TWENTY ONE

California Grassland Restoration

MARK R. STROMBERG, CARLA M. D'ANTONIO,
TRUMAN P. YOUNG, JEANNE WIRKA, AND PAUL R. KEPHART

Changes in California's grasslands associated with human activity vary along a gradient from complete destruction in the worst case to preserved fragments of presumed pristine stands in the best. Yet the most "pristine" California grasslands represent only a small proportion of California's current grasslands, and even they include some non-native species (Safford and Harrison 2001; Stromberg et al. 2001; Gelbard and Harrison 2003). Some grasslands mostly or entirely devoid of native grasses still harbor relatively rich floras of native herb species (Lulow 2004). More common are stands dominated by a few species of non-native grass, with scattered natives (both grasses and herbs) making up varying degrees of relative cover. The challenge of restoring California grasslands is to develop site-appropriate goals along with prescriptions that match this wide range of grassland conditions. While preserving and managing California grasslands with a higher component of native species may seem like an easier task, it is often those that have been completely destroyed that can be most easily restored, simply because they are less complex and the practitioner can start from a clean slate. This paradoxical quality of grassland restoration and the dilemmas faced by grassland restorationists are the subjects of this chapter.

Restoration is the complex set of efforts to reverse or mitigate effects of human activity on the landscape (Packard and Mutel 1996). The Society for Ecological Restoration (SER) has defined ecological restoration as

> the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed. An ecosystem has recovered— and is restored—when:
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> 1) it contains a characteristic assemblage of the species that occur in the reference ecosystem and that provide appropriate community structure, 2) it consists of indigenous species to the greatest practicable extent, 3) all functional groups necessary for the continued development and/or stability of the restored ecosystem are represented or, if they are not, the missing groups have the potential to colonize by natural means, 4) the physical environment of the restored ecosystem is capable of sustaining reproducing populations of the species necessary for its continued stability, 5) it apparently functions normally for its ecological stage of development, and signs of dysfunction are absent, 6) it is suitably integrated into a larger ecological matrix or landscape, with which it interacts through abiotic and biotic flows and exchanges, 7) potential threats to the health and integrity of the restored ecosystem from the surrounding landscape have been eliminated or reduced as much as possible, 8) it is sufficiently resilient to endure the normal periodic stress events in the local environment that serve to maintain the integrity of the ecosystem and 9) is self-sustaining to the same degree as its reference ecosystem, and has the potential to persist indefinitely under existing environmental conditions (SER 2004).

Restoration of California grasslands, once thought to be nearly impossible (Sampson et al. 1951; Heady 1988) is now under way at many sites, although usually with less ambitious goals than the complete eradication of exotics or complete ecological restoration as defined above. Restoration offers the hope of creating a landscape that is more weed-resistant, maintains its productivity over time and other ecosystem services, and is somewhat tolerant or resilient to a variety of stresses. A broad continuum of effort exists from small-scale landscaping and creation of prairie gardens, to landscape architecture projects focused on native grasses, to larger-scale reclamation and full "ecological restoration" as defined above. Reaching the idealistic definition of restoration may be exceedingly difficult in much of California's grasslands, because of constraints that will be discussed subsequently. Nonetheless, people are working along all parts of the continuum toward restoration of one or more of the attributes described by SER, and the issues discussed here are generally relevant at many levels. The term *restoration* will be used to refer to all of the efforts along the continuum.

Restoration practitioners, seed producers, academic researchers, consulting biologists, agronomists, ranchers, and landowners have made some significant advances in California grassland restoration. Many were involved in the establishment of the California Native Grasslands Association (CNGA) and the California chapter of the Society for Ecological Restoration (SERCAL), both in 1991. Hundreds of grassland restoration projects have been initiated across California. Initially, most were designed to establish permanent grassland habitats with native perennial grasses as the backbone (Anderson and Anderson 1996). Once established, individual native perennial grasses may survive for hundreds of years (Hamilton et al. 2002), and the basal clumps form the structural basis for a physically more complex habitat. The focus on perennial grasses in California grassland restoration is based on the assumption that by restoring the structural diversity of perennial bunchgrasses, colonization and survival of associated herbs, shrubs, insects, small mammals, and other community members will eventually occur (MacArthur et al. 1966; Bell et al. 1991; Huston 1994; Rosenzweig 1995; Vickery et al. 2001; Goerrissen 2005). Also, because native perennial grasses are persistent, it is assumed they will provide greater resistance to invasion and resilience to stress than annual species. Whether sites restored to native perennial grasses achieve the ultimate goal of a restored ecosystem, as defined by SER, however, has rarely been evaluated. More recently, there has been greater emphasis on other plant groups, such as native forbs. For example, a few grassland restoration projects have introduced up to 20 forbs (Kephart 2001).

Restoration typically involves the selection of a reference ecosystem that is chosen because it is a realistic target for the particular site conditions. Ecologists have a long legacy of historical ecology to determine reference ecosystems (Egan and Howell 2001). However, there are no formal guidelines for what defines a 'reference ecosystem" or remnant stand of native California grassland. What is considered as viable remnant grassland, and thus a reference ecosystem for restoration, will vary widely across California. For instance, in the dry interior habitats above the Central Valley, bunchgrasses may be rare and the "native" community may have been one largely dominated by forbs and shrubs (Schiffman 1995). By contrast, foggy coastal terraces are often dominated by plants other than grasses (Stromberg et al. 2001; Hayes and Holl 2003a), and total plant diversity may exceed 20 native species/square meter (Stromberg et al. 2001), whereas in interior dry grasslands, one may only find 5 to 10 species/square meter (Harrison 1999b). Drier slopes of the coastal ranges or the central valley foothills may be only co-dominated by grasses (Carlsen et al. 2000). It is not at all clear that the bunchgrass *Nassella pulchra* (purple needlegrass) dominated in the drier, upland plant communities there (see Keeler-Wolf et al., Chapter 3; D'Antonio et al., Chapter 6). Portions of California's central valley were locally inundated seasonally and may have been relatively diverse, supporting alkaline-tolerant plant communities and a variety of grasses other than *N. pulchra* (Holstein 2001; Lombardo et al. 2007).

By comparison to California, the Midwest has a rich literature on plant community composition, structure, and controlling processes of reference remnants of the tall grass prairies (Clements 1934; Packard and Mutel 1996). Yet even there, the definition of a successful restoration has been elusive and now includes some criteria for the amount and distribution of native plant diversity (Martin et al. 2005). Explicit inclusion of native animals in grassland restoration (Martin et al. 2005) is rare but may be critical in drier grasslands (see Schiffman, Chapter 15).

While little data exist with which to build a quantitative classification—or to reconstruct a historic flora—it is clear that remnant California grasslands have great geographic and floristic diversity (see Keeler-Wolf et al. Chapter 3) and high ecological value (Jantz et al., Chapter 23). Sawyer and Keeler-Wolf (2007) describe 25 vegetation series dominated by native perennial grasses in California, with an additional eight series dominated by introduced annual or perennial grasses. Most of the native grassland once thought to have occurred in and around the Great Central Valley and surrounding foothills has largely been converted to agriculture and urban uses (Huenneke and Mooney 1989b). Remnant grasslands provide habitat to many federally listed species (see Jantz et al., Chapter 23), including 48% of California's listed terrestrial invertebrates, 50% of the listed terrestrial vertebrates, and 82% of the listed vascular plants (HCPB 2006). California's native-dominated remnant grasslands are clearly of conservation importance—and therefore of interest to restorationists—throughout the state.

Ecological restoration is intimately related to the population biology of each of the species being assembled (Montalvo et al. 1997). A successful long-term restoration will include populations large enough to survive in a dynamic landscape and to allow adaptive natural selection (see Rice and Espeland, Chapter 11). Population biology in California grasslands has another unique implication for restoration planning. As California's grassland composition and relative species composition are largely driven in a particular year by annual rainfall patterns (Reever Morghan et al., Chapter 7; Dukes and Shaw, Chapter 19), and this can be highly variable (Jackson and Bartolome 2002), the use of a relatively pristine "aboriginal" grassland as a model for restoration (White and Walker 1997) with data taken from only one year could be misleading. The assembly of species in a restoration on a particular site represents a complex of decisions in a matrix of constraints.

Restoration Constraints: Legacies of the Past

Grassland restoration efforts must take into account the current and desired species composition of a site and effects of past human activity (Baker 1989). Some of the more important legacies to consider in restoration are discussed in the following paragraphs.

Invasive Non-native Species

Invasive non-native species represent the single greatest impediment to grassland restoration in California (and throughout the United States west of the Rocky Mountains). How they prevent the return of native perennial grasses is not clear, but introduced grassland species are highly competitive in many circumstances (Corbin et al., Chapter 13). They maintain a very large soil seed bank and can overwhelm native seedlings after fall rains. Some may take advantage of unique associations with soil biota (Reinhart and Callaway 2006) or anthropogenic sources of added nitrogen (Weiss 1999), while others may be allelopathic to natives (Tinnin and Muller 1971, 1972). The replacement of perennial grasses with annual grasses has also increased the deep soil water availability, thus providing a new resource for late-season, taprooted invasive plants such as starthistle (Reever Morghan and Rice 2005). Grasslands in California dominated by non-native species appear to be new stable states (Seabloom et al. 2003b, Seabloom and Richards 2003); these communities persist until some active restoration including native species are undertaken.

Soils and Land Use

Historical land use often involved plowing, including deep disking, and has been associated with the loss of much of California's perennial, native grasslands on deep, arable soils (Stromberg and Griffin 1996). Initially, such plowing completely eliminates the native perennial bunchgrasses. When formerly farmed fields are abandoned, exotics quickly invade. However, plowing may also create longer-term conditions that favor exotics over natives. Disrupting the relationship between native plants and their complex soil microbial communities often harms efforts to re-establish natives (Perry et al. 1989; Allen et al. 2002; Wardle 2006). Plowing California grassland soils results in dramatic loss of both microbial species diversity and composition (Steenwerth et al. 2002). These effects persist in old fields even if they are not further disturbed for up to 70 years (Jackson et al., Chapter 9). Partial restoration of a microbial community toward that of remnant native grasslands appears to take place in soils of native grass production fields, but these have been intensively managed through irrigation and repeated weed control (Potthoff et al. 2005b). Whether the "annual grassland" microbial communities in rangeland soils with a history of tillage will affect the success of re-establishing natives remains largely unanswered.

In addition to plowing, many areas in California were subject to mechanical raking or large-scale vegetation type conversion (Merenlender et al. 2001). Oak savanna edges or edges of abandoned agricultural fields in California (Stromberg and Griffin 1996), unlike the Midwest tallgrass/woodland edges, may be quite stable (Carmel and Flather 2004, 2006), defying the Midwestern concept of ecological succession (Clements 1916). Likewise, dense oak woodlands have been bulldozed in recent times and resist subsequent restoration efforts, remaining instead as weedy grassland (Brooks and Merenlender 2001; Merenlender et al. 2001; and see Tyler et al., Chapter 14). Also, there exists a decades-long recruitment gap in blue oaks and valley oaks in some wooded grasslands (Tyler et al. 2006), which may presage an eventual conversion to pure grassland unless oak restoration efforts are successful.

