention that the Fiordland National Park was conducting a program to eradicate Ammophila. Do you have any information on this program e.g., methods employed, success rates, etc.? Any information you could provide would be most appreciated.

Sincerely,

Paul A. Schmalzer

Paul A. Schmalzer, Ph.D.

cc: BIO-2/R. Hinkle, Ph.D.

Botany Division,
DSIR
Private Bag,
Dunedin,
New Zealand
25 May 1987

Dr Paul A. Schmalzer
Biomedical and Environmental Laboratories
BIO-2
Kennedy Space Centre
Florida 32899

Dr Alfred M Wiedemann
Faculty, Biology
The Evergreen State College
Olympia WA 98505

Dear Sirs,
I write to you both answering ssimilar requests for information on control of Ammophila arenaria. I am interested to hear that this species is as aggressive in your parts of the world as it is in New Zealand. Our native sand binders are principally the grass Spinifex hirsuta, and a sedge Desmoschoenus spiralis, an endemic and monotypic genus. Both colonise and form rather gently sloping foredunes then persist among later invaders on older dune surfaces. Ammophila arenaria has been widely planted in NZ to stabilise moving sands and has spread unaided by seed and rhizome fragments to most sandy sites on our coasts. By contrast with the natives it creates a dune of steeper profile, one which is often prone to erosion of its steep sides later. Most of our dune systems ane now dominated by marram grass, often to the total exclusion of the former native spp. On older sand surfaces Lupinus arboreus (from US) then forms a low scrub, and may in turn be replaced by elder, Sambucus nigra, from Europe. Add a few sheep and cattle and you end up with dune vegetation totally different to that of 150 years ago.

Fiordland National Park in the southwest of NZ still holds examples of dunes where native plants remain dominant, hence my interest in eradicating marram from this section of coast. I have not been closely involved with the actual eradication attempts, but the enclosed copy of a letter from the National Park people outlines some of the chemicals used with success, notably Valpa. In some adjacent dune systems, Roundup has also been succesful.

Also enclosed are portions of a report (DSIR, unpub., Feb. 1979, P.N.Johnson, "Vegetation of Fiordland Beaches") of some relevance to Ammophila behaviour and control.

I hope these comments are of some assistance to your own dune management issues.

Yours faithfully,

P.N. Johnson

the bionetics corporation

Biomedical and Environmental Laboratories
Mail Code BIO-2
Kennedy Space Center, Florida 32899
Telephone (305) 853-3281
FTS 253-3281

June 16, 1987
BIO-2-87-370

Peter N. Johnson
Botany Division
DSIR
Private Bag
Dunedin, New Zealand

Dear Mr. Johnson:

Thank you for the information on the problems caused by Ammophila arenaria in New Zealand. There is little information available on controlling Ammophila. The work you report from New Zealand and some evaluations of techniques at a site on the California coast by The Nature Conservancy, a private conservation group, are the only control programs we have found reference to so far. We will send you a copy of our report when it is completed.

Sincerely,

Paul A. Schmalzer

Paul A. Schmalzer, Ph.D.

cc: BIO-2/R. Hinkle, Ph.D.

the bionetics corporation

Biomedical and Environmental Laboratories
Mail Code BIO-2
Kennedy Space Center, Florida 32899
Telephone (305) 853-3281
FTS 253-3281

May 11, 1987
BIO-2-87-283

Steve McCormick
Director, California Field Office
The Nature Conservancy
San Francisco, California 94103

Dear Mr. McCormick:

We are currently conducting a literature review study of several exotic plants that cause management problems or are threats to native vegetation on Vandenberg Air Force Base, California. One of these is Ammophila arenaria which was planted in some locations for erosion control years ago and may now present a threat to the native dune flora.

There is extensive literature on how to establish Ammophila but very little on how to control it. A.M. Wiedeman in "The Ecology of Pacific Northwest Coastal Sand Dunes: A Community Profile," FWS/OBS-84/04, 1984 reported preliminary information on experiments carried out at The Nature Conservancy Lanphere-Christensen Dunes Preserve, Arcata, California and indicated that fire followed by herbicide (roundup) was effective in controlling Ammophila. Is there any further information available on this research project? Any information you could provide would be appreciated.

Sincerely,

Paul A. Schmalzer

Paul A. Schmalzer, Ph.D.

cc: BIO-2/R. Hinkle, Ph.D.

