Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

Restoration of Managed Marsh Units to Benefit California Black Rails and Other Marsh Birds: An Adaptive Management Approach

U.S. Department of the Interior
Bureau of Reclamation

June 2011

Lower Colorado River Multi-Species Conservation Program Steering Committee Members

Federal Participant Group

Bureau of Reclamation
U.S. Fish and Wildlife Service
National Park Service
Bureau of Land Management
Bureau of Indian Affairs
Western Area Power Administration

Arizona Participant Group

Arizona Department of Water Resources
Arizona Electric Power Cooperative, Inc.
Arizona Game and Fish Department
Arizona Power Authority
Central Arizona Water Conservation District
Cibola Valley Irrigation and Drainage District
City of Bullhead City
City of Lake Havasu City
City of Mesa
City of Somerton
City of Yuma
Electrical District No. 3, Pinal County, Arizona
Golden Shores Water Conservation District
Mohave County Water Authority
Mohave Valley Irrigation and Drainage District
Mohave Water Conservation District
North Gila Valley Irrigation and Drainage District
Town of Fredonia
Town of Thatcher
Town of Wickenburg
Salt River Project Agricultural Improvement and Power District
Unit "B" Irrigation and Drainage District
Wellton-Mohawk Irrigation and Drainage District
Yuma County Water Users' Association
Yuma Irrigation District
Yuma Mesa Irrigation and Drainage District

Other Interested Parties Participant Group

QuadState County Government Coalition
Desert Wildlife Unlimited

California Participant Group

California Department of Fish and Game
City of Needles
Coachella Valley Water District
Colorado River Board of California
Bard Water District
Imperial Irrigation District
Los Angeles Department of Water and Power
Palo Verde Irrigation District
San Diego County Water Authority
Southern California Edison Company
Southern California Public Power Authority
The Metropolitan Water District of Southern California

Nevada Participant Group

Colorado River Commission of Nevada
Nevada Department of Wildlife
Southern Nevada Water Authority
Colorado River Commission Power Users
Basic Water Company

Native American Participant Group

Hualapai Tribe
Colorado River Indian Tribes
Chemehuevi Indian Tribe

Conservation Participant Group

Ducks Unlimited
Lower Colorado River RC&D Area, Inc.
The Nature Conservancy

Lower Colorado River
Multi-Species Conservation Program

Restoration of Managed Marsh Units to Benefit California Black Rails and Other Marsh Birds: An Adaptive Management Approach

Prepared by:

Christopher P. Nadeau, Courtney J. Conway,
Meaghan A. Conway, and Mark Ogonowski

Lower Colorado River
Multi-Species Conservation Program
Bureau of Reclamation
Lower Colorado Region
Boulder City, Nevada
http://www.lcrmscp.gov

June 2011

TABLE OF CONTENTS

List of Tables

List of Figures

EXCECUTIVE SUMMARY

Proposed changes in points of water diversion in many reaches of the lower Colorado River are expected to reduce flow rates, change the range of daily water-level fluctuations, and cause changes in plant composition in backwater wetlands. California black rail and Yuma clapper rail (2 state and federally listed bird species) are thought to be sensitive to changes in water level and plant composition within wetlands. Hence, protection and restoration of existing habitat and the creation of new habitat is needed to maintain and recover populations of these rare birds in the lower Colorado River basin.

To ensure the success of efforts to maintain and restore wetlands at a time when water needs are increasing, our objectives were to: (1) evaluate the success of wetland plant restoration efforts in a newly created wetland (impoundment 18) at Imperial National Wildlife Refuge (INWR), (2) determine the vegetative preferences of California black rails and Yuma clapper rails, and (3) determine the optimal water depth for both rail species and the overlap of preferred water depths between the species. We created spatially explicit vegetation and bathymetric models of impoundments 16 and 18 on INWR, and mapped the locations of rails in each impoundment to achieve our objectives.

The restoration of impoundment 18 at INWR was very successful. Common threesquare became established in 96% of the area where it was planted, colonized 82% of the area where it was not planted, and grew in water depths ranging from -106 to 346 mm. Chairmaker's bulrush became established in 44% of the area where it was planted, colonized 55% of the area where it was not planted, and grew in water depths ranging from -106 to 263 mm. Creeping spikerush only became established in 21% of the area where it was planted, colonized 7% of the area where it was not planted, and grew in water depths ranging from -105 to 264 mm. Hardstem bulrush was present in 1 small patch in the eastern edge of the impoundment (where it was planted and where water was deepest). Southern cattail, phragmites, and river bulrush were not planted in impoundment 18, but colonized 78%, 31%, and 34% of the impoundment, respectively. Each of the non-planted species preferred shallow water areas.

We detected a maximum of 3 black rails and 3 clapper rails in impoundment 18 in 2009 (<1 year after impoundment 18 was planted with vegetation). We also detected least bittern, American bittern, Virginia rail, sora, pied-billed grebe, and common moorhen on ≥1 survey in impoundment 18 in 2009. We detected a maximum of 5 black rails and 13 clapper rails in impoundment 18 in 2010. The increase in the number of birds between 2009 and 2010 is likely due to (1) increased area covered by dense vegetation, and (2) our efforts to adaptively manage the water depth in the impoundment.

We detected a maximum of 3 black rails and 21 clapper rails in impoundment 16 in 2009, and 7 black rails and 11 clapper rails in 2010. Our efforts to stabilize and decrease the water depth in impoundment 16 in March 2009 and in January 2010 caused a 383% increase in the average number of black rails detected per survey in impoundment 16 between 2008 and 2010.

Moreover, clapper rails remained in impoundment 16, even after we decreased the water depth throughout the impoundment.

The probability of black rail occupancy in impoundments 16 and 18 was positively correlated with chairmaker's bulrush and southern cattail, negatively correlated with river bulrush, and highest if the water depth ranged between -44 and 40 mm. The probability of clapper occupancy in impoundments 16 and 18 was positively correlated with early successional southern cattail and phragmites, negatively correlated with river bulrush, and highest if the water depth ranged between 0 and 65 mm. Our results suggest that a wetland can be managed simultaneously for both California black rails and Yuma clapper rails by (1) maintaining mostly shallow water depths (saturated soil to <40 mm), (2) maintaining stable water in shallow areas (where black rails are expected), and (3) promoting chairmaker's bulrush in shallow water areas (<30 mm) where black rails are most likely to occur and southern cattail in deeper water areas (>30 mm) where clapper rails are most likely to occur. We do not recommend planting species other than chairmaker's bulrush or southern cattail. We suggest planting any new marsh restoration sites immediately after water is added to the site to discourage the growth of phragmites and other invasive plants. We strongly encourage the use of automated irrigation procedures such as those implemented in impoundments 16 and 18 in 2010.

We propose a simple wetland design for future managed wetland impoundments including 3 components: (1) an area with shallow and stable water depths (-10 to 30 mm) at one end of the impoundment planted with chairmaker's bulrush; (2) a gradual slope planted with a mix of 30% chairmaker's bulrush and 70% southern cattail; and (3) an area with deep water (250 to 350 mm deep) planted with southern cattail.

Suggested Citation: Nadeau, C. P., C. J. Conway, M. A. Conway, and M. Ogonowski. Restoration of managed marsh units to benefit California black rails and other marsh birds: an adaptive management approach, Final Report. Wildlife Research Report #2011-01, USGS Arizona Cooperative Fish and Wildlife Research Unit, Tucson, AZ, USA.

BACKGROUND

Freshwater emergent wetlands are among the most imperiled ecosystems in North America. The conterminous United States lost 21% of its freshwater emergent wetlands between 1950 and 2004 (Dahl 2006), and Arizona and California have lost 36% and 91% of their original wetlands, respectively (Dahl 1990). Two species of wetland-dependent birds are listed as wildlife of concern at both the state and federal level in Arizona and California due to the severe degradation and loss of wetlands in the Lower Colorado River basin: California black rail (*Laterallus jamaicensis coturniculus*) and Yuma clapper rail (*Rallus longirostris yumanensis*). The California black rail is listed as a bird of National Conservation Concern in the United States (USFWS 2008), federally endangered in Mexico (Diario Oficial de la Federacion 2002), state endangered in Arizona (Arizona Game and Fish Department 1996), and state threatened in California (California Department of Fish and Game 2006). The Yuma clapper rail is listed as federally endangered in the United States (USFWS 1983) and Mexico (Diario Oficial de la Federacion 2002), and state threatened in Arizona (Arizona Game and Fish Department 1996) and California (California Department of Fish and Game 2006). These species are also ranked as 2 of the 10 highest priorities for conservation action among birds in Arizona (Latta et al. 1999) and are 2 of 20 priority species in the Lower Colorado River Multi-species Conservation Program (2004). Wetlands in the lower Colorado River basin are essential to the persistence of these and other wetland-dependent bird species in the desert southwest due to the limited number of wetlands in the desert and the restricted distribution of these birds.