Large-scale grading and soil loss was common in much of the historic land use in California (1840s–1940s) (Kinney 1996; Heise and Merenlender 2002). The loss of the productive A horizons, exposing the less productive subsoils, was widespread. Some species commonly used in California grassland restoration (e.g., *Nassella pulchra*) can survive and perform well on these less productive soils (Lombardo et al. 2007) or subsoils (Jaymee Marty, personal communication, 2006), in contrast to establishment efforts on rich, deep soils, where competition with non-native, invasive plants is common. For example, native grasses achieved 75% cover with very few weeds on a two-acre site that had been spread with subsoil from a pond excavation (Maxwell Flat project; Table 21.1). When sites with deep, productive soils do become available for restoration and there is effective weed control in place, a variety of native grasses can quickly establish dense stands that effectively exclude exotics, as illustrated by the Mace site in the city of Davis (Table 21.1).

Viruses

Another historical legacy of the invasion of California grasslands is the presence of viral diseases introduced with European agriculture. For example, barley yellow dwarf virus (see D'Antonio et al., Chapter 6) can thrive on the widespread, abundant, non-native *Avena fatua* and other species and can infect and reduce the survivorship of the nearby perennial native grasses (Malmstrom et al. 2005a, b). Grazing appears to partially counteract the effects of these viral infections in *Nassella pulchra* (Malmstrom et al. 2006). At the very best, however, the presence of viruses may limit grasslands restoration goals to an equilibrium in which perennial, native grasses persist as low-density populations in a background of non-native annual grasses (Malmstrom et al. 2005b).

Road Construction

Roads increase both the spread of invasive species and the loss of native species (Gelbard and Belnap 2003; Gelbard and Harrison 2005). They promote and concentrate seed vectors (vehicles, domestic animals, etc.), and common road maintenance practices (e.g., annual grading) provide the disturbance required for the persistence of many invasive, non-native annuals.

Fire

With the arrival of humans in the late Pleistocene, and the development of fire as a tool by the indigenous people (Greenlee and Langenheim 1990), large areas of California were burned regularly, including grass-dominated sites (see Reiner, Chapter 18; Anderson 2005). Fires were set frequently (every 2–5 years) by Native Americans to keep grasslands relatively free of shrubs and trees (Margolin 1989) and for

FIGURE 21.1. (a) Headwaters of Wildcat Canyon, San Pablo Ridge, Contra Costa County, California, 1902. Bald Peak is on left in the distance, and Grizzly Peak is right of center. This is very typical of the Berkeley hills, where trees were largely absent except along watercourses. From: Lawson and Palache (1902), plate 15. (b) Headwaters of Wildcat Canyon, as in (a), July 2002, with Bald (=Vollmer) Peak on left and Grizzly Peak on right. Tilden Botanic Gardens is on the left, with mowed, irrigated lawn in foreground. Plantations of Monterey pine, eucalyptus, and other conifers, plus other woody vegetation, have replaced former grasslands (Edwards 2002).

many other purposes in grasslands (Anderson 2005). Since European settlement, fire frequency has been considerably reduced in many areas (Greenlee and Langenheim 1990), resulting in conversion of former grasslands to shrublands (McBride and Heady 1968; Edwards 2002). For example, the Berkeley hills and much of the San Francisco Peninsula were open grassland at the time of intensive European settlement (Figure 21.1). After decades without fire, they have converted to woody vegetation. Maintaining a fire return interval that is locally appropriate can be particularly challenging for a grassland restoration but may be critical (see Reiner, Chapter 18).

Grazing

Pleistocene California grasslands were one of the more spectacular grazing systems in the world (Wigand, Chapter 4; Edwards, Chapter 4; Schiffman, Chapter 4). With the arrival of humans in the Pleistocene, there was a precipitous drop in the larger animals ("megafauna"), perhaps due to overhunting by humans (Martin 1974; Alroy 2001). California's 13 species of large carnivores dropped to one, and the 18 large herbivores were reduced to five (Edwards 1996). With the arrival of hunting-gathering people in the Pleistocene, and the megafauna disappearing, it has been suggested there was some other sudden change (Lambert and Holling 1998) on the landscape scale (Owen-Smith 1987). This loss of megafauna may have been associated with a human-caused increase in fire frequency (Greenlee and Langenheim 1990), which would have landscape-scale effects. With European settlement, fires were suppressed and the last of the large herds of elk and antelope on the grasslands were eliminated and replaced with feral cattle and later domesticated livestock

TABLE 21.1
Selected Native Grass Restoration/Seeding Projects in Northern California 1990–2005

Project name and landowner	*County*	*Grassland type*	*Acres*	*Species used*	*Preplanting site treatment*	*Planting date, method and rate*
Corral Pasture Private[a]	Yolo	Foothill grassland Grazed pasture	30	*Bromus carinatus* *Elymus glaucus* *Melica californica* *Nassella lepida* *Nassella pulchra* *Poa secunda*	Burn 6/2000 Disking 10/2000	Drill seeded 12/2000 19 lbs/acre
Ranchette 1 Private[a]	Yolo	Foothill grassland	50	*Elymus glaucus* *Elymus multisetus* *Nassella lepida* *Nassella pulchra* *Poa secunda*	Pre-fire grazing 3/2002 Burn 5/2002 5/2003 Disking 11/2002 11/2003	Drill seeded 35 acres 11/2002 21 lbs/acre 25 acres 12/2003 21 lbs/acre
Back 40 Private[a]	Yolo	Foothill grassland	40	*Elymus glaucus* *Elymus multisetus* *Nassella lepida* *Nassella pulchra* *Poa secunda*	Burn 6/2000 Disking 10/2000 10/2001 Herbicide 4/2001 11/2001	Drill seeded 11/2002 20 lbs.acre

Postplanting management	*Initial site conditions/problems*	*Stand condition as of 2006*	*Lessons learned*
Grazing 4/2001–2005 Swathing 6/2002 Herbicide 12/2000 4/2001	Very compacted holding pasture at large cattle ranch. Heavily invaded with medusahead, goatgrass and yellow starthistle with virtually no native grass cover, although natives were presented in shaded riparian zone	Relative cover of native grasses approximately 30% after 5 years. While overall cover seems to have stabilized at the site, the relative cover of individual native grass species shifted with *B. carinatus* and *P. secunda* dropping to low levels and *N. pulchra* and *E. glaucus* persisting. Initial prescribed fire had a significant negative effect on relative cover of medusahead, goatgrass, and yellow starthistle, but by 2005 relative cover of goatgrass had rebounded to levels that are not significantly different from preproject levels.	Success of project due in part to highly cooperative rancher willing to move cattle in and out of pasture at appropriate times. Goatgrass very difficult to control with methods that work well for medusahead and starthistle (e.g., burning, grazing). Goal at rangeland sites should not be to eradicate non-native forage grasses (e.g., wild oats and soft chess) but to manage site for maximum biodiversity with appropriate grazing. Long-term management necessary.
Grazing Mowing Herbicide	Site dominated by medusahead and yellow starthistle (YST) with annual ryegrass in swale areas. Private ranchette with no commercial grazing made it necessary to import grazing animals. Very hilly; difficult to drill and mow.	Relative cover of native grasses approximately 31% in 2005, 3 years after initial burn and 2 years after seeding. Cover of yellow starthistle (YST) remains low due to treatment with herbicide, but cover of non-native grasses, especially medusahead, on the rise. Annual ryegrass persists in swale areas.	By third year after initial burn, medusahead had rebounded to near preproject levels, indicating that repeat burning may be necessary. Grazing was limited and done with sheep and goats and did not significantly control weeds. Repeated mowing was not sufficient to keep medusahead at bay.
Mowing 4/2003 4/2004 4/2005	Diverse mixed annual grassland with high cover of native and non-native forbs and scattered perennial bunchgrasses. Surrounded on two sides by neighboring ranch dominated by medusahead and goatgrass. High cover of starthistle.	No preplanting data are available, but one-year postplanting native grass cover is nearly 50%. Site is very hilly with individual native grass species alternating dominance depending on slope and aspect.	Site was kept fallow with disking for 2 years following initial burn treatment, which may explain initial stand success. Herbicide was not applied after grass planting to maintain existing populations of beneficial forbs. No resident population of grazing animals, so site was maintained with mowing instead of grazing.

(Continued)

TABLE 21.1 (CONTINUED)

Project name and landowner	County	Grassland type	Acres	Species used	Preplanting site treatment	Planting date, method and rate
Maxwell Flat Private[a]	Solano	Foothill grassland Grazed pasture	66	Three different mixes used with varying combinations of: *Elymus glaucus* *Elymus multisetus* *Koeleria macrantha* *Melica californica* *Nassella lepida* *Nassella pulchra* *Poa secunda* *Vulpia microstachys*	Burn 5/2003 5/2004 5/2005 Disking 11/2003 11/2004 Herbicide 11/2003 11/2004	Drill seeded 50 acres 11/2003 21 lbs/acre 16 acres 11/2005 21 lbs/acre
Colusa N USFWS[b]	Colusa	Wetland?	23	*Hordeum brachyantherum* *Nassella pulchra* *Elymus glaucus*	Burn Sum/1997 Disk 2 × Fall 97	Drill seeded 12/97 15 lbs./acre
Llano Seco Tract 1 USFWS[b]	Butte	Riparian understory	65	*Hordeum brachyantherum* *Nassella pulchra* *Elymus glaucus* *Elymus trachycaulis* *Leymus triticoides*	Burn 1999 Disking Herbicide	Drill seeded 30 acres 1/2002 (with fertilizer) 35 acres 11/2002 15 lbs./acre (no fertilizer)
Turtle Bay Discovery Park City of Redding[c]	Shasta	Riparian terrace	28	*Leymus triticoides* *Carex barbarae (sedge)*	Herbicide (no date given)	Plug planted 28 acres 11/2004 ~1500 plugs/acre

Postplanting management	*Initial Site conditions/problems*	*Stand condition as of 2006*	*Lessons learned*
Grazing 4/2004 4/2005 spot spraying	Site a large, relatively flat pasture adjacent to riparian areas. Historically grazed and farmed, with high cover of medusahead, goatgrass, and yellow starthistle. Subsoil from pond excavation covered 2 acres. Landowner leases grazing rights to neighboring ranchers, so timing of grazing episodes have to be coordinated among many pastures.	50-acre site planted in fall after 2 sequential years of pre-planting fire shows higher relative cover of native grasses (nearly 50% after 2 years) and lower weeds than 16 acre site also burned twice but at which planting was delayed a year. Rainfall and temperature seem to be a factor. Two-acre site covered in subsoil from pond excavation had very high cover of native grasses (close to 75% relative cover) but almost no native or non-native forb species.	“Cookbook” approaches to grassland restoration are inadequate. Analyze what is going on and tailor treatment regimes to that. Have patience; areas that start out with low cover of natives may catch up with nearby areas that start out stronger. High rainfall does not guarantee success; long periods of low temperature may hinder germination. Well-timed grazing key to success.
Herbicide 12/1997 4/1998 6/1998 4/1999 3/2001 Mowing Sum 2000 Burn 12/1999 11/2002 Sheep grazing 4-7/2001	Primary weed initially was yellow starthistle (YST) along with wild oats and ripgut brome. Surrounding areas weedy as well, but phenoxy herbicide restrictions in place after April 1.	Very robust stand as of fall 2005.	Could have used more weed control preplanting and in surrounding areas. A larger, later seeding (Colusa S, 49 acres in 2003) in same area using a similar seed mix and methods developed a very poor stand in comparison, possibly due to delay in seeding until January and February.
Mowing 3/2002 Herbicide 2/2003	Site borders Sacramento River with riparian communities on 3 sides. Historically dry farmed. Non-native invasive annual plants dominated the site with small patches of native shrubs and trees until habitat restoration began in 1999. Primary understory weed annual ryegrass with wild oats.	Excellent stand with close to 90% cover of native grasses, which are competing well with non-natives.	
Mowing 5/2004	Site is a low riparian terrace along the north bank of the Sacramento River in the City of Redding. Historically used for agriculture, the site was initially infested with vetch and moth mullein.	Good establishment. *Carex* growing well with drip irrigation.	

