Evaluating Moist-Soil Seed Production and Management in Central Valley Wetlands to Determine Habitat Needs for Waterfowl

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GENERAL INTRODUCTION

During winter, wetlands and agricultural habitats within the Central Valley of California support the largest single concentration of waterfowl in North America. These waterfowl (3-4 million) represent 60% of all waterfowl in the Pacific Flyway (excluding seaducks) and approximately 20% of North American waterfowl. In addition, nearly 60% of the continental northern pintail (*Anas acuta*) population winters in the Central Valley. Wetland loss in California has been extensive, resulting primarily from agricultural and urban development, water diversion and flood control measures. In fact, wetlands in California have declined by over 90% from approximately 2 million hectares historically to less than 180,000 hectares at present; only 120,000 hectares of Central Valley wetlands remain.

In 1990, private, state, and federal partners of the Central Valley Habitat Joint Venture (CVHJV) adopted a plan to implement the North American Waterfowl Management Plan within the Central Valley. The Implementation Plan describes a program to halt, and ultimately reverse, long-term wetland loss in California by protecting, enhancing, and restoring wetlands, securing water and power supplies for wetland management, and enhancing agricultural lands important to waterfowl. To establish habitat objectives for the Central Valley, planning focused on 3 questions: (1) how much habitat is needed to support desired waterfowl populations; (2) what types of habitats are needed to meet these objectives; and (3) where in the Central Valley are these habitats needed? The CVHJV adopted a bioenergetic approach as the central planning tool to answer these questions. Using this approach, the total energy requirements of desired waterfowl populations in the Central Valley were calculated, and the total food value provided by wetland and agricultural habitats was estimated to determine the acreage needed to provide the necessary energy.

Partners in the CVHJV recognize that the most immediate information needs deal with biological uncertainty about inputs in to the bioenergetic model. Currently, the foraging value of wetland habitats is the largest source of uncertainty in the CVHJV planning model. To address this information need this thesis: (1) evaluates the amount of food available in Central Valley wetlands; (2) investigates the influence of wetland management on seed production in wetlands; and (3) develops a new technique for monitoring wetland seed production.

In the original formulation of CVHJV objectives, the area of wetlands and agricultural lands needed to provide the required amount of food for waterfowl was calculated using assumptions about how much food is available to, and consumed by, waterfowl in each habitat type. Estimates of food available to Central Valley waterfowl were based on the results of studies that quantified moist-soil seed availability in wetlands in the Mississippi Alluvial Valley (MAV), because no estimates of seed production were available for Central Valley wetlands. Furthermore, estimates of seed consumed by waterfowl were based on observational data of seed consumption by waterfowl in MAV rice fields. The goal of **Chapter 1** was to reduce uncertainty in estimates of seed abundance and depletion in Central Valley wetlands. Increased accuracy in these estimates will allow the CVHJV to determine more correctly how much and what types of habitats are needed to support desired waterfowl populations. Specifically, **Chapter 1** focuses on 3 objectives: (1) determine the amount of seed present in Central Valley moist-soil habitats when waterfowl arrive in fall; (2) determine the degree to which these seeds are depleted throughout the winter; and (3) determine the seed density threshold below which waterfowl cease to forage in moist-soil habitats.

Wetland loss throughout North America during the past century has forced waterfowl managers to develop methods for supporting waterfowl populations with a reduced resource base. On the wintering grounds, managers have focused on providing abundant food supplies for migrating and wintering waterfowl. An important tool for accomplishing this goal is moist-soil management, the manipulation of soil and water to encourage the growth of waterfowl food plants. Habitat managers in the Central Valley employ moist-soil management, but few researchers have investigated the effect of moist-soil management techniques on seed production in Central Valley wetlands. Indeed, in the Central Valley, knowledge of the effects of management practices on moist-soil seed production exists largely as unwritten expertise of wetland managers. To address this information need, **Chapter 2** examines the effect of: (1) spring drawdown timing; (2) drawdown rate; (3) fall disking; and (4) summer irrigation on seed production in Central Valley moist-soil habitats. This study identifies the most effective management strategies in the Central Valley, hopefully enabling managers to make efficient use of limited resources to produce food necessary to support desired populations of wintering waterfowl.

To evaluate the efficacy of moist-soil management efforts, wetland managers need to estimate the amount of moist-soil seed produced in managed wetlands. In addition, information on moist-soil seed production is necessary to determine the waterfowl carrying capacity of wetland habitats. Traditional methods for collecting seed production data are time consuming and labor intensive, and additional methods to predict seed production using plant (primarily seed head) characteristics are often complex and may have limited utility for some moist-soil plants and in some regions. Wetland managers in the Central Valley have identified a need for a simple and reliable method to obtain an index of moist-soil seed production. To address this need, in **Chapter 3** we develop a new technique to predict seed yield using estimates of percent cover and seed-head characteristics of 6 common Central Valley moist-soil plants. We then evaluate the degree of inter-observer error in this method and use this technique to quantify moist-soil seed production on a large area of Central Valley wetlands. This new technique is useful for predicting overall seed production within a wetland, offering managers a simple method to track temporal changes in seed production within wetlands and across landscapes, estimate wetland carrying capacity and evaluate management actions with minimal resource investment.

CHAPTER 1: EVALUATING MOIST-SOIL SEED PRODUCTION IN CENTRAL VALLEY WETLANDS TO DETERMINE HABITAT NEEDS FOR WATERFOWL

ABSTRACT

In 1990, federal, state, and private partners of the Central Valley Habitat Joint Venture (CVHJV) adopted a plan to implement the North American Waterfowl Management Plan (NAWMP) within the Central Valley of California. In the bioenergetic approach, which is the core planning model for the CVHJV, the foraging value of agricultural and wetland habitats remains the largest single source of uncertainty. In this project, we focused on 3 objectives: (1) determine the amount of seed present in moist-soil habitats (i.e., wetlands managed for the production of plant species that germinate on exposed mudflats) when waterfowl arrive in fall; (2) determine the rate at which seed is depleted throughout the winter; and (3) determine the minimum seed-density threshold below which waterfowl abandon or avoid these habitats. We measured moist-soil seed abundance over a range of time and habitat types. Our results indicate that Central Valley wetlands produce less seed than previously assumed. In 1999-2000, moist-soil seed abundance in fall (before bird use) averaged 200 kg/ha. In 2000-2001, moist-soil seed abundance was higher, averaging 586 kg/ha. Seed production was highly variable among sites (range 8–1350 kg/ha). Considering both years, an average of 65% of the seed present at the beginning of the wintering period was removed by the end of winter, and sites containing the highest initial amounts of seed experienced the greatest levels of depletion, suggesting that waterfowl find and preferentially use areas with the high levels of seed. Threshold levels of seed abundance were evident, but the threshold

varied between study years (mean 30 kg/ha in 1999-2000; 160 kg/ha 2000-2001). Simulation analyses indicate that biological uncertainty in estimates of moist-soil seed production can significantly affect management objectives, and information from this study will help refine the bioenergetic model, improve habitat management practices, and guide long-term wetland planning.

INTRODUCTION

Research has shown that conditions on the wintering grounds affect several key aspects of the waterfowl life cycle, such as over-winter survival and subsequent reproductive output. For example, in years of increased rainfall, and therefore increased wintering habitat, mallard (*Anas platyrhyncos*) body weights increase (Heitmeyer 1985, Delnicki and Reinecke 1986), pair formation and molting occur sooner (Heitmeyer 1987), seasonal mortality rates decrease (Hepp et al. 1986, Blohm et al. 1987, Reinecke et al. 1987), and subsequent recruitment rates may increase (Heitmeyer and Fredrickson 1981, Kaminski and Gluesing 1987). These cross-seasonal effects are likely due to the increased food availability that can occur during times of increased rainfall and greater habitat availability (Nichols et al. 1983, Heitmeyer 1985). Our current understanding of waterfowl migratory and wintering ecology suggests that availability of food for energy is the primary factor limiting waterfowl populations during winter and migration (Conroy et al. 1989, Haramis et al. 1986, Jeske et al. 1994, Bergan and Smith 1993, Miller 1986).

During winter, wetlands and agricultural habitats in the Central Valley support the largest single concentration of waterfowl (3-4 million) in North America (Gilmer et al. 1982, Heitmeyer et al 1989). This represents 60% of all waterfowl wintering in the Pacific Flyway (excluding seaducks) and approximately 20% of all waterfowl wintering in North America. Wetlands in California have declined by over 90% from an estimated 2 million hectares historically to less than 182,000 hectares at present (Dahl 1990). In the Central Valley, only about 117,000 hectares remain, a result of agricultural and urban development, water diversion and flood control measures. This loss of wetlands exceeds that of any other state in the nation (Dahl 1990). Of the remaining wetlands, 70% are privately owned and managed primarily as duck hunting clubs; 60% of these remain unprotected (CVHJV Implementation Board 1990).

In 1990 partners of the Central Valley Habitat Joint Venture (CVHJV) adopted a plan to implement the North American Waterfowl Management Plan (NAWMP) (U.S. Fish and Wildlife Service and Canadian Wildlife Service 1986) within the Central Valley of California. The Implementation Plan (CVHJV Implementation Board 1990) describes a program to halt, and ultimately reverse, long-term wetland losses in California by protecting, restoring, and enhancing marshlands, securing water and power supplies for wetland management, and enhancing agricultural lands important to waterfowl. As a result of these efforts the Implementation Plan, when completed, will affect activities on 385,000 hectares of wetlands and agricultural lands at a capital cost of more than $528 million and an annual cost of about $38 million. The magnitude of these expenditures and area affected demands prudent decisions about where, when, and how limited dollars will be spent.

To establish habitat objectives for the Central Valley, planning for the CVHJV focused on 3 questions: (1) how much habitat is needed to support desired waterfowl populations; (2) what types of habitats are needed to meet these objectives; and (3) where in the Central Valley are these habitats needed? The CVHJV adopted a bioenergetic approach as the central planning tool to answer these questions and to provide a biologically sound basis for establishing implementation objectives (Heitmeyer 1989). The bioenergetic approach seeks to identify the amount of foraging habitat required to meet NAWMP / CVHJV waterfowl population objectives, evaluate the extent to which these needs have been addressed on a regional basis, and identify areas for priority action.

The use of a bioenergetic approach to address these goals is based on several underlying assumptions. First, increased foraging habitat will reduce non-harvest mortality and increase pre-breeding body condition of wintering waterfowl (Heitmeyer and Fredrickson 1981, Delnicki and Reinecke 1986, Miller 1986, Blohm et al. 1987, Hepp et al. 1986, Kaminski and Gluesing 1987, Reinecke et al. 1987, Heitmeyer 1989, Raveling and Heitmeyer 1989). Second, the quality of a given habitat, and therefore its priority for protection or enhancement, is determined by availability of food (seeds, vegetation, waste grain and invertebrates; Heitmeyer 1989). Finally, food availability is dictated by the type of wetland habitat (seasonal, semi-permanent, agricultural, etc.), water availability and by the management actions undertaken (Fredrickson and Taylor 1982). Given these working assumptions, changes in the amount and distribution of different habitat types and/or changes in their associated amount or availability of food (i.e., foraging value) will impact waterfowl population numbers and distribution and therefore should be the target of management efforts.

Using the bioenergetic approach, the total energy requirements of projected waterfowl populations in the Central Valley were calculated, and the total food value provided by wetland and agricultural habitats was estimated to determine the land needed to provide the required food resources (Heitmeyer 1989). Accordingly, it was determined that about 159 million kilograms of food would be required to support annual waterfowl populations in the Central Valley at objective levels (based on the desired use days of 112.5 million for geese and 750 million for ducks). On the basis of these projected needs, the CVHJV established habitat objectives for the Implementation Plan (CVHJV Implementation Board 1990). These include protecting 32,000 hectares of existing wetland, restoring 49,000 hectares of former wetland and enhancing waterfowl habitat on 180,000 hectares of agricultural land.

CVHJV partners recognize that the most immediate information needs deal with biological uncertainty about inputs into the bioenergetic model. These inputs comprise: (1) waterfowl population size, determined by NAWMP and CVHJV objectives; (2) seasonal distribution of birds throughout the nine drainage basins of the Central Valley; (3) amount of each habitat type available in each drainage basin; and (4) foraging value of those habitats to waterfowl.

The foraging value of agricultural and wetland habitats remains the largest single source of uncertainty in the CVHJV planning model. In the original formulation of CVHJV habitat objectives, the acreage of wetlands and agricultural lands needed to provide the required amount of food was calculated using assumptions about how much food is available to, and consumed by, waterfowl in each habitat type. About 280 kg/ha (250 lbs/ac) of waste grain, weed seeds, and invertebrates were thought to be potentially available and consumed by waterfowl in harvested grain (rice, corn) fields (Miller et al. 1989, Heitmeyer 1989). Wetlands provide more food per acre than harvested grain fields, and well managed marshes can produce more than 2250 kg/ha (2000 lbs/ac) of combined seeds, tubers, green forage, and invertebrates (Fredrickson and Taylor 1982). Production of a complex of these foods in well-managed wetlands may average 1680 kg/ha (1500 lbs/ac). It was assumed that waterfowl consume an average of 50 percent of foods available; the remaining 50% was thought to be either unpalatable or inaccessible due to physical barriers such as water depth, plant stems, or debris. Thus, a value of 842 kg/ha (750 lbs/ac) of food available for consumption by waterfowl in wetlands was used in the CVHJV calculations (Heitmeyer 1989).

Although the data used when the original objectives were established were the best available, several questions remain. Estimates of food production in moist-soil habitats are derived from studies conducted in Missouri (Fredrickson and Taylor 1982), where plant communities and environmental conditions differ considerably from the Mediterranean climate of the Central Valley. More recent estimates of food availability in Mississippi Alluvial Valley wetlands suggest an average of 450 kg/ha (Reinecke et al. 1989), and limited data from California suggest that food production in moist-soil habitats may be considerably lower (Mushet et al. 1992). The goal of this study was to reduce uncertainty in estimates of moist-soil seed abundance in Central Valley wetlands. Increased accuracy in these estimates will allow the CVHJV to determine more correctly how much and what types of habitats are needed to support objective waterfowl populations. To address these needs, we focused on 3 specific objectives: (1) determine the amount of seed present in moist-soil habitats when waterfowl arrive in fall; (2) determine the degree to which these seeds are depleted throughout the winter; and (3) determine the seed density threshold below which waterfowl cease to forage in moist-soil habitats.