The quality and extent of existing wetlands associated with the lower Colorado River in Arizona and California is expected to decline relative to current conditions (Lower Colorado River Multi-species Conservation Program 2004). Proposed changes in points of water diversion are expected to reduce flow rates in many reaches of the river, change the range of daily water-level fluctuations, and cause changes in plant composition in backwater wetlands. California black rail and Yuma clapper rail are thought to be sensitive to changes in water level and plant composition within wetlands (Conway et al. 1993, Conway et al. 2002, Conway and Sulzman 2007, Eddleman et al. 1994, Gibbs et al. 1992, U.S. Fish and Wildlife Service 1983). Hence, the consequences of these proposed changes could negatively affect populations of both species in the southwestern United States. Improving our understanding of the hydrologic and vegetative needs of both species is essential to minimize and manage the consequences of these proposed changes to wetlands in the Colorado River basin.

Protection and restoration of existing habitat and the creation of new habitat is needed to maintain and recover populations of these rare birds (Evens et al. 1991, Gibbs et al. 1992). The Arizona Game and Fish Department, U.S. Fish and Wildlife Service, Bureau of Land Management, the Bureau of Reclamation (BOR), and others are currently attempting to create and restore habitat for wetland-dependent birds in the Lower Colorado River basin. Indeed, one goal of the Lower Colorado River Multi-species Conservation Program is to create 207 hectares of new habitat for Yuma clapper rail and 52 hectares of new habitat for California black rail. To ensure the success of these and other wetland restoration efforts at a time when water needs are increasing, we need better information on: (1) the habitat requirements for each bird species, including the interaction between water depth and vegetation; and (2) the factors influencing the success of planted (and the colonization of unplanted) wetland plants in newly established or restored wetlands. Gaining this knowledge will help ensure that restoration efforts provide suitable habitat for both species of rails while minimizing cost and water.

Detailed information on hydrologic regime and vegetative composition in wetlands is difficult to obtain because emergent wetlands are often difficult to access without substantial disturbance of the emergent vegetation. For these reasons, researchers have often evaluated wetland composition by estimating the percentage of a defined area that is dominated by each plant species within a standard radius of survey points. Survey points are typically located at the interface between upland and emergent marsh vegetation or between open-water and emergent marsh vegetation. Authors have then used bird counts and vegetation composition at each of their survey points to build habitat models (e.g., Conway et al. 2007, Rush et al. 2009). This method has many drawbacks, including: (1) estimates of the area dominated by each plant species can be subjective (high observer bias), (2) surveyors often underestimate understory vegetation within a wetland because the understory is not visible from the edge of the wetland, (3) only sampling locations at the edge of a wetland (at the upland or open-water interfaces) may lead to biased estimates of habitat associations, and (4) water depth is either unknown (and hence excluded from habitat models) or inferred for every bird detected within a defined radius of each survey point based on a single measurement of water depth near the survey point. Excluding water depth from either wetland-dependent bird habitat models or from vegetation distribution models is especially serious because water depth can greatly affect the avian and vegetative composition of a wetland (Flores and Eddleman 1995, Bolduc and Afton 2008). Moreover, many researchers only sample wetland vegetation once during the year, ignoring the possibility that the composition and structure (e.g., height, and percent live and dead stems) of the wetland vegetation may change seasonally such that the vegetation data collected may not represent the conditions present when the researcher counted birds at a survey site. These drawbacks may lead to inaccurate conclusions about the vegetative composition of wetlands and the habitat preferences of wetland-dependent birds.

Our objectives were to: (1) evaluate the success of wetland plant restoration efforts in a newly created wetland (impoundment 18 at Imperial National Wildlife Refuge [INWR]) (2) determine the vegetative preferences of California black rails and Yuma clapper rails, and (3) determine the optimal water depth for both rail species and the overlap of preferred water depths between the species. We created spatially explicit vegetation and bathymetric models of 2 wetland impoundments (16 and 18) on INWR to achieve our objectives. These spatial models allowed us to limit the drawbacks of traditional vegetation models and to achieve our objectives without causing unnecessary destruction to the wetland vegetation in the study sites. In addition, we tested the utility of an adaptive management approach to water delivery in each impoundment as a potential approach to improve our knowledge of the hydrologic preferences of black rails and clapper rails. Adaptive management is an excellent tool in the evaluation of restoration efforts and habitat conservation plans (Bate 2009). The initial wetland restoration efforts planned for black rails and clapper rails as part of the Lower Colorado River Multi-species Conservation Program (including INWR field 18) are an excellent opportunity to employ adaptive management as a learning tool to improve future wetland restoration efforts.

METHODS

Study Area

INWR is located along the lower Colorado River approximately 25 miles north of Yuma, Arizona. INWR manages a large wetland impoundment complex for California black rail, Yuma clapper rail, and other wetland-dependent birds. We used 2 of these impoundments (impoundments 16 and 18) to address our objectives. Impoundment 16 is a 4.1 hectare wetland located at the southeastern corner of the wetland complex. We chose impoundment 16 because both California black rail and Yuma clapper rail have been present in the impoundment over the past 10 years. Impoundment 18 is a 4.9-hectare impoundment recently converted to wetland as part of the Lower Colorado River Multi-species Conservation Program and was designed to facilitate research on the hydrologic preferences of California black rail. The impoundment has a 450 mm range in elevation and was designed to have high points and low points separated by gradual slopes to create a range of water depths at all stages of the watering cycle (Fig. 1). The BOR planted 5 different emergent wetland plants in impoundment 18 on 3 June 2008: 1.94 hectare with a mixture of common threesquare (*Schoenoplectus pungens*) and chairmaker's bulrush (*Schoenoplectus americanus*), 0.95 hectare of creeping spikerush (*Eleocharis palustris*), and 0.08 hectare of hardstem bulrush (*Schoenoplectus acutus*). We had some initial confusion on the identification of common threesquare, because the original planting plan listed *Scripus* (recently changed to *Schoenoplectus*) *americanus* and *Scirpus olneyi* as the only planted bulrush species (Nadeau 2010). These scientific names are synonymous for chairmaker's bulrush. Hence, we were unaware that common threesquare had been planted in the impoundment.

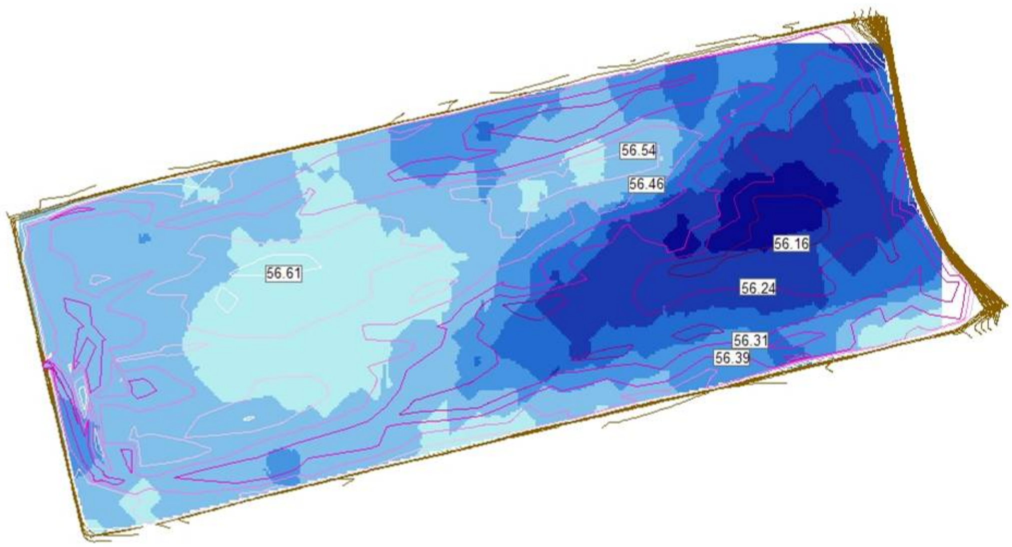

Figure 1. A comparison of a bathymetric model and the "as-built" contours of impoundment 18 at Imperial National Wildlife Refuge. We generated the bathymetric model using a spatial interpolation from hand measurements of water depth taken at 58 points throughout the impoundment. The bathymetric model is shown in shades of blue, where darker colors represent areas farther below sea level. The Bureau of Reclamation generated the "as-built" contour lines. Both the shades of blue in the bathymetric model and the contour lines change in 0.0762 m (0.25 ft) increments. Our bathymetric model is very similar to the "as-built" contours generated by the Bureau of Reclamation. This shows both the accuracy of our bathymetric models and the fact that the bottom contour of impoundment 18 has not changed much since it was graded in 2008.