(Continued)

TABLE 21.1 (CONTINUED)

Project name and landowner	*County*	*Grassland type*	*Acres*	*Species used*	*Preplanting site treatment*	*Planting date, method and rate*
Citrona Farms Road 26 Private[d]	Yolo	Foothill grassland	80	*N. pulchra* *E. glaucus* *P. secunda* *H. brachyantherum*	Burned 7/1992	Drill Seeded 11/1992 with Roundup
Citrona Farms Bottomland Private[d]	Yolo	Foothill Grassland	100	*N. pulchra* *E. glaucus* *Hordeum brachyanthum* *Elymus trachycaulis* *H. californicum* *P. secunda* *Melica californica* *Festuca idahoensis*	Burned, Disked 10/1993	Drill seeded 11/1993 with Roundup immediately after drilling.
Hedgerow Farms[d]	Yolo	Foothill Grassland	90	*N. pulchra* *E. glaucus* *Hordeum brachyanthum* *H. californicum* *P. secunda* *Melica californica* *Festuca idahoensis*	Complex series of restoration trials; spraying or burn in fall.	Drill in fall, starting in 1990. Continued through 2006.

Postplanting management	*Initial site conditions/problems*	*Stand condition as of 2006*	*Lessons learned*
Broadleaf Herbicide 2/1993, 2/1994, 2/1995, 2/1996. Mowed March-April each year, 1993–1997. Winter of 2002, 2003, 2004, grazed sheep.	CRP (Federal Conservation Reserve Program lands, under Farm Act; withdrawn from farming) were fallow for several years, previously dry-farmed. Weeds included YST, *Avena* sp., *B. diandrus*, annual rye grass, B. *hordeaceus*. CRP did not allow grazing.	In 2000–2001, medusahead grass began to show up. *N. pulchra* surviving but surrounded by medusahead. Grazing enhanced relative abundance of native perennials. Seed sources not known, would have preferred local ecotypes. *Hordeum, Nassella*, and *Elymus* had mixed successful stands throughout the site. After 4–5 years, clearly a separation of species relative to terrain; *Nassella* dominated some areas, *Elymus* others, and *Hordeum* dropped out entirely.	They had persistent broad-leaf treatment, and wiped out *Brodiea* and probably other forbs with persistent 2,4-D treatment. Grazing early in program is advantageous. Need to get rules for CRP changed to allow grazing. More selective herbicides coming into certification for use in 2006 can control YST without as much damage to the native forbs.
Broadleaf Herbicide 2/93, 2/94, 2/95, 2/96 to 2/97, 2/98 Grazed sheep March ’95 through June.	Previously dry land farmed and grazed. Very productive soils. Many, complex treatments and many complex seeding trials.	Excellent stand establishment, managed with sheep and spraying through 1998 then left alone. YST became abundant, especially in alluvial bottomland where *E. glaucus* and *N. pulchra* were established. YST and medusa head invaded much of the planting, especially the uplands. Stands did well through June of 2003.	Don’t let YST go to seed; stay after it with spot spraying. If you let it go one year, say from 20/plants/acre, it can become the dominant plant in a year. *N. pulchra* dominated the hillsides, and in this case, *E. glaucus* persisted and dominated in alluvial plains. The other species were only occasionally present for unknown reasons.
Various herbicides, mowing, grazing, burning, reseeding, and interseeding forbs.	Previously dry farmed (winter wheat, grain crops). Corning red gravel with shallow durapan in many places (standing water).	Stands are about 50–50; never have a thick stand of grass; 1 bunch/m^2 is as good as it gets. In-between is the struggle; *Hemizonia*, vinegar weeds (*Trichostema*), and other native forbs are coming in with mowing and burning. Dominant natives are *N. pulchra*, some areas good stands of *P. secunda*, patchy *Melica, Elymus glaucus* restricted to better soils (alluvial, swales, where oaks thrived). *Elymus multisetus* persists in shallow soils. Constant management for weeds between the established grass plants. Grazing makes the most sense; no smoke, relatively cheap.	Would like to do it all again. Would have used site-specific ecotypes. Continue monitoring and management on all sites. Medusahead has arrived in area, but prescribed fire, some grazing (sheep), and permanent fencing (to move cattle in) has helped. One of the best management options is sickle bar swathing, just before weeds make mature seed. Windrows burn easily and hot later in fall, and this kills seeds. Windrows may shade the established native bunches for one year, but they regrow the next year. Animals will eat windrows of ripgut and wild oats. Good for first-year stands when you can’t get animals in to graze to allow light into small plants. Baling windrows removes much of the seed.

(Continued)

TABLE 21.1 (CONTINUED)

Project name and landowner	*County*	*Grassland type*	*Acres*	*Species used*	*Preplanting site treatment*	*Planting date, method and rate*
Sunset Ranch The Nature Conservancy[e]	Butte	Riparian	30	*Hordeum brachyantherum* *Nassella pulchra* *Elymus glaucus* *Leymus triticoides*	Cover crop of legumes Mowed 4–5/2003 4/2004 Prism 11/03 Herbicide 2/2004	Drill seeded 12/2004 15 lbs/acre
Colusa CREP and WRP sites Various private[f]	Colusa	Former rice fields	8 properties totaling 257	*Hordeum brachyantherum* *Nassella pulchra* *Elymus glaucus* *Leymus triticoides* *Elymus trachycaulis*	Rice crops through fall 2002; fallow through summer 2003; Disked 3 × 9/2003	Drill seeded (on-site aerial broadcast 11/2003 13.5 to 16 lbs./acre
South Ranch, Diablo Canyon[g]	San Luis Obispo	Coastal Terrace	20	*Bromus carinatus* (20#) *Elymus glaucus* (15#) *Deschampsia cespitosa* (8#) *Nassella pulchra* (15#)	Disk	Drill seeded, 11/1997 50 lbs./ac.
Russian Ridge[h]	San Mateo	Coastal Prairie, Inland	200	12 forbs planted with *N. pulchra* *B. carinatus* *E. glaucus* *Festuca californica* *H. brachyantherum* *Koeleria macrantha*	Burn, mow, herbicide, graze (goats, sheep) hand weeding (1996–2000)	No-till drill

Postplanting management	*Initial site conditions/problems*	*Stand condition as of 2006*	*Lessons learned*
Herbicide 12/2004 3/2005 5/2005	Riparian site along Sacramento River, initially infested with rye grass and mustard. Cover crops were used preplanting as a smother mulch.	Excellent germination, but too early to determine ultimate stand quality. Ongoing problems with fluevellin, Johnson grass, and Russian thistle. A second larger TNC project (135 acres) on nearby USFWS land at the same time with similar techniques will prove an interesting comparison over time.	Thatch from ryegrass and other weeds caused problems with pretreatment weed control. Cover crops may not have been necessary. Perhaps best to keep the ground barren for 2 years prior to planting.
Disked sum-fall 2003. 2 sites ring rolled. Herbicide on only one site.	Former rice fields, very wet. Silty clay, frequently flooded. Wet conditions precluded use of ground equipment on one site, so seed was aerially applied. A variety of mesic soil weeds present, including smart weed, curly dock, rye grass, rabbit's foot grass, and clover.	Some sites had excellent initial germination, but prolonged flooding delayed or stunted some sites. Driest sites had the most growth first season.	Communication and coordination with private landowners is key. Success rates among the sites was correlated with how many times and for how long they flooded. Repeat flooding will slow growth rates of natives. Residual vegetation from fallowed fields proved difficult to deal with even with disking; preplanting fire or grazing would have helped.
Grazing continues. Site is mowed, native grass is baled and used for erosion control (and planting) on balance of site.	Former pea fields, abandoned and weedy before planting. Weeds were radish and mustards, decreased with mowing over time.	Current stand is *Nassella* and *Deschampsia*, the other species were lost. Brome lasted 3 years, now $<10\%$; *Elymus* $<2\%$; but cover of *Nassella* is 80% and *Deschampsia* at 20%.	Would have gone with different species, sometimes moved to site cattle too early in a year. First 3 years, *B. carinatus* did very well, with many nesting birds. *E. glaucus* not native/did not thrive on flats, but higher in scrub. Replace *B. carinatus* and *E. glaucus* with *Hordeum brachyantherum*. *Deschampsia* did very well, cattle select it first, and eat it to ground; care needed not to overgraze. Project successful without irrigation, herbicides, or fertilizer. Grazing reduced cover of fast-growing annuals. but over several years.
Fire in second and third year, then discontinued.	Abandonded pastures and dryland farm lots on coastal forbland, bald hills between deep ravines supporting forests/shrubs. Primary weed is yellow starthistle. Lowest cost/most effective reduction of YST was with spot spraying of Transline.	Herbicide reduced YST to near-zero. Spectacular flower shows for years after fire and planting. Where drill seeding, native grasses doing well; however, in other locations, YST is returning. Grazing with goats did not reduce YST adequately; adding sheep and increasing herd density resulted in near-eradication of YST rosettes and stems.	Counted on being able to burn to maintain the grasslands, but could not get permits and staff in subsequent years. Now need to find replacement for fire, considering grazing. Without sustained burning, the flowers are less abundant and YST is returning to pretreatment cover levels.

