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Model parameters for representative wetland plant functional groups

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Abstract. Wetlands provide a wide variety of ecosystem services including water quality remediation, biodiversity refugia, groundwater recharge, and floodwater storage. Realistic estimation of ecosystem service benefits associated with wetlands requires reasonable simulation of the hydrology of each site and realistic simulation of the upland and wetland plant growth cycles. Objectives of this study were to quantify leaf area index (LAI), light extinction coefficient (*k*), and plant nitrogen (N), phosphorus (P), and potassium (K) concentrations in natural stands of representative plant species for some major plant functional groups in the United States. Functional groups in this study were based on these parameters and plant growth types to enable process-based modeling. We collected data at four locations representing some of the main wetland regions of the United States. At each site, we collected on-the-ground measurements of fraction of light intercepted, LAI, and dry matter within the 2013–2015 growing seasons. Maximum LAI and *k* variables showed noticeable variations among sites and years, while overall averages and functional group averages give useful estimates for multisite simulation modeling. Variation within each species gives an indication of what can be expected in such natural ecosystems. For P and K, the concentrations from highest to lowest were spikerush (*Eleocharis macrostachya*), reed canary grass (*Phalaris arundinacea*), smartweed (*Polygonum* spp.), cattail (*Typha* spp.), and hardstem bulrush (*Schoenoplectus acutus*). Spikerush had the highest N concentration, followed by smartweed, bulrush, reed canary grass, and then cattail. These parameters will be useful for the actual wetland species measured and for the wetland plant functional groups they represent. These parameters and the associated process-based models offer promise as valuable tools for evaluating environmental benefits of wetlands and for evaluating impacts of various agronomic practices in adjacent areas as they affect wetlands.

Key words: functional groups; leaf area; native plants; nutrients; plant parameters; simulation modeling; wetlands.

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Introduction

Wetlands provide a wide variety of ecosystem services, including water quality remediation, biodiversity refugia, groundwater recharge, and floodwater storage (Smith et al. 2015). Wetlands also benefit agricultural landscapes providing wildlife corridors, migratory bird habitat, and reduction in soil erosion via trapping soil in runoff. Sediment trapping in excess, however, can be detrimental to the wetland itself, eventually destroying the wetland's functionality and associated environmental services (Smith et al. 2015). Realistic estimation of ecosystem service benefits associated with wetlands requires reasonable simulation of the hydrology of each site and realistic simulation of the upland and wetland plant growth cycles. Regional assessments of wetland impacts with process-based models such as Soil and Water Assessment Tool (SWAT; Arnold et al. 1998, Arnold and Fohrer 2005), Agricultural Policy/Environmental eXtender (APEX; Williams et al. 2000), or Agricultural Land Management Alternatives with Numerical Assessment Criteria (ALMANAC; Kiniry et al. 1992) require realistic estimates of plant parameters for the primary wetland plant functional groups. Research efforts associated with the wetland component of the Conservation Effects Assessment Project (CEAP-Wetlands) are designed to evaluate impacts of wetland preservation and wetland restoration in an agricultural landscape context (Smith et al. 2015). Wetland plants transpire water, take up nutrients, redistribute solutes, and provide wildlife food and habitat. Plant cover, water use by plants, and nutrient cycling by plants represent major aspects of wetlands that vary within each season and across years. As such, realistic simulation of plant growth and development is necessary for effective simulation evaluations.

The concept of plant functional groups has been used for a variety of applications and with a diversity of systems for grouping. Functional groups have been used to characterize responses to disturbance (Noble and Slatyer 1980, Nobel and Gitay 1996, Lavorel et al. 1997, 1999, Cousins et al. 2003, Boer and Stafford Smith 2003), and plant communities and productivity (Hooper and Dukes 2004, Domingues et al. 2007, Gitay and Noble 1997). These groups have been used to assess resistance to plant invasion into communities (Pokorny et al. 2005, Byun et al. 2013). Functional groups have also been used for managing rare plants (Franks et al. 2009) and for looking at drivers of soil biota (Eisenhauer et al. 2011).

There are a number of contexts in which it might be useful to simulate functional groups or communities rather than individual species. For example, large-scale regional assessments, such as those predicting plant community response to climate change or to conservation practices (like CEAP-Wetlands), may benefit from a coarser, functional group approach of plant community rather than a finer-scale individual species simulation approach. Work with process-based models continues to explore the potential to identify, parameterize, and simulate trait-based functional groups with process-based plant growth models. It is intended that this concept be expanded toward development of a workable plant functional group system that will inform which species or groups require better parameter development so that complex communities can be simulated by process-based models at a coarse scale.

Essential plant parameters used by the models listed include fraction of intercepted photosynthetically active radiation (FIPAR), maximum leaf area index (Max LAI), light extinction coefficient of Beer's law (k), and plant nutrient concentrations. Such values are valuable in applying Beer's law with measured FIPAR as a nondestructive method of calculating LAI. Values for FIPAR could be measured on the ground with linear photosynthetically active radiation (PAR) sensors (as in this study) or remotely with cameras estimating fraction of plant cover as a surrogate for FIPAR. The models require more parameters than those listed; however, these are crucial to model plant growth, while the others are often readily found in the literature.

