15. MANAGEMENT CONTROLS ON PRODUCTIVITY

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1. Introduction

California annual grassland productivity

California annual-type grasslands have higher herbaceous plant primary productivity than any extensive vegetation west of the Rocky Mountains in North America. Productivity averages about 2000 kg ha^{-1} yr^{-1} with a strong north–south gradient due to rainfall causing productivity to range from about 5000 kg ha^{-1} yr^{-1} in the north where perennials (Beetle 1947) and legumes are a larger component to about 1000 kg ha^{-1} yr^{-1} in the south (Bartolome et al. 1980). Most of the pristine valley grassland (Heady 1977) has been replaced by irrigated agricultural crops, but much annual grassland remains on the margin of the Great Valley in open grassland, oak (*Quercus* sp.) savannas, and as understory vegetation in the foothill oak woodlands of the Coast Ranges and the Sierra Nevada mountains below 1000 m elevation.

High diversity in climate, relief and parent material gives high variance to any average productivity statistics on either local or regional scales. For example, winter precipitation as rainfall is largely derived from storms arising out of the Gulf of Alaska that often drench the northern part of the grassland while leaving the southern part totally dry. Although less frequent, tropical moisture from the Pacific Ocean southwest of Baja California or from the Gulf of Mexico sometimes falls on the southern region in autumn and spring with little effect on the northern and central parts of the grassland. True desert climates in parts of the central San Joaquin Valley are a result of the area's usually being missed by both storm systems. Since precipitation is a main factor limiting production (Bentley and Talbot 1951; Duncan and Woodmansee 1975; George et al. 1985; Hedrick 1948; Hufstader 1976; Murphy 1970; Pitt and Heady 1978) these spatial differences in climatic patterns are important determinants of productivity potential.

The Coast Range mountains cause strong rainshadow effects on the west side of the Great Valley, and both this mountain range and the Sierra Nevada range cause strong elevational gradients in rainfall since orographic storms are common. The Coast Ranges also restrict summer fog intrusion from the Pacific Ocean causing strong spatial gradients in summertime temperatures across these ranges. Finally, annual grassland soils are extremely diverse because of complex topography, relatively dense dendritic pattern of stream courses, and primary effects of acid igneous parent materials in the Sierra Nevada and sedimentary materials in the Coast Ranges. Nitrogen deficiencies are common throughout the grassland except in years when annual legumes are locally abundant (Jones 1963b, 1967, 1974; Martin and Berry 1970). Phosphorus (Jones 1974; Woodmansee and Duncan 1980) and sulfur (Caldwell et al. 1985; Jones 1963a, 1964, 1974; Martin 1958) are widely deficient.

Great potential exists for enhancing forage productivity and quality in the annual grassland. Although many of the resident annual

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species produce high quality forage, some, including recent undesirable invaders, detract from forage quality especially in late spring and during the dry season. Technology has been developed to introduce annual legumes, reducing the nitrogen limitation on production and improving year-round forage quality (Murphy et al. 1973; Williams et al. 1956). However, the requirement of repeated fertilization usually every third year with phosphorus or sulfur, or both, and the need for more intensive management to reduce the risk of losing the improved pasture through competition from less desirable annual species has led to limited applications of the technology. More knowledge is needed on how to manage resident annual legumes and forbs in relation to the often rank growth of taller or poor quality grasses before this technology will be more widely accepted.

2. *Natural and human-derived grassland*

Unintentional introduction of alien plants, severe periodic drought, and abnormally heavy grazing with concomitant alteration of the fire regime before 1900 permanently reduced herbaceous perennial plants in the California grassland (Aschmann 1973; Baker 1978; Burcham 1957; Dodge 1975; Fritts and Gordon 1980; Heady 1977; Robbins 1940). Five of the 29 California plant communities described by Munz and Keck (1965) have been affected most by invasion of annual species. The Valley Grassland, Northern and Southern Oak Woodland, and Foothill Woodland plant communities probably changed to the greatest extent because of historical and current range management and fire exclusion practices. Abundant precipitation and summer fog probably helped maintain a greater competitive edge for native perennials in the Coastal Prairie, so this community has been less affected and therefore contains more perennials today (Burcham 1957). In the northern Coastal Prairie any alteration of fire regime would have been less important since fire has a lesser role there, and grazing pressure has been lower because of relative isolation from population centers.

Vegetation type conversion and seeding of improved forage species including perennial grasses, annual legumes and annual grasses in converted chaparral and dense oak-woodland communities have created grassland for livestock and wildlife grazing and fire hazard reduction (Bentley 1967; Longhurst et al. 1979; Love, Jones 1952; Nichols et al. 1984; Nichols and Menke 1984). Livestock productivity often has been increased from nearly nothing to that of adjacent 'natural' resident annual grassland, and where seeded perennial grasses have not persisted the grassland has taken on most of the characteristics of annual grassland. Since chaparral and other shrubs have encroached onto grassland (Dodge 1975; Hobbs and Mooney 1986; McBride 1974; McBride and Heady 1968), some of these vegetation conversions are really reconversions back to grassland.

Thinning or removal of deciduous oak trees in oak savannas and woodlands has become more common with rising fuelwood prices and increasing need for alternative income by private landowners (Menke and Fry 1979; Raguse et al. 1986). On densely wooded sites in northern California forage productivity can be enhanced by oak removal (Kay 1986b; Kay and Leonard 1979). However, under more xeric savanna conditions like those in the southern Sierra Nevada foothills, grassland productivity is higher in the shaded understory and oak removal may be detrimental to land productivity (Holland 1979). Recent research indicates that enhanced forage production above that of naturally open grassland due to removal of oak trees in the denser oak woodlands may only last for 10–15 years (Kay 1986b). Even on more mesic woodland sites tree removal benefits are limited, and the conversion effectively produces more acreage of open grassland and not a sustainable enhanced level of production above that of naturally open grassland.

Hence, California annual grasslands are often considered to include a complex mosaic of several highly altered plant communities. The valley grassland, oak savannas, and type-converted oak-woodland and chaparral communities share many attributes of a formerly more distinctly segregated set of plant communities. Reestablishment of woody plant communities after removal of livestock grazing in newly established state parks and around urban sprawl areas of the state with continued fire suppression indicates that much of our foothill land has the potential of supporting other than annual grassland vegetation. However, strong competition with annuals seems to be sufficient to continue to suppress increases in native perennial grasses and possibly deciduous oak seedling regeneration (Welker, Menke 1987), at least without natural fire.

1.3. *Management controls on productivity*

In a state as populated as California it is virtually impossible to allow nature to take its course especially with respect to fire management, so this strong environmental influence has been practically eliminated from having its natural effect on California grasslands. Restrictions such as this make ecologists suspect that many natural processes are altered and therefore difficult to interpret. Natural reserve managers as well as range managers should use fire periodically to maintain grassland productivity, especially for the removal of large litter accumulations and invading shrubs. The more prostrate annual legumes and other forbs, including aesthetically pleasing wildflower communities, are less abundant because of fire suppression (Ahmed 1983; Heady 1973; Hervey 1949; Ratliff and Westfall 1976).

Humans directly and indirectly control many processes affecting the productivity of annual grassland communities. They largely exclude fire but may also use it as a tool to remove unwanted woody plants or accumulations of litter. Livestock are grazed under various grazing systems to maximize economic returns or help pay property taxes while the landowner enjoys a rural lifestyle. Improved plant species are seeded to increase livestock carrying capacity and improve forage quality. Nutrients are added to soil to increase overall productivity or enhance certain species most affecting forage productivity. Water has been added as fall irrigation to shift the beginning of the growing season to an earlier date to extend the growing period. Pesticides are sometimes applied to control competing plants and animals, noxious or poisonous plants, or livestock predators. And finally shrubs or trees are sometimes removed to create more grassland or merely increase light availability to understory annual plants, thereby increasing forage productivity, at least in the short-term future.

.4. *Conversion of forage to animal products*

The primary use of annual grassland by humans is for grazing of domestic cattle and sheep, and the performance of these animals is the ultimate index of productivity. The mediterranean climate presents major obstacles to high animal performance both because of the long dry season, normally lasting from mid-May through October, and the dependence today on annual forage plants. With a continuing decline in summer irrigated pasture acreage, more restrictive public land grazing policies on forested rangelands, increasing costs of transporting animals, and high cost of supplemental feeds, dry season forage quality has become of increasing importance to livestock producers.

Native perennial grasses such as purple needlegrass (*Stipa pulchra*), nodding stipa (*S. cernua*), pine bluegrass (*Poa scabrella*), junegrass (*Koeleria cristata*), California oatgrass (*Danthonia californica*), and blue wildrye (*Elymus glaucus*) once supplied substantial available green forage longer into spring, and the regreening of these summer dormant perennial grasses often supplied high quality regrowth earlier in fall, prior to germinating rainfall for annuals. Jackson and Roy (1986) observed that the reproductive phenology of perennials was delayed about one month compared to annuals. Clausen et al. (1944) and Laude (1953) observed a tendency for photoperiod-controlled dormancy in several native perennial grasses. Three perennial grasses, including nodding stipa, broke summer dormancy in September before effective autumn rainfall (Laude 1953). Initiation of pine bluegrass summer dormancy was related to high temperatures and long day lengths in late spring while breakage of dormancy in fall was related to cool temperatures and moisture.