STUDY AREA

The climate and characteristics of the Central Valley have been described in Gilmer et al. (1982), Miller (1986), and Heitmeyer et al. (1989). This study was conducted in complexes of wetlands (both public and private) within the Butte, Colusa, and San Joaquin Basins of the Central Valley (CVHJV Implementation Board 1990) managed primarily for the purpose of providing waterfowl habitat. We do not consider wetland types such as permanent marshes and vernal pools. Wetlands in the Central Valley consist of three major habitat types: semi-permanent wetlands (managed primarily for waterfowl brood habitat) and seasonal wetlands managed for watergrass (*Echinochloa crusgalli*) or swamp timothy (*Crypsis schoenoides*) production (Smith et al. 1995). Sites were selected based on 4 criteria: (1) location within the Sacramento (SACV) or San Joaquin (SJV) valleys of the Central Valley (half of the sites in the SACV, half in the SJV); (2) the type of management (mix of units managed as semi-permanent wetlands or for either swamp timothy or watergrass production); (3) ownership (distributed among private, state, and federal); and (4) ability to gain access.

METHODS

Data Collection

Waterfowl in the Central Valley feed primarily on waste grain and seeds of moist-soil plants during winter (Miller 1987). Our efforts focused on the latter of these food items. To maximize our ability to describe the variation in seed abundance, a pilot study was conducted during the winter of 1999-2000 (hereafter 2000). Moist-soil seeds were sampled at 8 sites (4 private, 4 public) at the beginning (October – November) and end (March – April) of the 2000 wintering period. One wetland unit of each of the three habitat types was sampled at each site. Fifteen 66mm-diameter cores were taken from each unit during each period using a stratified-random sampling design. This sampling design was implemented by estimating the area of each unit, dividing the unit into a grid of 15 strata of equal area, and taking 1 core from a random location within each strata. We used this sampling design due to concerns raised by Reinecke et al. (1989) that food production in moist-soil habitats is difficult to assess because most studies present estimates for samples collected within stands of selected plant species rather than randomly within management units. Moist-soil seeds in these cores were returned to the lab and either washed through a 255μ-mesh sieve or frozen within 24 hours to halt seed deterioration. Frozen samples were washed at a later date. To prevent seed deterioration, washed samples were stored in ethanol until sorted. All samples were sorted by hand to remove seeds of 15 plants common to Central Valley wetlands (E. Burns, unpublished data; Appendix 1). Removed seeds were separated by genus or species, counted, dried at 80°C for 48 hours, and weighed to the nearest 0.0001g. Abundance of each species was calculated as the mean kg/ha of seed contained in a randomly selected subset of 5 of the 15 cores taken from each wetland unit (due to the constraints of time and resources, not all core samples could be processed in 2000). We summed the data for all species to calculate a total seed abundance value (kg/ha) for each wetland unit during each sample period (First and Last).

In 2000-2001 (hereafter 2001) we sampled moist-soil seeds in watergrass and swamp timothy habitats in 30 wetland units at 14 sites (2 public, 5 private in the San Joaquin Valley and 2 public, 4 private in the Sacramento Valley) at the beginning (September – October) and end (April – May) of the 2001 wintering period. Semi-permanent wetlands were not sampled in 2001 due to the low amount of seed found in these habitats (see Results). Sample collection and processing procedures were the same as in 2000, with the exception that in 2001 all 15 cores from each unit were included in analyses.

Statistical Analysis

Seed mass data were log transformed prior to analyses to stabilize variances. We compared seed mass among years and habitat types using analysis of variance. Fisher's protected least significant difference (PLSD) test was used to test for differences among means. We used simple linear regression to test for relationships between initial seed abundance and seed depletion. We used StatView (SAS Institute 1999) for all analyses.

RESULTS

Initial Food Abundance

The amount of moist-soil seed produced in 2000 was low. Considering the two most productive habitat types (swamp timothy and watergrass) the mean amount of moist-soil seed present at the beginning of the 2000 wintering season was 200 ± 63.3 (SE) kg/ha (Table 1). In 2000, seed abundance in semi-permanent wetlands was extremely low (24.12 ± 9.45 kg/ha; Table 1). In 2001, the amount of seed present was significantly higher than in 2000, averaging 585.49 ± 66.02 kg/ha ($F_{1,44} = 29.22$, $P < 0.0001$; Table 1). Production was highly variable and skewed in 2000. Some units produced over 1000 kg/ha of moist-soil seeds while most units produced less than 100 kg/ha (Figure 1). Variation in seed abundance was less skewed in 2001; 6 units produced over 1000 kg/ha while over half the units produced less than 400 kg/ha (Figure 1). Seed abundance was more unevenly distributed in swamp timothy habitats than in watergrass habitats. Given this skewed distribution, a more accurate estimate of the amount seed present in Central Valley wetlands may be provided by the median. This estimate indicated that production of moist-soil seeds in swamp timothy and watergrass habitats in 2000 was 84 kg/ha. In 2001 median seed production was 471 kg/ha (Table 1).

When the values from both years were considered, differences in seed production were associated with different management objectives (Figure 2). Units managed for watergrass production were significantly more productive than those managed for swamp timothy ($F_{1,42}$ = 7.29, P = 0.039), while units maintained as semi-permanent wetlands were the least productive (Table 3). The absolute difference in food production between habitats was greater in 2000 than in 2001 (Table 1, Figure 2), suggesting that the 2000 values may have had a greater influence on our results than the 2001 values; however, there was no significant interaction between year and habitat ($F_{1,42}$ = 2.61, P = 0.113). When only 2001 data are considered, seed abundance was not significantly different in swamp timothy and watergrass habitats ($F_{1,28}$ = 1.32, P = 0.26)

Food Depletion

Depletion of moist-soil seeds during winter was substantial. The amount of seed remaining was variable among sites, but the high between-site variability recorded in the first sample period was reduced by the last sample period (Figure 3). For example, seed abundance in 2001 varied from approximately 115 kg/ha to 1350 kg/ha at the start of the wintering period, but ranged only from 65 kg/ha to 580 kg/ha at the end (Figure 4). Considering both years, an average of 65% of seed initially present was removed by the end of winter. Seed depletion was highly correlated with initial seed abundance (Figure

5). This relationship was very strong with little residual variation when considering the absolute levels of seed depletion (R^2 = 0.92, $F_{1,51}$ = 578.69, P < 0.0001; Figure 5). Thus, sites with the highest abundance of moist-soil seeds in the fall exhibited greater levels of seed depletion.

Food Threshold

There appeared to be a threshold level of seed abundance below which seeds ceased to be depleted, such that most sites were reduced to a similar level of seed abundance within each year (Figures 3 and 4), but there was significantly more seed remaining in 2001 than in 2000 ($F_{1,42}$ = 66.94, P < 0.0001; Table 1). Over both years, seed abundance at the end of winter did not differ between habitat types ($F_{1,42}$ = 0.12, P = 0.487). Considering only swamp timothy and watergrass units, the amount of moist-soil seeds remaining after the winter of 2000 averaged 30.40 ± 8.77 kg/ha, while the amount of seed remaining in 2001 was 163.91 ± 20.21 kg/ha (Table 1). The amount of seed remaining was not related to initial seed abundance (R^2 = 0.072 in 2000; R^2 = 0.017 in 2001).

DISCUSSION

When CVHJV Implementation Plan objectives were established, the best information available suggested that moist-soil wetlands could be expected to produce an average of 1335 kg/ha and that half of this production was available to and utilized by waterfowl (CVHJV Implementation Board 1990). Thus, a value of 840 kg/ha of available food was used to set habitat objectives. Our estimates of seed production from the 2000 pilot study suggest that food availability (as measured by moist-soil seed abundance) may be 75% less than originally estimated. These findings were corroborated by our more extensive sampling in 2001, although the food deficit was less severe (food present was 30% less than assumed). It is important to note that in the original Implementation Plan, seeds, tubers, grasses, and invertebrates were all included in the estimate of food availability (CHVJV Implementation Board 1990). The bioenergetic model, however, only considers seed production. The variability observed in our estimates of seed abundance raises several concerns. Due to the highly skewed distribution of the moist-soil seed estimates, the arithmetic mean may not be the most appropriate indicator of the typical amount of seed produced in Central Valley wetlands. Rather, the geometric mean or the median may provide a more accurate estimate. Because wetlands producing over 1000 kg/ha are rare, units with unusually high levels of seed production could exert a large influence on estimates of "average" seed production and thereby disproportionately affect calculations of the amount of energy available to wintering waterfowl. For example, in 2001 mean seed production in swamp timothy and watergrass habitats was not significantly different. However, only 5 of 16 swamp timothy units produced over 500 kg/ha, while 10 of 14 watergrass units produced over 500 kg/ha. The amount of seed produced in swamp timothy habitats was likely overestimated by the mean due to the influence of a few highly productive units (e.g., 1 unit produced over 1300 kg/ha, the second highest seed production recorded in either year).

There are several possible explanations for the large between-year variability in our seed production estimates. First, data collection at some sites in 2000 began after fall flood-up and some waterfowl foraging may have occurred, making the estimates from that year conservative. In contrast, the first sampling period in 2001 occurred immediately prior to flood-up, ensuring that little or no waterfowl foraging had taken place. Second, seed production is influenced by many variables, such as climatic conditions and management history (Fredrickson and Taylor 1982), that were not measured in this study. The differences in our seed production estimates between years may represent real annual variation in seed production. Third, wetlands sampled in 2000 may have been, by chance, less productive (e.g., due to different soil types or management histories) than those sampled in 2001. For example, 2001 seed production in swamp timothy units was highly right skewed, while in 2000 production in swamp timothy habitats was consistently low. Possibly, productive swamp timothy units were not sampled in 2000, which may be likely due to the small pilot-year sample size. Evaluations of the effects of management activities on moist-soil seed production suggest that management activities undertaken on a wetland unit in a give year can have a large impact on subsequent moist-soil seed production (Chapter 2), so the between-year differences in seed abundance we detected could be a result of changes in wetland management practices.

If waterfowl respond to variation in the amount of seed present in moist-soil habitats, we would expect wetlands with higher initial seed abundance to experience higher levels of seed depletion (Sutherland 1996). Our results were consistent with this prediction. Even when data from both years are plotted together, the relationship between initial food abundance and amount of depletion was significant and positive (Figure 5). There was little residual variation around this relationship, suggesting that factors such as hunting pressure and distance from sanctuary may not have a large impact on waterfowl foraging use, possibly due to the tendency of ducks to feed nocturnally. Future analyses will examine the effect of hunting pressure and distance from sanctuary, for example, on waterfowl foraging use. We do not assume that all of the depletion observed was due to waterfowl foraging. Indeed, an analysis of seed decomposition in Central Valley wetlands (L. Naylor, unpublished data) suggests that decomposition may be a major source of seed loss. However, if decomposition were the only cause of seed loss from moist-soil habitats we would predict that the level of depletion would be constant among units. In contrast, we found that sites with the highest initial seed abundance experienced greater seed depletion, consistent with the expectations of foraging theory (Sutherland 1996).

Future CVHJV planning efforts should reconsider the assumption in the original implementation plan that waterfowl use only half of the seed produced by wetland plants. If this assumption were true, the energy deficit in Central Valley wetlands would be extreme. For example, using our estimates of moist-soil seed abundance, if waterfowl use only half of the seed produced, they would be able to utilize only about 200 kg/ha of seed during the wintering period. However, our estimates of the threshold levels of seed remaining suggest that waterfowl consume more than 50% of the seeds present in wetlands. In fact, we found that the percent depletion averaged 65% over both years. Although the proportion of seed depleted was similar among years, the threshold level of seed remaining varied among years. These differences could be due to annual variation in initial seeed abundance. More seed was present in 2001 and waterfowl may have utilized less of the available seed, leaving a larger amount remaining at the end of the

2001 wintering period. Increased availability of alternative habitat, such as flooded rice, or smaller populations of waterfowl (at least at our sites) in 2001 could also have influenced the amount of seed consumed.

Decreasing foraging efficiency as food resources are depleted probably prevents waterfowl from using all available food in foraging habitats (Reinecke et al. 1989). The threshold level of seed remaining at the end of 2000 was similar to threshold levels suggested by other authors (50 kg/ha; Reinecke et al. 1989), but the threshold in 2001 was 3 times as high. We suspect this difference could be caused by 2 factors. First, as discussed above, waterfowl may have left more seed remaining in 2001 due to higher overall seed abundance in Central Valley wetlands that year. Foraging waterfowl may have had more food-rich habitats to choose from, allowing them to forage less intensively at each foraging site. Second, the threshold level suggested by Reinecke et al. (1989) is based primarily on evidence from core samples collected in Mississippi Alluvial Valley rice fields after several weeks of feeding by dabbling ducks that averaged 40-60 kg/ha. Foraging ducks may be able to exploit more of the seed resource in rice fields than in moist-soil habitats due to the relatively homogenous structure of rice fields, leading to the observed differences between our estimates of the foraging threshold and those of other researchers (Reinecke et al. 1989).

The strong patterns of seed depletion observed in this study support the use of a bioenergetic model as the central planning tool in the CVHJV. The assumption that energy for food in winter could limit waterfowl populations (see Introduction) is the basis for a bioenergetic planning strategy. If this assumption were true, we would expect foraging habitats to experience a high degree of over-winter depletion, and that in periods of low food abundance food resources would be reduced to very low levels. Both predictions were supported by our results. In these instances food resources may be reduced to a level below that at which waterfowl can search efficiently (Reinecke et al. 1989, McKenzie 1987), thus reducing their ability to secure needed energy, which may limit populations by decreasing body weights (Heitmeyer 1985, Delnicki and Reinecke 1986), decreasing survival rates (Blohm et al. 1987, Hepp et al. 1986, Reinecke et al. 1987), delaying pair formation and molting (Heitmeyer 1987), and reducing subsequent recruitment rates (Heitmeyer and Fredrickson 1981, Miller 1986, Kaminski and Gluesing 1987, Raveling and Heitmeyer 1989).