Development of wetland plant parameters for process-based simulation models such as APEX and ALMANAC is a relatively new activity. Most plant parameter derivation research has been done for upland species. Process-based models, such as ALMANAC, are capable of realistically simulating production potentials of various and diverse species, including the competitive interactions between multiple species. For example, the ability of ALMANAC to realistically simulate the old world bluestem group (*Bothriochloa ischaemum* (L.) Keng) and buffelgrass (*Pennisetum* *ciliare* (L.) Link; Kiniry et al. 2013) suggests that it may be possible to apply ALMANAC to simulate plant functional groups. This possibility is bolstered by recent successes with ALMANAC simulating plant parameters developed for plant functional groups of grasses and forbs in the western United States (Kiniry et al. 2014).

It can be inefficient and impractical to simulate every plant species in an ecosystem. For more efficient evaluations, the primary wetland plant species within a region can be characterized into plant functional groups for modeling purposes. Such wetland plant groups can differ greatly even within a region if we consider restored wetlands, native wetlands, and prior converted croplands (Yepsen et al. 2014). Measurements of a representative species within each group provide estimates for the needed wetland plant functional group growth parameters. Errors in applying such plant group parameters can be evaluated by comparing model simulation outputs to those using parameters for individual plant species contained in the group. The parameters developed will be used for the actual species measured and for the plant functional groups they represent. "Functional groups" in this context is an operational term; our groups were based on similarities in plant type and in plant parameter values. Plant types included sedges and rushes, other forbs, and grasses. Parameter values used for grouping included FIPAR, Max LAI, and light extinction coefficient of Beer's law (k).

There are a diversity of wetlands in the United States where such process-based modeling will be beneficial: the mid-Atlantic Coastal Plain, the northern Prairie Pothole Region, and the Playa Region in the High Plains (Smith et al. 2015). The objective of this project was to develop plant parameters for representative species from some of the primary plant functional groups in these regions. Specific objectives of this study were to quantify LAI, k, and plant nitrogen and phosphorus concentrations in natural stands of representative plant species for some major plant functional groups in the above-mentioned regions of the United States (U.S.). Although the plant parameters were developed specifically for the ALMANAC model as part of the CEAP-Wetlands component, the resulting knowledge and parameters can also be readily applied in SWAT, APEX, and similar process-based models. The model outputs of these simulations could help assess ecosystem impacts and services associated with shifts in both species composition and management practices. For example, a process-based model could be implemented to help guide site monitoring and adaptive management approaches. In this way, it could be a valuable tool for conservation practice planning (Euliss et al. 2010).

Materials and Methods

Site-specific descriptions and management

We collected data for this effort at four locations (Fig. 1). For this study, more than one wetland was sampled close to the location listed. Therefore, the names primarily used are of the wetland ecosystem type instead of the location name. The term playas is used when referencing the data gathered near Lubbock, Texas. Central Texas refers to data gathered from the Temple, Texas wetlands. The label potholes refers to the wetlands near Jamestown, North Dakota. We refer to the wetlands in the mid-Atlantic region as Delmarva, as both wetlands were located on the Delmarva Peninsula (Delaware, Maryland, Virginia). Each location's soil type (NRCS), nearest weather station (NOAA), and the weather station's latitude and longitude are listed in Table 1. Table 2 contains the minimum and maximum temperatures for the sampling years at each site, along with the average total annual rainfall, and the total rainfall for the sampling years.

We sampled six playas near the Lubbock, Texas location. These playas received sufficient rain during the sampling year (2013, 2014) to have standing water and had some of the target species growing. We were unable to find all target species during all visits due to timing, drought, and flooding. The playas experienced a multi-year drought preceding this study which continued into 2013, while 2014 had 20% above average annual rainfall (Table 2). In 2015, this area received 748 mm of rain, 57% above average rainfall and the sixth highest on record. We were unable to sample playas in 2015 due to flooding. Once the water receded, it was too late in the season for targeted plants to germinate. Due to these weather conditions, sampling years

Fig. 1. Locations of field sites where plant parameters were measured.

at the playas were 2013 and 2014. All other locations were sampled in 2014 and 2015.

We sampled a depressional wetland and a creek near the Grassland, Soil and Water Research Laboratory at the Temple, Texas location. In 2015, this area received 60% above average rainfall (Table 2).

We sampled four potholes in the Cottonwood Lake study area near Jamestown, North Dakota. This study area has been used for decades by the U.S. Geological Survey (USGS) and the U.S. Department of Agriculture (USDA) to study prairie pothole wetlands (Winter et al. 2003).

Two wetlands were sampled in the Delmarva location, one in Queen Anne's County, Maryland, and the other in Kent County, Delaware. These two wetlands were further apart than the wetlands within the other three locations. Therefore, they are sometimes referred to separately as either Maryland or Delaware. Baltimore-Washington International Airport is the nearest weather station with the most complete data (Table 1). Annual rainfall values in 2014 and in 2015 were more than 20% above average (Table 2).