The Nature Conservancy

California Field Office
785 Market Street, San Francisco, California 94103
(415) 777-0487

May 22, 1987

Mr. Paul A. Schmalzer, Ph.D
Biomedical and Environmental Laboratories
Mail Code BIO-2
Kennedy Space Center, FLA 32899

Dear Dr. Schmalzer:

In response to your letter to Steve McCormick of The Nature Conservancy, I have enclosed a draft of an Element Stewardship Abstract for Ammophila arenaria. Of special interest are sections 7400, 7710 and 8000 which deal with eradication procedures. Please note that the bibliography is incomplete at this time.

You may also wish to contact Andrea Pickart of TNC's Lanphere-Christensen Dunes Preserve as she was involved in Ammophila eradication efforts there. Her address and phone are found in section 7710 of the enclosed report.

I hope this information proves useful.

Sincerely,

Leslie Friedman

Leslie Friedman
Stewardship Assistant

LF/mb

encl.

Western Regional Office, 785 Market Street, San Francisco, CA 94103
National Office, 1800 North Kent Street, Arlington, Virginia 22209

the bionetics corporation

Biomedical and Environmental Laboratories
Mail Code BIO-2
Kennedy Space Center, Florida 32899
Telephone (305) 853-3281
FTS 253-3281

June 16, 1987
BIO-2-87-369

Leslie Friedman
Stewardship Assistant
The Nature Conservancy
California Field Office
785 Market Street
San Francisco, California 94103

Dear Ms. Friedman:

Thank you for the information from the draft Element Stewardship abstract for Ammophila arenaria. It is very helpful; there is a considerable amount of scientific literature on Ammophila but little on its control. We will send you a copy of our report when it is completed.

Sincerely,

Paul A. Schmalzer

Paul A. Schmalzer, Ph.D.

cc: BIO-2/R. Hinkle, Ph.D.

the bionetics corporation

Biomedical and Environmental Laboratories
Mail Code BIO-2
Kennedy Space Center, Florida 32899
Telephone (305) 853-3281
FTS 253-3281

June 16, 1987
BIO-2-87-374

Charles Bruce
Oregon Department of Fish and Wildlife
Route 5, Box 325
Corvallis, Oregon 97330

Dear Mr. Bruce:

We are conducting a literature review on methods of controlling Ammophila arenaria as part of a project at Vandenberg Air Force Base, California. Ammophila was planted for dune stabilization there in the 1950's and is now considered a management problem. Information supplied by the California Field Office of The Nature Conservancy indicated that you were conducting a control program for Ammophila. Any information you could provide on methods and success rates would be appreciated.

Thank you.

Sincerely,

Paul A. Schmalzer

Paul A. Schmalzer, Ph.D.

cc: BIO-2/R. Hinkle, Ph.D.

Department of Fish and Wildlife
NORTHWEST REGION
ROUTE 5, BOX 325, CORVALLIS, OREGON 97330-9446 PHONE 757-4186

June 25, 1987

Dr. Paul Schmalzer
Biometrics Corporation
Mail Code Bio-2
Kennedy Space Center, Florida 32899

Dear Dr. Schmalzer,

It was a pleasure to receive your letter this week regarding your literature review on methods of controlling Ammophila arenaria. I'm sure not many people get excited about killing beachgrass but we do! As the attached proposal indicates (3/8/82) we have been interested in controlling European beachgrass for the benefit of a shorebird that nests only on fairly open dry sandy beach areas. Unless methods can be developed to control the grass the snowy plover will be eliminated from the Oregon coast in the near future.

We tried two years of very small scale herbicide treatments with mixed results on the Oregon Dunes National Recreation Area. This effort was temporarily discontinued due to an injunction prohibiting the use of herbicides on national forest lands. Details of those efforts are enclosed. Results were mixed. Round-Up didn't do much but Dowpon appeared to kill the grass in 1982, but not in 1983. We had rain shortly after application in 1983 so that may have neutralized the test. More extensive treatment over longer period of time may show that both chemicals have promise.

We do have something that will be of help. Al Wiedemann at The Evergreen State College in Olympia just completed a literature review on Ammophila for us as we hope to continue experimental control efforts next year if possible. As you can see he found no references on control of beachgrass, but was familiar with ongoing efforts in California and New Zealand.

We would be very interested in receiving a copy of your literature review when it is complete. By the way, Purisima Point beach on Vandenberg has a good sub-population of snowy plovers (estimated 109 adults in 1978) that could probably benefit from some Ammophila control.