Two interesting hypotheses emerge from comparing pristine perennial grassland with today's annual plant dominated grassland. First, in a summer dormant perennial grass dominated grassland, during years with above average spring rainfall, a window of mesic summer soil moisture conditions could have allowed oak regeneration because the grasses would have gone dormant before soil moisture depletion. Second, the summer dormant and more deeply rooted perennial grasses once provided a more reliable green forage source for herbivores when the beginning and end of the dry forage season was controlled by day length and temperature. So two major problems in California annual grassland management today, dry season forage quality and oak regeneration, relate to the drastically changed composition of the grassland, an evidently irreversible problem.

In the annual plant dominated grassland today, botanical composition at the end of the wet season establishes the forage quality for the next 4–6 months with an unpredictable beginning date for the next growing season. Therefore, species with good curing ability, high leaf/stem ratios, low susceptibility to shattering, high digestibility, and high nutrient content are the basis of the animal production system. Some examples are: soft chess (*Bromus mollis*) which cures exceptionally well as standing hay with high digestible crude protein and digestible energy content, broad-leaf filaree (*Erodium botrys*) which provides excellent early forage but matures early and shatters rapidly, and bur clover (*Medicago polymorpha*) and many native and introduced true clovers (*Trifolium* spp.) which provide excellent dry season grazing because of the nutrient-rich burrs, leaves and stems. The leaves and stems of all the desirable legumes are available and highly palatable to livestock in the dry season. Thus a considerable effort has been devoted to introduction of exotic annual legumes as well as perennial grasses that are tolerant of grazing.

Hart et al. (1932) did an extensive regional forage analysis of annual species and representative composite forage samples on 17 ranches along a north–south transect of the Central Valley of California. Figure 1 shows their data to illustrate seasonal and regional effects on nitrogen, phosphorus and crude fiber composition. Seasonal nitrogen content of composite forage samples range from nearly 4% N (22% crude protein, N X 6.25) in late winter to as low as 1% N in fall at the end of the dry season. Phosphorus contents in forage range from 0.45% to less that 0.1% P from winter growth through the dry season. As an example of animal requirements, minimum dietary N and P levels for 225 kg (500 lb) steers gaining 1.1 kg d^{-1} (2.5 lb d^{-1}) are about 2.0% and 0.27%, respectively, showing that substantial supplementation is required during the dry season for growing animals (NRC 1984). Fall calving cows require only 1.2% N and 0.2% P in their diet during the last third of pregnancy in summer, so, depending on the legume and forb content of the forage, supplementation may be required. Crude fiber is inversely related to digestibility, again indicative of declining forage quality from the adequate-green period to the dry-leached forage period described by Bentley and Talbot (1951).

The major north to south differences in N and P in forage shown in Fig. 1 are due to the typically higher legume composition in the north as illustrated in Fig. 2 for Ranch 1 (near Oakdale) with a bur clover, grass, filaree range versus Ranch 6 (near Madera) with a filaree and grass range. Seedlings of *Medicago* and *Trifolium* species are less drought resistant than filaree and grasses (Biddiscombe et al. 1954; Heady 1958; Robson 1969) and therefore are typically more abundant on heavier textured

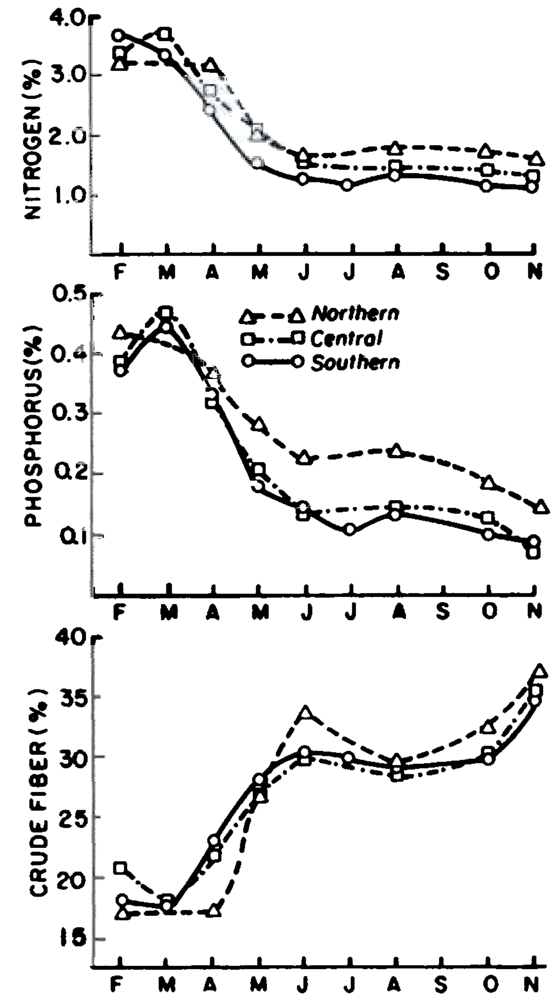

Fig. 1. Seasonal trends in nitrogen, phosphorus, and crude fiber content of composite forage samples taken from 17 ranches along a north-south transect from Red Bluff to Coalinga, California. Data from ranches 10–13 (Red Bluff area) were averaged for the northern area, ranches 14–18 (Marysville-Folsom-Ione) for the central area, and ranches 1–7 (Oakdale-Merced-Madera-Fresno-Coalinga) for the southern area (adapted from Hart et al. 1932).

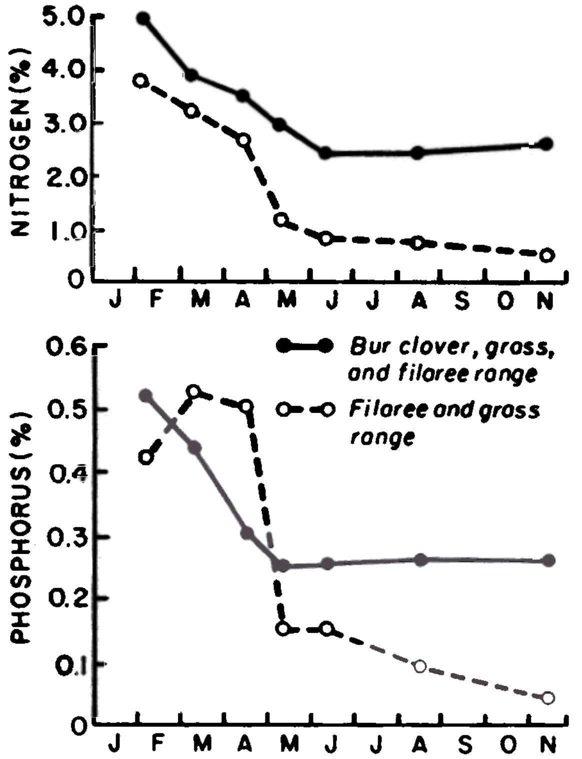

Fig. 2. Seasonal trends in nitrogen and phosphorus content of composite forage samples taken from two ranches with contrasting botanical composition. Ranch 1 in the foothills southeast of Oakdale, California had abundant bur clover (*Medicago polymorpha*) mixed with annual grasses and broad-leaf filaree (*Erodium botrys*) in comparison to Ranch 6, east of Madera, California with primarily filaree and annual grasses (adapted from Hart et al. 1932).

loams to clay-loams in higher rainfall areas in more northerly parts of the state. Since the abundance of legumes varies annually, the need for summer supplementation of livestock with nitrogen (protein) and energy also varies. While a good clover year should result in a higher seedbank of clovers the following year, the greater nitrogen fixation the previous year often causes abundant grass growth in the carry-over year (Caldwell et al. 1985) and shading of more prostrate legumes and other nutritious forbs (McCown and Williams 1968; Stern and Donald 1962a, 1962b). The effect of grazing intensity on competitive interactions of grasses, forbs and legumes, and the resulting composition of the stand will be discussed in greater detail in the ecology section below.

2. Technologies for enhancing productivity

Eight vegetation management activities are used to increase grassland productivity in California in the short and long-term (Fig. 3). Prescribed fire is used to reduce litter

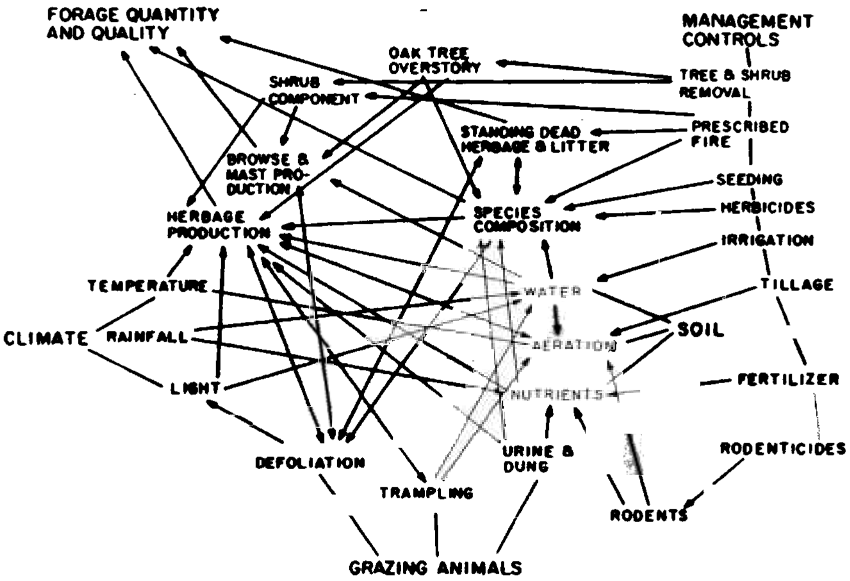

Fig. 3. Diagram of management control points and interactions between grazing animals and the livestock grazed annual grassland (adapted from Snaydon 1981).