MANAGEMENT IMPLICATIONS

Seed production was highly variable among and within wetlands. This variability occurred despite the common goal of wetland managers to produce high levels of moist-soil seed. Even so, lower estimates of seed abundance may be indicative of limited management efforts, whereas higher estimates illustrate potential yields with effective management (Reinecke et al. 1989). This finding could have an important influence on management priorities within the CVHJV. The focus of the CVHJV to date has been to restore and protect wetland acres with the assumption that most of these wetlands will provide quality waterfowl habitat. Our results suggest that, if moist-soil seed abundance is a reliable indicator, many wetlands are not meeting this objective. Evaluations of the effect of management actions on moist-soil seed production will prove useful in determining which forms of wetland enhancement (i.e., wetland management prescriptions) are needed to increase the quality of foraging habitat available to Central Valley waterfowl (Chapter 2).

When considering both years together, more moist-soil seed was present in wetlands managed for watergrass than in those managed for swamp timothy; however, this difference was not evident in 2001, the year with the most extensive sampling. It is evident from the 2001 data that swamp timothy habitats have the potential to produce as much or more seed than watergrass habitats. Management of moist-soil habitats for swamp timothy production is popular in California, particularly in the San Joaquin Valley. Due the prostrate growth form of swamp timothy, wetlands managed for that species provide “sheet-water” habitat that is attractive to species of management concern such as northern pintail (*Anas acuta*; Miller and Duncan 1999) and green-winged teal (*Anas crecca*) (Euliss and Harris 1987). In contrast, watergrass habitats are characterized by robust vegetation that provides both a quality food source and cover (Smith et al. 1995). Other studies (Mushet et al. 1992) have suggested that seed production is very low in swamp timothy habitats. Our data suggest the opposite, and we recommend that habitat managers prescribe management practices that provide a mixture of swamp timothy and watergrass habitats, both of which have the potential to provide large amounts of seed while providing a mosaic of structurally heterogeneous habitats (Reinecke et al. 1989).

To evaluate the potential impact of reduced food availability on waterfowl populations, we conducted a series of simulation analyses using the bioenergetic model currently adopted by the CVHJV, with 3 levels of moist-soil seed abundance (Figure 6). Under current assumptions, CVHJV implementation goals to restore and enhance 49,000 hectares of moist-soil habitats will provide sufficient habitat to meet the energetic needs of wintering waterfowl (Figure 6). If seed abundance is 500 lbs/ac, current CVHJV habitat goals will just meet foraging needs, although all seed will be depleted by the end of winter. If seed production is as low as 200 lbs/ac, our simulations predict that energy demands of wintering waterfowl will exceed supply by mid-January (Figure 6). Waterfowl wintering in the Central Valley may be able to avoid an energy deficit by feeding in flooded agricultural fields (see Miller 1987), but agricultural seeds likely do not contain enough protein or an adequate distribution of amino acids to provide a complete diet for wintering waterfowl (Baldassarre et al. 1983).

The effect of biological uncertainty in our estimates of moist-soil seed abundance on the habitat acreage required to support objective waterfowl populations is illustrated in Figure 7. According to these projections, if seed production in moist-soil habitats is as low as 300 kg/ha, as suggested by an average of the data from both years, CVHJV habitat objectives could be underestimated by more than 300,000 hectares. These results underscore the importance of accurate estimates of moist-soil seed production to landscape-scale management efforts, such as the CVHJV and other Joint Ventures. Without accurate measures of food energy available and an assessment of the patterns of temporal and spatial variation in food supplies in different wetland types, Joint Venture partners cannot effectively anticipate waterfowl habitat needs or determine priority areas for future protection and enhancement efforts. Furthermore, this analysis highlights the importance of wetland enhancement (e.g., the use of soil and water manipulation to increase seed production) to meet CVHJV habitat objectives.

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Table 1.1. Moist-soil seed abundance in the Sacramento (SACV) and San Joaquin (SJV) valleys of California during the wintering periods of 1999-2000 (2000) and 2000-2001 (2001).

Year	Habitat Type	Region	Period	Mean	SE	n[a]	Geom. Mean	Median
2000	Semi-Permanent	SACV	First	26.76	11.76	4	17.36	25.62
2000	Semi-Permanent	SACV	Last	14.58	4.89	4	.	18.84
2000	Semi-Permanent	SJV	First	21.64	16.62	4	8.89	6.09
2000	Semi-Permanent	SJV	Last	12.54	12.10	3	.	0.90
2000	Swamp Timothy	SACV	First	34.85	11.93	4	27.58	32.64
2000	Swamp Timothy	SACV	Last	16.60	5.75	4	13.18	15.95
2000	Swamp Timothy	SJV	First	158.91	63.64	4	117.47	139.53
2000	Swamp Timothy	SJV	Last	51.47	33.01	4	12.03	30.18
2000	Watergrass	SACV	First	399.94	216.76	4	246.64	252.79
2000	Watergrass	SACV	Last	26.32	12.95	4	17.36	18.79
2000	Watergrass	SJV	First	207.40	86.91	4	134.67	205.86
2000	Watergrass	SJV	Last	27.21	5.31	4	25.70	25.67
2001	Swamp Timothy	SACV	First	463.82	147.72	8	334.61	326.35
2001	Swamp Timothy	SACV	Last	112.68	20.38	8	103.46	98.90
2001	Swamp Timothy	SJV	First	585.85	121.23	8	518.38	423.14
2001	Swamp Timothy	SJV	Last	218.54	65.89	8	161.39	139.01
2001	Watergrass	SACV	First	820.75	122.93	7	764.12	762.73
2001	Watergrass	SACV	Last	176.24	27.45	7	167.03	149.41
2001	Watergrass	SJV	First	488.85	113.53	7	403.56	504.57
2001	Watergrass	SJV	Last	147.69	15.02	7	141.63	149.66

Table 1.1. Continued

Year	Region	Period	Mean	SE	n[b]	Minimum	Maximum	Geom. Mean	Median
2000	SACV	First	217.39	121.90	8	8.52	1019.92	82.48	69.93
2000	SACV	Last	21.46	6.81	8	4.79	62.28	15.13	16.00
2000	SJV	First	183.15	50.70	8	28.53	389.33	125.78	149.24
2000	SJV	Last	39.34	16.14	8	0.27	145.26	17.58	25.67
2000	Both	First	200.27	63.93	16	8.52	1019.92	101.85	83.57
2000	Both	Last	30.40	8.78	16	0.27	145.26	16.31	23.52
2001	SACV	First	630.39	105.16	15	115.95	1347.11	491.92	562.30
2001	SACV	Last	142.34	18.25	15	65.01	336.30	129.38	132.15
2001	SJV	First	540.59	81.64	15	122.46	1253.30	461.22	438.57
2001	SJV	Last	185.47	35.94	15	69.32	580.32	151.84	149.66
2001	Both	First	585.49	66.02	30	115.95	1347.11	476.32	471.57
2001	Both	Last	163.91	20.21	30	65.01	580.32	140.16	137.90

[a] n = number of wetland units sampled.
[b] In 2000, does not include units managed as semi-permanent wetlands.

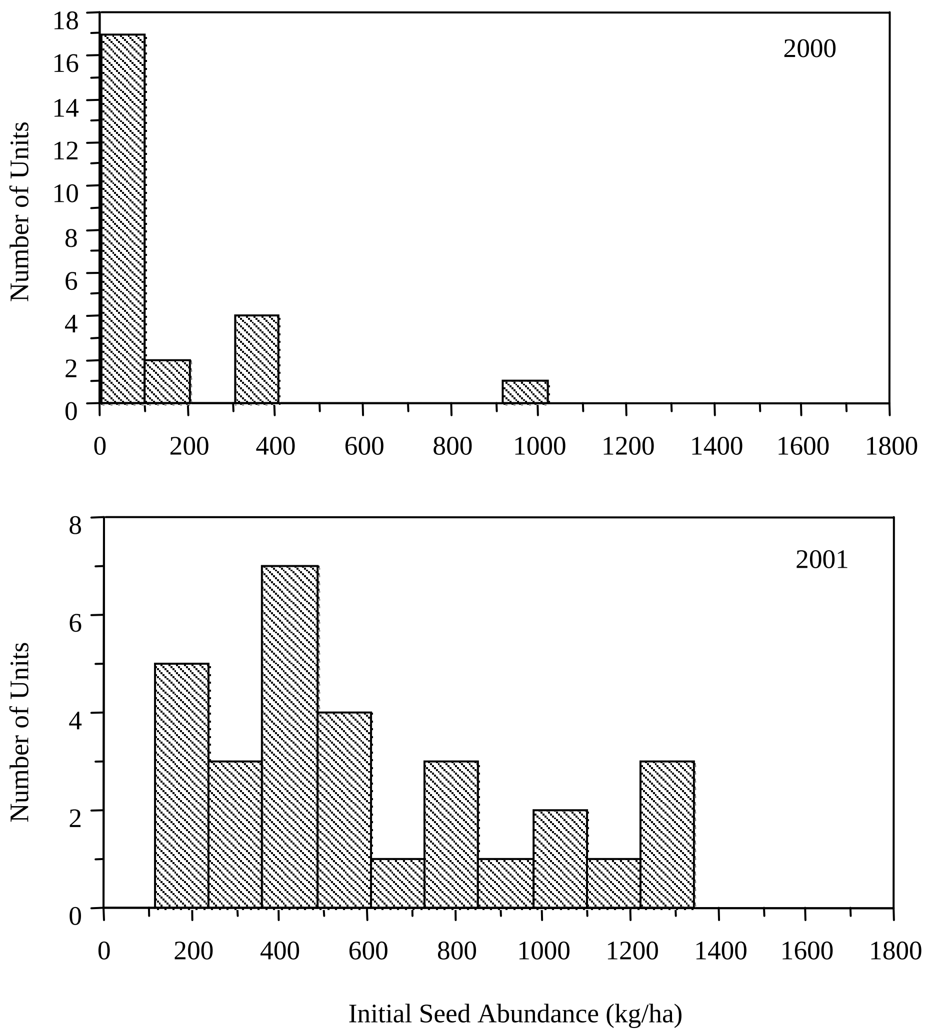

Figure 1.1. Frequency distribution of moist-soil seed abundance in Central Valley wetlands at the beginning of the 1999-2000 (2000) and 2000-2001 (2001) wintering periods.

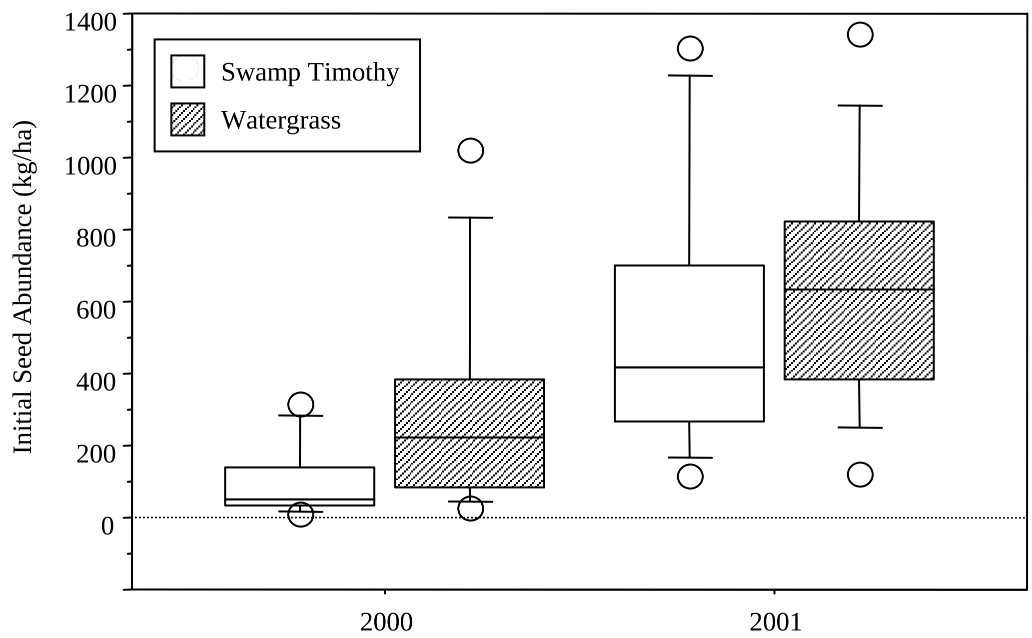

Figure 1.2. Comparison of moist-soil seed abundance at the beginning of the wintering periods of 1999-2000 (2000) and 2000-2001 (2001) in Central Valley wetland units managed for swamp timothy and watergrass production. Box plots indicate the median (horizontal lines within boxes), 25th and 75th percentiles (boxes), 10th and 90th percentiles (vertical lines) and extreme values (points).