Bird Surveys

We surveyed for California black rail, Yuma clapper rail, and other wetland-dependent birds in both impoundments approximately every 2 weeks between February and July of 2009 and 2010 following the North American Marsh Bird Monitoring Protocol (Conway 2009). We surveyed during 2 periods: (1) one half hour before sunrise until 9:00, or (2) 3.5 hours before sunset until dusk. On each survey, we counted birds at 17 survey points spaced 50 m apart along the periphery of impoundment 16, and 9 survey points spaced 100 m apart along the periphery of impoundment 18. We did not conduct surveys on days with rain or when the wind exceeded 16 km/h. Each point-count survey lasted 9 minutes and consisted of a 5-minute initial passive listening period followed by 1 minute of call-broadcast (30 seconds of digital calls broadcast and 30 seconds of silence) for each of the following species (in this order): black rail, least bittern (*Ixobrychus exilis*), Virginia rail (*Rallus limicola*), and clapper rail. This broadcast sequence is identical to that recommended by the U.S. Fish and Wildlife service during the multi-agency Yuma clapper rail survey that is conducted annually throughout the lower Colorado River region.

We used 2 surveyors during each survey: one surveyor recorded each wetland-dependent bird detected during the survey period on a standardized datasheet (Conway 2009) and the other mapped the location of each individual bird detected on a paper map of the impoundment. The 2 surveyors coordinated their efforts so that each bird on the map could be associated with each line on the datasheet. They also decided jointly whether a bird was a bird detected at a previous point. We used flagging placed in a 30-m grid pattern throughout each impoundment and the same grid pattern plotted on the paper map to aide our ability to locate each bird detected. We recorded movements of an individual bird on the map if we thought a bird moved during our survey.

Vegetation and Water Monitoring

We established a series of permanent monitoring points in a 30-m grid pattern in impoundment 16 (56 points) and impoundment 18 (58 points) and developed a trail network to access each point. We marked each point with a bamboo stake and surveyor flagging to ensure we recorded measurements at the same location during each sampling visit. We recorded the vegetation composition and structure, and measured water depth by hand at each point approximately once a month during the breeding season (March to July) and approximately every other month during the non-breeding season (August to February) between July 2008 and July 2010. We recorded water depth at each point with a ruler that had a square, wooden base to prevent the ruler from sinking into the soft bottom-substrate. This ruler greatly increased the accuracy and consistency of our measurements both within and among sampling visits. We counted the number of standing live and standing dead stems of each plant species within a 0.5-m by 0.5-m plot adjacent to the bamboo stake at each point during each trip. Counting the stems of each species greatly reduced 2 of the drawbacks of many past marsh bird habitat modeling approaches: (1) observer bias, and (2) under-representing the understory composition. We also measured the minimum, maximum, and mean height of each plant species and quantified the density and height of fallen dead vegetation within the 0.25-m^2 plot. We used a categorical system to quantify fallen dead vegetation where 0 represented no fallen dead vegetation, 1 represented some fallen dead vegetation that was easily penetrable, 2 represented fallen dead vegetation that was difficult to penetrate, and 3 represented fallen dead vegetation that was practically impenetrable.

We also installed a Remote Data Systems Ecotone WM water-monitoring piezometer at each point, which automatically recorded the water depth 6 times daily (i.e., every 4 hours). We modified the methods suggested by the U.S. Army Engineer Research and Development Center for installing piezometers in wetlands (Sprecher 2000). We used an auger to drill a hole for the piezometer casing, inserted the casing, backfilled the hole with sand, installed a bentonite cap at the top of the hole, and inserted the piezometer into the casing. However, in November and December 2008 we determined that the piezometers were not measuring water depth accurately (Nadeau and Conway 2008). We worked with the manufacturer of the piezometers for 2 years to try to resolve the problem, but despite tremendous amounts of effort we were unable to make modifications to remove the error (Ogonowski et al. 2009). After working with the manufacture to correct a mis-calibration issue with each well, the error in the water depth measurements from the piezometers ranged from -112 mm to 95 mm, despite a published accuracy of only "±3 mm / 0.1 in @ 71° F to 73° F" (Remote Data

Systems 2011). Hence, we were unable to use measurements from the individual piezometers to model water depth changes in each impoundment. We did find, however, that a measurement from all the piezometers pooled was significantly correlated (*P* < 0.001) with staff gauge measurements in both fields (r^2_{f16} = 0.438, r^2_{f18} = 0.632), and we therefore used that measurement as an index of water depth throughout each impoundment. This index allowed us to track changes in water depth during the duration of the study period and was an improvement over the use of staff gauge measurement because the index of water depth from the piezometers included negative values (i.e., when the water was subsurface), which was not possible with the staff gauges.

Creating Vegetation and Water Depth Surfaces

Interpolating Vegetation and Bathymetric Surfaces – We created interpolated surfaces of vegetation density, height, and water depth, which allowed us to estimate the value of each variable in each 1-m by 1-m cell throughout the entire impoundment, without traveling to each cell. This procedure significantly reduced our impact on the wetland vegetation and increased our ability to produce fine-scale habitat models and determine the success of wetland plant restoration efforts. To produce the interpolated surfaces we used a global positioning system (GPS) receiver to record the location of each monitoring point and used the *Add XY Location* tool in ArcMap to create a shapefile of the points. We attributed the monitoring point locations with the vegetation and water depth measurements from each sampling visit by joining the survey location shapefile to tables in an MS Access relational database. We used the *Inverse Distance Weighting* interpolation tool in ArcMap to create surfaces for live and dead standing stem counts and mean height for each plant species, fallen dead vegetation density and height, and water depth. We created a raster representation of both impoundments with a 1-m cell size to define the extent, define the cell size, and use as a mask during the interpolation procedure. We also snapped the interpolated surfaces to the impoundment raster to ensure the cells in each surface lined up for analysis. We used a power (which defines the strength of the relationship among adjacent points) of 3 and the 2 nearest points to model vegetation density and height, and a power of 1 and the 4 nearest points (1 point in each of the cardinal directions) to model water depth. These model parameters produced the lowest root-mean-squared error for each of the models when compared to a suite of other parameters (see Evaluating the Accuracy of Vegetation and Hydrologic Surfaces). The interpolation tool changes all integer values (i.e., stem counts and fallen dead vegetation categories) to floating point values. We used the following calculation to round each of the floating point values and convert them back to integers: int([input] + 0.5). We left all height and water depth measurements as floating point values.

We created vegetation surface models to represent the conditions present during each vegetation sampling visit. However, we created only 1 bathymetric model for each impoundment. We used hand measurements of water depth taken during a single vegetation sampling visit to create the bathymetric model for each impoundment. We chose a vegetation sampling date when the depth of water in each impoundment was high to ensure that the water depth was 0 at as few points within the impoundment as possible. We also chose a vegetation sampling date when water was not being added to the impoundment.

EXTRAPOLATING VEGETATION AND BATHYMETRIC SURFACES ON THE DATES OF BIRD SURVEYS -- We created extrapolated surfaces of standing stem density (both live and dead) for each plant species, standing stem height for each emergent wetland plant species, fallen dead vegetation density, and fallen dead vegetation height for each date that we surveyed the impoundments for wetland-dependent birds. These extrapolated surfaces allowed us to estimate the vegetative conditions on the date of the bird survey (rather than on the date of the nearest vegetation sampling visit). We used the rate of change in each variable between the 2 vegetation sampling visits surrounding each bird survey in each impoundment to create the extrapolated surfaces. Hence, the extrapolated models accounted for the changes in vegetation between the vegetation sampling visit and the bird survey. We used the following calculation in the *Single Output Map Algebra* tool in ArcGIS to generate the extrapolated surfaces for each bird survey date: *((([variable after survey] – [variable prior to survey]) / [# days between sampling visits]) * [# days between the sampling visit prior to the survey and the bird survey]) + [variable prior to the survey])*. We rounded floating point values and converted them to integers where appropriate. This extrapolation process assumes that the rate of change in each variable is linear. We believe this assumption is valid due to the short time frame between sequential sampling visits in each impoundment.

We created extrapolated water depth surfaces for each bird survey date based on the bathymetric model of each impoundment. We first calculated the difference in the pooled piezometer measurement on the day we collected the data used to create the bathymetric model and the pooled piezometer measurement on the day of the bird survey. We then added this difference to each 1-m^2 cell of the bathymetric model to adjust the bathymetric model to represent the water conditions on the date of each bird survey.

Ultimately, we produced a surface representing the conditions in each impoundment on each bird survey date for the following 6 variables: standing live stem count for each plant species present in the impoundment, standing dead stem count for each plant species, mean standing height of each emergent wetland plant species, fallen dead vegetation density, fallen dead vegetation height, and water depth. We created vegetation density surfaces for 7 plant species: chairmaker's bulrush, common threesquare, river bulrush (*Schoenoplectus robustus*), southern cattail (T*ypha domingensis*), phragmites (*Phragmites australis*), grass species (including creeping spikerush), and woody species. We created mean height surfaces for all plant species except grass and woody species. Neither common threesquare nor river bulrush occurred at enough points to model density or height for these species in impoundment 16.