Good luck with your effort. Let me know if we can be of further assistance. If it's not classified information, why is the Air Force interested in controlling beachgrass?

Sincerely,

Charles Bruce
Non-Game Biologist
encl.
cbs

the bionetics corporation

Biomedical and Environmental Laboratories
Mail Code BIO-2
Kennedy Space Center, Florida 32899
Telephone (305) 853-3281
FTS 253-3281

July 7, 1987
BIO-2-87-408

Charles Bruce
Department of Fish and Wildlife
Northwest Region
Route 5, Box 325
Corvallis, Oregon 97330-9446

Dear Mr. Bruce:

Thank you for the package of information on Ammophila arenaria and the results of your efforts to control it. This is very helpful; there is much more known about how to grow Ammophila than on how to control it.

Vandenberg Air Force Base contains some of the best preserved dunes in central California. Ammophila arenaria was planted for dune stabilization in some areas in the 1950's. Ammophila does not appear to spread as aggressively in central California as farther north. However, the Environmental Task Force at Vandenberg thinks it may be a threat to the native dune flora in which there are a number of special interest plants. In addition, snowy plovers (as you noted) and least terns require open sand for breeding. We were asked to review the literature on Ammophila and several other invasive exotics to determine the potential methods for control. We will send you a copy of our report when it is completed. At this point, however, I would agree with Dr. Wiedemann that controlling or eradicating Ammophila will be difficult.

Sincerely,

Paul A. Schmalzer

Paul A. Schmalzer, Ph.D.

cc: BIO-2/R. Hinkle, Ph.D.

the bionetics corporation

Biomedical and Environmental Laboratories
Mail Code BIO-2
Kennedy Space Center, Florida 32899
Telephone (305) 853-3281
FTS 253-3281

June 16, 1987
BIO-2-87-373

Andrea Pickart
Lanphere-Christensen Dunes Preserve
6800 Lanphere Road
Arcata, California 95521

Dear Ms. Pickart:

We are conducting a literature review on methods of controlling Ammophila arenaria as part of a project at Vandenberg Air Force Base, California. Ammophila was planted for dune stabilization there in the 1950's and is now considered a management problem. I recently received a package of information from Ms. Leslie Friedman of the California Field Office of The Nature Conservancy that included the draft Element Stewardship abstract for Ammophila. I understand from this abstract that several methods of control were attempted including burning, mowing, uncovering the upper rhizomes, covering with black plastic, digging up, herbicide application (roundup), and application of rock salt. Of these the most successful were digging up and application of rock salt followed by digging six months later. Is there further information available on this program or an update of your current control measures. Any additional information you could provide would be appreciated.

Thank you.

Sincerely,

Paul A. Schmalzer

Paul A. Schmalzer, Ph.D.

cc: BIO-2/R. Hinkle, Ph.D.

Lanphere-Christensen
Dunes Preserve
6800 Lanphere Rd.
Arcata, California 95521

July 8, 1987

Dr. Paul A. Schmalzer
Bionetics Corp.
BIO-2
Kennedy Space Center, FL 32899

Dear Dr. Schmalzer:

In answer to your inquiry about Ammophila eradication techniques, I do have some updated information but it is not yet in a published form. I am in the process of preparing a comprehensive Ammophila control program for the Lanphere-Christensen Dunes Preserve, but I do not anticipate completing this document for several months. The information I have is still tentative, as it is based on a small number of experimental plots. Over the next 2-3 years I will be implementing a large scale experimental program that will hopefully evolve into a full scale eradication program. I will be working with Humboldt State University faculty on this program. The University has recently become involved in a dune revegetation research program and I am attempting to dovetail their program with ours.

Since the preparation of the draft Element Stewardship Abstract which you received, recommendations for eradication have changed as a result of our program. During the past three years we have implemented a digging program, based on the results of Sue Van Hook´s study. While repeated digging does control the species and in some cases allows the reinvasion of natives, it does not eradicate the species and it is anticipated that, were digging to stop, the remaining plants would proliferate and soon reinvade the area. Digging has also led to increased erosion on the foredune. In some cases this is beneficial, as incipient blowouts sometimes bury the beachgrass sufficiently to kill it, and natives may then stabilize the blowout. This is a highly unpredictable process, however, and in some cases blowouts may not restabilize without artificial plantings.

