A simple method to predict seed yield in moist-soil habitats

Luke W. Naylor, John M. Eadie, W. David Smith, Mike Eichholz, and Matthew J. Gray

Abstract Information on production of moist-soil seeds is necessary to determine resource availability in wetland habitats and evaluate management efforts. Traditional methods (e.g., core sampling and seed-head clipping) are time-consuming and labor-intensive. Methods to estimate seed production using seed-head characteristics tend to be complex and may have limited utility for some moist-soil plants and in some regions. We developed a simple method to evaluate percent cover and seed-head characteristics of 6 common moist-soil plant types in the Central Valley of California. We estimated percent cover (AREA) and seed-producing potential of each plant type (QUALITY) using an ordinal scale for 13 wetland units on private duck clubs. The product of the AREA and QUALITY scores was calculated for each plant type and then summed over all plant types to provide a single index of seed production (Seed Production Index, SPI) for each unit. To evaluate the reliability of this index, we regressed the value of SPI for each unit against estimates of seed production derived by core sampling. The SPI index was correlated with estimates of moist-soil seed biomass (kg/ha) obtained by core sampling (R^2_{adj}=0.88, P<0.0001). To further assess the utility of this method in a field situation, 2 observers estimated SPI independently for 183 wetland units during annual site visits for the California Comprehensive Wetland Habitat Program. Estimates of SPI required <15 minutes for most wetlands and were repeatable for the 2 observers (intraclass correlation coefficient =0.79, P<0.0001). We suggest that this technique will provide managers with a simple method to estimate seed production in moist-soil wetlands, track temporal changes in food abundance within wetlands and across landscapes, estimate wetland carrying capacity, and evaluate management actions with minimal resource investment.

Key words California, Central Valley, food availability, moist-soil, seed production, waterfowl, wetland management

To evaluate the effectiveness of wetland restoration and enhancement efforts, wetland managers frequently need to estimate the amount of moist-soil seed (a primary food resource for wintering waterfowl) present in managed wetlands. Collecting this information can be labor-intensive (Low and Bellrose 1944, Gray et al. 1999*b*). Because of the time and cost involved, efforts to obtain quantitative estimates of seed availability for waterfowl have been limited and several methods to estimate seed availability have been developed. Laubhan and Fredrickson (1992) developed a

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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 inflorescence measurements. This technique was used to develop models for additional species by Sherfy and Kirkpatrick (1999). Gray et al. (1999*b*) modified the methods used by Laubhan and Fredrickson (1992) and Sherfy and Kirkpatrick (1999) to develop equations that more accurately and precisely estimated moist-soil seed production in Mississippi Alluvial Valley wetlands. Finally, Gray et al. (1999*a*) developed 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.

Although these methods clearly offer a more efficient method for quantifying moist-soil seed production than collecting core samples or clipping seed heads (Gray et al. 1999*c*, Taylor and Smith 2003, Smith et al. 2004), they nonetheless entail a considerable investment of time that may remain prohibitive if wetland managers lack the resources necessary for implementation. Moreover, these techniques have been developed for moist-soil plants primarily in the southeastern United States, and application to wetlands in other regions with different plant communities may be impractical or could lead to error in estimates of moist-soil seed production (Sherfy and Kirkpatrick 1999). 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 due to a lack of time, personnel, and region-specific techniques.

Wetland managers in California's Central Valley have identified a need for a simple and reliable method to obtain an estimate of moist-soil seed production. The ideal method could be used by managers in the field and implemented on a regular basis as part of normal management activities. Such a technique would be useful, not only to estimate moist-soil seed production in a given year, but also to track changes in production over time, thereby providing an opportunity to evaluate the effectiveness of ongoing management actions. We developed and tested a technique to estimate seed yield of moist-soil plants in the Central Valley of California using visual estimates of 2 easily collected variables, area coverage and seed-producing potential of each plant type.