EVALUATING THE ACCURACY OF VEGETATION AND BATHYMETRIC SURFACES -- We used a leave-one-out cross validation procedure to evaluate the accuracy of the interpolated vegetation surfaces and the bathymetric models. This procedure leaves 1 point out of the interpolation and then uses that point to test a model generated from all remaining points. This process is repeated for every point used in the interpolation (i.e., 56 and 58 points in impoundments 16 and 18 respectively). We used cross validation to test the vegetation interpolation surfaces for 4 different vegetation sampling visits (March and June of 2009 and 2010) in each impoundment and pooled the results. We chose these 4 vegetation sampling visits because they occur in the early (March) and late (June) breeding season of both California black rail and Yuma clapper rail. We evaluated the accuracy of each model in 3 ways: (1) a box-plot of the raw error (i.e., predicted – observed value), (2) a histogram of the standardized error (i.e., the absolute value of the ((predicted – observed)/observed mean), and (3) the proportion of sites where occupancy of a species was predicted correctly. The histogram of standardized error is a good method for evaluating both bias and precision of the models. The standardized error is a method used to evaluate the error relative to the mean value of a variable. For example, an error of 30 mm in height is worrisome for a plant with an average height of 40 mm, but less worrisome for a plant with an average height of 500 mm. The proportion of sites where the model predicts occupancy correctly is valuable to determine if the model correctly represents the vegetative composition of each impoundment.

We also used a validation procedure to evaluate the accuracy of the extrapolated surfaces representing the vegetative conditions on each bird survey date. The validation procedure involved data from 3 sampling visits that were all completed within a 3-month period. We used the interpolated surfaces from the earliest and latest of the 3 sampling visits to develop extrapolated surfaces to represent the vegetative conditions in each impoundment during the middle sampling visit, treating the date of the middle sampling visit as the date of a bird survey (see methods under Creating Extrapolated Vegetation and Hydrologic Surfaces on the Dates of Bird Surveys). We then used the point data from the middle sampling visit to evaluate the accuracy of the extrapolated vegetation surfaces by comparing the observed and predicted values for each vegetation variable. We also compared the observed and predicted values between the point data from the middle sampling visit and the interpolated vegetation surfaces from the earliest sampling visit. Calculating this second set of errors allowed us to determine if the growth rate models used to predict the vegetation on the date of each bird survey performed better than a vegetation model created from data collected prior to the bird survey (i.e., without accounting for changes in vegetation over time). We used 2 approaches to evaluate the accuracy of the extrapolated surfaces: 1) the raw errors, and 2) the proportion of sites where the models correctly predicted occupancy.

We evaluated the accuracy of the extrapolated water depth surfaces by creating extrapolated water depth surfaces (see methods under Creating Extrapolated Vegetation and Hydrologic Surfaces on the Dates of Bird Surveys) for each impoundment during the subset of sampling visits when we took hand measurements of water depth at each point. We evaluated the water depth surfaces for 2 different dates. We compared the observed and predicted water depth at each point. We excluded points where the hand measured water depth was 0 because the extrapolated water depth surfaces predict negative water depths, but the hand measured water depths could not measure depth to sub-surface water. Hence, estimates of errors are uninformative when hand measured water depths were 0. We used 2 approaches to evaluate the extrapolated water depth surfaces: (1) a box-plot of the raw error, and (2) a histogram of the standardized error.

Evaluating the Success of Wetland Plant Restoration Efforts

We evaluated the success of 6 emergent wetland plants that were either included in the planting plan (common threesquare, chairmaker's bulrush, and creeping spikerush) or that naturally colonized (river bulrush, southern cattail, and phragmites) impoundment 18. We determined the occupancy of each plant species in each 1-m^2 cell of impoundment 18 at the end of the study period using the interpolated standing stem count models. We used the interpolated models from June 2010 for all species but creeping spikerush. Creeping spikerush often falls over to form mats of vegetation, which we counted as fallen dead vegetation (not standing vegetation). Our standing stem counts for spikerush in June 2010 were low for this reason (Fig. 10). Hence we used the interpolated spikerush models for May 2010 because they more accurately represented the occupancy of spikerush in impoundment 18. We combined the interpolated occupancy models with a raster of the BOR planting plan to quantify the amount of area where each species was: (1) planted and present (i.e., successful plantings); (2) planted, but absent (i.e., unsuccessful plantings); (3) not planted, but present (i.e., successful colonization); and (4) neither planted nor present. We also stratified the 4 categories listed above into 50 mm water depth bins to determine how water depth affected the success of each plant species. We used the average water depth across the entire study period to create the bins. We determined the average water depth by averaging the water depth from the pooled piezometer measurements across the entire study period (excluding the time period when we were recalibrating the piezometers). We then adjusted the bathymetric model to represent the average water depth conditions in each 1-m^2 cell of impoundment 18. We overlaid the water depth model representing the average water depth conditions for the entire study period with the occupancy models for each plant species to quantify the amount of area occupied by each plant species in each 50 mm water depth bin.

Adaptively Managing Water Depth to Benefit Black Rails

We adaptively managed the water depth in impoundment 16 and 18 to optimize the hydrologic conditions for black rails, while maintaining populations of Yuma clapper rails. We based our adaptive management on (1) bird surveys in each impoundment (from within and outside the study period), (2) historic water depth conditions based on staff gauge readings during the breeding season, and (3) habitat suitability models based on water depth preferences of black rails described in the literature (see below). We worked closely with INWR staff to manage the water depths in each impoundment.

At the beginning of the 2009 breeding season, we recommended that INWR staff manage the water depth in impoundment 18 so that the high points on the west side of the impoundment remained exposed, except during watering events when the areas would become flooded. This recommendation ensured that impoundment 18 would have the full range of water depths intended for this study. We also recommended that they maintain their current watering strategy for impoundment 16. However, we did not detect black rails during our first 2 bird surveys in impoundment 16. Black rails had been present in impoundment 16 during every breeding season between 2000 and 2008, but their numbers declined in later years (Fig. 2; Conway and Nadeau, unpublished data). We suspected that an increase in water depth may have caused the decline and was responsible for the lack of black rails in early 2009. We examined staff gauge readings taken 1 to 4 times during the breeding season between 2006 and 2009 and found evidence that the water depth had increased in impoundment 16 (Fig. 2). The evidence was weak (because we had only 1 to 4 data points per year and INWR did not have past records of watering frequency), but in early April 2009 we worked with INWR staff to reduce the water depth in impoundment 16 so that the depth reading on the staff gauge stayed between 50 to 100 mm. This maintained an average depth of -10 to 40 mm in the impoundment. INWR staff put substantial effort into maintaining the water depths we recommended for the remainder of the breeding season in 2009. However, maintaining the water depth within such a narrow range proved difficult in both impoundments due to the other water needs on the refuge and the structure of the water delivery system that supplies water to the impoundments (Fig. 3).

During the 2009 to 2010 non-breeding season, we coupled an intensive literature search on the hydrologic preferences of black rails with spatial modeling to determine the range of optimal water depths in both impoundments. We reviewed 34 papers on black rails, 10 of which discussed water depth preferences. Of the 10 papers, 5 suggested that black rails prefer saturated soils with only small amounts of very shallow surface water scattered in small pools (Russell 1966, Weske 1969, Kerlinger and Weidner 1990, Evens et al. 1991, Legare and Eddleman 2001), while the other 5 papers suggested that black rails prefer water depths as deep as 20 to 100 mm (Manolis 1978, Repking and Ohmart 1977, Runde et al. 1990, Flores and Eddleman 1991, Conway and Sulzman 2007). Three papers also suggested that black rails prefer stable water depths (Repking and Ohmart 1977, Evens et al. 1991, Flores and Eddleman 1991).

We used the information from the literature to build spatial water depth suitability models for each impoundment. We reclassified each 1-m^2 cell of the bathymetric model so that areas with -50 (saturated soil) to 50 mm of water were considered highly suitable, areas with 50 to 100 mm of water were considered moderately suitable, and areas with <-50 or >100 mm were considered unsuitable for black rails. To ensure that we optimized water depth in areas that had the most appropriate vegetation, we combined the water depth suitability models with models of vegetation suitability. We created vegetation suitability models based on the interpolated stem density surfaces for fine-stemmed emergent vegetation at the end of the 2009 growing season (i.e., October). The literature suggests that black rails prefer high density fine-stemmed emergent vegetation (Repking 1975, Flores and Eddleman 1991, Flores and Eddleman 1995, Conway and Sulzman 2007). We defined fine-stemmed vegetation as common threesquare, chairmaker's bulrush, and river bulrush. We summed the stem density for each of the fine-stemmed emergent plants in each 1-m^2 cell of the impoundments. We considered areas with >75 stems/0.25 m^2 to be highly suitable, areas with 50 to 75 stems/0.25 m^2 to be moderately suitable, and areas with <50 stems/0.25 m^2 to be unsuitable for black rails. We determined these 3 stem density thresholds based on visual observations of overhead cover given different stem densities in the impoundment.