All samples were collected from wetlands with actively growing target species. None of the wetland sites were planted, fertilized, or intensively managed. Hydrology was not altered or managed during the study. Due to these conditions, not all species could be harvested every year of the study.

Table 1. Experimental locations, nearest weather stations, and the wetland soil type.

Location	Weather station, latitude, longitude	Soil type for vegetation
Lubbock, Texas (Playas)	Lubbock Airport, 33.6656, −101.8231	Randall clay, 0–1% slopes
Temple, Texas (Central Texas)	Temple Texas, 31.05, −97.34	Tinn clay, 0–1% slopes, frequently flooded
Jamestown, North Dakota (Potholes)	Jamestown Airport, 46.9258, −98.6691	Parnell silty clay loam, 0–1% slopes
Maryland/Delaware (Delmarva)	Baltimore Airport, 39.166, −76.683	Corsica mucky loam, 0–2% slopes

Table 2. Weather from each location's nearest weather station.

Location	Average minimum temperature		Average maximum temperature		Annual rainfall	Total rainfall	
	1st year	2nd year	1st year	2nd year		1st year	2nd year
Playas	8.2	8.3	24.0	23.7	474	320	573
Central Texas	13.3	14.5	24.9	25.2	891	845	1428
Potholes	−1.3	−0.3	10.0	11.4	472	535	569
Delmarva	6.9	7.9	17.7	19.1	1069	1336	1299

Notes: Average minimum and maximum temperatures in °C are listed for the first and second sample years at each location. Average total annual rainfall in mm is included along with the total rainfall during the first and second sample years.

Specific plant species measured varied among sites and among years (Table 3). While a wide range of plants were measured at the different locations, more facultative and facultative upland plants (Lichvar et al. 2014) were sampled in the playas than at other sites. Playas dry more frequently than the other wetlands in this study (Bolen et al. 1989). Therefore, more upland species encroach on playa wetlands than on other types of wetlands studied here. For simulation purposes, ALMANAC parameters have been developed for the majority of upland playa species.

Field measurements

At each site, we collected on-the-ground measurements of FIPAR (nondestructive), LAI (destructive), and dry matter (destructive) within the 2013–2015 growing seasons. All measurements were taken from well-established stands of the target species. Three replicate samples/measurements were taken for each species on each visit. The exception to this was black willow (*Salix nigra*) where eight trees were sampled once due to the destructive nature of harvests. Each target species at each site had its own consistent sampling area size for each replicate, but this varied between sites based on the yearly availability of the target species and to ensure we would not overharvest a stand. Sampling area at the playas was 0.25×0.8 m in 2013 and 0.25×0.3 m in 2014 for each replicate. In central Texas, each replicate of hardstem bulrush (*Schoenoplectus acutus*) was sampled within 0.5×0.8 m. Duck potato (*Sagittaria longiloba*) replicates were each sampled in

Table 3. Plant species measured.

Plant species	Common name	Wetland indicator status	Location
Ambrosia grayi	Bur ragweed	FAC (Great Plains)	Playas
Chenopodium leptophyllum	Narrowleaf goosefoot	FACU (Great Plains)	Playas
Eleocharis macrostachya	Spikerush	OBL (Great Plains)	Playas
Malvella leprosa	Cheeseweed	FAC (Great Plains)	Playas
Polygonum spp.	Smartweed	FACW/OBL (Great Plains)	Playas
Sagittaria longiloba	Arrowhead/Duck potato	OBL (Great Plains)	Central Texas
Salix nigra	Black willow	FACW (Great Plains)	Central Texas
Schoenoplectus acutus	Hardstem bulrush	OBL (Great Plains)	Central Texas
Phalaris arundinacea	Reed canarygrass	FACW (Great Plains)	Potholes
Polygonum amphibium	Water smartweed	OBL (Great Plains)	Potholes
Schoenoplectus acutus	Hardstem bulrush	OBL (Great Plains)	Potholes
Typha angustifolia	Narrowleaf cattail	OBL (Great Plains)	Potholes
Carex atherodes	Slough sedge	OBL (Great Plains)	Potholes
Scolochloa festucacea	Sprangletop	OBL (Great Plains)	Potholes
Cyperus pseudovegetus	Marsh flatsedge	FACW (Atlantic and Gulf Coastal Plain)	Delmarva (Delaware)
Juncus tenuis	Poverty rush	FAC (Atlantic and Gulf Coastal Plain)	Delmarva
Polygonum pensylvanicum	Pink smartweed	FACW (Atlantic and Gulf Coastal Plain)	Delmarva
Typha latifolia	Broadleaf cattail	OBL (Atlantic and Gulf Coastal Plain)	Delmarva (Maryland)

Note: Wetland indicator status follows the National Wetland Plant List 2014 (Lichvar et al. 2014) where OBL is obligate wetland, FACW is facultative wetland, FAC is facultative, and FACU is facultative upland.