accumulations of undesirable weed species and to remove shrubs and small trees, or so-called 'brush' plants. Trees and shrubs are removed from oak woodlands by several mechanical and chemical means to increase forage and remove barriers to livestock. A large effort has been devoted to seeding of improved forage species to increase production and palatability of forages for livestock, but the list of recommended species today is very short: only two clover species (*Trifolium* sp.) and two perennial grass species (*Dactylis* sp. and *Phalaris* sp.). Depending on the price of fertilizer, nitrogen, phosphorus or sulfur fertilization are used singly or in combination to increase production, but most commonly P and S are used as part of a larger legume seeding program. California ranchers sometimes irrigate improved annual grassland in fall to cause early germination and green-up of forage. On certain soil types and land topography annual grassland is farmed to dryland grain crops (oats, barley and other crops) to improve productivity by breaking up the compacted surface soil layer due to livestock trampling. Until recently, herbicides and animal toxicants were used extensively to remove unwanted woody and herbaceous weeds, aid in establishment of improved herbaceous forage species, and assist in rodent and predator control programs. More restricted use of chemicals occurs today. Finally, several livestock grazing systems, including continuous, rotated, deferred, and short-duration systems, sometimes are used to enhance livestock performance.

2. *Use of prescribed fire in annual grassland*

On ungrazed pastures, Hervey (1949) found that burning increased the broadleaf plant component from 7 to 58% with a concomitant reduction of grasses from 93 to 42%. Changes were less dramatic in pastures that had been heavily grazed. Similar results were obtained by Bentley and Fenner (1958) in their study of fire effects on seed reserves in woodland range. They attributed a compositional shift toward forb species to the greater susceptibility of grass seeds to damage by fire. Smith (1970) found that both fire and soil disturbance by fire fighting machinery reduced grasses more than clovers. Because of the potential improvement in forage quality due to greater abundance of legumes and other forbs, ranchers have used prescribed burning as a tool.

Control of the range weed, medusahead (*Taeniatherum asperum*), appeared to be an optimum candidate for prescribed fire management since it matures later in the spring than most annual grassland species and therefore could be burned before seed shatter (McKell et al. 1962). The plant is known for its slow litter decomposition rate causing dense litter mats (Savelle 1977) and low palatability (Lusk et al. 1961). However, Fig. 4 shows that inadequately high temperatures occur at or near the soil surface to get good seed kill. While both June and August burns achieved adequately high canopy temperatures to kill seed in inflorescences, the steep gradient in temperature from the canopy to the soil surface and below assured seed survival even in the hotter August burn (McKell et al. 1962). Additionally, Bentley and Fenner (1958) showed that litter buildup, which is characteristic of medusahead stands, reduced seedbed temperatures substantially (Fig. 4). Fire is a useful tool to remove medusahead litter and increase forb composition for a year or two following fire, but it is not a valuable tool in medusahead control.

Heady (1973), in a review of burning in California grasslands, proposed that seed survival in annual grassland after fire was adequate for regeneration of initial botanical composition and that fire effects on composition, growth and biomass production likely will not persist beyond the third year after burning. In annual grassland not infested with medusahead, Hervey (1949) documented the compositional shift to forb dominance, but he also found depressed production of both grasses and forbs following summer fire as indicated by reduced plant height (Fig. 5). He noted yields were reduced between 26 and 37%. Zavon (1982) documented the rebound to an unburned grassland composition of annual grasses and filaree at Hopland (Mendocino County), and showed Heady's prediction to be correct (Fig. 6). She found postburn compositions nearly converged to the unburned state after two years and were observed to be nearly identical by the third year following a summer fire. Zavon (1982) also corroborated Hervey's (1949) finding of depressed production following fire, observing lower plant density, height, and forage productivity. However, since Zavon's preburn grassland composition was largely grass with a considerable litter buildup, burning

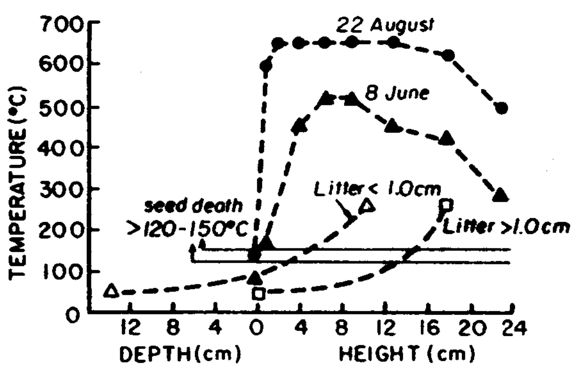

Fig. 4. Maximum temperatures at different depths in the soil and heights in the canopy during annual grassland fire on two dates in summer (adapted from McKell et al. 1962) and with two depths of litter (adapted from Bentley and Fenner 1958).

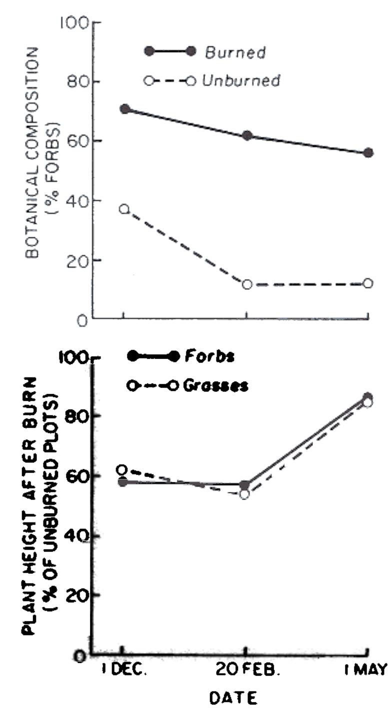

Fig. 5. Seasonal forb composition and reduction in grass and forb plant height following a July fire in annual grassland (adapted from Hervey 1949).

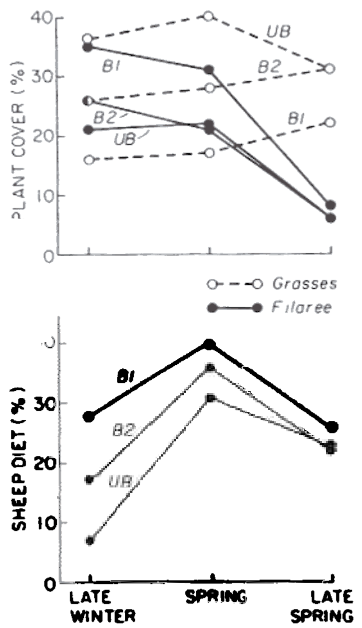

Fig. 6. **Seasonal grass and filaree plant cover and sheep diet composition on unburned, 1-yr postburn, and 2-yr postburn annual grassland manipulated with summer fire (adapted from Zavon 1982).**

substantially changed sheep diets and the expected benefit of improved sheep liveweight gains was found (Fig. 6). Sheep diets tracked available forage to a large extent and higher quality forbs made up a larger part of the sheep diet. Ewe lamb gains on pastures burned the previous year were increased 33% over animals grazing unburned grassland, primarily due to increases in filaree intake.

Nichols et al. (1984) and Nichols and Menke (1984) recently reviewed the literature on prescribed fire for shrub management in woody plant communities related to annual grassland. They also concluded that fire is a useful tool for removal of undesirable biomass accumulations as an initial step in vegetation management but not as a strong selective tool by itself. Only on sites where woody fuel loads are high enough and where hot fire conditions produce 'white ash' are seedbed populations of resident species reduced sufficiently to allow successful establishment of perennial grasses (Bentley and Fenner 1958). Interior live oak (*Quercus wislizenii*) is the most common target species range managers try to remove, but many others such as manzanita (*Arctostaphylos* sp.), ceanothus (*Ceanothus* sp.), chamise (*Adenostoma fasciculatum*), poison oak (*Toxicodendron diversilobum*), coyote brush (*Baccharis pilularis*), and other shrubby forms of oak are often managed intensively with fire and other means in brush control programs. Murphy and Leonard (1974) summarized a long term type-conversion study involving interior live oak and concluded that fire alone could not maintain human-derived grassland. Prescribed grazing by cattle, sheep or goats and periodic use of selective herbicides are usually necessary aids. Where resprouting live oak was not involved in the long-term Watershed II study at Hopland, forage productivity on the type-converted area as a whole was trebled with little maintenance herbicides required (Heady and Pitt 1979a).

Fire has been recognized as an integral component in the maintenance of perennial grasslands (Daubenmire 1968; Ehrenreich 1959; Vogel 1974; Weaver 1951). However, little fire research has been done on perennial grasses in California annual grassland, and because of a high density of dominant annual species it is difficult to extrapolate research from other grasslands. Omission of both livestock grazing and fire over a 20-year period at Hopland resulted in either no change or a population decline in the perennial grass, *Stipa pulchra*, but no long-term studies have been done with typical levels of light grazing and fire (Bartolome and Gemmill 1981).