We combined the water depth and vegetation suitability models to create an overall suitability model for black rails in each impoundment. In the overall suitability model, we considered areas with a stem density >75 stems/0.25 m^2 and water depths between -50 to 50 mm optimal for black rails, areas with a stem density <50 stems/0.25 m^2 and water depths <-50 or >100 mm unsuitable for black rails, and we considered all other conditions moderately suitable for black rails. We used the final suitability models to determine the optimal water depth in each impoundment by calculating the amount of suitable area in each impoundment given different water depths, as measured on the staff gauge for each impoundment (Tables 1 and 2). We tested the overall suitability models to determine if black rails were actually using areas that we classified as highly or moderately suitable habitat by overlaying the location of black rail detections in each impoundment on the suitability model for that impoundment given the water and vegetation conditions at the time of the rail survey.

Our models suggested that the optimal water depth range for black rails in impoundment 18 is when the water depth at the University of Arizona staff gauge (not the newly installed staff gauges; Table 1) is between 110 and 190 mm. When the water depth is within this optimal range, 41 to 47% of the impoundment is considered moderately or highly suitable habitat for black rails (Table 1), given the vegetation composition and density in the impoundment in October 2009. The optimal water depth range for black rails in impoundment 16 is when the water depth at the University of Arizona staff gauge (not the newly installed staff gauge; Table 2) is between 60 and 130 mm. When the water is within this optimal range, 72 to 82% of the impoundment is considered moderately or highly suitable habitat for black rails (Table 2). Five of 6 black rails detected during 2009 surveys were detected in moderately or highly suitable habitat. Hence, we felt that our models were accurately representing black rail habitat suitability and recommended that INWR staff maintain these water levels in each impoundment during the 2010 breeding season. We used data from our bird surveys in the 2010 breeding season to determine if the recommended water levels in each impoundment would be suitable for black rails, without deterring populations of clapper rails.

Table 1. The percent area in impoundment 16 at Imperial National Wildlife Refuge classified as suitable habitat for black rails given the vegetative conditions in October 2009 (i.e., the end of the growing season) and water depth conditions ranging between -20 and 230 mm as measured on a staff gauge in the impoundment. We used a spatial habitat suitability model to determine the percent area that was considered: unsuitable, <50 stems/0.25 m^2 or water depths <-500 mm or >1000 mm; optimal, >75 stems/0.25 m^2 and water depths between -500 to 500 mm; or moderate, all other conditions. We used interpolated spatial models of fine-stemmed emergent plants (i.e., common threesquare, chairmaker's bulrush, and river bulrush) to estimate stem density and a bathymetric model of the impoundment to estimate water depth. We used a simulation to vary the water depth in each 1-m^2 cell of the impoundment and used the results to estimate the optimal water depth for black rails (bold text) as measured on the staff gauge.

water depth (mm)				percent area for each classification			
staff gauge	min	max	avg	unsuitable	moderate	optimal	moderate + optimal
235	15	357	151	97%	3%	0%	3%
184	-36	306	100	68%	29%	3%	32%
159	-61	281	75	38%	52%	11%	62%
133	**-87**	**255**	**49**	**22%**	**47%**	**31%**	**78%**
83	**-138**	**204**	**-2**	**18%**	**17%**	**65%**	**82%**
57	**-163**	**179**	**-27**	**28%**	**13%**	**59%**	**72%**
32	-188	154	-52	54%	8%	39%	46%
-19	-239	103	-103	98%	0%	2%	2%

Table 2. The percent area in impoundment 18 at Imperial National Wildlife Refuge classified as suitable habitat for black rails given the vegetative conditions in October 2009 (i.e., the end of the growing season) and water depth conditions ranging between 0 and 220 mm as measured on a staff gauge in the impoundment. We used a spatial habitat suitability model to determine the percent area that was considered: unsuitable, <50 stems/0.25 m^2 or water depths <-500 or >1000 mm; optimal, >75 stems/0.25 m^2 and water depths between -500 to 500 mm; or moderate, all other conditions. We used interpolated spatial models of fine-stemmed emergent plants (i.e., common threesquare, chairmaker's bulrush, and river bulrush) to estimate stem density and a bathymetric model of the impoundment to estimate water depth. We used a simulation to vary the water depth in each 1-m^2 cell of the impoundment and used the results to estimate the optimal water depth for black rails (bold text) as measured on the staff gauge.

water depth (mm)				percent area for each classification			
staff gauge	min	max	avg	unsuitable	moderate	optimal	moderate + optimal
216	3	396	146	69%	20%	11%	31%
191	**-22**	**371**	**121**	**59%**	**22%**	**18%**	**41%**
165	**-47**	**346**	**95**	**53%**	**20%**	**27%**	**47%**
114	**-98**	**295**	**44**	**56%**	**18%**	**26%**	**44%**
89	-124	269	19	63%	14%	23%	37%
64	-149	244	-6	72%	9%	19%	28%
13	-200	193	-57	78%	7%	15%	22%
0	-251	142	-108	84%	5%	12%	16%

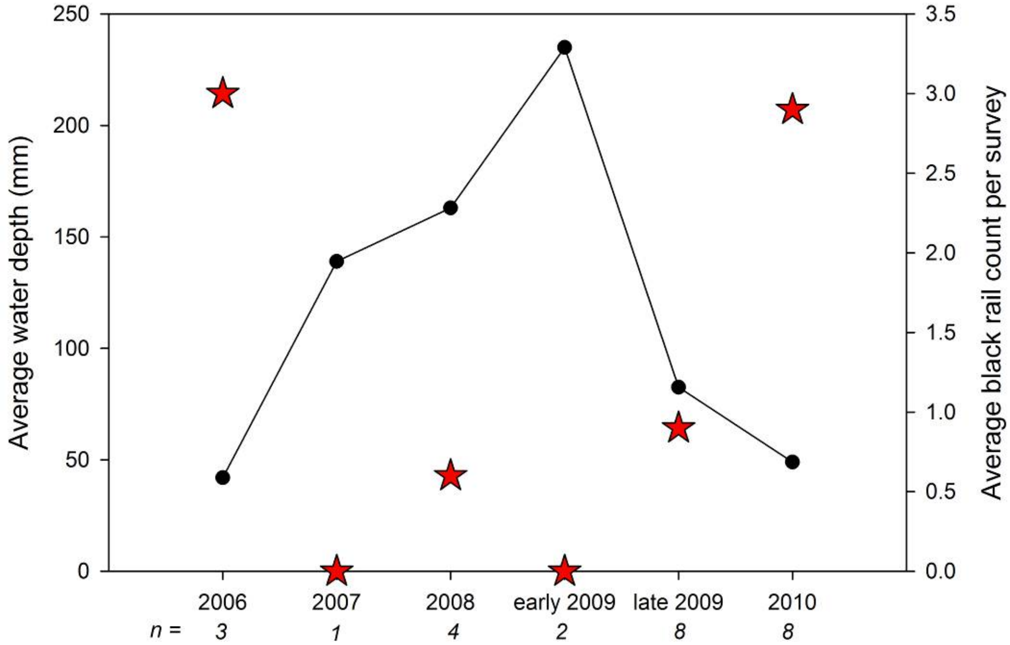

Figure 2. Average water depth as measured on the staff gauge (black circles) and black rail counts (red stars) from impoundment 16 at Imperial National Wildlife Refuge during the rail breeding seasons of 2006 to 2010. Early 2009 corresponds to surveys we completed in February and March of 2009, prior to working with INWR staff to reduce water levels. Late 2009 corresponds to surveys we completed between February and June 2009. Although the water depth data is based on only 1 to 4 observations of the staff gauge per year, this data lead us to believe that the water depth was too deep for black rails in impoundment 16 during March 2009. After examining this data we recommended that INWR lower the water level to 2006 levels. The number of surveys in 2009 and 2010 does not equal the number of surveys in Table 5, because we excluded surveys that were cancelled due to high winds.