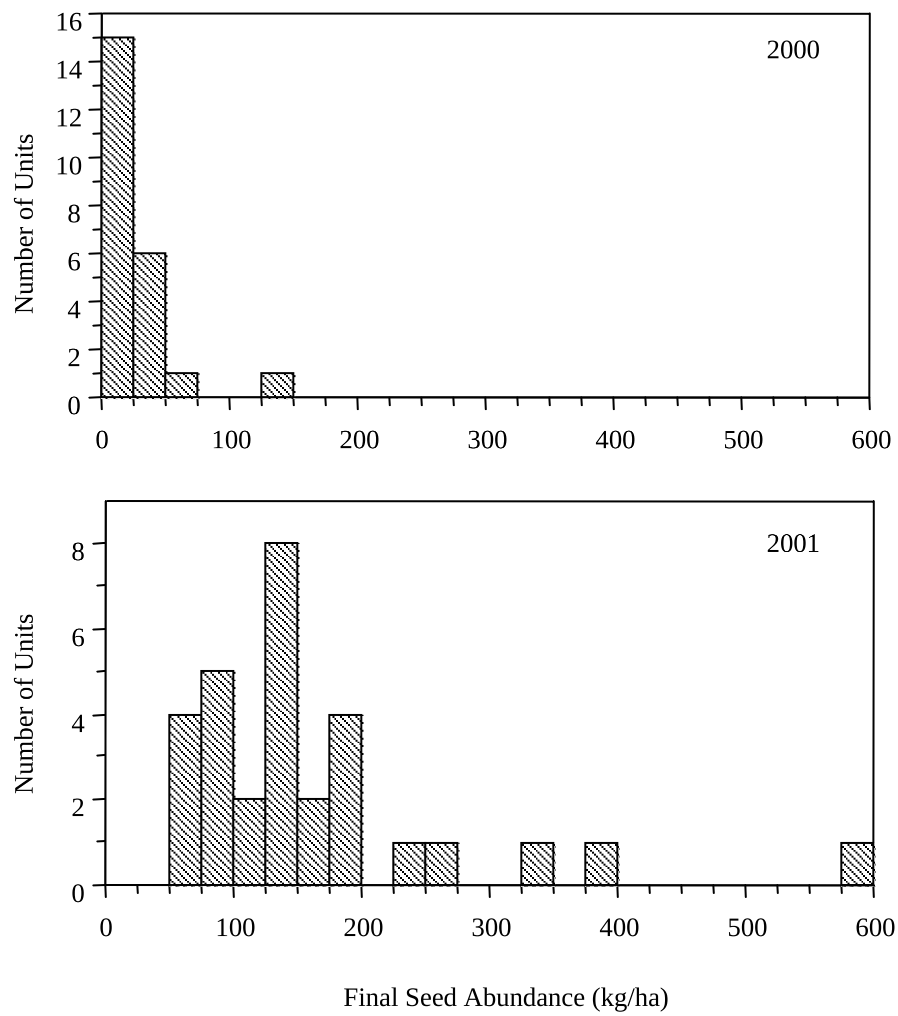

Figure 1.3. Frequency distribution of moist-soil seed abundance in Central Valley wetlands at the end of the 1999-2000 (2000) and 2000-2001 (2001) wintering periods.

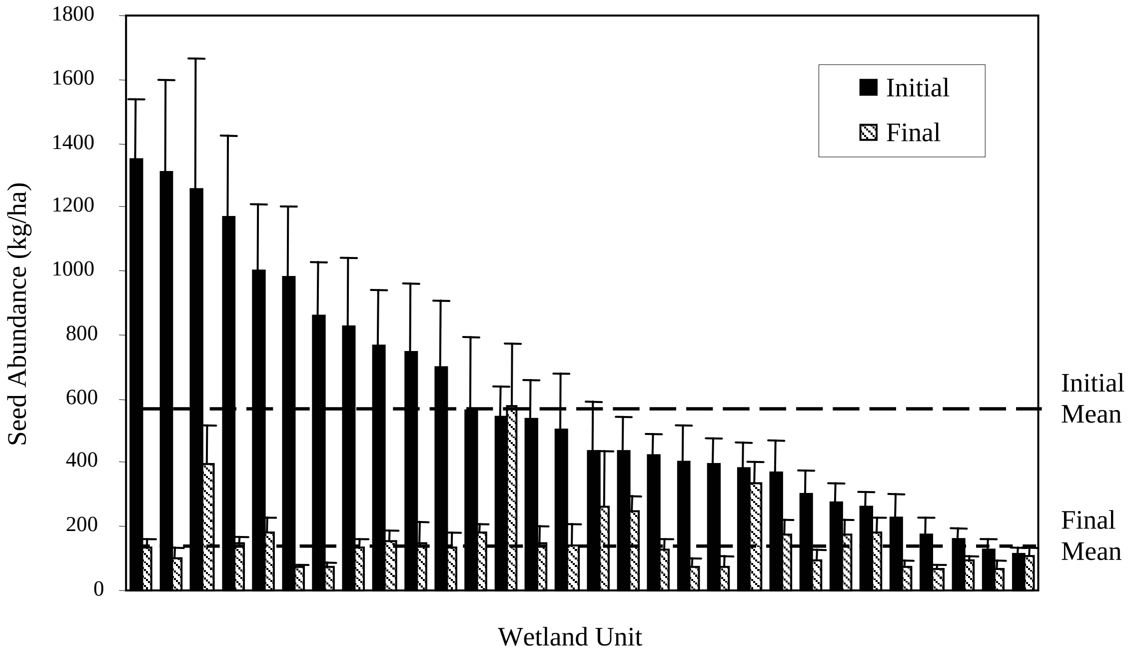

Figure 1.4. Ranked values of moist-soil seed abundance at the beginning and end of the 2000-2001 wintering period. Values are means plus 1 SE. Means among all units are shown by dotted lines.

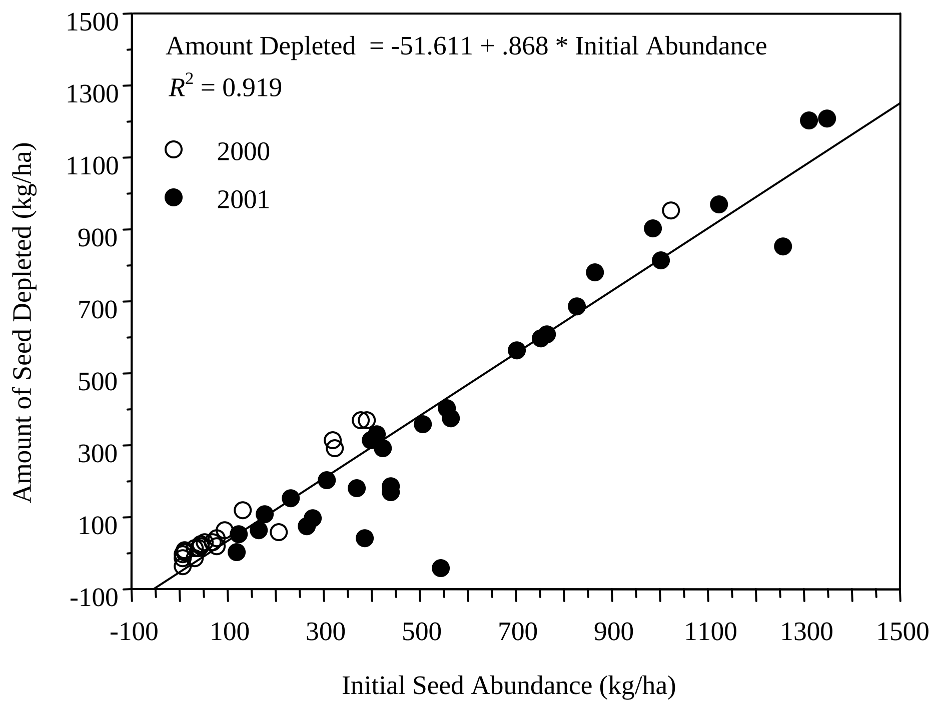

Figure 1.5. Depletion of moist-soil seeds in Central Valley wetlands as a function of initial seed abundance during the wintering periods of 1999-2000 (2000) and 2000-2001 (2001). Line fitted by simple linear regression.

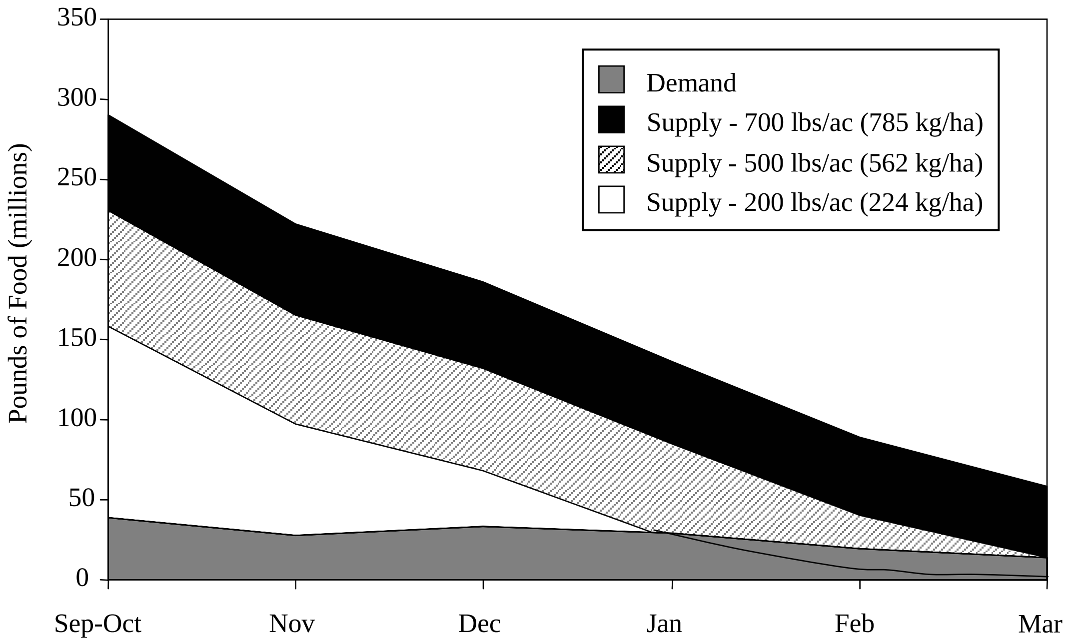

Figure 1.6. The effect of different assumptions about food availability in Central Valley wetlands on energy supply:demand ratios.

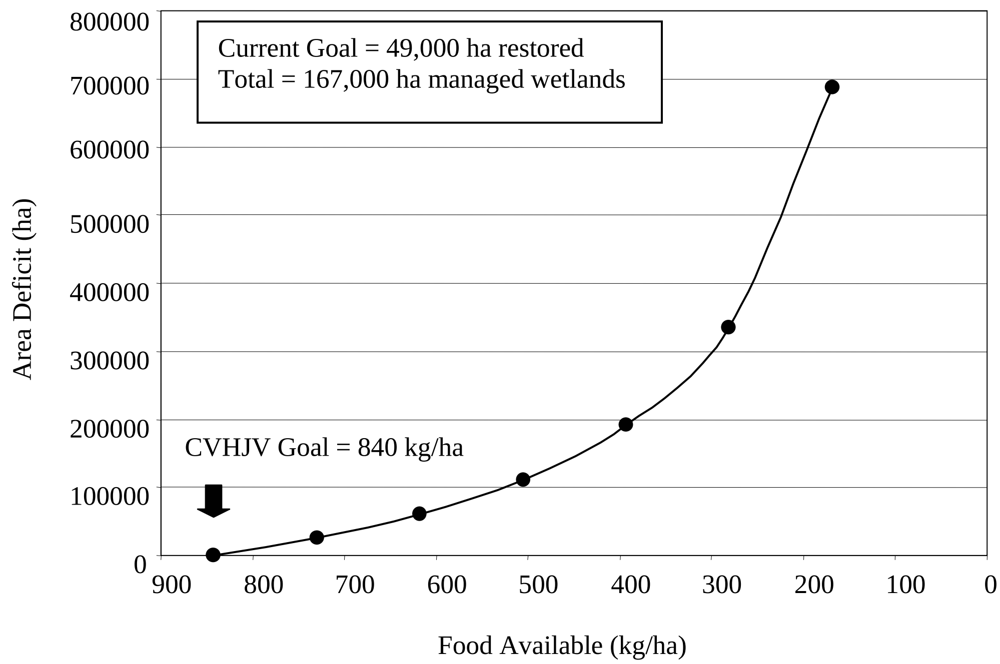

Figure 1.7. The effect of differences in food availability in Central Valley wetlands on the amount of wetland habitat needed to support objective populations of wintering waterfowl. Calculations based on assumptions of the Central Valley Habitat Joint Venture regarding the amount of energy provided by moist-soil seeds and the amount of energy needed to sustain populations at objective levels. Area deficit represents the amount of additional habitat necessary to support waterfowl populations as the quantity of energy available in Central Valley wetlands is reduced.

APPENDIX 1. Moist-soil seeds included in estimates of seed abundance in Central Valley wetlands.

Common Name	Scientific Name
watergrass	*Echinochloa crusgalli*
swamp timothy	*Crypsis schoenoides*
smartweed	*Polygonum* spp.
bulrush	*Scirpus* spp.
sprangletop	*Leptochloa* spp.
spikerush	*Eleocharis* spp.
dock	*Rumex* spp.
panic grass	*Panicum* spp.
pigweed	*Amaranthus* spp.
goosefoot/lamb's quarters	*Chenopodium* spp.
rabbit's foot grass	*Polypogon monspeliensis*
pondweed	*Potamogeton* spp.
aster	*Aster* spp.
horned pondweed	*Zannichellia palustris*
sweet clover	*Melilotus* spp.

CHAPTER 2: EVALUATING THE EFFECT OF MANAGEMENT ON MOIST-SOIL SEED PRODUCTION IN CENTRAL VALLEY WETLANDS

ABSTRACT

Moist-soil management involves the manipulation of soil and water to produce wetland plants that provide food for wintering waterfowl. Previous research, primarily in the Mississippi Alluvial Valley, has explored the relationship between management practices and moist-soil seed production, but few studies have addressed this subject in the Central Valley of California, a key wintering area for North American waterfowl. In this study, we evaluated the effects of moist-soil management practices on seed production in Central Valley wetlands, a region in which climatic and soil conditions differ from the humid subtropical climate of the Mississippi Alluvial Valley. We used core sampling to quantify moist-soil seed production in 27 wetlands during fall 2000, and collected information regarding the management activities carried out at each wetland; these included the effects of drawdown date, drawdown rate, summer irrigation, and fall disking. We used Akaike's Information Criterion to determine which combination of management variables best explained our seed production data. All 4 variables affected seed production; disking and irrigation had the greatest impact, appearing in 4, and 3 of 4 best approximating models, respectively. Moderate to high levels of disking led to the highest levels of seed production, and summer irrigation nearly doubled seed production at our sites. If increased moist-soil seed production is an important management goal, we recommend that Central Valley wetland managers include disking and summer irrigation in their management plans. Maximum benefits to wetland-dependent waterbirds would likely be achieved by timing drawdowns to coincide with spring migrations of shorebirds

and waterfowl. Similarly, we recommend slow drawdowns that lead to increased availability of food for foraging waterbirds. We found considerable variation in moist-soil management practices prescribed by managers, suggesting that efforts to educate managers about effective management techniques and programs that provide incentives for managers to implement these techniques could prove valuable in increasing moist-soil seed production and waterfowl food availability throughout the Central Valley.