0.5×0.5 m area in 2014 and 0.43×0.8 m area in 2015. The black willow sampling area varied based on the size of the tree's overhanging canopy. This ranged from 0.6×0.8 m to 2.4×2.4 m. In the potholes, each replicate's sampling area was 0.4×0.8 m in 2014 and 0.8×0.8 m in 2015. Sampling area at Delmarva was 0.5×0.5 m for both years for each replicate. Differences in the sampling areas were accounted for in our calculations. Non-targeted species were removed from within the sampling area before measurements were taken. Fraction of intercepted photosynthetically active radiation values were collected with an AccuPAR LP-80 ceptometer and external sensor (Decagon Devices, Pullman, Washington, USA) by synchronous measurements of PAR above and below the plant canopy. Plants were harvested, weighed fresh, and a subsample was weighed. Leaf area was measured on the subsample with an LI-3100 Area Meter (LI-COR Biosciences, Lincoln, Nebraska, USA).

FIPAR was calculated as:

$$\text{FIPAR} = 1 - (\text{PAR below plant canopy}/\text{PAR above plant canopy})$$

LAI was calculated as:

$$\text{LAI} = (\text{total fresh wt./subsample fresh wt.}) \times \text{leaf area of subsample}\,(\text{cm}^2) / (\text{ground area sampled})$$

k was calculated as:

$$k = (\text{logn}(1 - \text{FIPAR}))/\text{LAI}.$$

After leaf area measurement, the subsample was dried in a forced air oven at 65°C and weighed. After grinding the subsample, nutrient analysis was performed for nitrogen using a Leco FP-528 nitrogen/protein analyzer (LECO, St. Joseph, Michigan, USA) with Dumas combustion. Phosphorus and potassium concentration was determined using microwave-assisted acid digestion that was analyzed through a Thermo IRIS Advantage HX analyzer (Thermo Fisher Scientific, Waltham, Massachusetts, USA).

Results

Field measurements

Maximum LAI and k variables show noticeable variation among sites and years (Table 4), while overall averages (Table 5) and functional group averages (Tables 6 and 7) give useful estimates for multisite simulation modeling. Variation within each species gives an indication of what can be expected in such natural ecosystems. Maximum LAI (Max LAI) and light extinction coefficient for Beer's law (k) are two of the main driving parameters defining potential leaf canopy development, potential dry matter production, and potential plant water use. Each species' parameters by site for each year are presented in Appendix S1.

Multisite species groupings

Smartweed (*Polygonum* spp.) was sampled at four sites and had a mean maximum LAI of 1.20 and a mean extinction coefficient of −0.95 (Table 4). Measurements were taken at Delmarva over two years on pink smartweed (*Polygonum pensylvanicum*). Average FIPAR at the Maryland site was 0.47, and Max LAI and average k were 1.38 and −0.92, respectively. Delaware had Max LAI and k values twice as high in 2014 than in 2015. Average FIPAR at the Delaware site was 0.35, and Max LAI and average k were 1.55 and −0.77. Delmarva smartweed had total average FIPAR of 0.41, Max LAI of 1.46, and k of −0.85. Measurements were taken on water smartweed (*Polygonum amphibium*) at the potholes in 2014. Average FIPAR at the potholes was 0.77, and Max LAI and k were 2.14 and −1.47, respectively. Smartweed (*Polygonum* spp.) was measured at the playas over two years. Playas had about four times higher smartweed values in 2013 compared to 2014, but on average, the FIPAR was 0.35, Max LAI was 0.53, and k was −0.92.

Cattail (*Typha* spp.) was measured over two years at two locations, and had a mean maximum LAI of 1.79 and a mean extinction coefficient of −0.83 (Table 4). Narrowleaf cattail (*Typha angustifolia*) was measured at the potholes and broadleaf cattail (*Typha latifolia*) at Delmarva: Maryland. Averaged values showed high variability among years. For example, FIPAR ranged from 0.30 to 0.75. However, the averages for both sites were very similar; FIPARs were 0.54 in Delmarva and 0.53 in the potholes.

Bulrush, sampled in the potholes and the central Texas wetland, had a mean maximum LAI of 0.81 and a mean extinction coefficient of −0.79 (Table 4). The potholes had higher FIPAR and

Table 4. Multisite species seasonal FIPAR, Max LAI, and k values.