Rock salt or a saline solution is still being considered as a viable option. Research on this method will begin next year. It is expected to be more labor intensive and possibly more costly than the use of Roundup.

I implemented a small number of experimental Roundup plots in 1985-86, with some encouraging results, and further experimentation on a large scale will be carried out next summer. Van Hook had attempted to use Roundup in her two year study without success. I believe that the timing of application is critical to the success of this treatment. In 1985 I applied Roundup to 6 individual stands of beachgrass. The experimental plots ranged in size from 1.5 to 17 square meters. The first three were treated during anthesis (early July in that year) and the second three at a post bloom stage (mid-August). Both series were treated with a 2% solution with non-ionic surfactant, using

Lanphere-Christensen
Dunes Preserve
6800 Lanphere Rd.
Arcata, California 95521

mid-August when the second series of trials was first sprayed. The plants entered dormancy soon after and the treated post-bloom plots did not show any significant difference from nearby untreated stands. The second application also did not affect the surviving portions of the July plots.

In winter 1986 dead plant material was dug up from the July plots. Only the small areas that had not been initially killed continued to grow in the 1986 season. All six plots were again treated in July. The plants were observed to be past their peak flowering (June is actually a more typical month for peak flowering). The treatment had no observable effect on any of the plots. The plants remaining in the bloom plots did not recover sufficiently to flower in 1986.

Although these experiments were qualitative in nature, they indicate that the optimal time for application is during anthesis, which conflicts with earlier assumptions that plants should be sprayed just after emergence from dormancy. The bloom or post-bloom application was suggested by Monsanto. Post-bloom applications appear to be ineffective.

I will shortly be updating the element stewardship abstract with this information. Although tentative, it is to my knowledge the only successful attempt at eradication of <u>Ammophila</u> using Roundup. There are several agencies, in particular Cal. State Parks, who have proposed beachgrass eradication on their properties. As of my last communication with them, no progress has been made.

I hope this information is of use to you. Please call me at 707-822-6378 if you have any questions.

Sincerely,

Andrea Pickart

Andrea Pickart
Preserve Manager

Carpobrotus edulis

the bionetics corporation

Biomedical and Environmental Laboratories
Mail Code BIO-2
Kennedy Space Center, Florida 32899
Telephone (305) 853-3281
FTS 253-3281

October 24, 1986
BIO-2-86-582

Ms. Carla D'Antonio
Department of Biological Sciences
University of California, Santa Barbara
Santa Barbara, California 93106

Dear Carla:

I wanted to thank you again for meeting with us and discussing your research on Carpobrotus. Your work will be very important in understanding the biology of these plants and should help Vandenberg Air Force Base in managing the areas impacted by ice plant.

I have enclosed a few things I came across on the parasites and predators of ice plant scale insects that have been introduced to control the ice plant scale. Unfortunately, they appear to be successful where established.

I hope the rest of your research project goes well. If we can be of any assistance, please let me know.

Sincerely,

Paul A. Schmalzer

Paul Schmalzer, Ph.D.

Enclosures

cc: BIO-2/R. Hinkle, Ph.D. (w/o encl.)

the bionetics corporation

Biomedical and Environmental Laboratories
Mail Code BIO-2
Kennedy Space Center, Florida 32899
Telephone (305) 853-3281
FTS 253-3281

April 3, 1987
BIO-2-87-186

Dr. Paul H. Zedler
Biology Department
San Diego State University
San Diego, California 92182

Dear Dr. Zedler:

As part of the work we are currently conducting on Vandenberg Air Force Base we are preparing a fire history map. Ms. Diana Hickson, who is conducting much of this study, has observed that most recent burns (since 1981) of Burton Mesa chaparral contain populations of Carpobrotus edulis and/or Conocosium pugioniformis. Unfortunately, pre-burn data are not available for most of these stands. Reviewing your report on the controlled burn of the 35th Street Eriodictyon capitatum population, I noticed that you also found seedlings of Carpobrotus post-burn. Carpobrotus and to a lesser extent Conocosium are both well established in this burn now. As I interpret your report, Carpobrotus was present along the roadside but absent from the interior of the chaparral pre-burn. Is this correct? If fire allows the establishment and spread of Carpobrotus and Conocosium in Burton Mesa chaparral (as seems to be the case), then this becomes a management problem for the Air Force since this chaparral contains many endemic plants.

We would appreciate any additional observations or comments you might have.