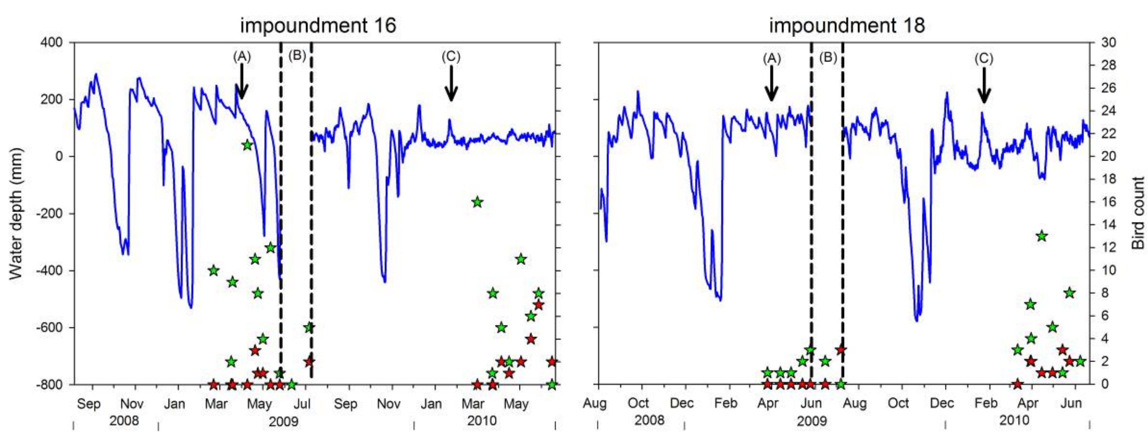

Figure 3. Hydrographs for impoundment 16 and 18 including the number of black rails (red stars) and clapper rails (green stars) detected on each bird survey at each impoundment. We created the hydrographs using the average daily measurement from the pooled set of piezometers (56 in impoundment 16, and 58 in impoundment 18). We worked with Imperial National Wildlife Refuge staff to change the watering strategy in (A) March 2009, and (C) January 2010. We removed each piezometer for recalibration between 26 May and 8 July 2009 (B). The reduction in temporal variation in water depth that resulted after the installation of the automated water delivery system in February 2010 is evident from both hydrographs.

Determining the Habitat Preferences of Black and Clapper Rails

We digitized the location of each California black rail and Yuma clapper rail detected during our bird surveys into a GIS using the paper maps and a geo-rectified air photo of each impoundment. We only digitized 1 point location to represent clapper rail pairs because the 2 birds were located in very similar locations. We did not digitize bird locations from surveys that occurred during the period in 2009 when we were recalibrating the piezometers (28 May to 8 July; Nadeau et al. 2009) because we did not have water depth data for these surveys and because we were working in each impoundment frequently during this time period. We attributed the digitized bird locations with the species, individual identification number, and date of detection. We also created a set of random points to represent available but unused points for each bird survey. We created a separate set of random points for black rails and clapper rails. We initially created 30 random points for each survey date and each species. We combined the use and random points for each species into 1 file and buffered the points with a 30-m radius. Using a 30-m radius around each point helped reduce the effect of mapping errors inherent in our bird locations. We removed random points if the 30-m buffer overlapped the buffer of another random point by more than 50% or if the buffer overlapped any part of the 30-m buffer around a bird location. We then randomly sub-sampled the random points so that there were no more than 7 random points for black rails and 21 random points for clapper rails for each survey date. These numbers are the maximum number of black rails and clapper rails we detected on any one survey (Table 5). Restricting the random points to this number helped balance the sample of use and random points. After sub-sampling the random points, we were left with samples of 214 points for black rails (39 black rail locations and 175 random locations), and 710 points for clapper rails (139 clapper rail locations and 571 random locations). We used the buffered use and random locations to sample the extrapolated vegetation and water depth surfaces created for each survey date, which provided the mean value within 30 m of each use and random point for the following variables: (1) standing live stem density of the 7 plant species (see *Creating Extrapolated Vegetation and Hydrologic Surfaces on the Dates of Bird Surveys*), (2) standing dead stem density of the 7 plant species, (3) height of 5 plant species (we did not create height surfaces for grass or woody vegetation), (4) density of fallen dead vegetation, (5) height of fallen dead vegetation, and (6) water depth. We used these variables to calculate 3 other variables at each use and random point: (1) total stem density, (2) a weighted mean height (i.e., the mean of the height across all plant species weighted by the proportion of stems present for each plant species), and (3) the number of plant species present.

We used a principal components analysis (PCA) with a varimax rotation to reduce the number of vegetation variables in our analysis because many of the variables listed above were correlated. We included all the variables listed above, except water depth in the principal components analysis. We excluded water depth because we were interested in parsing the roles of water depth and vegetation in predicting the presence of black rails and clapper rails. Hence, we did not want water depth to be included in a factor with vegetation. We used parallel analysis with 5000 repetitions to determine the number of components to retain in the analysis (Glorfeld 1995, Ledsma and Mora 2007). Determining the number of components to retain is one of the most important decisions in a PCA (Glorfeld 1995). Parallel analysis uses a Monte Carlo simulation to compare observed eigenvalues to those obtained from uncorrelated random variables (i.e., eigenvalues for components that are composed of only a single variable). The parallel analysis retains a component if the eigenvalue for that component is greater than that generated from random uncorrelated variables. This is a much more reliable method to select the number of components to retain than other commonly used methods (Glorfel 1995, Ledsma and Mora 2007). We completed a separate PCA for both black rails and clapper rails.

We used a mixed-effects logistic regression to determine which variables were most important in predicting the occupancy of both black rails and clapper rails. We conducted a separate modeling effort for black and clapper rails. We used a 2-step approach for both analyses to try to separate the effects of vegetation structure and composition from the effects of water depth.

In the first step, we determined which vegetation components from the PCA best explained the probability of occupancy for each bird species. We first built a global logistic regression model with occupancy (presence or absence) as the dependent variable, each of the components from the PCA as fixed-effect independent variables, and impoundment as a random independent variable. We tested to see if impoundment improved the model by comparing the global model (with impoundment as a random variable) to a reduced model that excluded impoundment as a random variable. We compared the models using Akaike's Information Criteria adjusted for small samples (AICc), and proceeded with the model that had the lowest AICc. We then used the model.average function in the MuMIn package (Barton 2010) in the statistical program R (R 2010) to assign a variable weight to each of the vegetation components. The variable weights are a sum of the Akaike's Information Criteria weights for all the models in which the variable is present. The variable weights can be used to rank variables in their order of importance and to determine which variables have predictive power (Burnham and Anderson 2001). We determined which vegetation components had predictive power by comparing the weight of each variable to that of a variable that has no predictive power, in the context of the other variables. We determined the weight of a variable that has no predictive power using a randomization routine (Burnham and Anderson 2001). The randomization routine randomly re-sampled (without replacement) one of the variables to create a variable that had no correlation with the dependent variable. We then determined the variable weight for the random variable in the context of all the other variables in the global model. We repeated this process 1000 times and used the median variable weight for the random variable as a baseline weight (i.e., the weight below which a variable has no predictive power; Burnham and Anderson 2001).

In the second step, we determined whether either of 2 models explained the probability of occupancy for each species better than the vegetation component(s) alone: (1) water, or (2) the interaction between water and a vegetation component considered important in the first step. We first tested to determine if a quadratic water term predicted rail occupancy better than a linear term. Our hypothesis was that the probability of rail occupancy would increase with water depth until an optimal water depth and then decrease as the water surpassed the optimal depth in a quadratic form. This relationship to water depth is common among waterbirds (Bolduc and Afton 2008). We tested this hypothesis by comparing 2 models with occupancy as the dependent variable and (1) a linear water depth term, and (2) a quadratic water depth term as a fixed-effect independent variable. We compared the 2 models using AICc, and used the water depth term in the model with the lowest AICc value in all subsequent models. We built a global model including the main effect of all the important components from the first step, the main effect of water depth, and the interaction between water depth and each important vegetation component. We used the same steps as above to determine which variables and interactions were most important in determining the occupancy of the 2 bird species. However, each variable must be in the same number of models when calculating variable weights to ensure that each variable has equal footing (Burnham and Anderson 2001). This is impossible with interaction terms, because the main effect of each variable must appear in each model where the interaction occurs. Hence, we divided the variable weight for each variable by the number of models each variable appeared in to standardize the variable weights. We were unable to use the randomization procedure to determine the weight of a variable with no predictive power for this stage of the analysis due to the complexity of the models we evaluated. Hence, we simply present the weights for each variable and discuss the importance of each accordingly.

We produced a final predictive model using model-averaged parameters from all combinations of models in the global model. Model-averaged models are preferred over selecting a top model because the model-averaged model incorporates model selection uncertainty and includes information from models that were not the top model (Burnham and Anderson 2001). Our results included a high degree of model selection uncertainty; hence, model averaging was the clear choice to produce a final predictive model. We used the final model to examine how the probability of occupancy varied with each variable and interaction that we found to be important.

We conducted a separate analysis for each of the 2 species after removing 20% of the rail observations with the most extreme water depths. We used the same procedures described above for the analyses with the reduced dataset. We wanted to analyze the data after removing 'extreme' values for water depth because one of our primary objectives was to determine the optimal water depth for each species. We defined extreme water depth observations as those with the largest absolute value of the Z-score. Hence, extreme values included very deep and very shallow water depths. Excluding 20% of rail observations from each dataset (i.e., those associated with the lowest and highest water depths) allowed us to produce a more precise prediction of the optimal water depth for each species given that (1) rails likely move through areas of unsuitable habitat and may be detected as they do so during surveys, and (2) our surveyors were undoubtedly less than 100% accurate in mapping the locations of birds detected during surveys. Also, logistic regression is sensitive to outliers in the independent variable (Pregibon 1981, Sarkar 2010). Hence, removing the most extreme water depth observations helped reduce the effect of these outliers.