Species	Reps	Dates	FIPAR	Max LAI	k
Smartweed					
Delmarva 2014 Maryland	3	5	0.47	1.47	−0.99
Delmarva 2014 Delaware	3	5	0.32	2.11	−0.59
Delmarva 2015 Maryland	3	6	0.46	1.28	−0.86
Delmarva 2015 Delaware	3	5	0.37	0.99	−0.95
Potholes 2014	3	3	0.77	2.14	−1.47
Playas 2013	3	1	0.55	0.66	−1.47
Playas 2013	3	1	0.41	0.54	−1.00
Playas 2014	3	1	0.10	0.39	−0.29
Average			0.43	1.20	−0.95
Standard deviation			0.19	0.68	0.40
Cattail					
Delmarva 2014 Maryland	3	5	0.62	1.51	−0.88
Delmarva 2015 Maryland	3	7	0.47	1.68	−0.45
Potholes 2014	3	3	0.75	3.53	−0.80
Potholes 2015	3	4	0.30	0.43	−1.20
Average			0.54	1.79	−0.83
Standard deviation			0.19	1.29	0.31
Hardstem bulrush					
Potholes 2014	3	3	0.41	1.26	−0.59
Potholes 2015	3	5	0.30	0.86	−0.79
Central Texas	1	1	0.25	0.30	−0.98
Average			0.32	0.81	−0.79
Standard deviation			0.08	0.48	0.20
Poverty Rush					
Delmarva 2014 Maryland	3	5	0.54	2.53	−0.66
Delmarva 2014 Delaware	3	5	0.36	2.12	−0.70
Delmarva 2015 Maryland	3	7	0.42	5.30	−1.07
Delmarva 2015 Delaware	3	5	0.56	4.64	−0.34
Average			0.47	3.65	−0.69
Standard deviation			0.10	1.56	0.30

Notes: Smartweed, cattail, hardstem bulrush, and poverty rush results by site and year. Reps are the number or replicates harvested at each event. Dates are the number of sampling events that occurred. FIPAR is the fraction of intercepted photosynthetically active radiation. Max LAI is the mean across data sets for maximum leaf area index during each season. "k" is the extinction coefficient for Beer's law. The averages and standard deviations were computed using the total average of the entire species (smartweed data $n = 8$).

Max LAI than the central Texas wetland. Mean FIPAR was 0.35 for potholes vs. 0.25 for central Texas wetland, and Max LAI values were 1.06 vs. 0.30, respectively.

Poverty rush (*Juncus tenuis*) was sampled at both Delmarva sites, and had a mean maximum LAI of 3.65 and a mean extinction coefficient of −0.69 (Table 4). Fraction of intercepted photosynthetically active radiation ranged from 0.36 to 0.56. Max LAI was higher in 2015 than in 2014. The Max LAI values ranged from 2.12 to 5.30. Values for k were also variable, ranging from −0.34 to −1.07.

Species averages

The averages for the four species measured at multiple sites showed realistic values for Max LAI and k (Table 5). Cattail had the highest FIPAR, followed by poverty rush, smartweed, and then bulrush. Max LAI was highest in poverty rush, followed by cattail, smartweed, and bulrush.

Several other species were measured in addition to the four highlighted above. Table 5 shows FIPAR, Max LAI, k, number of sites that measurements were taken from, the sites sampled, and the number of years sampled at each site. Narrowleaf

Table 5. Wetland species parameters listed alphabetically by common name including the multisite species.

Wetland species	FIPAR	Max LAI	k	Sites	Location	Years
Arrowhead/Duck potato	0.32	0.66	−0.60	1	Central Texas	2
Black willow	0.22	0.99	−0.34	1	Central Texas	1
Bur ragweed	0.31	0.54	−0.63	1	Playas	2
Cattail	0.54	1.79	−0.83	2	PH, DM: MD	2,2
Cheeseweed	0.29	0.80	−0.48	1	Playas	2
Hardstem bulrush	0.32	0.81	−0.79	2	PH, Central Texas	2,1
Marsh flatsedge	0.30	0.96	−0.79	1	DM: DE	2
Narrowleaf goosefoot	0.70	1.88	−0.66	1	Playas	1
Smartweed	0.43	1.20	−0.95	4	PH, Playas, DM: MD, DE	1,2,2,2
Poverty rush	0.47	3.65	−0.69	2	DM: MD, DE	2,2
Reed canarygrass	0.65	2.40	−0.75	1	PH	2
Slough sedge	0.67	2.86	−0.80	1	PH	2
Spikerush	0.19	0.30	−0.34	1	Playas	2
Sprangletop	0.54	0.98	−1.51	1	PH	2

Notes: Sites are the number of locations sampled to derive the parameters. PH stands for Potholes, DM stands for Delmarva, with MD for Maryland, and DE for Delaware. Years are the number of years sampled per site. FIPAR, fraction of intercepted photosynthetically active radiation; LAI, leaf area index; k, extinction coefficient for Beer's law.

goosefoot (*Chenopodium leptophyllum*) had the highest FIPAR with 0.70 followed by slough sedge (*Carex atherodes*) with 0.67. Spikerush (*Eleocharis macrostachya*) had the lowest FIPAR with 0.19. Poverty rush had the highest Max LAI with 3.65 followed by slough sedge with 2.86. Spikerush had the lowest Max LAI with 0.30.

Table 6. Two functional groups for wetland plants determined by Max LAI.