Sincerely,

Paul A. Schmalzer

Paul A. Schmalzer, Ph.D.

cc: BIO-2/R. Hinkle, Ph.D.
BIO-2/D. Hickson

San Diego State University
Biology Department
San Diego, CA 92182-0057

April 30, 1987

Dr. Paul Schmalzer
Bionetics Corporation
Biomedical and Environmental Laboratories
Mail Code BIO-2
Kennedy Space Center, Florida 32899

Dear Dr. Schmalzer:

Sorry to take so long in replying, but your request for information on Carpobrotus stimulated me to dust off a manuscript that was half-finished and bring it to the point where it is 4/5 finished. It should answer your questions, except that we concentrated on Carpobrotus and didn't do anything with the Herrea/Conocosium.

As we intend to submit this for publication in the next few weeks, we would appreciate any comments that you might have.

Sincerely,

Paul H. Zedler

the bionetics corporation

Biomedical and Environmental Laboratories
Mail Code BIO-2
Kennedy Space Center, Florida 32899
Telephone (305) 853-3281
FTS 253-3281

May 5, 1987
BIO-2-87-265

Dr. Paul H. Zedler
Biology Department
San Diego State University
San Diego, California 92182-0057

Dear Dr. Zedler:

Thank you for your manuscript on the invasion of Carpobrotus and Salix into the Eriodictyon site. This is very helpful. It has been our opinion that the occurrence of Carprobrotus in these recent burns was post-fire establishment and related to burning. However, without pre-fire data for most sites there could be some doubt. It also emphasizes the importance of long-term studies and permanent plots.

I have made a few comments on a copy of the manuscript. There are two other studies that may be of interest. Ms. Carla D'Antonio (UC Santa Barbara, Biology Department) is conducting a comprehensive ongoing study of the species biology of Carpobrotus as her dissertation research and is using Vandenberg as a study site. She has found that Carpobrotus seeds are animal dispersed, passage through the digestive system of rabbits enhances germination, and that heating from fire enhances germination. In a conversation last fall, she indicated that it would be about two years before her project was complete.

In a recent study, Dr. Frank Davis, Ms. Diana Hickson (UC Santa Barbara, Geography Department) and Mr. Dennis Odion (Santa Barbara Botanic Garden) have found that natural fire frequency on the Burton Mesa is low; all known fires between 1938 and 1985 were of anthropogenic origin (Davis, Hickson and Odion, Spatial and temporal dynamics of maritime chaparral on the Burton Mesa, California, manuscript). The situation for all of Vandenberg appears similar; there is only one record of a lightning fire and that occurred on Tranquillon Mountain. Your recommendation of long fire intervals for this system are in line with this low natural ignition rate.

Our report on fire history on Vandenberg should be completed this fall. We will send you a copy when it is available.

Thanks for your help.

Sincerely,

Paul A. Schmalzer, Ph.D.

cc: BIO-2/R. Hinkle, Ph.D.
BIO-2/D. Hickson

Cortaderia jubata

the bionetics corporation

Biomedical and Environmental Laboratories
Mail Code BIO-2
Kennedy Space Center, Florida 32899
Telephone (305) 853-3281
FTS 253-3281

December 8, 1986
BIO-2-86-647

Dr. Ruth L. Gadgil
Forest Research Institute
New Zealand Forest Service
Private Bag
Rotorua, New Zealand

Dear Dr. Gadgil:

We are conducting a literature survey study of methods of controlling pampas grass (Cortaderia jubata and C. selloana) as one part of a biological monitoring plan for Vandenberg Air Force Base, California. Cortaderia jubata has become established in disturbed areas on the base and is now invading chaparral vegetation. The grass may be a long-term threat to the chaparral vegetation there which contains many endemic species. It may also increase the fire hazard and the masses of wind-blown seeds cause equipment maintenance problems at the airfield.

I have read your paper in the Proceedings of the 37th New Zealand Weed and Pest Control Conference with interest. In it you mention an ongoing research program on Cortaderia control including screening of herbicides, examining the potential for control by pathogens, etc. If there is information available from this program in reports or government documents we would very much like to receive it. In most places on Vandenberg Air Force Base where Cortaderia has established, grazing or mowing are probably not practical as control measures; so, we are particularly interested in the potential for herbicides or biological control.

I have enclosed a preliminary summary that we have prepared. Any additional information you could provide would be appreciated.

Thank you.