(Continued)

TABLE 21.1 (CONTINUED)

Project name and landowner	*County*	*Grassland type*	*Acres*	*Species used*	*Preplanting site treatment*	*Planting date, method and rate*
Mace Site City of Davis[i]	Yolo	Alluvial along Putah Creek	85	*Elymus triticoides* *Others*	Recontoured to swales, breached levee for seasonal flooding. Disked and rolled	Drill seed 11/2000
Dye Creek Ranch TNC[j]	Tehama	Volcanic terrace and foothills	10	*Nassella pulchra*	Burn, nonburn, grazed, nongrazed. Seed is collected locally and then grown commercially and harvested as hay.	Fall, 1997 to present. 16 bales/acre = 10 lbs seed/acre
Sulphur Creek City of Redding[k]	Shasta	Seven projects in area; alluvial terrace Sacramento River	1 mile long, 40–100 feet in width.	*Elymus glaucus* *Elymus triticoides* *Deschampsia elongata* *Nassella pulchra* *Festuca idahoensis* *Bromus carinatus* *Lotus purshianus*	Restored stream banks, realigned stream, connected it to historic floodplain.	Fall 1997 to 2005
Rice Ranch Orcutt, CA[l]	Santa Barbara	Sandy, coastal grassland	10	*Nassella pulchra*	Excavated holes for individual plants with auger on Bobcat.	March–April, 2006

SOURCES: [a]Audubon California, Stewardship Program Yolo County; contact: Chris Rose. [b]U.S. Fish and Wildlife Service, Native Grass Working Group, Butte County; contact: Joe Silviera. [c]River Partners, Chico, California; contact: Tom Griggs or Dan Efseaff. [d]NRCS, Woodland Field Office and Hedgerow Farms; contact: John Anderson. [e]The Nature Conservancy, Chico, California; contact: Ryan Luster. [f]NRCS, Colusa County; contact: Jessica Groves. [g]Pacific Gas and Electric, Diablo Canyon Nuclear Power Plant; contact: Sally Kren. [h]Midpeninsula Regional Open Space District; contact: Cindy Roessler. [i]City of Davis; contact: Mitch Sears. [j]TNC, Chico; contact: Rich Reiner. [k]City of Redding, Sacramento Watersheds Action Group; contact: John McCullah. [l]Rice Ranch, LFR Inc.; contact: Mary Carroll.

Postplanting management	*Initial site conditions/problems*	*Stand condition as of 2006*	*Lessons learned*
Grazed (cattle), mowed, (swathed and baled), spot herbicide.	Tomato fields, managed as clean row crop agriculture. Two management zones; alternating grazing between years. Fires are planned.	Excellent stand establishment, almost entirely creeping wild rye. About 90% cover of *E. glaucus*. Very productive soils. Drip irrigation put in for shrubs and trees. Tolerating standing water in two of four years, period of inundation; several weeks.	Seeded immediately after farming. Weed seed bank depleted by long-term use in agriculture. Good soils produce excellent stands of creeping wild rye. Deep thatch was a problem; swathing and baling effective solution. Grazing with nearby, cooperating farmers very successful, justified adding permanent fencing.
Baled native hay is spread by hand or with a blower on experimental plots (grazed, ungrazed, burned).	Low-productivity annual grasslands on level or slightly sloping shallow soils. Site is dominated by *Bromus*, *Vulpia*, and forbs. Hay is spread on spring burns designed to reduce medusahead grass and improve native grass establishment.	Site is monitored, and data are available at TNC Chico. Cover of planted *Nassella* approaches that of remnant local stands.	Hay spreading into burned areas is a viable way to reintroduce *N. pulchra* at sites where seed drilling is not possible. Establishment is best on sites with soils and aspect similar to remnant stands of Nassella found on the ranch.
Hand broadcasted the seed. Covered with native or certified weed-free mulch.	Site historically mined with dredges, leaving huge boulders and cobbles. Did biotechnical erosion control in stream for stream bank stabilization (federally listed salmon).	Excellent stand establishment. YST control is still an issue. Stands are reproducing. No management since establishment.	Used everything from heavy equipment to volunteers to successfully restore native grasses in a site where extensive erosion control, soil stabilization and stream bank restoration were conducted.
Irrigated over summer months	Site dominated by *Nassella pulchra*, to be converted to housing; plants salvaged, moved to mitigation site on nearby old field (2 acres) and disturbed sandy coastal scrub (2 acrease)	Excellent survivorship, but areas between mature plants dominated by common non-native invasive weeds. Additional *Nassella* planting (from seed) planned for balance of mitigation sites.	Salvage on a large scale appears to be successful at early stages of project. More weed control before planting would have been helpful, but no time. Mulch mats helped control weeds around mature plants.

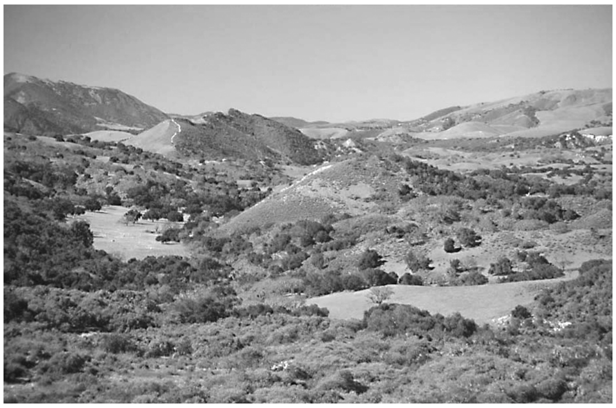

FIGURE 21.2. View from area near Tassajara road and Carmel Valley road, to west showing complex mosaic of grasslands, chaparral, and oak woodlands in central California Coast Range. Photograph by Mark Stromberg.

(McCullough 1969). Livestock grazing was intense and year-round, likely contributing to the loss of native perennial grasses and changes in soil structure. Over much of California, grazing pressure today is less than during much of the late 1800s and early 1900s, but land management today is often limited by effects of this intensive recent grazing. The role of grazing in California grassland restoration remains controversial (see Jackson and Bartolome, Chapter 17; Huntsinger et al., Chapter 20), but certain grazing practices can be effective tools in restoration, particularly in the roles of reducing exotic species (Marty 2005) and increasing native annual forbs (Hayes and Holl 2003a).

Given these constraints, it may be unrealistic to expect the re-creation of the original California grassland flora across extensive landscapes. Goals might be more appropriately focused on restoring a mosaic of patches of native grassland communities (including the associated animal and plant species) using similar aboriginal grassland communities (Keeler-Wolf et al., Chapter 3) as models, and these interspersed with other vegetation types as in the upper Carmel Valley in Monterey County (Figure 21.2). Native grasses can probably be found in almost any area of Mediterranean California that has not been entirely transformed by agriculture or housing, but patch size, even in very large, relatively undisturbed landscapes, can be highly variable (Taylor and Davilla 1986; Huenneke 1989). The scale of this patchy distribution may be fractal (Green et al. 2003), with areas of native grass populations varying in size from a few individuals to 2 hectares. We still have little evidence of large California landscapes dominated by native California grasses (Hamilton 1997a). Restoration and grassland management plans alike need to take this inherent nature of California grassland's patchiness into account.

This complex historical legacy presents significant challenges to restoring California grasslands. However, the widespread distribution and persistence of native species–dominated grasslands in small patches is encouraging and presents some models for restoration. Individual projects throughout the state also suggest that with intensive management, restoration toward native dominance is possible.

Practical Issues in California Grassland Restoration

Establishing Goals and an Implementation and Management Plan

The most important step in considering the restoration of a grassland area is to establish broad goals, discrete objectives, and measurable success criteria for the project. Clear goals will guide the initial plan and the implementation process according to the resources available. Measurable objectives will allow the project to stay on track and assist with adaptive decision making as the project site undergoes change.

Typical grassland restoration goals in California include increasing native species diversity and habitat protection, control of invasive non-native species, erosion control or soil stabilization on badly disturbed sites, site water management (water quality or water retention), forage quality improvements (See Box 21.2), or aesthetic improvements. Often restoration goals are associated with legal requirements, such as mitigation. Although many restoration projects are spatially delineated, all else being equal, bigger is better. One of the more general guidelines from ecological theory is that species diversity and persistence are positively correlated with the size of a functional habitat (MacArthur and Wilson 1967). However, small patches, even down to the size of gardens, can harbor an amazing diversity of native plants and insects and add interest and beauty to urban and suburban settings (see Box 21.1).

The goals and objectives of the project are the foundation of an implementation and management plan. The management plan should include a timeline for all restoration activities as well as a detailed management strategy for many years after the initial project implementation. Many native grasses require at least three years (Bugg et al. 1997) to establish, requiring more intensive weed control during the establishment phase. An accurate establishment evaluation of *Nassella pulchra* often requires up to seven years from seed to be readily apparent (personal observation, and J. Anderson, personal communication, 2006). Ongoing management (beyond three years) may be less intensive, but nevertheless critical.

Ecological restoration of California's grasslands is a long-term commitment involving inherent scientific, political, social, and economic uncertainties. Because uncertainty is a normal part of any scientific question or human endeavor, it should not prevent effective ecosystem restoration (Lemons 1996). Instead, it should be recognized as part of the decision-making process (Clark and Cragun 1994; Brunner and Clark 1997). Decisions in restoration can often benefit from considerations developed in social and policy sciences (Gobster and Hull 2000). Ethical issues in restoration (e.g., client wishes versus practitioner recommendations) should also be considered (Dickinson et al. 2006).

BOX 21.1 GREEN ROOFS

Living grassland on roofs can provide many ecological services in what is otherwise a relatively hard landscape of concrete sidewalks, impervious streets, and roofs. In Europe, the use of "green roofs" has continued for many centuries. Industry figures suggest that 10% of German roofs are greened. In Zurich, Switzerland, a large water storage tank project, covering a 5-acre (2 ha) site, was built 100 years ago. The builders needed soil to cover the concrete tanks for thermal insulation. The top layer of soil from a nearby pasture was excavated and placed on the roof. Now, the roof is home to 175 plant species, including several that have gone extinct elsewhere (Landolt 2001; Bazilchuk 2006). Between 1989 and 1999, German roofing companies installed nearly 350 million square feet of green roofs, and the rate is increasing (Penn State Center for Green Roof Research, http://hortweb.cas.psu.edu/research/greenroofcenter). In 2001 alone, Germany installed 13.5 million square meters (33,400 acres) of green roof (Grant et al. 2003). The history of green roofs can be traced from the hanging gardens of Babylon to the present (http://www.greenroofs.com/Greenroofs101/history.htm).

Living roofs are essentially a thin layer of soil (4–12", 10–30 cm) over a variety of roofing systems (Figures 21.3, 21.4, 21.5). The layer of soil and plants significantly increases the expected lifetime of the roof surface (membrane, concrete, etc.). Green roofs' advantages include:

- Providing an esthetically pleasing appearance and a natural landscape for relaxation and nature appreciation.
- Capture of storm water that otherwise would have to be treated in municipal water treatment plants. At Ford Motor Company's new River Rouge complex, the green roof of about 10 acres absorbs and transpires up to 4 million gallons of rainwater each year. The savings in decreased costs for treating storm drainage made the roof economically viable.
- Substantial reduction of the urban heat island effect (EPA 2001) and reduction of the heating and cooling costs for the building. Cooling occurs when the water in the roof's soil evaporates. The mass of plants, water, and soil insulates the roof in the winter.
- Substantial reduction of noise in the building, as the soil and plants absorb a great deal of urban noise.
- Metapopulations of native plants from the local flora that in turn can support native insects, birds, and other animals able to get to the roofs to use them for food or shelter.

Desirable plants for living roofs should be:

- Native in the local ecosystems
- Long-lived
- Slow growing
- Tolerant of summer droughts
- Tolerant of seasonal rainfall and inundation
- Tolerant of urban pollutants
- Tolerant of poor soils
- Capable of providing seasonal flowers

There are some excellent examples of green roofs in California, many of which are using some native grasses. William McDonough, architect for Ford Motor Company, designed a 69,000-square-foot (0.7 hectare) roof on the Gap corporate headquarters in San Bruno (Figures 21.3, 21.4). In San Francisco, the new California Academy of Sciences building will have a green roof of 250,000 square feet (2.5 hectares).