We used 2 approaches to test all 4 final models (a clapper rail and a black rail model produced with both the full dataset and the reduced dataset): (1) Hosmer-Lemeshow Goodness of Fit test (HL-GOF, Hosmer and Lemeshow 1980), and (2) the area under a receiver operating characteristic curve (AUROC; Metz 1978). The HL-GOF test evaluates the model calibration (i.e., do the predicted probabilities match the observed probabilities). The HL-GOF test is the most common goodness-of-fit test for logistic regression models. The AUROC determines the proportion of cases where the model will correctly predict a positive event (i.e., the presence of black or clapper rails in this case). Hence, the AUROC tests the ability of the model to discriminate between areas where the species is present versus areas where it's absent. This method is preferred to more commonly used classification tables (Metz 1978, Pearce and Ferrier 2000). AUROC values between 0.5 and 0.7 are considered poor, values between 0.7 and 0.9 are considered moderate, and values >0.9 are considered excellent (Pearce and Ferrier 2000).

RESULTS

Evaluating the Accuracy of Vegetation and Bathymetric Surfaces

The spatial interpolation models used to predict stem density and stem height for emergent wetland plants in impoundments 16 and 18 were unbiased and similarly precise for each of the 3 variables and for all plant species (Fig. 4). Eighty percent (i.e., the range between the whiskers in Fig. 4) of the errors in stem density were within 25 stems of the observed value for all but 2 plant species: (1) live chairmaker's bulrush in impoundment 16, and (2) live common threesquare in impoundment 18. These species have a large range in stem density (0 to 340 stems for live chairmaker's bulrush in impoundment 16, and 0 to 454 stems for live common threesquare in impoundment 18), which is one reason that imprecision was higher in those models. The stem density models were generally more precise in impoundment 16 than 18, likely because stem density varied more in impoundment 18. Height models were similarly precise between the 2 impoundments and among plant species. Eighty percent of the errors in height were within 566 mm of the observed height for all plant species. The standardized errors were similar among plant species and vegetation variables. The mean standardized errors ranged between 0.15 and 0.65 times the observed mean (Fig. 5). The models had a moderate ability to predict the occupancy of a plant species in locations throughout each impoundment. The overall percent of correct predictions ranged between 51.9 and 81.9% (Table 3). The models were generally better at predicting presence than absence (Table 3).

The bathymetric models interpolated from hand measurements of water depth were unbiased but imprecise (Fig. 6). Eighty percent of the errors were within 35 mm and 135 mm in impoundments 16 and 18, respectively. The errors were larger in impoundment 18 because the water depth is both deeper and more variable in impoundment 18 (Fig. 6). The mean standardized errors were similar between the 2 impoundments and similar to those observed with the interpolated vegetation models (Fig. 6).

The extrapolated vegetation models used to account for changes in vegetation between the date the most-recent vegetation data was collected and the date of each bird survey were either less bias and more precise or similarly bias and precise when compared to spatial vegetation models that did not account for the changes in the vegetation (Figs. 7 and 8). The spatial vegetation models that accounted for the change in vegetation also predicted the occupancy of each plant species more accurately when compared to models that did not account for the changes in vegetation (Table 4), with one exception: southern cattail in impoundment 16.

The models used to predict water depth on the date of each bird survey were biased slightly low in impoundment 16 and unbiased in impoundment 18 (Fig. 9). Eighty percent of the errors were between -25 and 11 mm in impoundment 16 and between -42 and 43 mm in impoundment 18. Some of this error can be attributed to error in the pooled piezometer measurement and error in the hand measurement.

Table 3. The predictive ability of spatial vegetation models used to predict the occupancy of 8 emergent wetland plant species. We generated the spatial models using point samples of stem density for each species at 56 points in impoundment 16 and 58 points in impoundment 18. We used a leave-one-out cross validation procedure to test the predictive ability of the models. Chairmaker's bulrush and river bulrush were not found in impoundment 16.

		Percent Correctly Predicted		
Impoundment	**Species**	**Presence**	**Absence**	**Overall**
16	chairmaker's bulrush	96.1	13.5	81.9
16	southern cattail	69.7	54.3	60.6
16	phragmites	73.0	27.7	51.9
18	chairmaker's bulrush	66.2	52.4	56.7
18	southern cattail	85.1	43.7	64.6
18	phragmites	43.1	70.9	64.2
18	common threesquare	87.2	31.5	65.8
18	river bulrush	72.8	74.2	73.8

Table 4. A comparison of the predictive ability of 2 different spatial vegetation models used to predict the occupancy of 8 emergent wetland plant species: (1) a model that does not account for the changes in vegetation between the time we collected the data used to build the model and the time we collected the data used to validate the model, and (2) a model that uses a linear growth rate to account for changes in the vegetation between the time we collected the data used to build the model and the time we collected the data used to validate the model. The growth rate model allowed us to account for changes in vegetation between the time we collected the vegetation data and the time we mapped bird locations in each impoundment.

		Percent Correctly Predicted					
		Not Accounting For Veg Growth			Accounting For Veg Growth		
Impoundment	**Species**	**Presence**	**Absence**	**Overall**	**Presence**	**Absence**	**Overall**
16	chairmaker's bulrush	95.7	100.0	96.3	95.7	85.7	94.4
16	southern cattail	60.9	96.8	81.5	78.3	96.8	88.9
16	phragmites	77.4	91.3	83.3	80.6	87.0	83.3
18	chairmaker's bulrush	59.1	89.5	78.3	68.2	89.5	81.7
18	southern cattail	79.3	96.8	88.3	96.6	90.3	93.3
18	phragmites	43.8	100.0	85.0	50.0	100.0	86.7
18	common threesquare	88.6	96.0	91.7	94.3	88.0	91.7
18	river bulrush	67.6	88.5	76.7	76.5	88.5	81.7