Sincerely,

Paul A. Schmalzer

Paul A. Schmalzer, Ph.D.

cc: BIO-2/R. Hinkle, Ph.D. (w/o enc.)

FOREST MANAGEMENT AND RESOURCES DIVISION

FOREST RESEARCH INSTITUTE
Private Bag, Rotorua, New Zealand

IN YOUR REPLY
PLEASE QUOTE REF.

FS 28/9/42/36
RLG:RO

22 December 1986

Dr P.A. Schmalzer
Biomedical and Environmental Laboratories
Mail Code B10-2
Kennedy Space Center
FLORIDA 32899

Dear Dr Schmalzer

Thank you very much for your letter of 8 December and the enclosed summary, which I found most interesting.

George Zabkiewicz and David Preest are the scientists responsible for the particular aspects of research that relate to your problem, and I have asked them to contact you.

Yours sincerely

Ruth L. Gadgil

Ruth L. Gadgil
for Director

TELEGRAMS AND CABLES 'FRESTRA' ROTORUA, N.Z., TELEX NZ21080; TELEPHONE 475-899

FOREST HEALTH AND IMPROVEMENT
DIVISION
FOREST RESEARCH INSTITUTE
Private Bag, Rotorua, New Zealand

IN YOUR REPLY
PLEASE QUOTE REF.

44/0
JAZ:FMJ

22 December 1986

Dr P.A. Schmalzer
Bionetics Corporation
Biomedical and Environmental Laboratories
Mail Code B10-2
Kennedy Space Centre
Florida 32899
USA

Dear Dr Schmalzer

Your letter to Dr Gadgil has been passed to me for a response in my capacity as leader of the Pampas Special Project research group.

We were most interested in your description of the problem occurring with C. jubata around the Vandenberg Air Force Base. We have not been aware of a significant problem with pampas grass outside New Zealand, although its spread has now been reported in South Africa and Australia as well as the USA.

We have had a specific project on pampas for several years. This has resulted in several leaflets and a large amount of as-yet unpublished information. I enclose copies of what I think will be most useful for your purposes.

In essence, low levels of infestation are treated with herbicides; high concentrations are grazed for control (or even eradication). There is some potential for oversowing exposed ground to prevent seedling establishment; to date there is no other known method of biological control.

We have found that germination of C. jubata is relatively unaffected over the range 6-30°C nor is light required. Once established C. jubata survives in all parts of New Zealand. C. jubata was an inadvertent introduction into New Zealand and has now been declared a noxious weed with compulsory eradication in certain areas. It is not fully known at present as to why it does not seem to spread as much in the cooler, drier regions of New Zealand.

Apart from hexazinone (Velpar) and glyphosate (Roundup), a more recent selective grass killer is haloxyfop-methyl*(Gallant in New Zealand). The other herbicides you mention are not current recommendations. Granular Velpar can be useful as well for spot applications. Various helicopter spray methods can be used, including single clump treatments (photograph enclosed).

* Dow Chemical Co.

TELEGRAMS AND CABLES FRESTRA ROTORUA, N.Z. TELEX NZ21080 TELEPHONE 475 899

I doubt if this brief response has answered all your questions. We will be glad to answer any other specific questions you may have. Alternatively if further practical measures or assesments are required we would be glad to participate in a joint programme. There is a lot of information and expertise at FRI that has not been produced in published form and will not be for some time to come. *

I look forward to your response.

Yours faithfully

J.A. Zabkiewicz
for Director

Encls

* PS. We also have an extensive slide & photograph collection on pampas & its control

the bionetics corporation

Biomedical and Environmental Laboratories
Mail Code BIO-2
Kennedy Space Center, Florida 32899
Telephone (305) 853-3281
FTS 253-3281

February 4, 1987
BIO-2-87-057

Dr. J.A. Zabkiewicz
Forest Health and Improvement Division
Forest Research Institute
Private Bag
Rotorua, New Zealand

Dear Dr. Zabkiewicz:

Thank you for the information on your research program on control of Cortaderia (Ref:44/0). It is very helpful.

Currently, we are conducting several research projects for Vandenberg Air Force Base. The work on Cortaderia control is part of literature review project on four problem exotic species on the base. The others are Carpobrotus edulis, Gasoul crystallinum, and Ammophila arenaria. We will advise the Air Force authorities on the expertise existing in the Forest Research Institute on control of Cortaderia. If a decision is made to implement a control program at Vandenberg, there may be an opportunity for us to participate in a joint program.