INTRODUCTION

With the rapid disappearance of wetlands in North America over the past century, waterfowl managers have been faced with the challenge of supporting waterfowl populations with a dwindling resource base (Bellrose and Low 1978). On the wintering grounds, efforts have focused on providing sufficient food supplies to meet the needs of migrating and wintering waterfowl. Moist-soil management, the manipulation of soil and water to encourage the growth of waterfowl food plants, was adopted as a potential method to accomplish this goal (Fredrickson 1996). Research in moist-soil habitats has subsequently focused on quantifying moist-soil seed production (Low and Bellrose 1944, Singleton 1951, Laubhan and Fredrickson 1992, Gray et al. 1999*a*, 1999*b*, Sherfy and Kirkpatrick 1999) and relating management practices to seed (Meeks 1969, Knauer 1977, Fredrickson and Taylor 1982, Mushet et al. 1992, Gray et al. 1999*c*) and invertebrate (Reid 1983) abundance in wetlands. These and other studies greatly enhanced our understanding of moist-soil systems. The vast majority of research, however, has been conducted in the Mississippi Alluvial Valley (MAV). Plant communities, wetland management techniques, and environmental conditions in the MAV likely differ considerably from those present in the Mediterranean climate of the Central Valley. Ecological studies of wetlands in California have been neglected and Heitmeyer et al. (1989) suggest that integrated investigations of nutrient, plant, invertebrate, and chemical aspects of wetlands and the effects of management should be productive avenues for research. Certainly information from the MAV is useful elsewhere, but the need exists for research investigating the link between management practices and seed production in other regions, including the Central Valley of California.

The Central Valley is extremely important to wintering waterfowl (Heitmeyer et al. 1989), but over 90% of the wetlands in the region have been converted to agriculture or lost due to flood control and water diversion projects (Gilmer et al. 1982). Maximizing the value of remaining wetlands (e.g., by increasing food production) is critical. Currently, seed production in Central Valley wetlands is meeting the needs of wintering waterfowl (Chapter 1), but if the number of waterfowl wintering in California returns to mid-1970s levels, management of wetlands will have to increase production and quality of resources to meet waterfowl requirements (Heitmeyer et al. 1989). However, in the Central Valley, knowledge of the effects of management practices on moist-soil seed production exists largely as unwritten expertise of wetland managers.

In this study, we evaluated the effects of management practices on seed production in Central Valley moist-soil habitats. Only one similar study (Mushet et al. 1992) has been conducted in California wetlands, and that investigation addressed only a single management action (summer irrigation) thought to influence moist-soil seed production. Of the studies relating management activities to seed production, few have used explicit quantitative methods to assess these relationships (Mushet et al. 1992, Gray et al. 1999*c*). Our objective was to quantitatively evaluate the impact of key predictor variables believed to affect moist-soil seed production (Fredrickson and Taylor 1982). Specifically, we examined the effect of: (1) spring drawdown timing; (2) drawdown rate; (3) fall disking; and (4) summer irrigation on moist-soil seed production in Central Valley wetlands. This study will identify the most effective moist-soil management strategies in the Central Valley, enabling managers to make efficient use of limited resources to produce food necessary to support desired populations of wintering waterfowl.

Few explicit a priori predictions have been developed to address the effect of moist-soil management practices. Nonetheless, most wetland managers prescribe management actions with specific goals in mind. We expect all 4 factors investigated to influence total moist-soil production. More specifically, based on discussions with wetland managers in the Central Valley (see Smith et al. 1995) and the results of other investigations (Fredrickson and Taylor 1982, Gray et al. 1999*c*), we make the following predictions regarding each of the management activities investigated: (1) early drawdowns will result in higher levels of seed production than mid and late season drawdowns, respectively; (2) slow drawdowns will promote greater seed production than fast drawdowns, with the caveat that the interaction between drawdown date and rate will be important. This caveat is based on the suggestions of Fredrickson and Taylor (1982) that later drawdowns (which occur during times of higher temperature) inhibit plant establishment, but this inhibition can be offset to some degree by slow drawdowns which allow for longer periods of soil saturation during drawdown; (3) disking a high percentage of a wetland unit will result in high levels of seed production; and (4) irrigation will increase seed production, and there will be an interaction between irrigation and drawdown date due to the temperature effects noted above.

STUDY AREA

The climate and characteristics of the Central Valley have been described in Gilmer et al. (1982), Miller (1986), and Heitmeyer et al. (1989). This study was conducted in managed wetland complexes (both public and private) within the Butte, Colusa, and San Joaquin Basins of the Central Valley (CVHJV Implementation Board 1990). Central Valley wetlands managed for moist-soil seed production consist primarily of seasonal wetlands managed for either watergrass (*Echinochloa crusgalli*) or swamp timothy (*Crypsis schoenoides*) production; thus our research focused on these habitat types (Smith et al. 1995). Sites were selected based on 4 criteria: (1) location within the Sacramento or San Joaquin Valley regions of the Central Valley; (2) the type of management (mix of units managed for either swamp timothy or watergrass production); (3) ownership (distributed among private, state, and federal); and (4) ability to gain access.

METHODS

Seed Production Data

We used core sampling to quantify moist-soil seed production at each of the wetland units under examination in fall 2000. Fifteen 66mm-diameter cores were taken from each unit immediately prior to fall flood-up (i.e., at the end of the 2000 growing season) using a stratified-random sampling design. This sampling design was implemented by estimating the area of each unit, dividing the unit into a grid of 15 strata of equal area, and taking 1 core from a random location within each strata. Moist-soil seeds in these cores were returned to the lab and either washed through a 255μ-mesh sieve or frozen within 24 hours to halt seed deterioration. Frozen samples were washed at a later date. To prevent seed deterioration, washed samples were stored in ethanol until sorted. All samples were sorted by hand to remove seeds of 15 plants that constitute the majority of moist-soil seed produced in Central Valley wetlands (E. Burns, unpublished data). Removed seeds were counted, dried at 80°C for 48 hours, and weighed to the nearest 0.0001g. Production of each species was calculated as the mean kg/ha of seed contained in the 15 cores taken from each wetland unit. We summed the data for all species to calculate a total seed production value (kg/ha) for each wetland unit. This value was used in all analyses (i.e., each wetland unit contributed a single datum).

Management Data

We gathered information from property managers on management practices conducted during the 2000 growing season. Specifically, we collected data regarding spring drawdown timing and rate, irrigation, and mechanical manipulations (i.e., disking). Table 1 provides a description of the levels of each factor investigated. In the Central Valley, wetland managers disk wetlands in the late summer and fall with the goal of influencing moist-soil plant response during the subsequent growing season (Smith et al. 1995); thus, values for disking are from 1999.

Data Analysis and Modeling

We used analysis of variance in the standard least squares procedure in the statistical package JMP (SAS Institute 2001) to test for effects of treatments on total moist-soil seed production. Seed production values were log transformed to correct for nonnormality. We were uncertain how our collection of disking information might affect our ability to detect a biologically meaningful relationship between disking and seed production. Disking data was quasi continuous since the area (i.e., percent) of each unit disked was approximated, not measured. Therefore, we created a disking variable by classifying levels of disking into 3 categories: low, < 20% of the wetland unit disked; medium, 20 – 70%; and high, > 70%. A second disking variable assumed a linear relationship between the percent of a wetland disked and seed production. Thus, analyses included the categorical variables drawdown date, drawdown rate, irrigation, and 2 disking terms (3 categories and linear).

We used Akaike's Information Criterion corrected for small sample size (AIC_c) to identify best approximating and competing models (Burnham and Anderson 1998; Anderson et al. 2000, 2001). We then ranked the models from lowest to highest AIC_c value, and calculated the difference between the best approximating model and competing models (Δ_i) and respective Akaike weights (w_i). We also report adjusted R^2 as an additional measure of model fit (Anderson et al. 2001).

Due to logistic limitations on the number of sampling units, we could not examine a model that included combinations of all factors and all possible interactions. Instead, we constructed a subset of candidate models based on a priori expectations regarding which variables, combinations of variables, and interactions might be biologically meaningful. First, we modeled each factor independently. Another candidate model simply included all 4 factors that were of initial interest. To highlight the influence of single factors on model fit, we included additional models that contained only 3 of the 4 factors (i.e., 1 factor was excluded). As discussed in the Introduction, we thought that interactions between drawdown date and drawdown rate, and between drawdown date and irrigation may be important, so additional models included all 4 factors and either 1 or both interaction terms.. Models that included disking as a factor were examined with a different 1 of the 2 disking variables (see above) included in each. We report least squares means and their associated standard errors for the best approximating model (see Results) as an indicator of the direction and size of effects of the levels of each factor.

RESULTS

We found considerable variation in habitat management practices undertaken for the wetland units in this study (Table 1). This variation provides 2 insights. First, it indicates a wide range of management approaches adopted by wetland managers in the Central Valley, suggesting that a wide range of management philosophies exists. Second, this wide range of variation provides us with more than sufficient variation with which to examine the effects of management practices on moist-soil seed production.

An examination of effect size revealed the following patterns. First, mid-season drawdowns produced greater amounts of seed (LSMean 824.72 ± 126.31 (SE) kg/ha) than early (626.81 ± 181.24 kg/ha) and late (430.56 ± 145.87 kg/ha) drawdowns (Figure 1A). Second, drawdowns classified as evaporations produced the greatest amounts of seed (884.16 ± 221.83 kg/ha), followed by slow (538.28 ± 130.96 kg/ha) and fast (459.65 ± 132.29 kg/ha) drawdowns (Figure 1B). Third, irrigated wetlands were characterized by much greater seed production than non-irrigated wetlands; irrigated wetlands produced an average of 804.13 ± 194.73 kg/ha, while non-irrigated wetlands produced 450.59 ± 135.68 kg/ha of moist-soil seed (Figure 1C). Finally, wetlands that received high levels of disking produced greater amounts of seed (804.33 ± 268.60 kg/ha) than those that received moderate (699.33 ± 170.53 kg/ha) and low (378.43 ± 105.12 kg/ha) levels of disking (Figure 1D).

Only 3 seed production models were ≤ 2 AIC_c units from the best approximating model. The model with the lowest AIC_c included a term for drawdown rate, irrigation, and the categorical disking variable (Table 2). The difference between the best model and competing models was small (Table 2), leading to model-selection uncertainty (Burnham and Anderson 1998). Adjusted R^2 values for the top 4 models ranged from 0.33 – 0.59. A model containing all 4 variables explained the data nearly as well as the best model ($\Delta AIC_c = 0.27$) and had the highest adjusted R^2. Due to the discrepancy between the 2 model-selection criteria and the apparent interchangeability of the top 2 models, we used the model containing all 4 variables as our best model. Doing so provided the opportunity to explore the effect of all 4 variables on moist-soil seed production, thereby increasing our explanatory power and ability to make management recommendations.

DISCUSSION

Fall disking appeared in all of the best approximating models, suggesting that this management treatment had the strongest effect on total moist-soil seed production. Our results suggest that the greater the area disked in each unit, the greater the benefit in increased seed production. Disking can promote increased moist-soil seed production by elevating seeds to upper soil horizons (Kelley 1986:40-41, Kirkman and Sharitz 1994), where more favorable conditions for germination exist (van der Valk and Davis 1978), and by reducing litter and incorporating it into the substrate (Gray et al. 1999*c*), promoting accelerated litter decomposition and nutrient assimilation by plants (Gray et al. 1999*c*). The key benefit of disking may be that it promotes the growth of highly productive annual plants (i.e., plants that produce large amounts of seed) that require disturbance or bare soils for germination. Thus, an increase in the area of a wetland disked leads to greater amounts of annual plants which leads to increased seed production (Fredrickson and Taylor 1982).

A previous study of the effects of management on seed production in Central Valley wetlands suggested that irrigation had no effect on seed production of moist-soil plants (Mushet et al. 1992). In contrast, at our study sites irrigation had a strong, positive effect on moist-soil seed production. In fact, seed production was nearly 2 times as high in irrigated wetlands as in non-irrigated wetlands. The Central Valley is characterized by dry, hot summers with little or no rainfall during the growing season (Gilmer et al. 1982). Thus, wetland plants may become drought-stressed as the moisture content in wetland soils declines; the provision of supplemental water through irrigation can alleviate this stress, possibly leading to high levels of seed production. Indeed, watergrass and smartweed will rarely grow in the San Joaquin Valley without irrigation (Smith et al. 1995).

The effect of drawdown rate on moist-soil seed production followed our expectations. Very slow drawdowns (i.e., evaporations) resulted in the highest levels of seed production, and slow drawdowns promoted greater seed production than fast drawdowns. As with irrigation, this pattern is likely due to climatic conditions in the Central Valley. Slow drawdowns allow wetland soils to remain saturated for longer periods than fast drawdowns, even in the humid conditions of southeast Missouri

(Fredrickson and Taylor 1982). This effect is likely exaggerated in the Central Valley due to the warm, arid conditions present during late spring and early summer when drawdowns are implemented. Thus, soil moisture levels favorable for moist-soil seed germination may occur over a longer period during evaporation and slow drawdowns than during fast drawdowns, leading to increased germination rates and subsequent seed production.