Ahmed (1983) found that *Stipa pulchra* tiller production and basal cover increased regardless of season of burning from late spring through early fall at Hopland. Reduced annual plant density was hypothesized to be one of the causes along with the beneficial effect of litter removal impeding the growth of large tussocks. The litter reduction certainly influenced the light quantity and quality reaching stem bases which may have caused a stimulation similar to that for other perennial grasses (Deregibus et al. 1985). Heady (1966) found that *Stipa pulchra* density gradually increased in all litter removal treatments without grazing. Jones and Love (1945) also showed that mowing to reduce competition from annuals was beneficial and increased the number of *Stipa pulchra* plants the following year. It remains to be seen whether prescribed fire alone, or with regulated grazing, can increase perennial grass density in the long-term. It is likely that litter accumulation alone can suppress productivity of some *Stipa pulchra* grasslands on good soil sites like Jepson Prairie in the Central Valley in a way found by Knapp and Seastedt (1986) on tallgrass prairie in Kansas.

2.2. *Tree and shrub removal in oak savannas and woodlands*

In oak woodland communities in northern California opportunities exist to increase forage quantity and quality for livestock animals by tree removal (Johnson et al. 1959; Kay 1986b; Kay and Leonard 1979; Murphy 1979; Murphy and Berry 1973; Murphy and Crampton 1964; Pitt 1975; Pitt et al. 1978). Increased availability of light, moisture, heat, and soil nutrients are suggested as causes for the response. Over the first 15 years of a long-term study at the Sierra Foothill Range Field Station (SFRFS) annual herbage productivity on oak-removed sites consistently (except for 3 years) was higher than in natural openings which consistently were higher than under oak canopies (Kay 1986b; Kay and Leonard 1979). By the 16th year the cleared grassland productivity converged to that of the naturally open grassland.

The technology of either tree cutting alone, basal frilling and applying 2,4-D, 2,4,5-T or a mixture, or cutting and applying 2,4-D herbicide to the stump is well understood (Leonard 1959; Leonard et al. 1956). The primary shift after clearing in forage composition and therefore quality was described by Murphy and Crampton (1964) at Hopland where soft chess (*Bromus mollis*) and slender wild oat (*Avena barbata*) increased and ripgut (*Bromus diandrus*) and mouse barley (*Hordeum leporinum*) decreased in abundance on oak removed sites. Shade-adapted forbs of inferior forage quality such as hedge parsley (*Torilis nodosa*), bur chervil (*Anthriscus scandicina*), geranium (*Geranium molle* and *G. dissectum*) and shortpod mustard (*Brassica geniculata*) disappeared from the site by the third year following oak treatment.

Holland (1973, 1979) and Holland and Morton (1979) described differences in herbaceous vegetation under blue oak savanna canopies in comparison to adjacent open grassland, including faster growth rates, taller vegetation, about twice as much biomass, and longer green vegetation under the canopy at the San Joaquin Experimental Range (Madera County) and at Hastings Natural History Reservation (Monterey County). They attributed these differences to litter and leached material from the tree that secondarily resulted in higher soil nutrients, organic matter, more distinct aggregate structure, greater friability, lower bulk density and greater water holding capacity of soil. These factors along with a more favorable temperature regime accounted for a longer growing season. Persistence of the canopy effect after tree death is apparently due to improved soil conditions.

The differences in results between the northern and central California studies described above are primarily due to woodland versus savanna community structure but also are likely due to edaphic and climatic factors. Oak-woodland cover on a slightly north-facing slope (SFRFS) would be expected to suppress understory forage production, while tree cover in a widely spaced oak savanna on relatively less developed coarse textured soils with only two-thirds the average annual precipitation (SJER) would be expected to improve nutrient and water relations of understory forage plants.

Obviously the application of the tree removal technology for enhancing forage production for livestock needs to be limited in many blue oak communities where there is poor regeneration (Muick and Bartolome 1986). Removal should be limited to those sites where favorable responses are possible and alternative forage sources are unavailable to the landowner. Additionally, the decision maker must be aware that the enhanced productivity of a cleared site above that of naturally open grassland is limited to about 15 years after clearing, and the technology should probably be considered only in the more mesic oak woodlands in the northern part of California.

Raguse et al. (1986) recently published guidelines for foothill woodland range improvement on private land where tree removal is one step in the process of increasing the carrying capacity for livestock and where multiple use concerns affect the rancher's decision. They recommend leaving all woody vegetation along natural drainageways or riparian zones to reduce erosion and on rocky outcrops or thin soil sites where forage production potential is low. With reference to aesthetic and wildlife values they recommend leaving scattered groups or corridors of trees of all age classes present, especially in visually sensitive areas or where special wildlife management objectives require woody plant habitat. They recommend not clearing slopes in excess of 30–40% to minimize erosion hazard, except as needed to aid in livestock surveillance and handling. Finally, to maximize the benefit to agricultural production, they recommend concentrating management by completely clearing areas of the ranch best suited for range or pasture related activities such as reseeding to improved forage species, fertilization, agroforestry and irrigation.

2.3. *Introduction of improved forage species*

The primary technology for enhancing productivity of California annual grassland has been by the introduction of two annual clover species, subterranean clover or subclover (*Trifolium subterraneum*) and rose clover (*T. hirtum*). Grassland improvement research on the two species began with field testing in the early 1940's (Jones and Love 1945). Murphy et al. (1973) summarize the technology and describe methods of establishment, requirements for proper inoculation, seedbed preparation and sowing, and fertilization and grazing management. Subclover is the more prostrate of the two species, it is more competitive under heavy livestock grazing and more palatable to livestock, and therefore it has received the greatest study and evaluation for range improvement. Love (1985) recently reviewed the role of rose clover in range improvement. Overly light stocking of livestock (Williams et al. 1956), inadequate fertilization with phosphorus and/or sulfur (Jones 1974), ineffective *Rhizobium* bacterial inoculation (Jones et al. 1978), intolerance to basic soils above pH 7.0, and late maturity dates were some of the more important hurdles that had to be overcome to successfully establish and appropriately prescribe the technology to ranchers.

University of California, Cooperative Extension specialists and farm advisors continue their testing of new cultivars produced by Australian plant breeders, our original and continuing source of subclover varieties. Subclover variety 'Clare' and several medics (*Medicago* spp.) are best adapted for legume seeding on ranges with soil pH above 6.5 (Murphy et al. 1973). As insurance for good establishment and stand maintenance, 3–7 subclover cultivars are sown together to help cope with the vagaries of fall, winter and spring drought (Murphy et al. 1973). Successful subclover establishment as part of a chaparral type conversion to grassland has been particularly successful because of reduced competition from resident annual species following fire (Williams et al. 1956).

The main benefits derived from annual clover introduction are increased winter and spring forage production (Fig. 7) and improved forage quality for livestock year round (Jones 1974; Jones et al. 1957; Torell et al. 1972), although deer and quail also may benefit (Kay 1986a). Vaughn and Murphy (1982) describe 1,200 to 2,000 kg $ha^{-1} yr^{-1}$ increases in forage production in a 20-year study at Hopland. Periodic fertilization with phosphorus and sulfur was required to get maximum sustained benefit from these seedings. Since this increase was

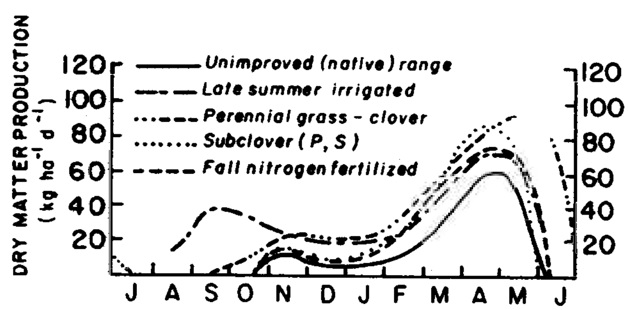

Fig. 7. The pattern of seasonal dry matter production of unimproved, late summer irrigated, perennial grass and clover improved, subclover improved, and fall nitrogen fertilized annual grassland pastures.

achieved at an ideal location for subclover introduction and the test was conducted by managers very experienced with subclover management, this estimated productivity enhancement may be high.

Six species of perennial grasses that have been recommended for annual grassland range improvement and as part of chaparral type conversion to grassland, in order of importance, are: perla koleagrass (*Phalaris tuberosa* var. *hirtiglumis*), hardinggrass (*P. t.* var. *stenoptera*), Berber orchardgrass (*Dactylis glomerata*), tall wheatgrass (*Agropyron elongatum*), smilograss (*Oryzopsis mileacea*), and mission veldtgrass (*Ehrharta calycina*). Much of the early work related to type conversion looked promising (McKell et al. 1965), but stand maintenance under moderate to heavy grazing proved to be poor in many cases.

Most of the research effort on perennial grass introduction into the annual grassland itself has been devoted to hardinggrass (Kay 1968, 1969; McKell et al. 1966). Perennial grass and subclover mixtures provide a longer green forage season with substantially increased forage production (Fig. 7, adapted from Kay 1968, 1969). However, perennial grass range improvement has been limited because of difficulty of establishment and low tolerance to selective grazing by livestock (Adams and Kay 1985). Kay (1966, 1968) and Kay and Owen (1970) investigated the use of the contact herbicide paraquat as a band spray or full coverage treatment after fall germination of annuals to reduce grass competition and aid in establishment. The technique of band spraying worked well to increase the chances for a good stand.