Study area

We conducted fieldwork on private duck clubs enrolled in the California Department of Fish and Game's Comprehensive Wetland Habitat Program (CWHP) within the Butte, Colusa, and San Joaquin basins of the Central Valley of California, USA (Central Valley Habitat Joint Venture 1990). We sampled 13 wetlands ranging in size from 5–75 ha that were managed as seasonal wetlands with the goal of producing moist-soil plants, primarily swamp timothy (*Crypsis schoenoides*) or barnyardgrass (*Echinochloa crusgalli*). Further description of these and other Central Valley wetlands can be found in Smith et al. (1995) and Naylor (2002). Sites in the Butte and Colusa basins were restored agricultural lands (rice fields) while sites in the San Joaquin Basin primarily were restored grazing lands. Hydrology of these sites was entirely artificial (i.e., human-controlled), and water for wetland management was derived from a combination of ground- and surface-water sources. In the Central Valley, a typical annual wetland management cycle consists of a drawdown from late March to late April, 1 or more summer irrigations (typically for barnyardgrass management), late-summer disking, and a September or October floodup. Due to the warm, Mediterranean climate of the Central Valley (Gilmer et al. 1982, Miller 1986), moist-soil plants reach maturity as early as June (primarily swamp timothy) and seed set typically is complete by late August or early September. Seasonal wetlands in the Central Valley typically are characterized by a heterogeneous mosaic of moist-soil plants, but seed production is dominated by 2 species and 4 genera (see below).

Methods

We collected ocular estimates of moist-soil seed production in August and September 2000 during field visits to wetlands after plants had reached maturity. At each wetland unit, we assigned AREA and QUALITY scores for each of 6 plant genera or species (hereafter, type) that, on average, account for over 90% of the seed production in Central Valley moist-soil habitats (E. Burns, University of California, Davis, unpublished data). These plant types include barnyardgrass, swamp timothy, smartweed (*Polygonum* spp., primarily *P. lapathi-*

Table 1. Criteria used for assigning QUALITY scores for 6 moist-soil plant types (barnyardgrass, swamp timothy, smartweed, sprangletop, spikerush, and bulrush) in managed wetland units in California's Central Valley in 2000. For each plant type, the observer categorized the seed-producing potential of each plant type by estimating the seed-head density and size of individuals of each type.

QUALITY	Score assigned	Estimated seed-head density[a]	Seed-head size[b]
Excellent	4	High	Large
Good	3	Moderate	Large
Fair	2	Moderate	Small
Poor	1	Low	Small

[a] We assigned seed-head density values by visually assessing the relative abundance of seed heads within a patch of each plant type. Small amounts of bare ground present and a high proportion of seed heads to plant stems (e.g., the majority of barnyardgrass plants in a patch had seed heads) represented high seed-head density. Conversely, large amounts of bare ground present and a low proportion of seed heads to plant stems represented low seed-head density. Mid-range values were assigned moderate seed-head density scores.

[b] Seed-head size categorization was plant-type specific and based on the deviation of the average size of inflorescences (for each plant type) within a wetland from that of the observed average size throughout managed wetlands enrolled in the California Department of Fish and Game's Comprehensive Wetland Habitat Program.

folium), sprangletop (*Leptochloa* spp.), spikerush (*Eleocharis* spp.), and bulrush (*Scirpus* spp.; Hickman 1993). We assigned the AREA score based on a visual estimate of percent horizontal coverage of each plant type using the following ordinal scale: 1 = 1–10% coverage; 2 = 11–25%; 3 = 26–50%; 4 = 51–75%; or 5 = 76–100%. We determined estimates of coverage by walking or driving through each wetland and visually observing the distribution of each plant type. We assigned a QUALITY score on an ordinal scale as follows: 1 = poor; 2 = fair; 3 = good; or 4 = excellent, based on the seed-producing potential of individuals of each plant type (Table 1). We assessed seed-producing potential based on relative seed-head size (large vs. small) and density (i.e., number of seed heads per area equated to low, medium, and high categories) for a particular plant type. We based seed-head quality assessments on an a priori biological agreement of seed-head size/density for each type. Thus, knowledge of natural seed-head variability for our plant types in the Central Valley was required. We multiplied AREA by QUALITY to derive a total score (TOTAL) for each plant type. We then summed the total scores for all types to produce a single value that represented an index of the total seed production within each wetland unit (seed production index, SPI).