Of the 4 measured variables, drawdown date had the weakest effect on moist-soil seed production. Drawdown date may have a stronger effect on plant species composition than on total seed production in moist-soil habitats (Fredrickson and Taylor 1982), although we did not investigate this possibility here. The climatic characteristics (particularly temperature) of the Central Valley likely allow for favorable germination conditions for different species of wetland plants to exist over a long period of time. For example, early drawdowns may result in smartweed germination, while mid and late season drawdowns likely result in swamp timothy and watergrass germination, respectively (Fredrickson and Taylor 1982, Smith et al. 1995). All 3 of these species potentially can produce large (or small) amounts of seed, leading to high (or low) levels of total seed production regardless of species composition. Testing the effects of management activities on seed production of individual plant species was beyond the scope of this study, but the effect of drawdown date could be magnified if species were considered independently.

We urge readers to use caution in interpreting the effect sizes and directions reported in this study, since the values of effect size and direction do not imply a cause-and-effect relationship. First, our study was observational. Although all the treatments for each variable we measured were applied independently to each experimental unit (i.e., wetland), we did not randomly prescribe and apply management treatments. Additional factors not investigated or controlled for in this study could have influenced our results. Second, the effect size values reported in this study are least squares means, not traditional means. Least squares means are a statistical construct that reveals the effect of 1 variable while the effects of all other variables are held constant. For example, least squares means indicated that irrigation increased seed production nearly 2-fold at our sites. But, the increase in seed production due to irrigation can only be described as nearly doubling when the effects of all other variables are held constant. Thus, although certainly important, the real-world effect of irrigation on seed production would depend on a suite of other factors including, but not limited to, the management variables we investigated. Furthermore, single-factor analyses (when other variables are not considered or held constant) may provide different results than a least squares means analysis. For example, a one-way analysis of variance for the categorical disking variable indicates that moderate levels of disking are more productive than high levels, contrary to the results of the least squares analysis. Biologically, this result could be explained if the beneficial effects of disking are characterized by diminishing returns as the amount of each wetland unit disked increases past some intermediate, highly productive level. Furthermore, the beneficial effects of disking a large percentage of a wetland may not be realized the first growing season after treatment. This is consistent with the findings of Thomas et al. (2001) who showed that, in Central Valley wetlands, swamp timothy stem density (seed production was not measured) was reduced the first year after disking but increased in the second year post-treatment. In summary, our results do not make predictions about effect sizes that may occur at other sites in response to management activities, but we can conclude that, at our sites, the 4 management practices we investigated impacted moist-soil seed production, and the effects of irrigation and disking were the strongest.

MANAGEMENT IMPLICATIONS

Our results indicate that disking and irrigation are effective management practices for increasing seed production in Central Valley wetlands. Fall disking had a large impact on moist-soil seed production in our study, and medium to high levels of disking led to the highest levels of production. In addition to increasing seed production, disking has the added benefit of increasing interspersion of vegetation and aiding in the control of unwanted vegetation (Gray et al. 1999*c*). Fall disking can provide both benefits simultaneously, thereby reducing costs incurred when managers disk once in the spring or early summer to set back succession (Fredrickson and Taylor 1982) and once in the fall to increase vegetation interspersion with the goal of providing areas of open water after flooding (Gray et al. 1999*c*; Heitmeyer et al. 1989). In wetlands dominated by nuisance vegetation multiple diskings throughout the summer that encompass a large portion of the wetland area may be necessary to eliminate unwanted vegetation. Disking a large percentage of a wetland in the fall (though likely to promote increased seed production in the following year) will have the undesired effect of decreasing food availability and habitat quality in the current year. Ideally, managers should implement a proactive program of annual disking to control areas invaded with unwanted vegetation to setback succession on these sites, thus avoiding circumstances in which management must react to problem vegetation that has established over several years of neglect.

Due to the arid climate of the Central Valley we expected summer irrigation to impact moist-soil seed production; the effect we observed in the present study was large. We recommend that wetland managers in the Central Valley implement summer irrigations as part of their management scheme. In the Central Valley, irrigation is limited primarily by 2 factors. Historically, the most limiting factor was water availability and cost. Water costs in the Sacramento Valley are generally lower than in the San Joaquin Valley, but the Central Valley Project Improvement Act has improved water availability and reduced water cost in the northern San Joaquin Valley (Smith et al. 1995). Programs such as the California Waterfowl Habitat Program of the California Department of Fish and Game provide financial assistance to help offset the costs of wetland management (e.g., irrigation) to private wetland managers. Relative to the annual operations budget of many wetland complexes (both public and private) the cost of irrigating at least a portion of their wetland acreage is small. The exception to this scenario is the Tulare Basin, a region where water costs remain prohibitive for many managers. Recently an increase in the activities of mosquito abatement districts, especially in the Sacramento Valley, has limited the ability of many wetland managers to conduct summer irrigations. Summer irrigations can promote mosquito hatches, and the cost to the landowner for mosquito abatement effectively doubles the cost of irrigation in many cases. The availability of reliable, low-cost water for management is critically important for ensuring the long-term viability and productivity of Central Valley wetlands.

The effect of drawdown date and rate on moist-soil seed in Central Valley wetlands was relatively small. Possibly mid-season drawdowns will lead to the highest levels of seed production, thereby providing large amounts of food for wintering waterfowl. The greatest benefit to wetland-dependent birds, though, would likely be achieved by timing drawdown dates to coincide with spring migrations of waterfowl and shorebirds. Many (private) wetland managers in the Central Valley initiate drawdowns when convenient, typically in late January (at the close of duck season). Wetlands managed in this way provide little habitat for spring migrating birds. A better scenario may be for managers to delay drawdowns on most of their wetland units until March or April and stagger these drawdowns among units within complexes to provide a mosaic of wetlands with different water depths, thereby increasing spring habitat availability. Similarly, drawdown rate could be used most effectively to increase availability of spring wetland habitat. Slow drawdowns provide shallow-water areas of particular value to shorebirds (Fredrickson and Taylor 1982), and our results suggest that evaporations (the slowest of drawdowns) lead to high levels of seed production. Thus, managers can achieve multiple benefits by conducting slow drawdowns. In wetlands where salt is abundant, however, lengthy drawdowns can concentrate salts to high levels, so we advise against implementing evaporations at such sites.

The large variation in management practices executed by managers in this study indicates that the seed producing potential of many wetlands in the Central Valley may be unmet. This variation occurred despite the common goal among wetland managers of high levels of moist-soil seed production. As we have discussed, drawdown date and rate do not appear to affect seed production to as large a degree as irrigation and disking, so variation in the former likely has only a small impact on seed production throughout the Central Valley. In contrast, the fact that nearly half the units in our study were not irrigated and many units received little disking could affect seed production (and food availability for waterfowl), if this pattern is consistent valley-wide. Of the habitat management activities used by managers, irrigation and disking are the most costly, so increasing the acreage on which these techniques are applied could be met with some resistance. Educating wetland managers about the beneficial effects of irrigation and disking and efforts to help reduce the cost of implementing these activities could help increase moist-soil seed production in the Central Valley.

This study identifies effective moist-soil management strategies in the Central Valley, enabling managers to make efficient use of financial and human resources to produce food that will support desired waterfowl populations in a limited habitat. By documenting effective management techniques, we hope that this study will facilitate dissemination of information to a broad range of interested persons. Obviously, moist-soil management can not be reduced to a simple cookbook of techniques—wetland management will always be as much art as science (Fredrickson 1996). Management efforts that focus on the beneficial techniques discussed here offer a valuable supplement to current efforts of the CVHJV and its partners to protect, restore and enhance Central Valley wetlands.

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Table 2.1. Frequency of management actions undertaken in Central Valley moist-soil habitats, 2000. Drawdown date is the date when most of the wetland is mudflat; drawdown rate is the number of days from drawdown initiation to drawdown date; irrigation consists of 1 or more shallow floodings during the growing season; disking is scarifying the wetland substrate with a stubble disc during the late summer or early fall of 1999.

	Habitat type	
	Swamp timothy	Watergrass
Management action	n[a]	n
Drawdown date		
Early (15 Feb – 15 Mar)	4	2
Mid (16 Mar – 15 Apr)	9	6
Late (after 16 Apr)	1	5
Drawdown rate		
Evaporation (> 17 days)	3	2
Slow (10 – 17 days)	8	5
Fast (< 10 days)	3	6
Irrigation		
Yes	7	8
No	7	5
Disking		
0-20% of wetland	9	4
20-70%	2	6
71-100%	2	4

[a] The number of wetland units.

Table 2.2. Seed production models for 27 managed wetlands in California's Central Valley, 2000.

Model[a,b]	P^c	AIC_c	ΔAIC_c	w_i	Adj. R^2
DR + IR + DK(cat.)	5	-22.549	0.00	0.294	0.490
DD + DR + IR + DK(cat.)	7	-22.283	0.27	0.258	0.588
DK(cat.)	2	-21.659	0.89	0.189	0.330
DD + IR + DK(cat.)	5	-21.598	0.95	0.183	0.472
DD + DR + IR + DK(linear)	6	-17.437	5.11	0.023	0.444
DR + IR + DK(linear)	4	-16.707	5.84	0.016	0.307
DD + DR + DK(cat.)	6	-16.628	5.92	0.015	0.427
DD + IR + DK(linear)	4	-15.720	6.83	0.010	0.281
IR	1	-14.047	8.50	0.004	0.055
DK(linear)	1	-13.536	9.01	0.003	0.037
DD + DR + IR + DK(cat.) + DD*IR	9	-12.579	9.97	0.002	0.561
DD	2	-12.278	10.27	0.002	0.052
DD + DR + IR + DK(linear) + DD*IR	8	-9.890	12.66	0.001	0.431
DR	2	-9.055	13.49	0.000	-0.068
DD + DR + IR + DK(linear) + DD*DR	10	-7.072	15.48	0.000	0.553
DD + DR + DK(linear)	5	-6.564	15.99	0.000	0.078
DD + DR + IR	5	-5.003	17.55	0.000	0.023
DD + DR + IR + DK(cat.) + DD*DR	11	0.685	23.23	0.000	0.523
DD + DR + IR + DK(linear) + DD*DR + DD*IR	12	9.476	32.02	0.000	0.526
DD + DR + IR + DK(cat.) + DD*DR + DD*IR	13	19.981	42.53	0.000	0.495

[a] DD = drawdown date; DR = drawdown rate; IR = irrigation; DK(cat.) = categorical disking variable; DK(linear) = linear disking variable.
[b] + indicates an additional model term; * indicates an interaction term.
[c] The number of parameters in each model.

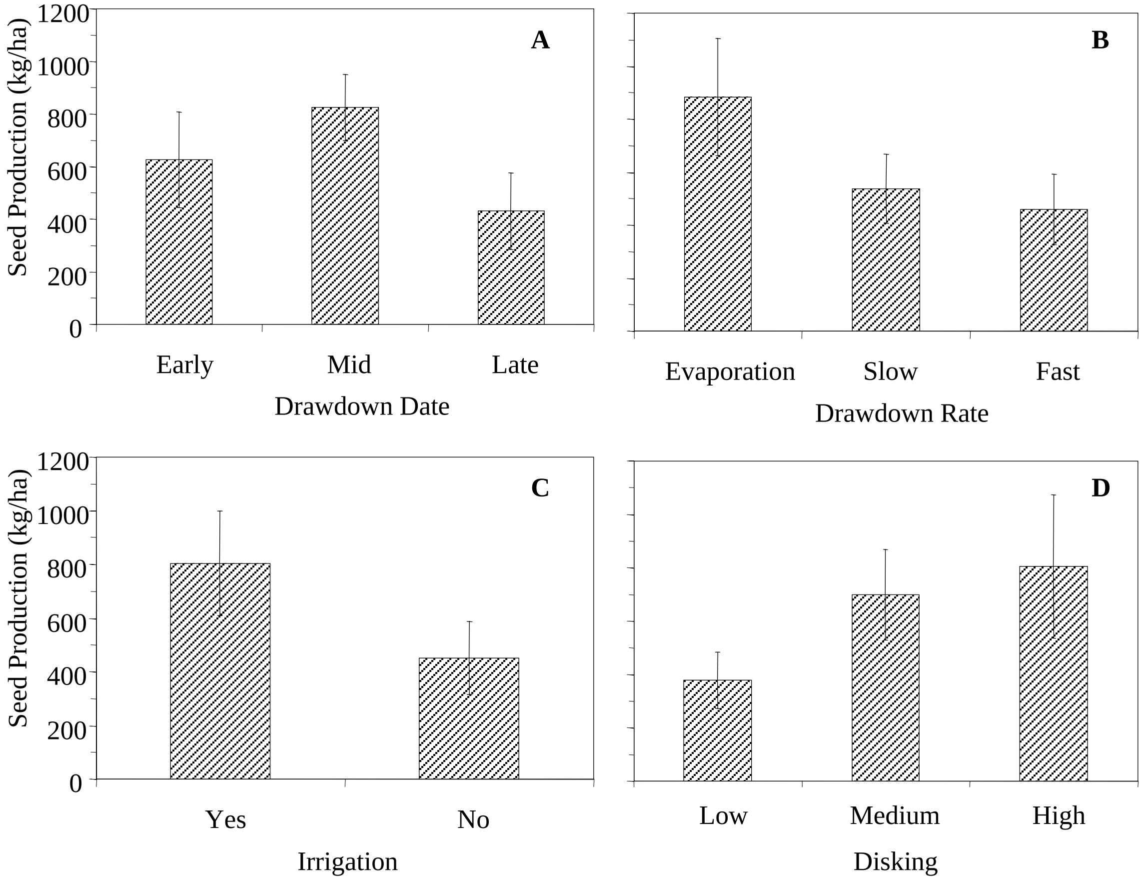

Figure 2.1. The effect of management activities on moist-soil seed production in Central Valley wetlands, 2000. Activities shown are: (A) drawdown date (date when majority of wetland mudflat): early (15 Feb. - 15 Mar.), mid (16 Mar. - 15 Apr.), or late (after 16 Apr.) growing season; (B) drawdown rate (days from drawdown initiation to mudflat): evaporation (> 17days), slow (10 - 17), or fast (< 10); (C) summer irrigation conducted (Yes) or not (No); and (D) the percent (expressed categorically) of the wetland unit disked in the late summer or fall of 1999. Values are least squares means ± 1 SE.