If ecologists would seek out architects in the design phase of new buildings with green roofs or green sloping sides, there is a huge opportunity for designing experiments to build and study grassland ecosystems (Felson and Pickett 2005).

FIGURE 21.3. Green roof on bath house at Esalen Institute, Big Sur, California. Photograph by Paul Kephart.

FIGURE 21.4. Coastal terrace grasses on roof of Gap headquaters, San Bruno, California. Photograph by Paul Kephart.

FIGURE 21.5. Coastal terrace grasses on roof at Gap headquarters, San Bruno, California. Photograph by Paul Kephart.

Implementation should consider all the activities required at and around the site. For example, if a landowner or land manager is going to spray or mow a site anyway, try to coordinate that activity with mowing or spraying to support the restoration activity. Or, if you know a weed-clean cropland will be abandoned to a restoration use, then establish the plants there immediately, before weeds have a chance to arrive (Mace site, Table 21.1). If native grasses are going to be incorporated into a riparian or wetland restoration project, make sure the land managers responsible are aware of the specific cycle of management required for grasses, which may differ from other plants at the site.

Site Survey

The importance of an initial site survey cannot be understated. A thorough survey for both the biological and physical characteristics of the site not only will establish benchmark conditions against which future stages of the restoration can be compared, but will determine the overall strategy for the restoration itself. Depending on the condition of the site, the site survey may also reveal an appropriate model ecosystem for the restoration (Clements 1934). Knowledge of similar, nearby sites, particularly as they change over several years with varying rainfall, will greatly enhance the choice of a reference site or help to clarify what sorts of "natural successional processes" might be expected to occur at the site regardless of management activities (e.g., whether shrubs are likely to encroach).

In general, there are two main strategies for grassland restoration, and each is driven by the site characteristics (Packard and Mutel 1996). If the site has a considerable population or populations of remnant native grassland species and is not completely overrun with weeds, a "passive" restoration strategy can be less intrusive and focus on management (Hayes and Holl 2003a; Bartolome et al. 2004). On the other hand, if a site has no native species (including the native soil seed bank), or almost none, and is heavily infested with weeds, it would be far more effective to plan an "active" restoration from scratch; for example, an expanse of bare soil as free of weeds (including weed soil seed bank) as is practical.

The site survey will also determine whether and which permits will be required by local, state, or federal government agencies. If a wetland or stream course is included in the restoration, the permitting process can be more complex. If the restoration is deemed a significant change in the environment, it may require review under the California Environmental Quality Act (CEQA) (Jantz et al., Chapter 23). A query of the California Natural Diversity Database might reveal the presence of listed species. If federally or state-listed species are present, permits and planning will involve both state (California Fish and Game) and federal (U.S. Fish and Wildlife, Office of Endangered Species) agency involvement.

Land managers often hire consultants to conduct site surveys, but it is possible to explore cooperative actions with local watershed groups, local resource agencies and extension offices, or state and federal agencies (Jantz et al., Chapter 23). These include field offices of the Natural Resources Conservation Service, California Fish and Game, California Department of Transportation, chapters of the California Native Plant Society, and others. For a list of restoration projects in California, consult the Web site of SERCAL or CNGA (Table 21.1). These can provide a start for finding a qualified restoration practitioner to evaluate the site.

The initial survey should describe the biota of the site. Any native plants on the site or nearby should be listed and considered clues to restoration potential. Ideally, several samples of the soil should be taken from throughout the site for evaluation of the seed bank, as well as for soil tests to determine the soil properties. In practice, such sampling, particularly for soil seed bank composition, is rarely done. Presence of state or federally listed plants and animal species must be reported, and the areas of their occurrence should be treated as remnants and left undisturbed even if they have many exotic species, unless specific permissions are obtained. If the site has a population of native grasses or other native plants, one must decide whether they are abundant enough to warrant on-site management that will both increase their abundance (see subsequent discussion) and not further degrade the site. Grassland communities may have site-specific protocols; for example, coastal dune grassland restoration presents unique challenges and requires unique methods (Pickart and Sawyer 1998; Pickart and Barbour 2006).

Abiotic site characteristics that influence site potential include slope and aspect, soil chemistry, texture, rockiness, drainage, and depth, plus local climate, rainfall, and the probability and duration of flooding. These can be critical factors in selecting appropriate plants for the restoration as well as planting and management techniques (for example, rocky sites may preclude drill seeding and mowing with heavy equipment, leaving managers to rely on manual or innovative seeding methods such as native grass straw and grazing; see Dye Creek Project in Table 21.1). Finally, the evaluation should consider practical constraints. Some sites will only have seasonal access. Some sites can be grazed, sprayed with herbicides, or burned, while others will have strict limits on some of these restoration activities. Some sites require vegetation to be low, either for visibility (such as highway interchanges) or to maximize water flow (Yolo Bypass, Mace Site, Table 21.1).

Site Preparation

Except in the cases of conversion of clean agricultural fields to native grassland or simple enhancement of existing grasslands, some kind of site preparation is necessary. The extent of site preparation and the techniques chosen will depend on the restoration goals, the results of the site survey, the type of plant material to be introduced (e.g., seed, rhizomes, plug plants, or hay) and on communication with the landowner and the resources available to do the preparation. For most grassland projects, site preparation involves mostly weed control and seed bed preparation. The most common techniques for initial weed control are burning, disking, mowing, mulching, the use of selective or broad-spectrum herbicides, or a combination of these (see DiTomaso et al., Chapter 22; Table 21.1). Postplanting weed control in small sites or at individual (woody) plantings can also include hand-pulling, spot spraying, hoeing, and so forth. Often, glyphosate can be applied at the time of drill seeding (Hedgerow Farms, Citrona Farms, Table 21.1) to eliminate germinating weeds, as it is not persistent and will selectively control growing plants. It is important to begin weed control at a site as soon as possible; even several years prior to planting of native species, depending on the weed species present and the abundance of the weed seed bank (Mace Site, Table 21.1). Soil treatments as a part of site preparation (increasing/decreasing soil fertility or pH, adding microbial elements, or ripping to enhance infiltration) are at early experimental and observational stages. Soil ripping depth was only weakly, but positively, associated with cover of *Nassella pulchra* in year two in one experiment (Montalvo et al. 2002). Additional trials of soil treatments are needed.

It is very important to time preparation actions to maximize their effectiveness. For example, weed control burns should ideally be timed to occur after the annuals have committed to reproduction (and death) but before the seeds have fully matured and dispersed (Moyes et al. 2005). Burning in the spring and early summer provides the greatest control of the noxious weeds medusahead *(Taeniatherum caput-medusae)* and yellow starthistle *(Centaurea solstitialis)*, respectively (Hastings and DiTomaso 1996). Spring burning is nearly as effective as the more expensive solarization of soils with plastic sheeting, as measured by *Nassella pulchra* establishment (Moyes et al. 2005). Although burning in the fall will not be as effective in killing annual weeds, it can provide an excellent seedbed, especially for no-till planting methods in the Central Valley (Anderson and Anderson 1996) (Citrona Farms, Table 21.1).

Most annual exotic grasses germinate shortly after the first fall rains (October to December), and their seed bank has little carryover into the next year (Marañon and Bartolome 1989; Rice 1989b). Tillage during these months will often germinate additional seeds in the soil seed bank. Several cycles of tillage following the flush of additional weeds germinating can reduce the annual exotic seed bank (Stromberg et al. 2002). Irrigation in the fall, and subsequent repeated tillage of the germinating annual exotics, before the winter rains is another option. Various herbicides can be used as preemergents (see DiTomaso et al., Chapter 22) to selectively reduce annual weeds, yet allow native grass establishment or growth. Controlling weeds that germinate with the native plant materials is far more difficult, as each strategy for weed control must then consider the continued survival of the natives (see DiTomaso et al., Chapter 22).

One of the most effective ways to impede invasive weeds in sites where they have been reduced is to establish dense stands of native species (Carlsen et al. 2000; Reever Morghan and Rice 2005; but see Hamilton et al. 1999). It can reasonably be said for many heavily invaded grassland sites that there can be no effective restoration without weed control, and there can be no effective weed control without restoration.

Although soil disturbance should be minimized wherever possible, some grassland restorations occur after construction or other activities have already disturbed the site significantly. In such cases, tillage such as disking, imprinting, or deep ripping along contour lines may be required to reduce soil compaction and maximize seed germination (Montalvo et al. 2002). Controlling erosion at such sites may require additional grading and erosion control measures (ABAG 1995). Where ongoing surface erosion is a problem, bioengineering using native grasses and other plant materials in conjunction with geotextiles, willow wattles, and/or straw (Sulphur Creek, Table 21.1) has proven successful in stabilizing soils (ABAG 1995).

One of the functional groups that may need to be restored are those soil fungi intricately associated with the root system and known as arbuscular mycorrhizae, or AM fungi (Snyder 2003). Topsoils serve as reservoirs of AM fungal spores and hyphae, but disturbance (compaction, vegetation removal, physical destruction of hyphae, etc.) almost always reduces the diversity and abundance of AM fungi (Allen and MacMahon 1985; Jasper et al. 1989). There are about 150 species of AM fungi (Morton et al. 1995), forming associations with about 70% of the plants worldwide. Nearly all grasses form mycorrhizal relationships. Virtually any AM fungus can associate with a vascular plant species capable of forming arbuscular mycorrhizae (Allen et al. 1995), but local sources of AM fungi are probably best to use, although commercially produced AM fungal inoculum is available (Snyder 2003). Soil assays could determine the inoculum potential at a site, or one could look for any plants present known to be mycorrhizal. If they are still present and vigorous, there is likely a remnant mycorrhizal community (Snyder 2003). Mycorrhizal fungi can be reintroduced onto a site using a variety of methods (Snyder 2003), including culturing soil to amplify inoculum, translocating inoculated plants with some associated soil, or culturing spores in sterile soil (Sylvia and Williams 1992). Although plants that can form arbuscular mycorrhizal associations perform much better with the fungi, evaluating the improved performance of target species on restoration sites where AM fungi have been inoculated remains an area where more research is needed (Peters 2002).

Remnant patches of native plants can be salvaged (Rice Ranch, Table 21.1), particularly from sites where they will be destroyed by a planned disturbance (mining, road cuts, construction). They can then be handled like other plant materials. One of the first grassland restoration projects, on the Curtis Prairie in Wisconsin, used this method (Umbanhowar 1992; Howell and Stearns 1993; Sperry 1994). Sod or bunchgrass clumps with a significant root/soil mass can be propagated in a nursery, layered on the ground, irrigated, or covered with straw or shade cloth until transplanted into the grassland restoration site. Salvaging intact grasses ensures that site-specific plants are used for restoration and will preserve local soil microorganisms as well as some of the soil seed bank. Plants may also be clonally fragmented and numerous "sibling" plants divided, thereby substantially increasing plant material available.

Seed/Plant Material Selection

Plant species chosen for the restoration should come from the palette of species that naturally occur on or near the site or can be (with more risk) reasonably inferred to have been native to the site. Also, they should be matched to the site characteristics (see Rice and Espeland, Chapter 11). A database is available for over 300 California native grasses (http://www.dot.ca.gov/hq/LandArch/grass.html), and it includes historical geography, preferred soil type, elevation, and species characteristics. This could help the practitioner select species for use. For instance, only a few native perennial grasses can tolerate several days of flooding. Some species can tolerate clay soils and periodic inundation; others will only thrive in upland, well-drained soils with generally lower soil moisture. That information can be found on the same Web site.