Hardinggrass is rather intolerant of livestock grazing and forage removal during active growth periods reduced yields and increased plant death (McKell et al. 1966). Kay (1960) found it to be fire tolerant in follow-up burns in chaparral type conversion programs which makes this grass a good candidate species for erosion control. But after reevaluating all known effects of livestock grazing on stand maintenance, only light grazing levels (> 20 cm stubble heights) can be sustained or the stand will be lost (B. Kay, pers. comm.). For erosion control and light grazing in type conversions the introduced perennial grasses have a role, but not under moderate to heavy grazing regimes. While orchardgrass is easier to establish (Adams and Kay 1985), its higher palatability to livestock makes it even more difficult to maintain in a grazed grassland than hardinggrass (M. Bell, Glenn County Farm Advisor, pers. comm.).

Today perla koleagrass is the suggested replacement for hardinggrass because of higher seedling vigor, greater winter production and better survival (Adams and Kay 1985). While it has been through preliminary testing since 1956, the dominance of hardinggrass in past seedings and current limited use of perennial grasses will not provide enough data for years to come to evaluate its stand stability. Smilograss only had limited use in chaparral burns from 1940 to the early 1960s and is not of significance today (Adams and Kay 1985). Mission veldtgrass has seen limited use but stands persist and have spread in sandy areas near the coast where it apparently competes with native species. Its primary value is limited to soil stabilization. Finally, tall wheatgrass is used infrequently to seed thin soil and serpentine sites in the annual grassland with favorable production and soil protection results (M. Bell, pers. comm.).

2.4. *Fertilization of annual grassland*

Nitrogen limits annual grassland productivity wherever legumes are in low abundance (Jones 1963b; Jones and Woodmansee 1979; Martin and Berry 1970). Phosphorus and sulfur deficiencies are also widespread and these nutrient limitations normally become most critical in justifying investment in a legume seeding improvement program (Jones and Ruckman 1973). Molybdenum, and on acid soils, potassium, boron and lime are often deficient on annual grassland pastures seeded with legumes and maintained with phosphorus and sulfur fertilization (George and Jones 1985; Jones 1974). Except for bur clover (*Medicago polymorpha*) and several locally abundant *Lotus* species, native or alien resident annual legumes are rarely in adequate abundance to alleviate the severe limitation of nitrogen deficiency on nonseeded annual grassland.

Given the historically and continuing high cost of inorganic nitrogen fertilizer and the well developed annual legume seeding technology described in the previous section, little nonseeded annual grassland fertilization is done in California today except that subsidized by USDA Agricultural Conservation Program (ACP) funds. George and Jones (1985) do not recommend nitrogen fertilization outside the 300–750 mm (12–30 inch) precipitation zone because of drought and leaching risk. Urea (40-0-0) is the most economical nitrogen fertilizer for sites where sulfur and phosphorus are not limiting (Jones 1960). Ammonium sulfate (21-0-0) may be used on nitrogen and sulfur deficient areas.

Ammonium phosphate sulfate (16-20-0), containing all three elements, N, P and S, is most expensive and therefore is prescribed for sites deficient in all three nutrients (George and Jones 1985). Carryover-year productivity effects with phosphorus applications (Jones and Ruckman 1973) are higher than that for sulfur (Caldwell et al. 1985; Woolfolk and Duncan 1962). Poultry and other manures from feedlot or dairy wastes are used if they can be applied economically (Jolley and Raguse 1981).

Fall application of nitrogen fertilizers is recommended and is justified to increase winter and early spring forage production prior to the rapid spring growth phase (Fig. 7). Jones (1963b) determined that maximum yields of annual grassland resulted from fertilization with 90 kg ha^{-1} of nitrogen, but recommendations today normally range from 45 to 65 kg ha^{-1} nitrogen added. Additional spring forage production will also occur but usually inadequate winter feed is the incentive for nitrogen fertilization programs. Since grass competition with annual legumes is increased with nitrogen application, the practice is normally limited to sites where legumes are in low abundance (Jones and Winans 1967).

On sites where nonseeded or seeded legumes are abundant, deficiencies in sulfur and/or phosphorus are amended with elemental (soil or 'popcorn') sulfur, gypsum, single or triple superphosphate (described above as part of the annual legume technology). Caldwell et al. (1985) recently reviewed the use of sulfur fertilizers on nonseeded grasslands and cautioned the use of the practice because of the high risk of inadequate first and carryover-year responses to justify the investment. Under the right rainfall conditions major benefits can be gained from sulfur application (Bentley et al. 1958; Wagnon et al. 1958). Given alternative sources of forage from rental land and the high risk caused by drought in any given year, ranchers only sparingly elect to fertilize annual grassland except as part of a maintenance program for annual legume improved pastures. Unless the extra benefit from improved forage quality, both in the spring as well as cured dry season forage, can be gained from enhanced legume composition, fertilization usually cannot be justified except on a limited acreage and intensive management basis (Demment et al. 1987; Phillips et al. 1987).

2.5. *Irrigation of annual grassland*

Only one study has been published on irrigation potential for enhancing productivity of California annual grassland. Taggard et al. (1976) studied the effects of late summer sprinkler irrigation on seedling development, forage yield and management problems for two annual clovers and two annual grasses. Given the five to six month dry season, earlier nutritious green forage in fall could greatly enhance livestock productivity and reduce the need for protein and energy animal feed supplementation. Fall growth of annual legumes following natural germinating rainfall usually is slow because of cool fall temperatures. By artificially germinating the plants early when temperatures are higher, greater productivity is expected.

Annual grasses, *Avena barbata*, *Bromus mollis* and *Lolium multiflorum*, irrigated on August 3, 16 or 31 flowered in the fall which depressed yields (Taggard et al. 1976). August irrigation exposed the plants to summer insect infestations with greatest damage to bur clover and lesser damage to rose and subterranean clovers by the beet armyworm (*Spodoptera exigua*). A fungus damaged rose clovers in the most productive treatments. While no control productivities (natural rainfall germinated) were reported, 6000 to 7500 kg ha^{-1} of annual yields of legumes were obtained with late summer irrigation. Lack of irrigation water on most ranches probably prohibits much use of fall irrigation.

2.6. *Weed control*

Grazing capacity of annual grassland is severely decreased by weed infestations and therefore considerable effort has been devoted to research on weed management and control methods. Weeds or undesirable plants invading annual grassland span a wide range of woody and herbaceous plant families, some poisonous, some noxious, and others that occupy space which could be more productive if covered by desirable species. Prescribed fire, discussed above with a focus on brush control, is the most common tool used today to control many of the woody plant weeds in genera such as: *Adenostema*, *Arctostaphylos*, *Baccharis*, *Cytisus*, *Quercus*, *Salvia*, and *Toxicodendron*. Herbicides and mechanical control methods are often used in combination with fire to reduce dense stands.

Two herbaceous weeds that have had extraordinary research efforts devoted to them with strikingly different results are the poisonous, perennial forb Klamath weed or St. Johnswort (*Hypericum perforatum*) and the unpalatable annual grass medusahead. The introduction of the leaf-beetle (*Chrysolina quadrigemina*) in 1946 as a biological control reduced the infestation of the former tremendously and has kept the problem under reasonable control (Huffaker and Kennett 1959). A classic example of reduction in apparent plant competition was shown by Huffaker (1951) where the native perennial grass *Danthonia californica* recolonized space vacated following Klamath weed decline.

In contrast to the control success with Klamath weed, medusahead continues to spread and increase in abundance despite extensive research on control methods in California and other states in the northwestern U.S. (Hilken and Miller 1980). Burning, herbicides, fertilization, tillage, mowing, seeding of legumes, and various combinations of these control methods have all been unsuccessful in long-term control over significant acreages. Low palatability (Lusk et al. 1961) due to stiff awns and slow litter decomposition caused by high silica content (Swenson et al. 1964) allows the plant to build up dense litter mats that exclude desirable forage species. Late phenological development effectively allows medusahead to avoid competition with other rapidly growing plants in spring.

Weed problems with both Klamath weed and medusahead are greatest in the northern half of the state but infestations of medusahead in central and southern California continue to increase.

Currently, seven noxious, spinescent, herbaceous species (*Cynareae* Tribe of the sunflower family) are of greatest concern to annual grassland managers (Maddox and Mayfield 1985; Thomsen 1985; Thomsen et al. 1986). The annuals yellowstar thistle (*Centaurea solstitialis*), Italian thistles (*Carduus pycnocephalus* and *tenuiflorus*), and milk thistle (*Silybum marianum*) are a widespread problem throughout the annual grassland. The biennial purple starthistle (*Centaurea calcitrapa*) and perennial artichoke thistle (*Cynara cardunculus*) are locally common in Sonoma, Marin, Napa and Solano, and Alameda, Contra Costa, Solano and Orange counties, respectively. All periodically have been under herbicide control programs by county agricultural commissioners, private landowners or state agencies. Presence of these species decreases the quantity of edible forage both by spatial exclusion of desirable species as well as access by livestock through the often dense stands. Artichoke, yellow and purple starthistles produce much of their biomass after annual plants have matured and their standing dead litter ('skeletons') excludes desirable species. Yellow starthistle is acceptable forage, except for horses, during winter and spring before it bolts and flowers. Italian thistles when dry are grazed by sheep.

2.7. *Livestock grazing systems*

Unlike range research on other temperate grasslands in North America, very little research has been done on livestock grazing systems in California annual grassland. Federal land management agency methods of rating range condition consistently have put annual grassland into the poor condition class because of dominance by non-native species, and this has further discouraged federal support for research on native plant improvement. The need to keep annual legume improved range rather heavily grazed to reduce clover competition with the taller annual grasses has not helped develop a range management mentality in California to graze livestock at light to moderate levels. This tendency to graze heavily has made it difficult to maintain perennial grass seeded pastures. Over the last decade promotional efforts on the part of Allan Savory have stimulated local interest in one grazing system, short duration grazing, but no support for research to determine mechanisms underlying any favorable or unfavorable annual or perennial plant responses.