We conducted this study in conjunction with a large-scale analysis of seed abundance and depletion in Central Valley wetlands during which we used core sampling to quantify abundance of moist-soil seeds (Naylor 2002, Naylor et al. 2002). We chose core sampling because it allowed quantification of seed abundance throughout the wintering period for waterfowl, including periods when seed plants were inundated. Moist-soil plants reach maturity as early as June, and by early September the majority of seeds have matured and fallen to the substrate, where they can be sampled effectively using a core sampler. Seeds of swamp timothy do not fall from the seed head, but the prostrate growth form and early maturation of this species make the seeds accessible to core sampling in late summer. We conducted sampling for the present study immediately prior to fall flood-up (September–October 2000) using a systematic-random sampling design in which we took 15 cores, 66 mm in diameter and approximately 5 cm deep, from each unit. We implemented this sampling design by estimating the area of each unit, dividing the unit into a grid of 15 subunits of equal area, and taking 1 core from a random location within each subunit. We returned moist-soil seeds in these cores to the lab and either washed them through a 255-µ mesh sieve or froze them within 24 hours to halt seed deterioration. We washed frozen samples at a later date. To prevent seed deterioration, we stored washed samples in ethanol until they were sorted. We sorted all samples by hand to remove seeds of the 6 plant types listed above. We counted seeds, dried them at 80°C for 48 hours, and weighed them to the nearest 0.0001 g. We calculated production of each species 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 regress values of seed production (kg/ha) determined by core sampling in each wetland on values of the seed production index (SPI). We calculated both the 95% confidence intervals of the mean (CI) and 95% prediction intervals (PI) of the sample for the regression equation. The 95% confidence intervals of the mean indicate the degree of confidence in the range of predicted values of the mean (Y) for given values of X (Equation 17.26, Zar 1984:274), whereas the 95% prediction intervals of the sample indicate the degree of confidence in a single predicted value of Y for a given value of X (Equation 17.29, Zar 1984: 274). Both measures may be of interest to wetland managers. For example, the 95% CI of the mean would be most relevant to a manager wishing to predict the average seed production from a series of wetland units, given estimates of the SPI from those units. Conversely, the 95% PI of the sample would be more relevant to a manager wishing to predict seed production for a single wetland unit given an estimate of the SPI for that unit. In our sample, SPI scores ranged from 12–68; prediction beyond these ranges is not possible. Values of SPI <12 indicate extremely low seed production, whereas SPI scores >68 indicate extremely high seed production in Central Valley wetlands.

Evaluation of repeatability

During CWHP site visits in 2001, 2 observers independently classified wetland plant production using our method. Observers did not communicate during the scoring process. They estimated SPI scores for each of 183 wetland units located throughout the Central Valley. We used SPI scores to calculate total predicted moist-soil seed production (kg/ha) using the regression model described above. Units with a SPI value <12 were assigned a seed production value of 0 kg/ha (no units had a SPI >68). We calculated the repeatability (r) of these estimates using the intraclass correlation coefficient (Zar 1984: 323–325):

$$r = \frac{\text{group MS} - \text{error MS}}{\text{group MS} + \text{error MS}},$$

where groups (k) correspond to the 183 wetlands, with each group containing 2 observations (n=2). We tested the statistical hypothesis that r differed significantly from 0 using:

$$F = \frac{\text{group MS}}{\text{error MS}}$$

with groups DF =182 and error DF = 183 (Zar 1984:324).