Increasingly restorationists are seeking to include as many "functional groups" of plants (Dukes 2001a; Hooper and Dukes 2004) as possible on a given site and include broad categories such as "deep-rooted perennial grasses," "deep-rooted biennial native forbs." "native annual forbs," "nitrogen-fixing forbs," or "early" and "late" phenology forbs (Lulow 2004). Ideally, an experienced plant ecologist should be consulted to help determine a species list that encompasses the full breadth of functional groups. Although some useful sample species lists for certain common grassland types are available (Anderson and Anderson 1996), these should be tailored to the individual site.

One of the most important considerations in choosing a source for seeds or other plant materials is to preserve the genetic integrity of what is potentially a community of locally adapted populations. The number of studies of genetic variation and adaptation in California grassland plants is fairly small (see Rice and Espeland, Chapter 11), but what information is available suggests a fairly large amount of variation between populations of most species. For example, in *Elymus glaucus* (blue wild rye), the population structure suggests reduced gene flow associated with genetic differences between distant populations (Knapp and Rice 1996). In addition to long-distance genetic differences, there is also substantial within-population variation, perhaps because the plants are not entirely self-pollinating. In *Nassella pulchra* (purple needlegrass) there is highly restricted gene flow resulting from limited seed dispersal distances (Dyer and Rice 1997a), but across the landscape there are only weak differences between nearby populations, probably reflecting the much greater dispersal distance of pollen.

In general, a species occurs as distinct genotypes (or populations) associated with a specific, local environment, and these "ecotypes" (Hufford and Mazer 2003) can interbreed with other ecotypes. Simply observing a group of individuals with some unique traits in a species (color, size, enzymes) does not define an ecotype, because individuals of many species, indeed the same ecotype, can exhibit a wide variety of physical traits (phenotypic plasticity) yet have little genetic variation. The classic approach to detecting ecotypes (Clausen et al. 1940; Linhart and Grant 1996; Hufford and Mazer 2003) requires common gardens and reciprocal transplants, and this has been done for a few grasses used in California restoration (Dyer and Rice 1997a; Knapp and Rice 1998). Newer genetic analyses using molecular markers (microsatellites, sequencing, etc.) hold the promise of a less labor-intensive method to determine levels of local adaptation; however, the evidence for their value in this regard is inconsistent (Hufford and Mazer 2003). Molecular genetics are still best used with common garden studies, and for the few grassland restoration species so far studied in California, the suggestions for restoration continue to support the use of very local seed sources (Knapp and Rice 1996, 1997, 1998; Rice and Knapp 2000). With regard to more practical restoration, if enough common garden studies were done, as have been done in conifer forest restoration (Kitzmiller 1990), "seed zones" could be mapped (Parker 1992). Seeds for restoration in each zone could be harvested in the same zone, and the zones would roughly match ecotypic zones for each species (Hufford and Mazer 2003). Efforts were made to establish the required common gardens to establish seed zones for native grasses (Amme 2003). Market demand for source-identified seed was very low, and native grass seed is no longer included in the California Crop Improvement Association programs to certify seed sources and founder populations.

Because of the lack of common garden studies, we do not always know whether observed genetic variation reflects a history of adaptation to local conditions. We therefore recommend that every effort should be made to preserve genetic differences that are obvious between populations. We also do not know, in most cases, the extent to which nearby populations are related to one another and what a reasonable zone for genetic similarity should be. Studies of the genetics of our native plants in relation to restoration (McKay et al. 2005) have suggested that restoration should be done, as far as practical, with plant material (seeds, rhizomes, etc.) collected as near to the restoration site as possible. A precautionary principle is to collect seed from within the same watershed as the site. If this is not possible, then match climatic and physical conditions (e.g., soil properties) as closely as possible within a reasonable geographic distance. Use plant materials with genetic characteristics (outcrossing, inbreeding, ploidy level) that match those found on the remnant or adjacent ecosystems.

Another consideration in selecting plant materials is how much genetic variation to introduce for each of the species to be planted. Intraspecific heritable genetic variation plays a critical role in the potential for further adaptive change in response to new selective challenges. In the face of global environmental change, allowing for evolution seems critical to the persistence of many species. Although we do not know how rapid the local adaptive selection process is for most California native grassland plants, significant changes can occur over only a few generations (Rice and Emery 2003). Thus, it is important to include a reasonable amount of intraspecific variation in source materials; this may not be too difficult with some of our native grasses (Dyer and Rice 1997a), because even local populations show characteristics found across their range. Additional research on the genetic structure of our grasslands' plants and their rates of microevolution is needed and could provide relevant information for decisions in restoration.

Another issue that can be a problem in restoration is genetic swamping (Rice and Emery 2003); this occurs when a small population of a locally adapted ecotype is surrounded and swamped with pollen or dispersal propagules of a different species or ecotype (intraspecific swamping). Most of the concern related to genetic swamping is related to the potential loss of fitness in a population by introduction of nonadapted ecotypes (Hufford and Mazer 2003). An emerging concern is contamination from either other similar species or genes. If transgenic crops and specialty plants are introduced near restoration sites, they may contribute genes that could be troublesome to nearby native plants (Ellstrand 2006). In California for example, "pollen contamination from cultivated walnut may hybridize the (endangered) Hind's walnut out of existence" (Ledig 1992). Currently in California, genetically modified grasses are being developed by the turf industry (e.g., *Agrostis stolonifera, Poa pratensis*) to be resistant to glyphosate. Field trials of other grasses indicate that effective pollen dispersal occurs as far as 0.6 mile (1 kilometer) (Ellstrand 2006). These grasses are currently regulated in California (Ellstrand 2006), but if these transgenes escape to unwanted grasses, or if these genetically modified grasses themselves escape from cultivation, California would be faced with yet another weed, and this time the weed would be resistant to one of the most important restoration tools available: the herbicide glyphosate.

Often a remnant does not have a large enough population of native plants to provide enough seed for a nearby restoration project. In these cases, it is common to collect some seed on the local site and then provide it to contract growers who will perfom a "seed increase." The U.S. Department of Agriculture (USDA)'s Natural Resources Conservation Service (NRCS) has many plant material centers, including one at Lockeford, California. Along with other federal agencies (U.S. Forest Service, National Park Service), they have detailed seed collection and seed increase protocols (D. Dyer 2003). Commercial growers of native seed can also be engaged. Typically, the seeds are raised in small gardens, harvested and planted in larger gardens, and then planted in agricultural fields for large-scale seed production. Seeds for the restoration should be intentionally selected from all parts of the production field over the entire period of time that the seeds are viable. This avoids unintended selection, and thus genetic shifts that can occur when the fields chosen for seed increase are in very different environments than the restoration site. Seed increases should also be done in a production field as physically close and similar (soils, elevations, etc.) as possible to the native seed sources (McKay et al. 2005).

Seeds or plant material from commercial growers (CNGA 2003) should be correctly labeled with regard to seed source sites and collection dates, be free of weed seeds, and have a "percent live seed (PLS)" rating, or at least informal germination tests to ensure viability (see subsequent discussion). Because PLS can vary for the same species among years and among growers, restorationists should always ask for current PLS data from their supplier. Seed companies in California and elsewhere may have special "reclamation" seed mixes that represent statewide collections of particularly vigorous selections, which may not be suitable to individual sites in terms of either species or ecotypes. Care should be taken to obtain site-specific seed sources from seed vendors.

Planting Technique

The choice of planting techniques will depend largely on the size and nature of the project, the budget, and local site conditions (Robins 2002a). Small projects can be effectively planted entirely with small transplants or "plugs" (Discovery Park, Table 21.1). Larger areas can be planted using vehicles (tractor-operated seed drills or hydroseeders). In either case, the planting must be properly timed so that plants, whether from seed or from plugs, are able to take advantage of available rainfall to become fully established prior to summer drought. Irrigation, common for individual plantings of woody species, is rarely done for broadly planted grasses.

In general, restorations using seed are more successful if planted after the first germinating rain in the late fall or early winter (Colusa, Table 21.1). If seeds are planted before the rains arrive, many are lost to seed predators, or they lose viability as they dry out. Waiting until after the first germinating rains also allows managers to eradicate the first flush of weeds prior to or just after seeding native grasses. For instance, a site can be tilled after the first germinating rain, but just before planting. If the site is planted before the first germinating rain, herbicides (2,4-D, glyphosate, etc.) can be applied if there is a window between the germination of weeds and that of the native plants or if the herbicide can be selectively applied to weeds only, for example, using wick applicators to swipe taller weeds (Llano Seco Project, Table 21.1). Planting from seed in spring is likely to be unsuccessful because many native grasses and forbs require a longer period of warm and wet soils for germination and establishment than is generally available in the spring, and some forbs may require a cold stratification period.

Using plugs is cost effective in smaller projects (~2 acres) or in those in which establishment must be rapid. Both grasses and forbs can be established from plugs (Brown and Bugg 2001). One benefit of plug planting is a very high (often ~90%) survival rate (Cunliffe and Meyer 2002; Corbin and D'Antonio 2004b; Huddleston and Young 2004), perhaps offsetting its higher cost. Another advantage is that plug planting can be done later in the season (mid- to late-winter), allowing site managers to eliminate (by spraying or tillage) a larger component of weed cover. They can also be used in conjunction with pre-emergent herbicide that would otherwise inhibit native grass seed. Grass plugs can be contract-grown at greenhouses using locally collected seed or even rhizomes from obligate vegetative reproducing species. Alternatively, plugs may be ordered from a seed company using commercially available native grass seed. Typically, plugs of grass are planted in arrays 12 to 18 inches (30–46 centimeters) apart to yield an appropriate final density desired for the adult plants (Stromberg and Kephart 1996; Huddleston and Young 2004). However, some situations such as erosion control projects may require higher initial density.

Planting from seed is generally less expensive and therefore more appropriate for larger sites (Robins 2002a). Seed can be broadcast with hand-held or all-terrain vehicle (ATV)-towed rotary seed spreaders and then lightly covered with soil and compacted using harrows or ring-rollers. An example of this kind of planting is the restoration of Holsclaw Levee in the Colusa area, under the supervision of Jessica Groves, NRSC, USDA. Seed can be sown with 8-foot or 12-foot wide tractor-towed seed drills. Seed germination is generally higher if the seeds are drilled shallowly into the soil and covered (Stromberg and Kephart 1996; Kephart 2001; Stromberg et al. 2002). Seeds should not be buried deeply (e.g., with a disc), but good seed/soil contact is required. Cross-drilling the area (seeding twice, but with the second drill lines at right angles to the first) will improve the seed distribution and seed/soil contact, but the drill should then be calibrated appropriately. Several no-till drills have been manufactured (e.g., Truax) that can cut through litter and sod, open a slot in the soil at a set depth, drop the seeds in, and roll the soil back tightly over the slot. Very light or fuzzy native grass seed can be mixed with coarse vermiculite or wheat bran to improve flow through the drill. Seeds with large awns, such as *Nassella* spp., *Hordeum brachyantherum,* or *Elymus multisetus,* often need to have the awns removed before sowing, but de-awning can cause higher seed mortality in long-term storage through desiccation.