Wetland plants	FIPAR	Max LAI	k
Low LAI			
Spikerush	0.19	0.30	−0.34
Bur ragweed	0.31	0.54	−0.63
Arrowhead/Duck potato	0.32	0.66	−0.60
Cheeseweed	0.29	0.80	−0.48
Hardstem bulrush	0.32	0.81	−0.79
Marsh flatsedge	0.30	0.96	−0.79
Average	0.29	0.68	−0.60
Standard deviation	0.05	0.23	0.18
High LAI			
Sprangletop	0.54	0.98	−1.51
Smartweed	0.43	1.20	−0.95
Cattail	0.54	1.79	−0.83
Narrowleaf goosefoot	0.70	1.88	−0.66
Reed canarygrass	0.65	2.40	−0.75
Slough sedge	0.67	2.86	−0.80
Poverty rush	0.47	3.65	−0.69
Average	0.57	2.11	−0.88
Standard deviation	0.10	0.94	0.29

Note: FIPAR, fraction of intercepted photosynthetically active radiation; LAI, leaf area index; k, extinction coefficient for Beer's law.

Groupings into functional groups by Max LAI or plant type

Using the values from Table 5, plant species were placed into functional groups based on their Max LAI (Table 6) or their plant type (Table 7). Black willow was left out of functional grouping due to its woody form, longevity, and growth habitats being incongruous with the other species sampled. The functional groups in Table 6 were split based on LAI. The Low LAI group had average FIPAR, Max LAI, and average k of 0.29, 0.68, and -0.60, compared to 0.57, 2.11, and −0.88 in the High LAI group.

The functional groups in Table 7 were split based on plant type and can be read two ways, as having either three or four different groupings. Species were split into plant type groups of sedges and rushes, other forbs, and grasses to make three functional groups. The sedges and rushes group can be split again into Low and High LAI groups to make four functional groups. Spikerush was left out of plant type functional grouping because its measurements (mean Max LAI was 0.30) are outliers in the sedges and rushes group (mean Max LAI was 2.07). Low LAI sedges and rushes had average FIPAR, Max LAI, and average k of 0.31, 0.88, and −0.79. High LAI sedges and rushes had average FIPAR, Max LAI, and average k of 0.57, 3.25, and −0.75. All sedges and rushes grouped together had average FIPAR, Max LAI, and average k of 0.44, 2.07, and −0.77. The other forbs group had average FIPAR, Max

Table 7. Three or four functional groups for wetland plants determined by plant type.

Wetland species	FIPAR	Max LAI	k
Low LAI rushes and sedges			
Marsh flatsedge	0.30	0.96	−0.79
Hardstem bulrush	0.32	0.81	−0.79
Average	0.31	0.88	−0.79
Standard deviation	0.02	0.11	0.00
High LAI rushes and sedges			
Poverty rush	0.47	3.65	−0.69
Slough sedge	0.67	2.86	−0.80
Average	0.57	3.25	−0.75
Standard deviation	0.14	0.56	0.08
All rushes and sedges			
Average	0.44	2.07	−0.77
Standard deviation	0.17	1.41	0.05
Other forbs			
Bur ragweed	0.31	0.54	−0.63
Arrowhead/Duck potato	0.32	0.66	−0.60
Cheeseweed	0.29	0.80	−0.48
Smartweed	0.43	1.20	−0.95
Cattail	0.54	1.79	−0.83
Narrowleaf goosefoot	0.70	1.88	−0.66
Average	0.43	1.14	−0.69
Standard deviation	0.16	0.58	0.17
Grasses			
Sprangletop	0.54	0.98	−1.51
Reed canarygrass	0.65	2.40	−0.75
Average	0.60	1.69	−1.13
Standard deviation	0.08	1.00	0.54

Note: Spikerush is an outlier and thus withheld from the rushes and sedges group. FIPAR, fraction of intercepted photosynthetically active radiation; LAI, leaf area index; k, extinction coefficient for Beer's law.

LAI, and average k of 0.43, 1.14, and −0.69. The grasses group had average FIPAR, Max LAI, and average k of 0.60, 1.69, and −1.13.

Nutrient concentrations

Nutrients were processed from the 2014 growing season for select species: spikerush, reed canarygrass (*Phalaris arundinacea*), smartweed, cattail, and bulrush. Plant nutrient concentrations showed much variability among species, among locations, and even within species among locations (Table 8). For example, smartweed N concentration varied from 3.08 at the playas to 0.93 in Delaware. Hardstem bulrush and cattail similarly showed large variability between the sites where they were each measured. For P and K, the concentrations from highest to lowest were spikerush, reed canary grass, smartweed, cattail, and bulrush (Table 9). Spikerush had the highest N concentration, followed by smartweed, bulrush, reed canary grass, and then cattail. For Lubbock, 2014 was the first year with above average annual rainfall following a three-year drought, which included the driest year on record. Due to the influx of rain which released nutrients into the system, playas had the highest nutrient concentrations of any site. Nutrient concentrations in smartweed were highest in the playas and lowest in the Delmarva: Delaware. Playa smartweed nitrogen concentration was 1.5 times higher than potholes and 2.5 times higher than Delmarva. Cattail had 1.4 times higher

Table 8. 2014 plant nutrient concentration means by site.