Sincerely,

Paul A. Schmalzer

Paul A. Schmalzer, Ph.D.

cc: BIO-2/R. Hinkle, Ph.D.
BIO-2/J.R. Puleo

the bionetics corporation

Biomedical and Environmental Laboratories
Mail Code BIO-2
Kennedy Space Center, Florida 32899
Telephone (305) 853-3281
FTS 253-3281

February 4, 1987
BIO-2-87-058

Michael McElligott
Ecologist
1 STRAD/ETN
Vandenberg Air Force Base, California 93437-5000

Dear Mike:

Enclosed are copies of some pamphlets we have received from researchers with the Forest Research Institute in New Zealand regarding control of Cortaderia. We will, of course, summarize this and other information in our final report regarding the four exotic species we are reviewing at Vandenberg but we wanted to provide this as additional interim information on Cortaderia given its current priority on base.

In the cover letter accompanying these reports, J.A. Zabkiewicz of the Forestry Research Institute indicated that their group has had a research project on Cortaderia control for several years. Currently they use herbicides and grazing as control measures. Herbicides used are hexazinone (Velpar) and glyphosphate (roundup); recently, haloxyfop-methyl (Dow Chemical Company) which is selective for grasses has been used. Other herbicides mentioned in the preliminary review are no longer recommended. Various application methods including spot applications from helicopters have been developed. Dr. Zabkiewicz indicated that his group has considerable unpublished information on Cortaderia control. He expressed a willingness to respond to specific questions or to participate in a joint program if that was desired. The current project (Task 4.0) is intended as a literature review only. If Vandenberg AFB decides to implement a control program for Cortaderia, the expertise of the New Zealand group could prove valuable. You might want to talk with Ross about looking into a more detailed control program with Bionetics if you are interested.

Sincerely,

Paul A. Schmalzer

Paul A. Schmalzer, Ph.D.

cc: BIO-2/R. Hinkle, Ph.D.
BIO-1/J.R. Puleo

Gasoul crystallinum

C-2

the bionetics corporation

Biomedical and Environmental Laboratories
Mail Code BIO-2
Kennedy Space Center, Florida 32899
Telephone (305) 853-3281
FTS 253-3281

December 16, 1986
BIO-2-86-670

Dr. P.M. Kloot
South Australian Department of Agriculture
GPO Box 1671
Adelaide, Australia 5001

Dear Dr. Kloot:

We are currently conducting a literature review study of methods of controlling several invasive exotic species that cause management problems on Vandenberg Air Force Base, California. One of these species is iceplant, Mesembryanthemum (=Gasoul) crystallinum. The main study site of Vivrette and Muller (Ecological Monographs 47:301-318, 1977) located at Surf is within the general boundaries of Vandenberg Air Force Base.

I have read with interest your article on the invasion of iceplant into Australian pastures and cereal grains (Australian Journal of Ecology 8:301-306, 1983). In it you mention the possibility of using post-emergence herbicides for controlling iceplant. I would be interested in knowing if any specific herbicides have been tested against iceplant or if other methods of control have been attempted. I would appreciate receiving any additional reports or articles you have prepared in your study of this plant.

Thank you for your consideration.

Sincerely,

Paul A. Schmalzer

Paul A. Schmalzer, Ph.D.

cc: BIO-2/R. Hinkle, Ph.D.

SOUTH AUSTRALIAN
DEPARTMENT OF AGRICULTURE
G.P.O. Box 1671, Adelaide, South Australia 5001
25 Grenfell Street, Adelaide 5000. Telegrams: "SAGRIC". Telex: 88422

Your ref. ....
Our ref. ......P.S.D. 104/329......
Please refer to.....Dr. P.M. Kloot.
Telephone No. 266 8334

5th January, 1987.

Dr. P.A. Schmalzer,
The Bionetics Corporation,
Biomedical and Environmental Laboratories,
B10-2,
Kennedy Space Centre,
FLORIDA 32899, U.S.A.

Dear Dr. Schmalzer,

Thank you for your letter of 16 December regarding herbicidal control of iceplant. This weed has been a problem in cereals for a long time and control techiques are fairly standard. We do not seem to have specific literature, so I am enclosing a copy of last year's Cereal Spraying Chart which contains this Department's recommendations for controlling iceplant. I trust that you will find them useful and suitable for adapting to your particular problem.