Results

The seed production index (SPI) was related to estimates of total seed mass determined by core sampling (Figure 1; $F_{1,12}=15.09$, $P=0.0025$; $R^2_{adj}=0.54$). Two units appeared to be outliers (open circles in Figure 1). These units were on the same duck club on which disking occurred after visual estimates of SPI were completed but prior to core sampling; hence, a high plant AREA score was assigned when, in fact, much of the wetland area was bare dirt following disking when the core samples were taken. Accordingly, AREA scores were biased high, leading in turn to an upward bias in estimates of seed production based on SPI. Outlier analysis indicated that both samples had a high influence on the regression analysis (studentized residuals: –2.09 and –1.48; Cook's D influence: 0.47 and 0.22 respectively). Given these concerns, we repeated the analysis after removing these values from the model. The relationship between the SPI and seed production estimated by core sampling remained (Figure 1; $F_{1,10}=73.0$, $P<0.0001$). For the 11 wetland units sampled intensively, 89% of the variation in seed yield was accounted for by the regression on the SPI (Figure 1).

We correlated estimates of moist-soil seed pro-

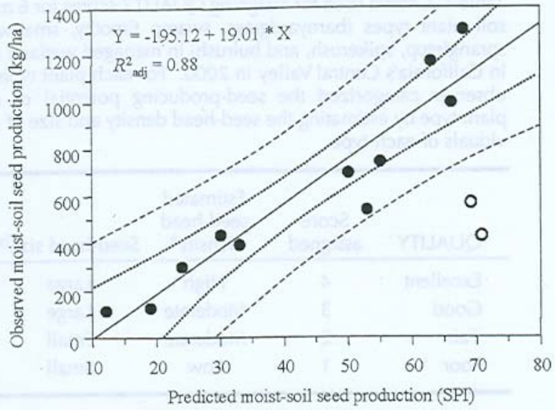

Figure 1. The relationship of observed moist-soil seed production and estimated seed production (SPI) in managed wetland units in California's Central Valley in 2000. For each wetland unit, a TOTAL score was calculated by multiplying a visual estimate of area coverage (AREA) by an estimate of seed-producing potential (QUALITY) for each of 6 common moist-soil plant types (barnyardgrass, swamp timothy, smartweed, sprangletop, spikerush, and bulrush). TOTAL scores for the 6 plant types were summed to provide a single index of the total seed production within each wetland unit (SPI). Solid line fitted by simple linear regression; 95% confidence intervals of the mean shown by the inner dotted lines; 95% prediction intervals of the sample shown by outer dashed lines. Two sites (open circles) were disked after the seed production index (SPI) was measured but before core samples were collected; these sites were excluded from the final regression model.

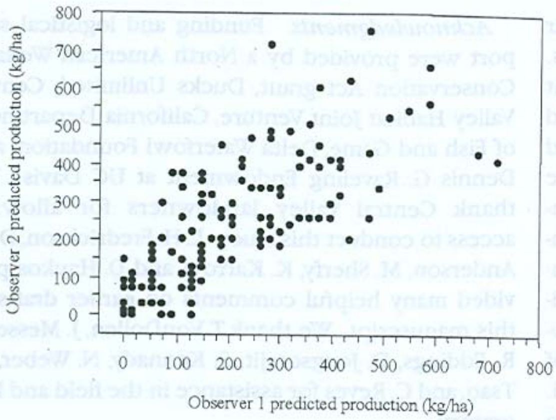

Figure 2. Comparison of the predicted moist-soil seed production (kg/ha) by 2 independent observers for 183 wetland units in the Central Valley of California in 2001. Each observer estimated the seed production index (SPI) for each wetland unit; then these values were used in the regression model of seed production based on core sampling to predict seed production (kg/ha) for each wetland unit.

duction by 2 observers using our method for a large number of wetland units in the Central Valley ($F_{182,183}$=8.61, P<0.0001; Figure 2). The intraclass correlation coefficient (Zar 1984:323)), a measure of repeatability (Lessells and Boag 1987), was 0.792 (95% CI: 0.731–0.840).