CHAPTER 3: A SIMPLE, EFFICIENT METHOD FOR PREDICTING SEED YIELD IN MOIST-SOIL HABITATS

ABSTRACT

Information on moist-soil seed production is necessary to determine the carrying capacity of wetland habitats and to evaluate management efforts. Traditional methods (e.g., core sampling) are time consuming and labor intensive. Methods to predict seed production using primarily seed-head characteristics have been developed, but they tend to be complex and may have limited utility for some moist-soil plants and in some regions. We developed a simple, field-based method that evaluates the percent cover and seed-head characteristics of 6 common moist-soil plants in the Central Valley of California. These values were then summed and compared to seed production data collected by core sampling. Our estimates accurately predicted total seed production in Central Valley wetlands ($P < 0.0001$; $R^2_{adj} = 0.88$). Further, this method is repeatable among observers ($P < 0.0001$; $R^2_{adj} = 0.67$). We used this technique to evaluate seed production on approximately 5000 hectares of managed wetland habitat and found that Central Valley wetlands produce and average of 178 kg/ha of moist-soil seed, much less than data from other studies suggests. This technique is useful for predicting overall seed production within a wetland, offering managers a simple method to track temporal changes in seed production within wetlands and across landscapes, estimate wetland carrying capacity and evaluate management actions with minimal resource investment.

INTRODUCTION

Over the past several decades, resource managers have undertaken increased efforts to restore and enhance wetlands to provide habitat for waterfowl and other wetland-dependent wildlife (Fredrickson and Taylor 1982). To evaluate the effectiveness of these efforts, wetland managers frequently need to estimate the amount of moist-soil seed (a primary food resource for wintering waterfowl) produced in managed wetlands. Collecting this information can be labor-intensive (Low and Bellrose 1944, Gray et al. 1999*a*). Because of the time and cost involved, efforts to obtain quantitative estimates of food availability for waterfowl during winter have been limited. Recently, several new methods to provide an index of food availability have been developed. Laubhan and Fredrickson (1992) developed the first method to estimate seed production in wetlands using phytomorphological measurements of some common moist-soil plants. They used multiple regression techniques to develop equations that predicted seed production of selected plants using combinations of one or more inflorescence measurements, plant stem height, and stem density. This technique was used to develop models for additional species by Sherfy and Kirkpatrick (1999). Gray et al. (1999*a*) further modified the methods used by Laubhan and Fredrickson (1992) and Sherfy and Kirkpatrick (1999) to develop equations that more accurately and precisely predicted moist-soil seed production in Mississippi Valley wetlands. Finally, Gray et al. (1999*b*) estimated seed production using simple linear regression to develop predictive models based on a single inflorescence characteristic, the number of dots on a sheet of paper obscured by the seeds on an individual seed head.

While these methods clearly offer a more efficient method for quantifying wetland plant production than collecting core samples, for example, they nonetheless entail considerable time investment and the required effort may remain prohibitive if wetland managers do not have the financial or human resources necessary to implement these assessment techniques on large wetland complexes. This is evidenced by the fact that, in California, many state and federal wetland managers do not use any of the aforementioned techniques to quantify moist-soil seed production on the areas they manage. Moreover, these techniques have been developed for moist-soil plants primarily in the southeastern United States, so applying these techniques to wetlands in other regions that have different plant communities may be impractical or could lead to error in estimates of moist-soil seed production (Sherfy and Kirkpatrick 1999). Laubhan and Fredrickson (1992) and Sherfy and Kirkpatrick (1999) include samples from the southwest and northeast United States, respectively.

Wetland managers in California's Central Valley have identified a need for a simple and reliable method to obtain an index of moist-soil seed production. The ideal method could be used by managers in the field and could be implemented on a regular basis as part of their normal management activities. Such a technique would be useful not only to predict moist-soil seed production in a given year, but would also be useful to track changes in production over time, thereby providing an opportunity to evaluate the effectiveness of ongoing management actions.

To address this need, we developed a new technique to predict seed yield in moist-soil habitats of California's Central Valley. The objectives of this study were threefold. First, we developed a technique to predict seed yield of moist-soil plants using ocular, field-based measurements of two easily collected variables. We then assessed the predictive ability of this technique using seed production data collected by core sampling as a measure of actual seed production. To evaluate the potential magnitude of observer error in this method, we compared seed production estimates of 2 independent observers. Finally, we used this method to quantify seed production on 5000 hectares of managed wetlands in the Central Valley to determine how these values compare to available estimates of wetland seed production (Chapter 1) and to evaluate how our findings may affect Central Valley wetland habitat planning. We show that this simple, field-based method provides an accurate index of moist-soil seed yield in Central Valley wetlands and offers a simple tool for managers to estimate seed production in wetlands.

STUDY AREA

Field work was conducted on private duck clubs within the Butte, Colusa, San Joaquin, and Tulare Basins of the Central Valley (CVHJV Implementation Board 1990). The climate and characteristics of the Central Valley have been described in Miller (1986) and Gilmer et al. (1982). Model development data were collected on 13 wetland units on 7 clubs in the Sacramento and San Joaquin valleys. Paired assessments of observer error were conducted on 183 wetland units distributed throughout the Sacramento (N = 38) and San Joaquin (70) valleys and the Tulare (75) Basin of the Central Valley.

METHODS

Model Development

Estimates of moist-soil seed production were collected in 2000 during late-summer field visits to privately owned wetlands enrolled in the California Department of Fish and Game's California Waterfowl Habitat Program (CWHP) which ranged in size from 5 – 150 ha. At each wetland unit, an AREA and QUALITY score were assigned for each of 6 wetland plants that, on average, account for over 90% of the seed production in Central Valley moist-soil habitats (L. Naylor, unpublished data). These plants were watergrass (*Echinochloa crusgalli*), swamp timothy (*Crypsis schoenoides*), smartweed (*Polygonum* spp., primarily *P. lapathifolium*), sprangletop (*Leptochloa* spp.), spikerush (*Eleocharis* spp.), and bulrush (*Scirpus* spp.). The AREA score was assigned based on the estimated area of each wetland unit covered by each species using the following ordinal scale: 1 = 1-10% coverage; 2 = 11-25%; 3 = 26-50%; 4 = 51-75%; 5 = 76-100%. A QUALITY score was assigned on an ordinal scale as follows: 1 = poor; 2 = fair; 3 = good; 4 = excellent, based on the seed producing potential of the plants of each species considering characteristics such as seed-head size and density (Table 1). We multiplied AREA times QUALITY to derive a TOTAL score for each species. TOTAL scores for all species were added to produce a single value, denoted SUM-T, that represented a prediction of the total seed production within each wetland unit.

We used core sampling to quantify moist-soil seed production at each of the wetland units under examination. Fifteen 66mm-diameter cores were taken from each unit immediately prior to fall flood-up using a stratified-random sampling design. This sampling design was implemented by estimating the area of each unit, dividing the unit into a grid of 15 strata of equal area, and taking 1 core from a random location within each strata. Moist-soil seeds in these cores were returned to the lab and either washed through a 255μ-mesh sieve or frozen within 24 hours to halt seed deterioration. Frozen samples were washed at a later date. To prevent seed deterioration, washed samples were stored in ethanol until sorted. All samples were sorted by hand to remove seeds of the 6 plants listed above. Seeds were counted, dried at 80°C for 48 hours, and weighed to the nearest 0.0001g. Production of each species was calculated as the mean kg/ha of seed contained in the 15 cores taken from each wetland unit. We summed the data for all species to calculate a total seed production value (kg/ha) for each wetland unit.

Statistical Analysis

We used simple linear regression to develop a model of observed total seed production (response variable) vs. SUM-T (predictor variable). Analysis were conducted using StatView (SAS Institute 1999). Estimates of SUM-T scores ranged from 12 – 68, therefore prediction beyond these ranges is not possible (Figure 1). Values of SUM-T < 12 indicate extremely low seed production, while a SUM-T score > 68 likely represents extremely high seed production in California wetlands (see Chapter 1). Although not the focus of this study, we also investigated the ability of our method to predict seed production of individual species using simple linear regression to develop species-specific models. Seed mass of each species (response variable) was regressed against the TOTAL score (predictor variable) for each species. In all analyses, the adjusted coefficient of determination (R^2_{adj}) was calculated as an indicator of model precision (Gray et al. 1999*b*).

Analysis of Method Repeatability

During 2001 CWHP site visits, 2 observers independently classified moist-soil seed production using our method. The same 2 observers classified all sites. Observers did not communicate during the scoring process. We calculated SUM-T scores for each wetland unit and used these values in our seed-production equation to calculate an estimate of total predicted moist-soil seed production (kg/ha). Units with a SUM-T value < 12 were assigned a seed production value of 0 kg/ha (no units had a SUM-T > 68; see above). We used simple linear regression to determine the strength of the relationship between estimates of seed production for both observers. If this method is repeatable, we would expect predicted seed production values for both observers to be highly correlated (high adjusted R^2) with a regression equation slope close to 1.0. We also calculated mean predicted seed production values for each observer for each basin to illustrate size and direction of observer effects.

Landscape-Scale Seed Production

We averaged predicted values of moist-soil seed production between observers to provide an estimate of the amount of seed potentially available to wintering waterfowl in each of the 3 regions under examination (Sacramento and San Joaquin valleys and Tulare Basin). These values were compared to available estimates of moist-soil seed production gathered by core sampling (Chapter 1) to examine the effect of differences in methodology and scale of observation on estimates of moist-soil seed abundance within the Central Valley.

RESULTS

Model Precision

The regression of total seed mass against SUM-T was highly significant and the ocular estimate accounted for over 50 percent of the variation in observed seed mass ($P = 0.0025$; $R^2_{adj} = 0.54$). Two units appeared to be outliers; i.e., they were predicted to have high seed production, but in reality had only “average” seed production. These units were both part of the same duck club (Laughing Mallard), so we suspect that scoring may have been inaccurate at that site. We suspect this inaccuracy because scoring at the Laughing Mallard club was conducted prior to fall disking, while core sampling was done after disking. Disking likely buried a portion of produced seed, leading to a discrepancy between the 2 estimates. To evaluate the effect of those units, we eliminated them from the model and repeated the analysis. The regression for the new analysis was highly significant and exhibited greater precision than the original model ($P < 0.0001$; $R^2_{adj} = 0.88$; Figure 1). Thus, we used this equation in subsequent analyses. Regressions of seed mass against TOTAL for each species were significant for watergrass, swamp timothy, and sprangletop ($P < 0.01$; $R^2_{adj} = 0.46 – 0.66$; Table 2). The regression for spikerush was significant, but less precise ($P < 0.05$; $R^2_{adj} = 0.33$; Table 2). The regressions for smartweed and bulrush were not significant ($P > 0.05$; Table 2).

Method Repeatability

The regression of moist-soil seed production predicted by Observer 2 against production predicted by Observer 1 was positive and significant ($P < 0.0001$; $R^2_{adj} = 0.67$; Figure 2). The slope of the regression line was 0.92. To further illustrate the similarity of estimates between observers, predictions by each observer of mean seed production in each region are shown in Table 3.

Landscape-Scale Seed Production

Estimates using our technique indicate that Central Valley wetlands produce an average of 177.73 ± 8.76 (SE) kg/ha of moist-soil seed. Seed production is higher than the average in both the Sacramento (224.12 ± 17.76 kg/ha) and San Joaquin (201.27 ± 14.56 kg/ha) valleys, while it is much lower in the Tulare Basin (132.26 ± 12.99 kg/ha; Figure 3). Values for all regions using our technique are much lower than estimates of seed production gathered by core sampling (Chapter 1), which suggest an average of 585 kg/ha of moist-soil seed present in Sacramento and San Joaquin Valley wetlands at the beginning of winter.

DISCUSSION

We found that a simple visual estimate of 2 easily measured variables can provide a reliable estimate of the moist-soil seed production in Central Valley wetlands. The ability of our models to explain variation in seed production is likely due to the simplicity of the model structure and the ease with which AREA and QUALITY scores can be assigned. Ordinal categories by which a species is scored are broad, allowing the observer to make a coarse characterization of the area covered by each species and the quality of the plants within that area. Even on this coarse scale, models for 5 of 6 of the species investigated predicted actual seed production of those species, some with precision approaching that achieved with the more time- and labor- intensive methods developed by other researchers (Laubhan and Fredrickson 1992, Sherfy and Kirkpatrick 1999, Gray et al. 1999*a*, *b*).

The predictive ability of our model occurred despite a small sample size of only 13 wetland units with which to validate the method. We would expect model precision to increase as sample size increased. Sample size was limited due to the extensive time and resources needed to collect and process core samples (in our study, data collection by core sampling, including field and laboratory work, required approximately 24 hours per wetland unit). However, even with this small sample size the wetlands we examined exhibited a wide range of moist-soil seed production. Indeed, seed production values for some species varied 10-fold from the least productive to most productive wetland (Figure 1), thus providing sufficient variation with which to test our model.

A criticism of this method might be that ocular descriptions of plant characteristics are too subjective to provide reliable or consistent information. However, the strong between-observer correlation in seed production estimates indicates that this method is repeatable. A high degree of repeatability in seed production estimates would be indicated by a regression slope of 1.0 (i.e., when 1 observer predicts production of 400 kg/ha, a second observer would also predict production of 400 kg/ha). In this study, the slope of the regression line was 0.92, close to 1.0. The similarity in estimates of seed production occurred despite the fact that 1 observer had 15 years of experience working in Central Valley wetlands, while the other had only 1 year of experience. The observed similarity in estimates of seed production between observers resulted from the observation of nearly 200 wetland units. We caution, though, that estimates for individual wetland units in a given year may differ between observers (i.e., in a few instances, predictions of seed production by Observer 1 and Observer 2 differed by as much as 400 kg/ha; Figure 2).