Yours sincerely,

PMK/et

(P.M. Kloot)
PRINCIPAL BIOLOGIST

Encl.

the bionetics corporation

Biomedical and Environmental Laboratories
Mail Code BIO-2
Kennedy Space Center, Florida 32899
Telephone (305) 853-3281
FTS 253-3281

February 4, 1987
BIO-2-87-056

Dr. P.M. Kloot
South Australian Department of Agriculture
G.P.O. Box 1671
Adelaide, South Australia 5001

Dear Dr. Kloot:

Thank you for the information on the herbicides recommended for controlling iceplant (Gasoul crystallinum) in cereals in South Australia. This will be quite useful in developing our report for Vandenberg Air Force Base on methods of controlling this plant.

Sincerely,

Paul A. Schmalzer

Paul A. Schmalzer, Ph.D.

cc: BIO-2/R. Hinkle, Ph.D.

Report Documentation Page

NASA
National Aeronautics and Space Administration

1. Report No. NASA TM 100980	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle Species biology and potential for controlling four exotic plants (Ammophila arenaria, Carpobrotus edulis, Cortaderia jubata, and Gasoul crystallinum) on Vandenberg Air Force Base, California	5. Report Date November 1987
	6. Performing Organization Code BIO-1
7. Author(s) P. A. Schmalzer and C.R. Hinkle	8. Performing Organization Report No.
	10. Work Unit No.
9. Performing Organization Name and Address The Bionetics Corporation Mail Code: BIO-1 Kennedy Space Center, FL 32899	11. Contract or Grant No. NAS10-10285
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address NASA Biomedical Operations and Research Office Mail Code: MD Kennedy Space Center, FL 32899	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Invasive exotic plants can displace native flora and modify community and ecosystem structure and function. Ammophila arenaria, Corpobrotus edulis, Cortaderia jubata, and Gasoul crystallinum are invasive plants present on Vandenberg Air Force Base, California designated for study by the Environmental Task Force because of the perceived threat they represent to the native flora.

Ammophila arenaria was planted on Vandenberg for dune stabilization in the Purisima Point area, dominates the dunes there, and excludes native plants. A. arenaria is native to Europe but has been widely planted for dune stabilization; it is extremely well adapted to dune habitats. Few insect pests and no known plant diseases affect A. arenaria. Several herbicides and treatment with salt offer some potential to control the plant, but techniques are not well developed.

Carpobrotus edulis, a perennial mat-forming succulent native to South Africa, was planted on Vandenberg as an ornamental and along roadsides for erosion control. It has spread into native communities, particularly coastal dune shrub and chaparral. Seeds are animal-dispersed. Fire stimulates seed germination and appears to encourage the spread of the plant. C. edulis is attacked by two scale

17. Key Words (Suggested by Author(s)) Ammophila arenaria, Carpobrotus edulis, Cortaderia jubata, Gasoul crystallinum, Exotic plants, Vandenberg Air Force Base	18. Distribution Statement Unlimited National Technical Information Service

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of pages 94	22. Price

16. Abstract (Continued)

insects and several fungal diseases. A biological control program is unlikely because of its extensive use as an ornamental. Sensitivity to different herbicides is unknown, and there is insufficient information available to design a complete control program. Removal of the plant by hand from high priority sites or recent burns is a possibility, but the effectiveness of this would have to be determined.

Cortaderia jubata, a grass native to South America, was introduced into California as an ornamental and has escaped in the coastal region. It is established primarily in disturbed areas but is spreading into undisturbed native vegetation. *C. jubata* produces large numbers of wind-dispersed seeds. Control techniques are best developed in New Zealand where grazing and herbicides are used. No potential for biological control other than grazing is known.

Gasoul crystallinum, an annual, prostrate herb native to South Africa, occurs along the coastal bluffs and adjacent grassland areas on Vandenberg. It does not appear to be as serious a problem as the three previous taxa, but it does have the potential to expand in coastal areas. *Gasoul* accumulates salt while growing; leaching of salt on death of the plant limits establishment of other species. Herbicides are used to control *Gasoul* in cereal crops in South Australia but would have to be tested for use in coastal vegetation. Removal of the plant by hand before it releases seed or leaches salt is a potential control.

Many other introduced species occur on Vandenberg. The one with the most potential to affect native vegetation is *Conicosia pugioniformis*, a succulent perennial, that invades disturbed sites and burned areas and establishes dense mats that exclude native plants. *Erechtites glomerata* and *Ehrharta calycina* also pose problems.