Discussion

We found that a simple ocular estimate of 2 easily measured variables can provide a reliable estimate of moist-soil seed production in Central Valley wetlands. The ability of our model to explain variation in seed production likely was due to the simplicity of the index and ease with which AREA and QUALITY scores can be assigned. 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, but we used relatively broad categories to minimize the effect of these errors. Assignment of QUALITY scores can be subjective, particularly for individuals unfamiliar with wetland plants. However, 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 among observers regarding proper categorization prior to the scoring of wetlands. We also recommend that representative plants of each seedhead category (Table 1) per plant type be collected for training and used to standardize classifications among observers. The amount of time required to gain the necessary level of familiarity with wetland plants is small. Indeed, brief training sessions (1–2 days) by personnel familiar with regional moist-soil plants would facilitate use of this technique by a wide array of interested persons with differing levels of experience.

A criticism of this method might be that ocular descriptions of plant characteristics are too subjective to provide reliable or consistent information. However, we found a high level of repeatability, as measured by the intraclass correlation coefficient between 2 observers who applied this technique to a large number of wetlands during CWHP assessment site visits. Application of this method was straightforward, and estimates of the SPI required <15 minutes for most wetlands. Further efforts to evaluate the repeatability of this method, using additional observers and additional wetland types, would be desirable. Nonetheless, our initial evaluation for over 180 wetland units demonstrated the potential of this technique to provide a consistent index of wetland seed production.

Estimates of the precision of this index should, however, be interpreted cautiously. Despite the high repeatability for the 2 observers, predictions of seed production for some individual wetland units differed considerably (i.e., by as much as 200–400 kg/ha). Moreover, the categorical nature of the SPI index (based on ordinal scores for QUALITY and AREA) may mask underlying variation among wetland units. For example, a wetland with AREA score = 1 and QUALITY score = 4 would yield the same TOTAL score for a given plant species as a wetland with AREA and QUALITY scores = 2, although the structure of those habitats would not be similar. Indeed, of the 20 possible values for each plant species (5 AREA scores × 4 QUALITY scores), only 13 are unique, given that several can be generated with more than one combination of AREA and QUALITY scores. Hence, variation among wetlands in the composition of the plant community will not be fully captured by our method. However, our goal was to provide an overall index of seed production and our working hypothesis was that sites with similar overall SPI scores, regardless of how generated, will yield similar levels of total moist-soil seed production. Additional tests of this hypothesis are needed.

We encourage researchers to develop similar models for key moist-soil plants in other regions. Model development does require an independent measure of seed production using an established method, such as core sampling or clipping seed heads. We used core sampling in this study because we required a technique with which we could continue to assess moist-soil seed availability throughout the winter after flood-up. However, core sampling is time consuming and may introduce additional variation into models to predict seed production, depending on the plant type and timing of collection relative to when seeds are dropped. Other methods, such as clipping seed heads within randomly located plots, may require less time investment and provide an accurate estimate of seed production in situations where sampling can be completed before inundation. A new technique in which seeds are removed from the wetland substrate using a vacuum (Penny 2003) could provide an efficient alternative.

Management implications

Recording wetland plant characteristics is a simple and quick technique to predict seed yield of moist-soil plants. Our method provides an alternative to available methods that require measurement of multiple phytomorphological variables (Laubhan and Fredrickson 1992, Sherfy and Kirkpatrick 1999, Gray et al. 1999*b*) or those based on a single inflorescence characteristic (Gray et al. 1999*a*). The amount of time necessary to implement our technique is small, potentially allowing wetland managers to conduct assessments as a part of their normal daily activities.

The simplicity of our method could facilitate the collection of moist-soil seed production data where none currently are being collected. 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). Estimates of moist-soil seed production also would be useful to Joint Venture partners of the North American Waterfowl Management Plan (NAWMP) to calculate available duck-use days (Reinecke et al. 1989) on a yearly basis and track temporal changes in wetland food abundance, allowing managers to better plan for the habitat needs of wintering waterfowl.