When planting from seed, it is very important to determine both the appropriate overall seeding rate and the relative proportions of seeds from different species in the seed mix (Russian Ridge, Table 21.1). Overall seeding rate will vary depending on the method and the objectives of a particular site. Drill seeding rates are generally lower than broadcast seed rates because drilling usually results in better seed/soil contact and therefore higher germination rates. Drill seeding rates can be adjusted by calibrating the seed drill (drive the drill over a swept hard surface or tarp, weigh or count the number of seeds being dropped, and adjust the drill accordingly) and are usually set between 12 and 20 lbs/acre (see Table 21.1). Broadcast seeding rates are mostly determined visually by the experience of the applicator and may be as high as 35 pounds per acre. Determining the relative proportion of different species in a mix, however, is complicated by the fact that species vary widely in the PLS per pound, larger-seeded species tend to have greater success per seed than smaller-seeded species (Lulow et al. 2007), and some species are "fast-starters" and tend to dominate early while others may have delayed germination. A typical seeding density for California native perennial grasses with large seeds (e.g., *Nassella, Elymus*) is 60 live seeds per square foot (600/m^2). When seeding a single species, the calculation of pounds per acre needed to yield roughly 60 live seeds per square foot is relatively straightforward using the PLS number multiplied by 43,560 square feet per acre. However, to achieve a mixed-species stand in which the relative density of the species varies according to the desired species mix in the resulting stand, the calculations are complicated by the fact that species vary widely in their PLS rating (for example, *Nassella lepida* can have 10 times as many live seeds per pound than *N. pulchra*), and this number will vary between growers and between years. Experienced grassland restorationists often use spreadsheets in which PLS ratings are used to calculate ratios of pounds of seed in a mix. The most important thing to remember, however, is to base the seed mix on the current PLS rating, not simply on pounds per acre.

Hydroseeding native grass is an option, especially on slopes that are too steep for equipment or on sites with very wet soils that preclude access by tractors with drills. Most effective hydroseeding is done in two passes. The first pass sprays seed and water, often with a very light binding agent to ensure good seed/soil contact. The next pass will typically distribute 3,000 to 4,000 pounds per acre of straw, compost, or 3/8" chipped wood (CalTrans 2004). Mulch increases available soil moisture, provides thermal insulation (night radiation cooling), and is often required as a soil erosion control measure. If the seed and mulch are mixed in one pass, much of the seed is suspended above the soil in the mulch. Subsequent wetting- drying cycles will see the mulch expand and shrink, uprooting the grass seedlings.

Swathing and baling native grass when it has mature seeds, either in seed production plots or in particularly dense native grass stands, allows one to move native grass seeds in bales and then plant them by spreading the native straw (Dye Creek, Diablo Canyon, Table 21.1). This method is particularly useful for rocky sites where traditional seeding methods are impossible (Dye Creek, Table 21.1). In bales of *Nassella pulchra* straw, the seeds retain their awns, which naturally "drill" the seed into the ground as the awns curl in response to changes in moisture. Such native straw also provides mulch and erosion protection for the seedlings (Hujik 1999) and may provide seeds of additional native species from diverse source communities. Native hay may spread weedy species, so care should be taken to harvest in areas relatively free of weeds.

Erosion Control

Sites on slopes or on historically eroded areas will be vulnerable to soil erosion during winter storms. Many erosion control methods have proven effective in limiting loss of planted seed to erosion (Goldman et al. 1986; ABAG 1995). Generally, erosion is most severe after the soils are saturated in the late winter. If the seeding was done in the fall at the time of the first germinating rains, by late winter a relatively good mat of seedling roots should be present to prevent minor erosion if the soil was not compacted. If the restoration site is on a slope, control of run-on from the slopes above the restoration site (ditches, drains, etc.) may be required. Erosion control measures should be in place by mid-October to prevent large-scale soil losses. In California, restoration projects subject to erosion might be deferred if a strong El Niño winter is predicted. Erosion can be mitigated by changing length of slope, steepness of slope, and vegetative mulch to promote water infiltration into the soils. On highly disturbed soils, incorporation of organic matter is critical for plant growth (Curtis and Claassen 2005). Erosion control measures (Discovery Park, Table 21.1) often include installation of filter cloth or fiber mats/blankets pinned to the slope, contoured furrows, fiber rolls, vegetated gabions, application of thatch or tub-ground wood shreds, woven willow check dams, and similar devices (ABAG 1995).

Long-term Site Management

Whether a restoration consists of planting new material or is based on managing what is already there, long-term site management is the key to successful grassland restoration. Unfortunately, it is typically the most challenging part of a restoration project, because of the intensely competitive environment created by exotic species. In restoration sites where the primary weeds are annuals, managers can use the differences in life history and growth characteristics between annuals and perennial species to promote the native species. However, if the primary weeds are exotic perennial grasses (such as sites dominated by *Holcus lanatus, Festuca arundinaceae*, or *Ammophila arenaria*), other strategies are necessary and in general have not been developed. Most of the annual, exotic grasses in California produce far more seeds than needed for replacement (Young and Evans 1989) and far more seeds than native perennial grasses. In a typical grassland the germinable seed pool is typically dominated by non-native species (see, e.g., Major and Pyott 1966) that germinate earlier than native perennials and form dense stands early in the growing season (Deering and Young 2006). Exotic annual grasses can limit the growth and survivorship of native seedlings (Brown and Rice 2000). Higher soil N availability, which may characterize some restoration sites, often favors annual exotic species over native perennials (Huddleston and Young 2005; Corbin et al. 2006).

Because of the intense competitive environment created by the high density of exotic annual species (Dyer and Rice 1997b; Hamilton et al. 1999; Brown and Rice 2000), management treatments have focused on trying to shift this competitive balance. This can be achieved by trying to force nitrogen immobilization through additions of carbon to soil, timed mowing, timed livestock grazing, prescribed fire (Corbin et al. 2006), herbicide application, and supplemental irrigation. Here, we briefly review these various management options.

Addition of nitrogen to soils during restoration in California grassland sites should be avoided (Brown et al. 2000). Although productivity of natives may increase with additional N, there are often even greater increases in weed density and biomass (Brown et al. 2000). In grasslands where N availability has been increased by fertilization, N-rich mulch (Huddleston and Young 2005), or the presence of some nitrogen-fixing invasive plants (e.g., *Genista*, *Lupinus*), there are large-scale shifts in grassland composition from native perennial to exotic annual species (Maron and Connors 1996). This has led some restorationists to suggest the impoverishment of soils as a restoration technique, through topsoil removal, burning, or carbon supplementation. At sites where native grasses have been seeded on N-poor subsoil resulting from mine reclamation or other excavations, native species have tended to perform well because of lower weed competition (see for example, Maxwell Flat project, Table 21.1). One way to decrease nitrogen availability to plants is to add carbon to provide an energy source for increased microbial growth and associated nitrogen uptake by microbes. Sawdust is a low-cost carbon source that is widely available for potential use in restoration. In coastal dune systems enriched by N from *Lupinus*, addition of sawdust to change the C:N ratio reduced the annual invasive grasses, but increased the frequency of both native and non-native forbs (Alpert and Maron 2000). In general, increasing the ratio of C:N with the addition of sawdust or other carbon sources on restoration sites has had little long-term effects in efforts to shift the competitive advantage to native perennial grasses in California (Corbin and D'Antonio 2004a; Huddleston and Young 2005; Haubensak and D'Antonio 2006), but more research may be productive. In tallgrass prairie restoration, there have been some successful reductions in competition with exotics by changing the C:N ratio (Averett et al. 2004). Three conditions must be met for carbon supplementation to be an effective tool in prairie restorations (Blumenthal et al. 2003): Weeds must suppress native species in the absence of C addition, weeds must be nitrophilic relative to native species, and C addition must result in a decrease in available N sufficient in magnitude and duration to alter the balance of competition between native species and weeds.

There is some evidence that exotic invasive species leave a biochemical legacy of toxins in the soil that prevent germination of native grasses (Robinson 1971; Callaway and Aschehougdagger 2000). If so, the addition of activated carbon (charcoal) may be an effective soil amendment for restoration (Kulmatiski and Beard 2006), particularly in abandoned agricultural fields. However, this has yet to be broadly tested in restoration settings.

Mulch on restoration sites should be used carefully. Mulch is detrimental to establishment of native annual wildflowers (Hayes and Holl 2003a) but can improve biomass accumulation in the establishment phase of a restoration site (Curtis and Claassen 2005). Mulch (or standing biomass from the previous growing season) also provides some winter thermal insulation that promotes establishing seedling grasses and reduces soil erosion (Jackson and Bartolome 2002). Mulch should be as free as possible from weeds and should decompose slowly. Rice straw is often used in restorations for these benefits (Brown et al. 2000), and it is widely available in the Central Valley.

Mowing as a tool for restoration in California grasslands may be valuable only in certain conditions (Hayes and Holl 2003b). Mowing has been effective in controlling non-native grasses in some cases (Maron and Jefferies 2001; Wilson and Clark 2001). Mowing might control exotic annuals through several mechanisms. Mowing after exotic annuals have immature seed, but before the native perennials have initiated annual growth, can control some non-native annuals such as yellow starthistle, *Centaurea solstitialis* (Benefield et al. 1999). In some sites, frequent mowing favors non-native forbs over exotic grasses but has no effect on native grasses in the short term (Hayes and Holl 2003b). Because the soil seed bank of annual exotics is generally not long-lived (Marañon and Bartolome 1989; Rice 1989b), repeated well-timed mowing might favor native perennials, but more studies are needed. In restoring old fields, swathing (mowing with a sickle bar and leaving windrows) the elongating stems and flowers of weeds (wild oats, yellow starthistle, medusahead, etc.) just before seed maturity allows either baling and removing much of the seed, or fall fires hot enough in the windrows to kill the seeds (Hedgerow Farms, Table 21.1). Mowing is generally not effective in shifting the competitive balance toward native perennial grasses if non-native perennial grasses are the primary source of competition, as in many coastal prairie locations (see D'Antonio et al., Chapter 6). More research is needed to determine whether long-term mowing programs are effective in reducing available soil N in degraded perennial grasslands (Corbin et al. 2006).

Grazing as a tool for restoration is controversial (see Huntsinger et al., Chapter 20). Goats, sheep, or cattle are used to selectively "mow" exotic annual species, which are often more palatable than native perennials early in the growing season. Grazing animals can also be chosen depending on their forage preferences. Cattle, for example, generally select grasses, whereas sheep (or goats) may be used to target problem forbs (Russian Ridge, Table 21.1). Grazing may also be used to target thistles later in the growing season. Grazing must be carefully timed and intensive enough (high density of animals) to force selective removal of exotic annuals (Huntsinger et al., Chapter 20). Such grazing can reduce exotic grass cover and thus favor native plants, as has been done in Bay Area serpentine grasslands to favor native forbs that support rare butterflies (Weiss 1999) and in a wide array of rangeland projects (see Table 21.1). Livestock grazing in central valley grasslands improved species richness in native plant species and aquatic invertebrates in vernal pools (Marty 2005). Livestock grazing, or vegetation clipping and removal, has had variable results in regard to increasing native grassland species (Hayes and Holl 2003b; Corbin et al. 2006), and additional, controlled experiments are needed.