At the San Joaquin Experimental Range the first formal grazing studies on California annual grassland showed little response of the grassland to grazing intensity (Talbot and Biswell 1942). Artificial 'mulch' manipulation studies have been used to estimate stocking rate effects on productivity, again showing that the grassland does not respond unless abusively grazed (Bartolome et al. 1980; Heady 1956, 1966). In a 4-year grazing intensity trial with sheep at Hopland, Pitt and Heady (1979) showed that only under the 2.5X the moderate stocking did productivity of the range decline following one year of rest from grazing. Animals died under the high stocking rate indicating that animal performance declines would probably be detected by the rancher before any range deterioration. Rosiere (1987) found a similar lack of response on some of the same pastures at Hopland in a 5-year trial, but he did find substantial botanical composition shifts with heavy stocking.

Weather impacts on plant productivity have been shown to have such an overriding impact in the annual grassland (Pitt and Heady 1978) that animal performance variability from year to year is usually greater than is the grazing system effect. Animal performance is usually reduced whenever a seasonal grazing system is imposed, compared to the normal system of continuous grazing (Duncan and Reed 1973; Heady 1961; Heady and Pitt 1979b). Ratliff (1986) presented results from an 8-year comparison of continuous, repeated seasonal, and rotated seasonal grazing systems at moderate grazing intensity on cow and calf responses at the San Joaquin Experimental Range and showed no benefit of seasonal grazing systems over continuous grazing.

However, the need to have some systematic method of controlling degree of forage utilization on annual grasslands has led to the development of a 'residual dry matter' (RDM) assessment procedure. Hooper and Heady (1970) gave an economic argument for 'restrained' grazing, but it was not until greater environmental awareness that management agencies wanted to have more control over their grazing management programs. Minimum presence of residual herbaceous plant litter in the fall is recommended for various regions of the state based on average annual precipitation (Bartolome et al. 1980; Hormay and Fausett 1942; Clawson et al. 1982; USDA Forest Service 1984). Depending on whether the range site is on lower flat slopes to upper steep slopes, 225–390 kg ha^{-1} (200–350 lbs ac^{-1}), 450–900 kg ha^{-1} (400–800 lbs ac^{-1}), and 840–1400 kg ha^{-1} (750–1250 lbs ac^{-1}) is the recommended minimum RDM for southern California with 250 mm (10 inches), central coast and central valley foothills with 250–1000 mm (10–40 inches), and the north coast with > 1000 mm (40 inches) precipitation, respectively. Imposition of this simple standard by government and private range managers has substantially reduced overgrazing problems in much of the annual grassland. However, given the annual plant productivity in each of these regions and these RDM standards, the resulting forage utilization level is still substantially higher than would be recommended for perennial bunchgrasses (usually 45–55% utilization) throughout the rest of North America, where standards have been established based on physiological requirements of the plants. In effect, annual grassland managers hold no hope for widespread reestablishment of perennial grasses given intense competition from alien annual grasses and forbs. Whether these forage utilization rates are sustainable in the long-term is unknown.

2.8. *Rotation of farming and grazing of grassland*

Large acreages of lowland annual grassland on the west side of the Sacramento Valley (M. Bell, pers. comm.) and on the central and south Coast Range foothills are periodically farmed to dryland grain crops (oats, barley and other crops) to reduce soil compaction problems. Tillage has been promoted by the U.S. Department of Agriculture, Soil Conservation Service for many years and ranchers and farm advisors have found that the practice increases grassland productivity for several years. Grasslands on certain gravely soils containing sufficient clay become 'sealed' and somewhat cemented due to livestock grazing during the wet season. Tillage breaks up this impervious layer increasing water infiltration and aeration. Recently Cooperative Extension has recommended a cereal crop-annual legume rotation program as practiced in Australia and northern Africa for these range and grain lands (Weitkamp and Graves 1987). Twenty-two cultivars of six species of annual *Medicago* species, covering 62 to 106 days from germination to flowering, are available to enhance forage quality and increase soil nitrogen levels.

Managers of mediterranean annual grasslands in France also periodically disk their livestock ranges, including oak savannas, to improve productivity (L. Jackson, pers. comm.). The need for these practices should caution range managers about possible long-term and unknown cumulative changes that may be affecting the productive potential of other annual grasslands in California. More research on physical processes and water dynamics of intensively grazed grassland is needed on these lands.

2.9. *Herbicide and other pesticide use in annual grassland*

Development of most of the annual grassland management technologies took place during an era of 'technological fixes' never equalled in the history of mankind. Range management technology development was certainly active in this period. Few of the technologies related to herbicides and pesticides are practiced today for the purpose of enhancing annual grassland productivity because either they are now illegal or they are uneconomical or ineffective. By far the most widely practiced chemical-based plant control technology was with the phenoxy herbicides. 'Brushkiller', a 50:50 mixture of 2,4-D (2,4-dichlorophenoxyacetic acid) and 2,4,5-T (2,4,5-trichlorophenoxyacetic acid), applied to standing brush, basal frill cuts, or injected into the cambium of trees during the active carbohydrate storage phenological stage, or painted on cut surfaces of tree stumps, kills root and shoot systems of woody plants including resprouting species (Leonard 1959; Leonard et al. 1956; Leonard and Harvey 1965). This 'ultimate' technology in the herbicide field was used throughout range and forest management programs in the U.S. until the discovery of dioxin contamination of 2,4,5-T, poisonous to humans. Virtually all woody plant control programs either used these chemicals as a pretreatment desiccant prior to prescribed burning, as an initial tool to kill plants, or as a follow-up treatment after prescribed burning or mechanical removal of brush, or some combination of these uses. The herbicide provided the most powerful and inexpensive means of type converting brushlands to grasslands throughout the western U.S. There has been a major effort to identify substitutes, but none that equal the effectiveness of 'brushkiller' has been developed. Tolerance studies were done to determine which seeded annual legumes were least affected by follow-up 2,4-D applications (Ormrod and Williams 1960).

By comparison, minor herbicide-based technologies used to control herbaceous plant weeds have been developed. The herbicide paraquat (1,1′-dimethyl-4,4′-bipyridinium ion) has been used as a band spray to reduce annual plant competition and allow perennial grass seeding into annual grassland (Evans et al. 1975; Kay 1966; Kay and Owen 1970). The technique worked but was never applied. Paraquat and dalapon (2,2-dichloropropionic acid) as post-emergence herbicides and simazine [2-chloro-4,6-bis(ethylamino)-s-triazine], EPTC (ethyl N,N- dipropylthiolcarbamate) and atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine) as pre-emergence herbicides were tested to control medusahead but the practice was never applied to commercial size acreages (Kay 1963, 1965; Kay and McKell 1963; Young et al. 1971).

Use of forage by rodents and rabbits as direct competitors with livestock was recognized early in the field of range management in California (Fitch and Bentley 1949). Poison baits, trapping, shooting and exclusion techniques were developed (Howard 1953; Storer 1953). Use of the pesticides strychnine, thallium sulfate, zinc phosphide, and until banned, compound 1080 (sodium fluoroacetate) is common. While the degree of livestock competition with one of the most important rodents, the California ground squirrel (*Spermophilus beecheyi fisheri*), has been well documented (Howard et al. 1959; Schitoskey and Woodmansee 1978), only rarely is it economical for the rancher to conduct a squirrel control program. Health considerations on military training bases located on annual grassland often require control programs to reduce the risk of bubonic plague and this is the most common use of rodenticides on range in California. Zinc phosphide is the most commonly used substance on military bases today.

2.10. *Combining technologies for multiple use benefit*

All of the management technologies discussed above to a greater or lesser degree also affect productivity and other aspects of the annual grassland such as watershed production, wildlife habitat, aesthetic values, and potential for game-farm recreation and secondary income for ranch owners. In some cases research initially designed to study management effects on these allied products has been followed-up by other research and development activity to enhance multiple use benefits. For example, woody plant removal to reduce summertime transpiration and therefore increase water output from watersheds (Lewis 1968; Rowe 1963; Rowe and Reimann 1961) provides an opportunity to revegetate land with valuable forage plants (Murphy et al. 1973; Williams et al. 1956) that, at the same time, protect soil from surface erosion. Fire hazard reduction has often been discussed as a complement of wildlife habitat enhancement, forage improvement for livestock, and watershed improvement to economically justify management decisions.

Mission-oriented research, development and extension activity to enhance multiple uses of land is not without problems, especially when long-term studies are required and early results do not parallel ultimate findings. For the purpose of illustration, early results from Watershed I and II research at the University of California, Hopland Field Station were misperceived by the public as a general management prescription for range improvement. Initially this research was done on two adjacent tree and shrub covered watersheds to determine the potential for enhancement of watershed output for on-site and downstream water users (Burgy and Papazifiriou 1974; Pitt et al. 1978); for example, they found a 59% increase in runoff, as a proportion of total precipitation, due to the type conversion on Watershed II. Increased erosion was expected so elaborate soil erosion monitoring was done. Because the early results of enhanced water yield and forage production looked promising, the practice of vegetation type-conversion was promoted as an effective tool in watershed management. It was not until the woody plant root systems had decomposed sufficiently 8–10 years after treatment that the researchers learned of the excessive soil slips that would more than cancel the positive benefits.