The simplicity of the method likely accounts for the high reliability of estimates between observers. Differences in assignment of AREA scores for a species would more likely be due to detection error than inter-observer differences, because AREA scores are defined by distinct categories. Indeed, errors in assignment of AREA scores may occur if observers differ in their assessment of how much of a wetland unit is covered by a species, particularly at the extremes of the range of each score. In contrast, QUALITY is a more subjective measure, but observers are required only to classify species on a 1 – 4 scale. We suspect that most observers would give the same score to wetlands with "Poor" and "Excellent" production of a particular species. Error could arise when discriminating between "Fair" and "Good" categories, but this error could be reduced through discussions between observers regarding proper categorization *prior* to the scoring of wetlands. Admittedly, this technique can not be implemented by persons unfamiliar with wetland plants, but the amount of time required to gain the necessary level of familiarity is small. Indeed, training sessions by personnel familiar with regional moist-soil plants would facilitate the use of this technique by a wide array of interested persons with different levels of experience.

We encourage other researchers to develop similar models for important moist-soil plants in their regions. Model development requires gathering test data using an acceptable method, such as core sampling, which can be time consuming. We recommend against core sampling to collect test data because other available methods, such as seed-head clipping within randomly located plots, may require less time investment. A new method currently being developed in which seeds are removed from the wetland substrate using a vacuum (R. Kaminski, pers. comm.) could be useful for gathering test data to use in new model development.

Estimates of average moist-soil seed abundance in Central Valley wetlands using our new technique are much lower than those of other available estimates (Chapter 1). This could be due to several factors. First, Chapter 1 did not include wetlands in the Tulare Basin, a region that appears to be characterized by wetlands that produce low amounts of moist-soil seed. Even so, seed production estimates in the Sacramento and San Joaquin valleys (regions included in both studies) were much lower in this study than in Chapter 1. Second, the wetlands sampled in Chapter 1 may have been, by chance, more productive wetlands than those sampled in this study. Furthermore, Chapter 1 included only 30 wetland units, while nearly 200 units were sampled in this study. Possibly sampling fewer, more productive wetlands in Chapter 1 led to the large differences in estimates of moist-soil seed production between Chapter 1 and the present study. Finally, the estimates presented in this study could represent reality. Seed production in moist-soil habitats is dynamic (Fredrickson and Taylor 1982), and we would expect to detect differences between years in seed production in Central Valley wetlands. In fact, our estimates of seed production are similar to those from the pilot year in Chapter 1, suggesting that seed production during the second year of their study may have been unusually high. If so, the seed production values from the pilot year in Chapter 1 and this study may more closely represent reality than the levels of seed production observed in the second year of Chapter 1. Certainly, moist-soil seed production in Central Valley wetlands is less than the 840 kg/ha assumed when CVHJV plans were written (CVHJV Implementation Board 1990), but to what degree remains unknown.

MANAGEMENT IMPLICATIONS

Recording wetland plant characteristics is a simple and quick technique to predict seed yield of moist-soil plants. This method provides a viable alternative to available methods that require measurement of multiple phytomorphological variables (Laubhan and Fredrickson 1992, Sherfy and Kirkpatrick 1999, Gray et al. 1999*a*) and even those in which the observer records only 1 easily measured variable (Gray et al. 1999*b*). The amount of time necessary to implement our technique is small. We estimate that scoring each wetland unit required < 10 minutes, with larger wetlands requiring slightly more time. Because of the small time investment necessary, these assessments could be completed as a part of the normal daily activities of wetland managers. This is significant because in California, for example, neither quantitative or systematic qualitative methods for estimating moist-soil seed production are used by state and federal wetland managers due to the time-intensive nature of available methods. Failure to utilize existing seed production estimation techniques may, in many instances, be a function of priority setting by refuge and wildlife area staff. However, the absence of such monitoring is likely an indicator of the significant increases in wetland management responsibilities over the last 2 decades and the lack of commensurate increases in staff as well as operation and maintenance funding. Further, the continental movement toward “all-bird conservation” manifested in the North American Bird Conservation Initiative, recent policy direction of the North American Wetlands Conservation Act, and the establishment of new bird conservation initiatives such as Partners in Flight and the U.S. Shorebird and Colonial Waterbird Conservation Plans provides guidance for state and federal agencies to manage wetland complexes for a wide range of species, ranging from waterfowl and shorebirds to grassland and riparian-associated neotropical migrants. Habitat restoration and management for these other bird groups comes with a public trust responsibility to conduct monitoring and evaluation as necessary to measure the effectiveness of the management actions, which results in greater demands on state and federal biological staff.

Therefore, the simplicity and minimal time requirements of our method may result in the collection of meaningful moist-soil seed production estimates where none is currently being collected. Developing seed production estimates has the potential to promote a greater level of wetland management efficiency and foster science-based moist-soil management decision making lacking in many regions. It will also allow managers to quantitatively assess the compatibility and trade-offs of integrated bird conservation efforts as they relate to wintering waterfowl management. Furthermore, managers of wetland complexes can use our technique to track temporal changes in moist-soil seed production within individual units and the complex as a whole. Doing so would be particularly useful in evaluations of the effect of management actions on moist-soil seed production (i.e., before and after specific management actions are executed).

There is considerable potential for this method to be applied on a large scale. For example, if our technique were implemented on all wetland areas operated by state and federal resource agencies (areas with a biological staff) and on those properties enrolled in the CWHP (all of which receive yearly site visits in late summer, after moist-soil plants have matured), Central Valley waterfowl managers would have an estimate of moist-soil seed production on over half of the managed wetland area in California. Due to the discrepancy in estimates of moist-soil seed production between the present study and Chapter 1, such an evaluation is needed to provide a large-scale estimate of moist-soil seed production in Central Valley wetlands. This information could be used by partners of the Central Valley Habitat Joint Venture to calculate available duck-use days (Reinecke et al. 1989) on a yearly basis and track temporal changes in moist-soil seed production, allowing managers to better plan for the habitat needs of waterfowl wintering in the Central Valley.

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Table 3.1. Criteria used for assigning QUALITY scores for moist-soil plants in Central Valley wetlands.

QUALITY	Score Assigned	Estimated Seed-head Density	Seed-head Size
Excellent	4	High	Large
Good	3	Moderate	Large
Fair	2	Moderate	Small
Poor	1	Low	Small

Table 3.2. Regression equations and statistics for estimating dry seed mass (kg/ha) of 6 species of moist-soil plants via visual estimates of the predicted seed production of the species (TOTAL), calculated as the area of a wetland covered by a species (AREA) times the estimated productivity of the plants of that species (QUALITY), Central Valley of California, 2000.

					kg/ha moist-soil seed [a]	
Plant species	n	Equation (Y = kg/ha seed)	*F*	R^2_{adj}	Minimum	Maximum
Watergrass	13	-85.026 + (33.954 × TOTAL)	24.14[b]	0.659	0.273	1020.247
Spikerush	13	3.508 + (6.84 × TOTAL)	6.98[c]	0.333	0.546	162.058
Swamp Timothy	13	-493.286 + (57.655 × TOTAL)	11.32[b]	0.462	7.756	1268.498
Sprangletop	13	-4.987 + (3.889 × TOTAL)	17.22[b]	0.575	1.462	115.444
Smartweed	13	4.694+ (0.929 × TOTAL)	1.92[d]	0.071	0.450	48.387
Bulrush	13	28.356 + (1.776 × TOTAL)	0.37[d]	0.033[e]	0.136	147.325

[a] Model performance beyond these ranges is unknown.
[b] $P < 0.01$
[c] $P < 0.05$
[d] $P > 0.1$
[e] R^2 reported since R^2_{adj} could not be calculated due to low value of R.

Table 3.3. Predictions of moist-soil seed production (kg/ha) in wetlands within the Sacramento (SACV) and San Joaquin (SJV) valleys and Tulare (TUL) Basin of the Central Valley by 2 independent observers, 2001.

Basin	n	Observer	Mean	Std. Error	Median	Minimum	Maximum
SACV	38	1	234.44	25.67	242.16	0	527.34
	38	2	213.80	24.79	223.15	0	508.33
	76	Both	224.12	17.76	232.66	0	527.34
SJV	70	1	212.07	21.15	185.13	0	622.40
	70	2	190.47	20.07	147.10	0	717.46
	140	Both	201.27	14.56	185.13	0	717.46
TUL	75	1	150.98	20.53	71.05	0	755.49
	75	2	113.53	15.76	71.05	0	584.38
	150	Both	132.26	12.99	71.05	0	755.49

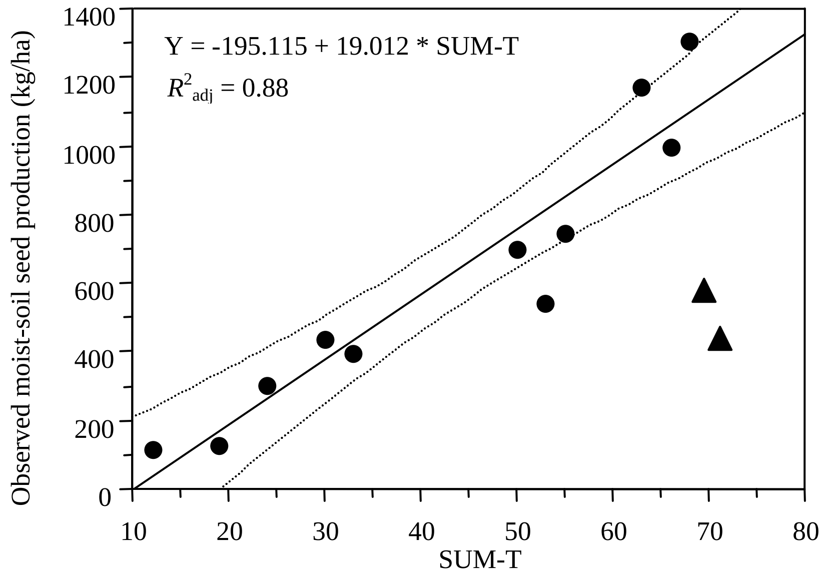

Figure 3.1. The relationship between observed moist-soil seed production and predicted seed production (SUM-T) in Central Valley wetlands, excluding both units from the Laughing Mallard club (triangles). Solid line fitted by simple linear regression; 95% confidence intervals of the mean shown by dotted lines.

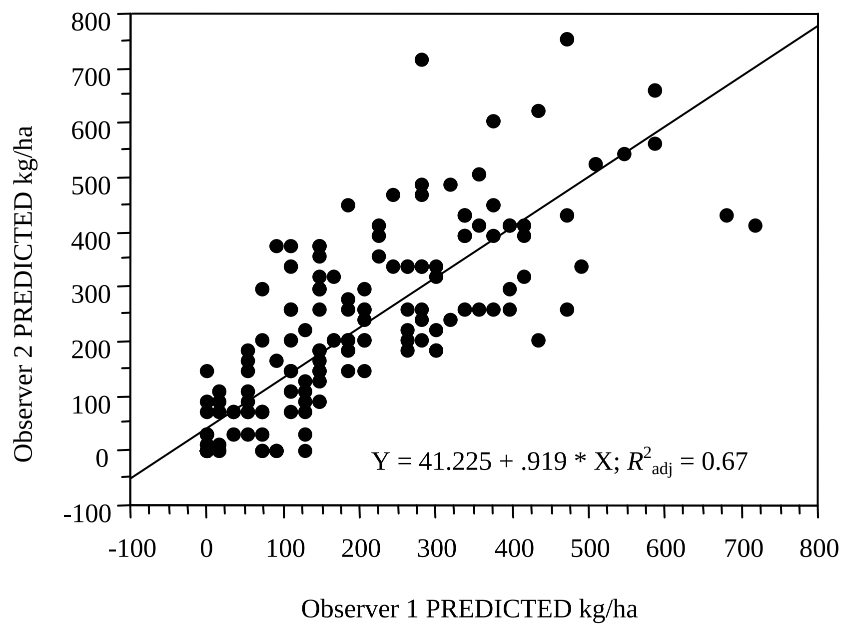

Figure 3.2. The relationship between predictions of moist-soil seed production (kg/ha) by Observer 1 and Observer 2 in Central Valley wetlands. Line fitted by simple linear regression.

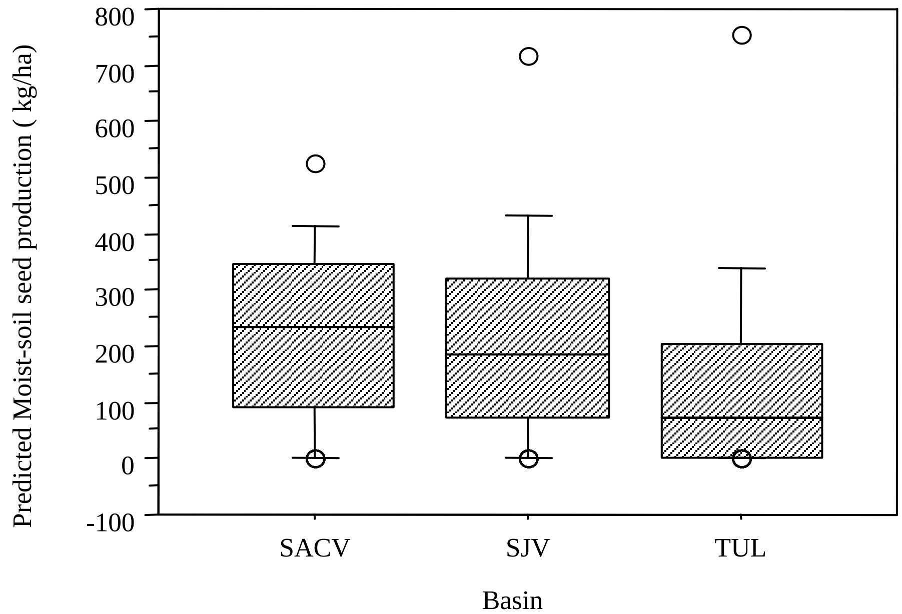

Figure 3.3. Comparison of predicted moist-soil seed production in wetlands in the Sacramento (SACV) and San Joaquin (SJV) Valleys and Tulare (TUL) Basin of the Central Valley, 2001. Values are the averages of the predictions of 2 independent observers. Box plots indicate the median (horizontal line within boxes), 25th and 75th percentiles (boxes), 10th and 90th percentiles (vertical lines) and extreme values (points).