If used correctly, selective post-emergent herbicides may remove broadleaf forbs or annual grasses without harm to perennial grasses (see DiTomaso et al., Chapter 22). Some pre-emergent herbicides are also effective on broad-leafed plants but not grasses (Lanini et al. 1996), but all herbicides should be used carefully in a planned restoration that may include native broad-leafed plants. Herbicides are generally the most cost-effective method of those discussed here in restoration projects in which stand-dominating exotic invasive weeds are to be selectively removed (DiTomaso et al. 1999b; Kephart 2001). The long-term and unintended environmental effects of herbicides are variable, and manufacturers are increasingly trying to develop more short-term, targeted products. Nonetheless, many land managers still restrict herbicide use.

Prescribed fire is often a difficult option because of air pollution and safety considerations (Russian Ridge, Table 21.1), but it has been effective in some instances in restoring native grasslands (DiTomaso et al. 1999a; Kephart 2001; Kyser and DiTomaso 2002), especially when a particular weed such as *Centaurea solstitialis* is targeted (Keeley 2006). Site managers need to be aware of the life history strategies of all species guilds at the site in order to avoid inflexible prescriptions that may benefit one native guild (e.g., grasses) at the expense at of others (e.g., forbs; see Reiner, Chapter 18). For example, research at the Santa Rosa Plateau suggested that repeat spring burning over three years increased native grass cover and frequency while reducing that of annual forbs, even desired native forbs (Wills 2000). Management plans should vary treatments among years to more closely mimic the stochasticity inherent in natural disturbance regimes. Some weeds that are highly susceptible to fire, such as medusahead, may reinvade burned sites within 3–5 years (Ranchette 1, Table 21.1). In such cases, managers should be prepared to commit to a long-term site fire management plan or other long-term strategies. For more detailed discussion of the role of fire, see Reiner, Chapter 18.

Where more certainty and speed in restoration of a grassland are required (after road construction, urban development, or landscaping), irrigation may provide an attractive alternative to depending upon the erratic California rainfall. To best promote native perennial grasses, irrigation should mimic natural patterns in rainfall that favor native perennial grasses (Jackson and Roy 1986). For example, years with early saturating (fall) rains followed by prolonged winter drought favor perennials and are associated with reduced total biomass of exotic, annual grasses. However, these kinds of winters can be devastating on newly seeded restoration sites. By contrast, years with continual rainfall following fall wet-up are associated with relatively high standing crop of exotic, annual grasses (Pitt and Heady 1978) and are the kinds of winters that increase the success of restoration plantings. Timing and amount of rainfall can be more closely correlated with establishment and growth of native, perennial grasses than any grazing or burning treatments (Marty et al. 2005).

Sometimes the establishment and management of different functional groups can require conflicting management actions. For instance, the a broadleaf-specific post-emergent herbicide may be applied only over establishing native perennial grasses before native forbs are introduced to the restoration. A more complete restoration may take several years of planting and management, adding a new functional group at each cycle. This is complicated by the fact that many grassland restoration sites in California that have lost most or all of their native grasses still have substantial native forb diversity (Lulow 2004; Keeler-Wolf et al., Chapter 3). In these situations management options include fire, timed herbicide application, and timed mowing or grazing.

Monitoring

Monitoring responses to treatments as well as changes going on in reference communities is critical to continued management of a restoration project. There are a multitude of monitoring procedures and protocols that can be tailored to the objectives and resources of a given restoration project (Elzinga et al. 1998). Monitoring protocols are typically laid out along with the specific objectives of the project and should be designed to be able to determine whether specific objectives are being met. SER recommends monitoring of a wide range of ecosystem properties. Yet a review of over 460 restorations described in the journal *Restoration Ecology* showed that only 68 projects evaluated success after planting or treating sites using SER suggestions to measure diversity, vegetation structure, or ecological processes (Ruiz-Jaen and Mitchell Aide 2005). This proportion is likely even lower among projects that are not described in scientific journals.

Because diversity is one of the most commonly measured attributes, it is worth a brief discussion. There are different mathematical measures of diversity including the most simple measure, species richness. Each measure depends on the area sampled (Gotelli and Colwell 2001). A reasonable scale for comparing diversity among California grassland sites is to sample 1 meter $\times$ 1 meter (Stromberg et al. 2001; Harrison et al. 2003) plots. An appropriate area of the restoration site should be sampled using a stratified, random design and recording species presence and cover in the 1 m^2 quadrats.

Vegetation structure and change over time can be monitored with a variety of indices including plant cover, plant density, biomass, plant height, or a combination of these. Data should be collected and recorded, not only for the restoration site but for a comparable site that is not being manipulated and may be the reference site used for the particular restoration. Such comparisons to reference sites could be included as a contractual obligation. Photographic monitoring from fixed locations is a relatively simple, cost-effective measure that should be instituted at all restoration sites in addition to quantitative data collection (Merenlender et al. 2001; Hall 2002), although it should not substitute for quantitative methods. Sometimes paired photographs (Figure 21.1) can be dramatic tools in explaining complex changes over time. Additional ecological processes that can be measured using relatively well-developed methods (Bonham 1989; Elzinga et al. 1998; Knapp et al. 1998) include describing changes in soil processes, animal use of sites, herbivory on planted species, seed dispersal into sites, pollination, predation, and parasitism.

Hundreds of restoration projects that are currently under way could be transformed, with relatively little modification, into experiments in local adaptation (McKay et al. 2005). However, to do so, information would be needed on (1) where the plant material came from, (2) where it was planted on the site, (3) how it performed, using some index of individual or stand-level plant performance, and (4) site environmental characteristics. If metadata and quantitative measures of ecological processes and composition were available from a large number of sites, it would be possible to infer a great deal more about what influences success of particular restoration techniques (Young 2000; Young et al. 2005). Finding and retrieving metadata (Michener and Brunt 2000) in ecological research requires cooperation and participation of restoration ecologists. A data registry has been developed for discovering and sharing information on restoration projects in California (NRPI 1997), and readers are urged to register their restoration projects. In addition, the U.S. Fish and Wildlife Service (USFWS), The Nature Conservancy, the USDA, and others are compiling records of restoration projects in California (see Table 21.1). If restoration ecology is to develop into a mature science, such monitoring and reporting are critical, especially when combined with thoughtful initial restoration designs.

Managing Remnants

When a system has a significant natural component that is still functional, the restoration may include a combination of management techniques without the resource-intensive step of planting new vegetation or intensively managing invasive species. The intensity of these measures will vary depending on the ecological integrity of the site, the weed species present both on site and in the nearby area, and available resources. In any case, management strategies should be long-term and flexible to adapt to changing conditions.

Although intensive planting is usually not necessary at such sites, many restoration methods can be used to augment both the grasses and the forbs of a remnant. The success of each of these methods has varied (see Reiner, Chapter 18 and Huntsinger et al., Chapter 20), and additional monitoring of the trials of these management tools is needed. We encourage restoration practitioners to implement long-term monitoring programs, record observations of what works, and write up their observations in the publications of the CNGA or SER.

There are two special cases in which restoration or re-creation of native California grasslands will occur in places that the citizens of California use or see on a daily basis. These are large roof surfaces (Box 21.1) and roadsides (Box 21.2). Although such small-scale patches may be viewed as artificial, they still fulfill some functions desired in ecological

BOX 21.2 FARM EDGE AND ROADSIDE RESTORATION

Highway rights-of-way are almost all covered with noxious, invasive weeds (Wrysinski 2002). California's Department of Transportation, at various regional offices, has supported research and demonstration plots for restoring roadside vegetation to a stable state that requires little annual management, and it is committed to trying to use native plants along new or replacement state highways. The California Department of Transportation maintains a native grass database and restoration guidelines (http://www.dot.ca.gov/hq/LandArch/index.htm) and supports many university-level research projects in grassland restoration (Brown and Rice 2000).

Replacing weedy roadsides with native grass buffers between roadsides and farm fields (Figure 21.6) is an alternative to typical roadside management regimes of annual grading, and spraying (Anderson and Anderson 1996; Robins 2002a). By restoring most of the road edge area to relatively long-lived native perennial grasses and halting the annual sources of disturbances (grading, etc.), farm edges can be improved dramatically and may resist reinvasion. Although long-term studies of roadsides revegetated with native grass have not been done in California, field research at the University of California at Davis has shown that *Elymus glaucus* can successfully maintain dominance even when seeds of yellow starthistle are introduced into the plot (unpublished data; Joe DiTomaso, personal communication, 2006).

Yolo County probably leads the state of California in establishing native grassland vegetation along irrigation ditches (Figure 21.7), between road surfaces and farmed fields, and in tailwater ponds. The county has published a useful landowner handbook (Robins 2002a), also available online (http://www.yolorcd.org/library/index.shtml), which describes in detail successful methods to convert ditch edges and road edges to native vegetation, often with native grasses. There is an amazing opportunity here; there are over 10,000 miles of roadside, ditches and levees in California's central valley (Steve Greco, UC Davis, Landscape Architecture, personal communication). Detailed and useful instructions are included for landowners seeking agency cost sharing (Robins 2002b) for restoring hedgerows, tailwater ponds, and road and ditch edges.

Conversions of these edges to strips of native grassland provide a wide variety of ecological services, including:

- Reducing annual costs of "clean" agriculture associated with removing all vegetation from road and canal edges.
- Providing weed-free areas adjacent to agriculture and roads
- Providing habitat for beneficial insects and a wide variety of wildlife
- Reducing soil erosion, stabilizing earthen levees
- Improving water quality through biological filtering
- Recharging groundwater

Roadsides and levee restoration are widespread in California, and observant readers with time to stop—or the ability to do grass species identification at 60 miles per hour—can appreciate these restoration efforts as they travel through California.

FIGURE 21.6. Roadside planted with native grasses and, after several years of establishment, native forbs drilled to increase diversity. Photograph by John Anderson.

FIGURE 21.7. Irrigation ditch planted with native grasses for wildlife, soil stabilization, and reduced annual maintenance costs. Photograph by John Anderson.

restoration, such as supporting a diverse array of successfully reproducing native plant species, reducing local weed populations, and supporting insects and other higher trophic levels. Also, they can be used as a resource for public education about grassland biodiversity and its values.

Future Challenges

Restoration of California's grasslands is proceeding along many fronts. This review of the current field has revealed some major knowledge gaps, and research needs. These include:

- Better definitions of success and clearer, broader-scale criteria for evaluating characteristics of "restored" sites. This would allow evaluation of the extent to which grassland restorations in California comply with SER goals (SER 2004).
- Better tracking of restoration projects, both to measure success and to add to the knowledge base regarding causes of successes and failures. To do this, it is necessary to implement long-term collection and compilation of monitoring data and metadata.
- More information on genetic variation and local adaptation in native species on which to base seed collection criteria.
- Strategies to engage private landowners in long-term management approaches that favor native grasslands across the landscape.
- Evaluation of which restoration techniques are both practically effective and cost-effective.
- More detailed evaluation of soil processes and their effects on restoration.