Three important things were learned from this research and extension effort, in addition to the original research goals of determining water and sediment yield and slope stability responses to type-conversion. First, it was found to be difficult or impossible to predict whether continuous surface stream flow will result from vegetation type-conversion. In this classic study, one watershed (II) showed the favorable surface water delivery response and the other (I) did not, so a landowner may or may not reap any on-site water benefit whatsoever. The practice can hardly be considered a useful technology for enhanced water output for the landowner since results are unpredictable.

Second, considering the 2–4 fold forage productivity increase alone would cause the conversion to appear overly inviting to a rancher if other potential impacts on his land were unknown. We now know that this high success of clover and perennial grass establishment was due to the small soil seedbank of competitive annuals, a characteristic of most chaparral and dense woodland sites, and also that high resident annual seed mortality was caused by the extraordinarily hot fire utilized to clear the watershed of woody vegetation. Watershed II was far too steep to serve as a model for public view and as the basis for making recommendations on range improvement.

In a water deficit state like California many water users probably view any type-conversion from perennial to annual vegetation to be favorable at the regional or statewide level, because even though a watershed is not tight, subsurface flows eventually fill reservoirs downhill from the site of conversion. The third lesson to be learned by the landowner from this research is that off-ranch interests, both public and private, may be strong supporters of the activity but not for the landowner's benefit. As recently as the mid-1980s, the University of California has been criticized for most of its research on tree removal. Where fire hazard reduction in chaparral communities is the primary goal, several exceptionally successful multiple use vegetation type conversions have been accomplished, for example, the Grindstone Project on the Mendocino National Forest (Murray and Wright 1982).

Lack of adequate research on the cumulative effects of extensive type conversion of large blocks of land makes such activities very questionable. Other examples of opportunities and concerns about various annual grassland management technologies will be discussed below in the section on stability of intensively managed systems.

3. Ecology of grazed annual grassland and oak savannas

Major questions on ecological effects of alien plant introduction, tree removal, vegetation type conversion, and intensive livestock grazing remain unanswered. Literature related to these and other questions will be discussed to formulate hypotheses and hopefully stimulate research on some of these important questions.

Alien annual grasses and forbs of Mediterranean origin largely replaced native perennial grasses in California before 1900 (Burcham 1957). Grazing management and range reseeding efforts in California have not been successful in reestablishing perennials except where annual plant competition is low, such as in chaparral type conversions; and in this case as well, greatest successes have been obtained with herbivore-adapted species from other mediterranean-type climatic regions of the world. Alternatively, a very successful technology has been developed to establish and manage annual legumes, and this focus on replacement of species rather than on management of resident annuals has further de-emphasized the need for grazing management research. The prime grazing management requirement for seeded annual legume stand maintenance is moderate-heavy early grazing to reduce grass competition (Jones and Love 1945; Love and Williams 1956). However, increased costs of seeding annual legumes and required periodic fertilization with phosphorus and/or sulfur have stimulated interest to again look more closely at annual grassland grazing system responses, most recently the short duration grazing systems. Since the resident annuals are adapted to heavy grazing there is certainly a potential to manipulate them favorably.

3.1. *Effects of livestock grazing through defoliation*

Research and experience to date indicate that California annual grassland is very resilient to heavy livestock grazing (Heady and Pitt 1979b; Pitt and Heady 1979), but too heavy grazing can significantly reduce productivity (Bartolome et al. 1980; Bentley and Talbot 1951). Resilience is a prerequisite attribute for a range being capable of responding to seasonal or rotational grazing, since unless sufficiently heavy stocking is imposed, genetic potential of livestock and not plant communities and the land limit productivity. The major constraint to annual grassland managers may be a logistical one due to the six-month dry forage season coupled with the typical operation of yearlong cow-and-calf or ewe-and-lamb enterprises where inadequate numbers of animals are available to graze heavy enough during the green forage season to achieve potentially favorable responses of legumes and desirable forbs. This constraint and inadequate grazing research findings may be responsible for the common recommendation of continuous grazing. The increasing trend of grazing seasonal stocker cattle could provide greater opportunities to manipulate botanical composition and productivity by concentrating grazing use to smaller acreages. Recent work with sheep grazing on intensively managed small pastures shows promise for very high production by concentrating management inputs on only a small part of a ranch (Demment et al. 1987; Phillips et al. 1987).

Several researchers studying mediterranean, annual-plant dominated grassland have shown that exclusion of or light livestock grazing during the growing season quickly leads to grass dominance, especially ripgut brome (*Bromus diandrus*) and slender wild oat (*Avena barbata*), with associated loss of nutritious legumes, notably clovers (*Trifolium* spp.), medics (*Medicago* spp.), and filarees (*Erodium* spp.) (Bentley and Talbot 1951; Biswell 1956; Freckman et al. 1979; Jones and Evans 1960). This tendency for taller-growing grasses to dominate lower-growing dicots is primarily due to shading effects (Stern and Donald 1962a, 1962b), but recent evidence also indicates that dormant filaree seeds require exposure to summer heat for germination and it may not break dormancy under a cover of grass litter (Rice 1985). Similar heat treatment requirements for many small-seeded legumes have been known for a long time (Williams and Elliott 1960). Moderation of summertime diurnal temperature variation and reduction of maximum temperature at the soil surface by litter cover significantly reduces the softening rate of filaree seeds in the soil and thus reduces germination. The more litter present during the dry forage season in summer the lower the filaree density the following year.

Since virtually all the previous grazing system studies in California have been done with cows and calves or ewes and lambs where the objective of year-round forage supply was a controlling factor on stocking rate, considerable amounts of forage residue left in summer have resulted. Therefore, grazing enhancement of forbs and legumes on unimproved range has not been recognized by researchers except in odd corners of pastures where animals naturally congregate and keep litter buildup to a minimum. During pre- and post-drought (1976–1977) heavy grazing by cattle at Fort Hunter Liggett in Monterey County, I observed extensive acreages of the grassland dominated by filarees and foxtail fescue (*Vulpia megalura*), and the change persisted for years following relaxed grazing pressure; Rosiere (1987) found similar responses under heavy sheep grazing at Hopland. Recolonization by taller grasses took several years to spread from adjacent more lightly grazed areas and from refuge populations in heavily grazed area itself after the stocking rate was reduced.

Mulch manipulation studies used to simulate grazing intensities have had litter removed too late in summer (last week of August, Heady 1966), to get the required heating effect to break seed dormancy in filaree and clovers; thus, it is not surprising that Heady (1956) and Pitt and Heady (1979) did not get the expected filaree responses. Since filaree is a key element on the California grassland community and previous studies have apparently not manipulated litter or mulch cover in a realistic manner, we need to reevaluate the responses of the annual grassland to grazing. Pitt and Heady (1979) conducted a grazing intensity study with sheep at Hopland, but again the grazing system was yearlong-continuous. In addition, June sampling of botanical composition heavily biased against filaree since it shatters before then and grasses would typically over-top filaree residue by June. In several locations at Hopland where moderate-heavy grazing intensity takes place each year (Lambing and Middle-Horse Pastures), filaree is the strong dominant. Earlier, Rossiter (1966:29, 35) observed that Heady (1961) did not get the expected heavy grazing (low mulch) response for filaree or the light grazing response (high mulch) for ripgut brome. Rossiter's (1966:27) statement, 'A great deal of emphasis has been placed on grazing management quite apart from stocking rate per se, by California workers', appears now to be appropriately critical of mulch studies as inadequate surrogates for animal stocking rate trials. Inappropriate timing of sampling species abundance further exacerbates our already weak understanding of the community responses to grazing.

3.2. *Large herbivore trampling, mulch removal and oak canopy effects on soil structure and water relations*

Trampling by herbivores may be depressing productivity throughout the annual grassland. For years researchers and managers have observed unusually soft and friable surface soil conditions on livestock free areas at the Hopland and Sierra Foothill Range Field Stations, the San Joaquin Experimental Range, and the Hastings Natural History Reservation. At Hopland and Hastings even less compacted soil conditions have been observed on livestock-and-deer-free areas showing that trampling effects of native ungulates are an important contributor to compacted soil. Trampling has important effects on soil water status and runoff and therefore grassland productivity. Four studies have investigated the effect of livestock trampling on the soil water status and runoff regimes in California annual grassland (Assaeed 1982; Liacos 1962a, 1962b; Ratliff and Westfall 1971) and two other related studies have looked at bulk density responses to mulch (Heady 1966) and blue oak (*Quercus douglasii*) overstory (Kay and Leonard 1979).

On clay loam soils (Los Osos series, Typic Argixerolls) developed on sandstone parent material in the hills east of Berkeley, bulk density, structure, color and pH were affected by trampling (Liacos 1962a). Bulk density of the surface horizon ranged from 1.40 Mg m^{-3} on ungrazed sites to 1.60 Mg m^{-3} on sites heavily grazed by cattle for 35 years, while light to moderate grazed sites were intermediate. Granular surface horizons only existed on sites moderately to lightly grazed or protected from livestock. Darker olive brown subsurface soil colors indicated poorer aeration on grazed sites, and pH of surface soil ranged from 5.4 to 5.7 on ungrazed and heavily grazed sites, respectively. Root penetration exceeded 0.9 m and root development was extensive on protected sites, while shallow and poorly developed root systems were typical of grazed sites. Earthworm activity was markedly lower on heavily grazed sites.