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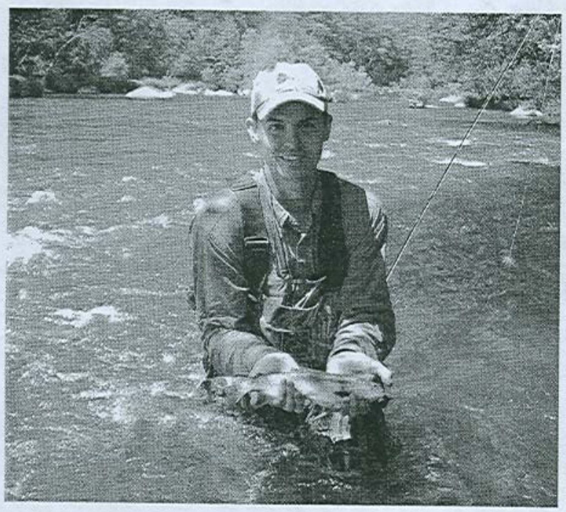

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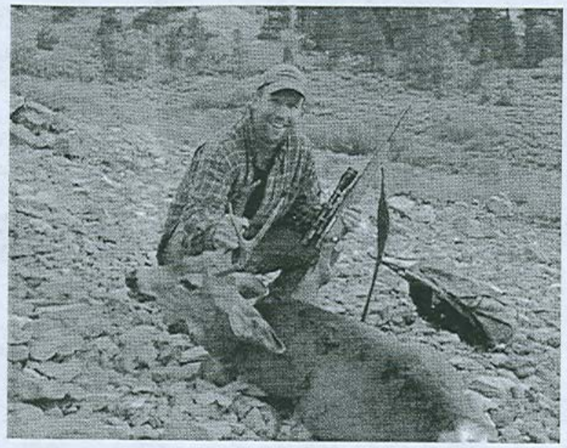

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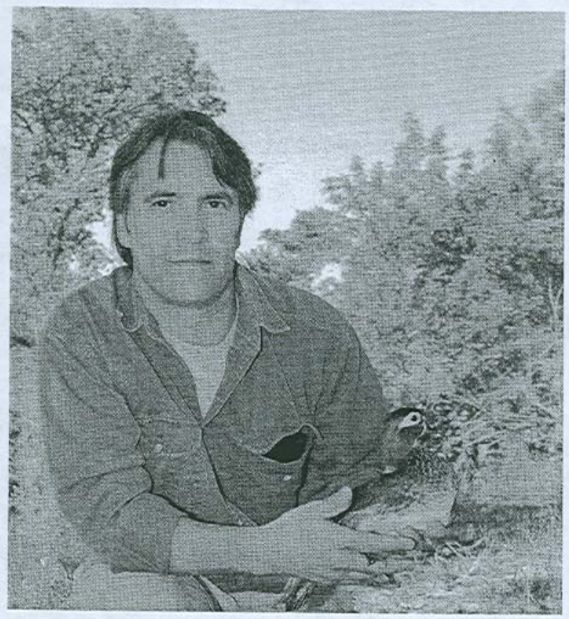

the evaluation and monitoring coordinator for the Central Valley Habitat Joint Venture and is currently an assistant professor of zoology at Southern Illinois University, Carbondale. Mike received a B.S. in zoology from SIUC and his M.S. and Ph.D. from the University of Alaska Fairbanks in wildlife biology. His research interests include the response of individual vital rates and populations of waterfowl to nutrient availability and other environmental factors. ***Matthew J. (Matt) Gray*** is an assistant professor of wetland ecology at the University of Tennessee-Knoxville. He has conducted research on moist-soil wetlands in Mississippi, Puerto Rico, Texas, and Tennessee. Dr. Gray conducted previous studies on predicting seed yield of moist-soil plants using efficient field assessment techniques.

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