Site	Species	Dates	N (%)	P (ppm)	K (ppm)
Playas	Spikerush	1	3.08	5077	31927
	Smartweed	1	3.70	3423	26160
Central Texas	Hardstem bulrush	1	1.35	1284	9308
Potholes	Reed canarygrass	3	1.47	2889	20660
	Smartweed	3	2.05	2663	11702
	Cattail	3	1.17	1888	17139
	Hardstem bulrush	3	2.02	1575	17026
Delmarva: Maryland	Smartweed	2	1.53	2933	16159
	Cattail	3	0.81	1448	14287
Delmarva: Delaware	Smartweed	5	0.93	2489	11513
Average	Smartweed Delmarva		1.23	2711	13836
Average	Smartweed		2.05	2877	16384
Average	Cattail		0.99	1668	15713
Average	Hardstem bulrush		1.69	1430	13167

Notes: Dates are the number of sample dates used to derive nutrient concentrations. N values are plant nitrogen concentrations, P is phosphorus, and K is potassium.

Table 9. 2014 plant nutrient concentrations averaged by species with "*n*" as number of locations.

Site	Species	*n*	N (%)	P (ppm)	K (ppm)
Playas	Spikerush	1	3.08	5077	31927
Potholes	Reed canarygrass	1	1.47	2889	20660
Potholes, Delmarva, Playas	Smartweed	4	2.05	2877	16384
Potholes, Delmarva: Maryland	Cattail	2	0.99	1668	15713
Potholes, Central Texas	Hardstem bulrush	2	1.69	1430	13167

Table 10. 2014 plant nutrient concentrations by LAI functional group.

Site	Group	*n*	N (%)	P (ppm)	K (ppm)
Playas, Potholes, Central Texas	Low LAI	2	2.38	3253	22547
Potholes, Delmarva	High LAI	3	1.50	2478	17586

Notes: This was determined based on species averages with "*n*" as the number of plant species. LAI, leaf area index.

nitrogen concentration in the potholes than in Delmarva. Bulrush in the potholes had 1.5 times more nutrients than bulrush in central Texas wetland.

When grouped by LAI functional groups (Table 10), the Low LAI group had higher nutrient concentrations for all three nutrients. This should be investigated in future studies, with repeated sample dates to determine how these values vary with growth stages.

The nutrient concentrations by plant type functional group (Table 11) showed that spikerush had the highest values for all three nutrients, while relative rankings varied among the three nutrients measured. With few species processed for nutrients, only smartweed and cattail were combined to create the other forbs group; the remaining species were each the sole member of their group. While these values provide a first estimate of appropriate values, future more extensive sampling should be done to determine how these concentrations for the functional groups also vary with growth stages.

These nutrient concentration values give additional detail to some of the previous values reported for herbaceous wetland plant groups sampled in the fall in the mid-Atlantic Coastal Plain, United States (McFarland et al. 2016). In that study, N concentrations and P concentrations were similar to those reported herein. The N concentrations (%) of wetland plant groups were 0.88 for natural wetlands, 1.16 for restored wetlands, and 1.82 for prior converted croplands. For P concentrations (ppm), these values were 790, 1770, and 2550, respectively. With a separate set of restored site wetlands measured in that study, N values were 1.25% and 2.13% and *P* values were 1950 and 2550 ppm. Values from McFarland et al. (2016) along with those shown in this study reveal how variable nutrient concentrations can be among a species, between species, within a wetland ecosystem type, and across regions.

Discussion

Wetlands are an important component of many landscapes, providing ecosystem services by improving wildlife habitat, sequestering carbon, storing floodwaters, and trapping eroding soil, anthropogenic chemicals, and nutrients

Table 11. 2014 plant nutrient concentrations by plant type functional group.

Site	Group	*n*	N (%)	P (ppm)	K (ppm)
Playas	Spikerush	1	3.08	5077	31927
Potholes, Central Texas	Low LAI rushes and sedges w/o spikerush	1	1.69	1430	13167
Potholes, Central Texas	All rushes and sedges w/o spikerush	1	1.69	1430	13167
Potholes, Delmarva, Playas	Other forbs	2	1.52	2272	16048
Potholes	Grasses	1	1.47	2889	20660

Notes: This was determined based on species averages with "*n*" as the number of species used for averaging. There were no High LAI rushes and sedges, or black willow measured. LAI, leaf area index.

(Brinson and Eckles 2011, Duffy and Kahara 2011, De Steven and Lowrance 2011, Faulkner et al. 2011, Fennessy and Craft 2011, Gleason et al. 2011). These services can be complementary, but some can be conflicting and may be unsustainable and detrimental to the wetland (Smith et al. 2011, 2015). As we strive to assess wetland benefits using simulation models, besides hydroperiods (Euliss and Mushet 1996), perhaps the most dynamic aspect the model needs to appropriately capture is the plant community (De Steven and Gramling 2013). Realistic simulations with process-based models require accurate plant parameters inputs to simulate the impacts of key indicator plant species and groups of species on the ecosystem services that wetlands provide. Accuracy in these parameters is vital for assuring that simulations reflect reality in the main processes simulated (e.g., water use, nutrient uptake, wildlife habitat, and wildlife vegetation for food), especially as these simulation models are used to explore potential impacts of a variety of conservation practice and policy changes related to wetland functionality.