On coarse, sandy loam soils (Visalia series, Cumulic Haploxerolls) developed from coarse-textured granitic alluvium on swale sites and the same textured soils (Ahwahnee series, Mollic Haploxeralfs) on slope sites at the San Joaquin Experimental Range (SJER), Assaeed (1982) observed higher bulk densities due to grazing only on swale sites in the surface 0–5 cm layer. Swales ungrazed by cattle for 10 years had densities of 1.22 Mg m^{-3} while those continuously grazed had densities of 1.38 Mg m^{-3}. No grazing effect was found for the 5–10 cm layer on either site, but the bulk density was higher.

Ratliff and Westfall (1971) compared adjacent areas on the same Ahwahnee soil series at SJER, one ungrazed by cattle from 1936 and the other moderately grazed during the rapid-growth season from the first of February to early June from 1960. Ground squirrels had also been excluded from the ungrazed area but gophers had equal access to both areas. Using a relatively large sample of 50 cores per area they found dramatic differences in bulk density and pH. The ungrazed area had a bulk density 24% lower than the grazed site. Soil acidity was higher on the grazed (pH 5.6) compared to the ungrazed area (pH 6.2). These unexpectedly large effects for light textured soils must have been due to grazing during the period of abundant soil moisture. Ratliff and Westfall (1971) noted that gophers were also most active near the surface when the soil was most compacted in late winter and spring, and that cattle trampling recompacted gopher mounds and cattle hooves broke into surface burrows reversing the loosening effect of gophers.

Heady (1966) found that late-summer removal of dry plant residue reduced herbage production as well as increased bulk density on fine, sandy loam soil with clayey subsoils (Sutherlin series, Ultic Haploxeralphs) on ungrazed sites at Hopland. Bulk density at the end of eight years of treatment ranged from 1.14 Mg m^{-3} on untreated plots to 1.36 Mg m^{-3} where all residue was removed each year; corresponding average (1954–1960) peak herbage biomass standing crop was 116 and 256 g m^{-2}. Lower organic matter and lower pH in the surface horizon correlated with higher bulk densities. Heady (1966) also observed a decline in the loose, crumb structure with residue removal, indicating reduced soil structure and aeration. He did not observe a reduction in soil nitrogen and phosphorus probably because of the late date of herbage removal and his conscious effort not to remove seeds from the plots. Greater exposure of bare soil to raindrop impact in autumn and early winter prior to full herbage canopy coverage and reduced root growth due to drier soil conditions caused by higher runoff and lower infiltration were probably the primary causes of soil compaction.

Kay and Leonard (1979) found significantly lower soil bulk densities under blue oak canopies (1.07 Mg m^{-3}) than in natural openings (1.18 Mg m^{-3}) on well drained, reddish-brown, loamy surface soils with varying degrees and depths to a clayey subsoil (Auburn, Las Posas and Sobrante series complex; Ruptic-Lithic Xerochrepts, Typic Rhodoxeralfs and Mollic Haploxeralfs, respectively) following 14 years of protection from cattle and deer grazing at the Sierra Foothill Range Field Station. Standing herbage was removed along sampled transects in September (well after seed shatter) in most years of the study to reduce unnatural buildup of litter. Soil bulk densities on adjacent sites where oaks were removed 14 years previously became as compacted as those in natural openings. These results indicate that the oak canopy and oak litter may provide protection from raindrop impact and provide for increased soil organic matter and a more porous soil structure.

Liacos (1962a) found low soil moisture storage with heavy cattle grazing due to low rates of infiltration and percolation. Soil moisture in the lower half of the profile only increased by about 3% during the rainy season, and roots were so sparse that only a 6% depletion occurred during the growing season. Deep cracks in the surface soil allowed the 24–40 cm layer to be wetted during the first big autumn storm, but sealing of the cracks after that event retarded further infiltration. Both the low infiltration and percolation rates and the almost insignificant withdrawal of soil moisture from the lower layer by shallow-rooted plants reduce water storage in compacted soils on heavily grazed sites, and therefore runoff is enhanced. Ungrazed plots had high infiltration and percolation rates and heavy use of stored moisture from throughout the profile by deeply rooted annual and perennial grasses, so little runoff occurred. The soil moisture regime of the lightly grazed plot was similar to the ungrazed plot, except less water was extracted from deeper layers in spring. Our annual grassland model, ELMAGE (Pendleton et al. 1983), has also shown decreased transpiration and soil moisture depletion with grazing while not accounting for trampling effects.

Most rain in the California annual grassland ecosystem occurs during cool months when plant growth is slow or stagnant, so this is the period of soil profile recharge. During warm spring growing conditions under dense swards the smaller and more scattered spring rain storms are ineffective in recharging the soil (Liacos 1962a). Compacted soils reduce the effective depth of water storage and concentrate roots near the surface. Concomitant heavy grazing reduces shoot biomass and therefore root biomass and rooting depth. The result is a smaller effective pool of water and nutrients, low water and nutrient use efficiency, and depressed grassland productivity.

4. Efficient use of annual grassland

Most California annual grassland ranges are continuously grazed yearlong with little or no attention given to grazing systems. Typically, replacement heifers in the beef cow herd are grazed in the best pasture available and are given concentrate supplementation whenever the range cannot supply quality forage. The rest of the herd is likely supplemented with a liquid molasses and urea mixture in late summer and early fall to make up for the lack of digestible energy and protein in the forage. The result of continuous moderate intensity grazing is a range that could be called 'overgrazed and underutilized' (Allan Savory, pers. comm.). Patches of the range are very heavily grazed (overgrazed) and other areas are avoided (underutilized) by animals because of rank growth of tall grasses, undesirable or noxious species. Effectively only a proportion of the rancher's acreage is used for grazing. Cost of fencing, water development, and management normally precludes more sophisticated range management activities. The tradeoff between capitol investment in ranch development, either for more controlled grazing or range forage improvement, or both, verses status quo management usually causes the rancher to select the latter. To a large extent this decision can be rationalized on the basis of minimum financial risk.

Given the strong evidence of benefits from annual legume range improvement, potential for increased efficiency in the use of annual grassland is very high. Williams (1966) clearly illustrated the potential for improving the solar energy conversion of annual grassland by a combination of rose clover introduction and sulfur fertilization. Solar energy conversion to harvestable forage was improved three-fold for a typical range in central California. Higher producing subclovers are now available and certainly by careful site selection greater increases in efficiency could be possible. Given this forage enhancement potential and a controlled grazing program many ranches could likely produce the same animal products on only one-half to one-third of the ranch acreage. In effect this range improvement option requires that the range manager become a forage manager with less attention given to livestock management.

5. Stability of intensively managed grassland

Annual grassland management systems in Australia can serve as a model system for estimating the stability of intensively managed, legume-improved California annual grassland given similar climate and edaphic conditions and the typical system of continuous grazing by cattle or sheep. Annual legume-based pastures in southern Australia have been developing for about 70 years (Stern 1985). Serious concerns continue to develop about instability of these heavily fertilized, wet season grazed systems. The legume composition of the pastures is becoming 'disturbingly low' due to several edaphic and management factors. Especially under heavy grazing pressure and heavy phosphorus fertilization soils are becoming acidified and compacted causing excessive run-off and inadequate burr burial and seedbank replacement. Reduction in fertilizer use because of rising phosphate fertilizer costs is further contributing to the loss of legumes due to grass and weed competition. Smith (1965) recognized the problem more than 20 years ago when he observed that *Erodium* and *Bromus* species were replacing subclover due to the relatively xeric condition of the soils on intensively managed pastures. Range conservationists have shown concern about the intensive dryland grain-legume pasture rotation systems on the west side of the Sacramento Valley, and rightfully so.

6. Summary

Replacement of the native perennial flora of California grasslands by alien annual plants has had a major impact on management options available to stewards of the grassland. The tenacity of highly competitive annual species has made it difficult to control productivity for the purpose of improving performance of domestic livestock. On the other hand, the resilience of the annual vegetation forgives abusive practices time and time again. Availability of small-seeded annual legumes from other mediterranean-climate regions of the world has provided a technology that alleviates one of the primary factors limiting productivity, nitrogen. This technology is well developed and available to the rancher. Poor returns from ranching in general, due to national agricultural policies, seems to be the only obstacle to greater adoption of annual legume pasture improvement programs.

Eight vegetation management technologies have be used to increase grassland productivity. Prescribed fire is used to reduce litter accumulations of undesirable weed species and to remove competing shrubs and trees of low forage value. Annual legumes and perennial grasses are seeded to increase the seasonal availability of high quality forages. Fertilizers are used alone or as part of a legume-based pasture improvement program. Irrigation has been used to lengthen the growing season of annual species. Some annual grasslands subject to soil compaction problems and also suitable for farming are used in a dual fashion for dryland grain farming and livestock grazing on a rotational basis. Until recently, herbicides were used in an array of different ways to make other improvements possible. Lack of response of the annual plants to season and intensity grazing has resulted in little application of grazing systems but new systems are being investigated. Need for fire control, wildlife habitat improvement, and increased watershed production can fit into range improvement programs for multiple use benefits.

Serious questions remain about the sustainability and cumulative effects of our grassland management activites. Clearly the demand for cordwood can and does exceed the supply, given the large and rapidly growing population of California. Grassland weed problems and lack of regeneration of deciduous savanna and woodland communities are problems needing greater attention. Educators and extension persons alike must take the long view in teaching the public about the long-term value of its natural resources.

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