The process-based modeling approach differs from some of the models previously used to assess ecosystem services of wetlands (Euliss et al. 2011, Wardrop et al. 2011). These previously applied models developed valuable systems of assessing and quantifying benefits of conservation practices relative to ecosystem services using inventory data. The proposed modeling approach described herein is aimed at simulating the actual processes involved in plant growth, hydrology, etc. Thus, once parameterized, such a model will ideally be transferable among regions without recalibration and without the need for extensive survey data. Furthermore, process-based models capable of adequately describing the interactions between wetlands and the agricultural landscape could be used by land managers and policy makers alike, in order to simulate potential outcomes of decisions around wetland development, conservation, or restoration.

As expected, the level of detail in such simulation models depends on the modeled scale (temporal and spatial) and the metric assessed. If the conservation goal is to reduce soil erosion impacts on local streams and rivers, the model will be relied upon to assess how a wetland captures soil and sediment moving through it; the physical structure of the wetland vegetation and the way the vegetation responds to siltation may be of interest. However, simulation of wetlands in the context of providing key wildlife habitat requires an understanding of species-specific demands on plants; to meet these needs, functional group plant parameters for representative plant species are required as model inputs. Likewise, assessment of current or potential nutrient recovery within a wetland requires knowledge of which plants are present, potential dry matter growth, tissue nutrient concentrations, and seasonal nutrient translocation dynamics.

The parameters described herein offer promise for simulating typical wetland plants using process-based models. Given the large variability in plants in various natural environments, the parameters offer an excellent first step in quantifying these plant parameters. These data are exactly what is needed to begin work modeling these wetlands. Functional groups are crucial for simulating a large and varied habitat. Future work should address the variability exhibited in these data and how stable they are across environments. These models will be useful for evaluating plant transpiration through the leaf area cover (LAI), for evaluating plant nutrient uptake through the simulated plant dry matter accumulation and N and P concentrations in the plant, and for evaluating wildlife habitat through plant cover simulation. In future, more detailed simulation of seed production of useful plants for wildlife foods is possible with detailed measurements of harvest index, similar to what has been done for crop plants (Kiniry and Bockholt 1998, Kiniry et al. 2001, 2005). This will potentially extend previous work on quantifying seed production of wetland plants using plant sampling and regression techniques (e.g., Laubhan and Fredrickson 1992, Sherfy and Kirkpatrick 1999, Naylor et al. 2005).

Effects of wetland plant cover on wildlife can be both positive and negative. If increased plant cover offers improved nesting conditions, then increased LAI of the preferred nesting vegetation will be important. However, the utility of a wetland as a resting point for migrating waterfowl may benefit from low plant cover, thus providing birds such as ducks a clear view of predators. Appropriate modeling of the landscape relationships between the wetland and other land uses and the timing of leaf area increase and decrease are crucial to appropriate assessment of wetland benefits. Process-based models need to be capable of simulating plant community types to evaluate such aspects.

An advantage of process-based simulation models is their ability to simulate grasses, trees, crops, and their interactions. Thus, such models can be used to not only simulate plants growing directly in a wetland, but also plants growing in surrounding upland areas or in intermittently flooded adjacent areas. Environmental impacts, both negative and positive, of various native and introduced plant systems near a wetland can be evaluated with a single model. Impacts include runoff, nutrient movement into and out of the wetland, and soil erosion by wind and water.

There are well-defined feedbacks between hydroperiods, plant communities, and wetland types. Ephemeral wetlands with sufficiently long dry periods can have plant communities dominated by obligate upland plants, even if only until the next flooding event. In contrast, long-hydroperiod natural wetlands typically have obligate wetland plants dominating their plant community. Likewise, wetlands constructed with the sole goal of nutrient recovery may be dominated by a single species, such as narrowleaf cattails. Once the cattails become a monoculture, the open water space is reduced along with the number of other species that can use the wetland. Each of these scenarios and wetland types can be simulated with process-based models, provided that appropriate parameters are available to realistically simulate the plant community.

Specific goals of future wetland projects will drive further efforts at refining process-based models and further quantification of required plant parameters. The plant parameter values described herein serve as an important starting point and will be useful for projects to simulate the water balance and the nutrient balances of wetland ecosystems along with many of the other processes described above.

Conclusion

The parameters described in this project are needed for simulating the actual wetland species measured and for simulating the wetland plant functional groups they represent, which allows these results to be applied outside of the immediate systems in which they were developed. These parameters and their associated process-based models offer promise as valuable tools for evaluating environmental benefits of wetlands and for evaluating impacts of various agronomic practices in adjacent areas as they affect the wetlands.

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Supporting Information

Additional Supporting Information may be found online at: http://onlinelibrary.wiley.com/doi/10.1002/ecs2.1958/full