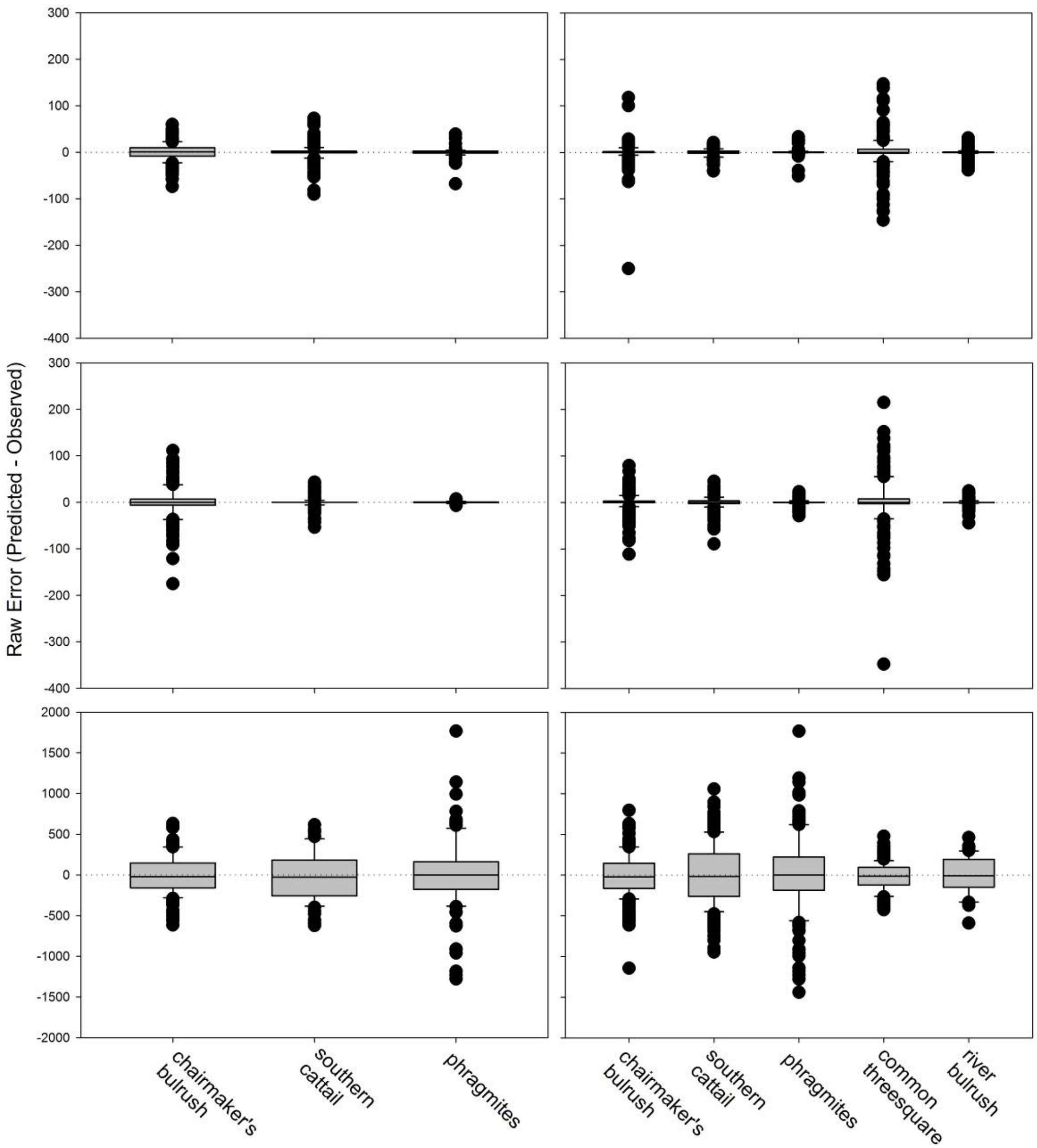

Figure 4. Raw error associated with spatial models used to predict (top) standing dead stem density (stems per 0.25 m^2), (middle) standing live stem density (stems per 0.25 m^2), and (bottom) mean stem height (mm) for 5 emergent wetland plant species in impoundments 16 (left) and 18 (right) at Imperial National Wildlife Refuge. We used a leave-one-out cross validation procedure to estimate the errors. To generate the spatial models, we used interpolation from point samples of stem density for each species at 56 points in impoundment 16 and 58 points in impoundment 18. The upper and lower bounds of the boxes represent the 75^{th} and 25^{th} percentiles of error, respectively. The upper and lower whiskers represent the 90^{th} and 10^{th} percentiles of error, respectively. The black line in the box represents the median error.

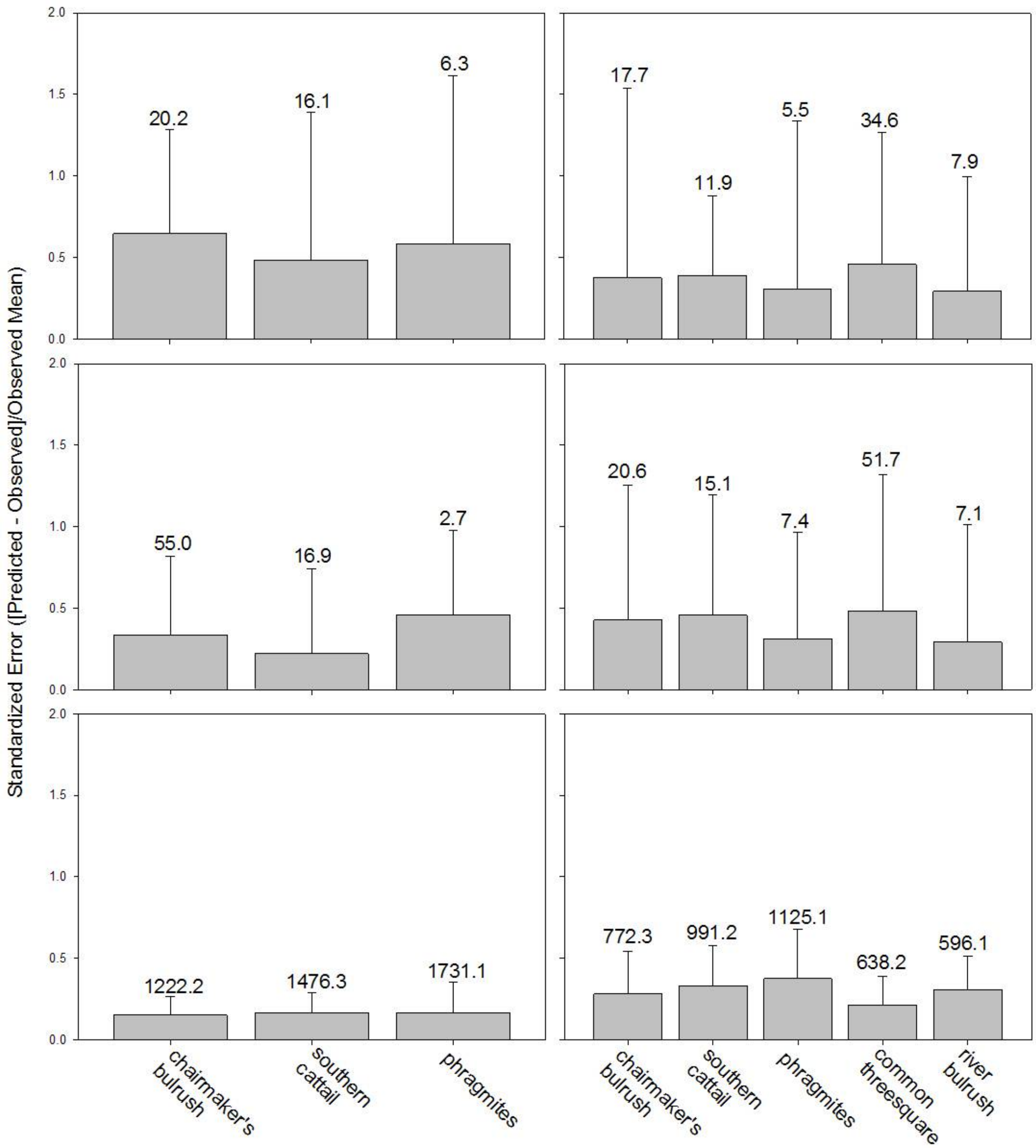

Figure 5. Mean standardized error associated with spatial models used to predict (top) standing dead stem density (stems per 0.25 m^2), (middle) standing live stem density (stems per 0.25 m^2), and (bottom) mean stem height (mm) for 5 emergent wetland plant species in impoundments 16 (left) and 18 (right) at Imperial National Wildlife Refuge. We used a leave-one-out cross validation procedure to estimate errors. To generate the spatial models, we used interpolation from point samples of stem density for each species at 56 points in impoundment 16 and 58 points in impoundment 18. The error bars represent 1 SD and the numbers above the bars are the observed mean value.

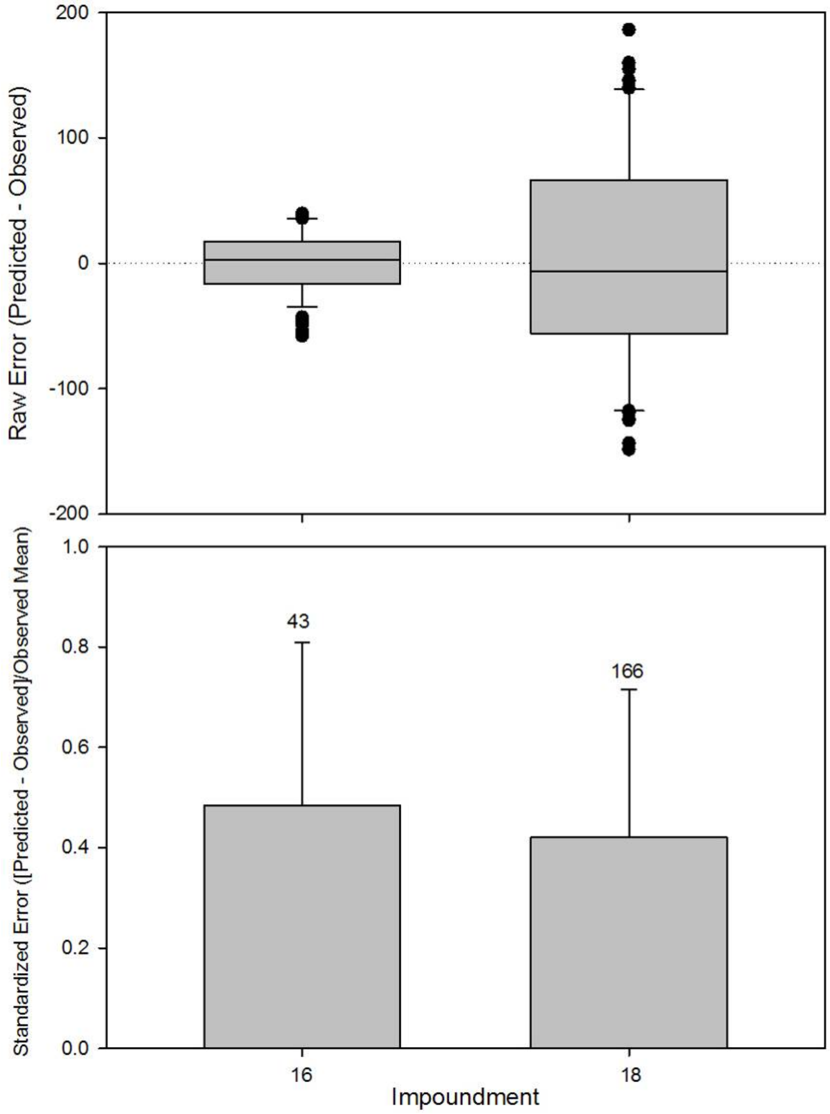

Figure 6. Raw error (top) and mean standardized error (bottom) associated with bathymetric models used to predict water depth in impoundments 16 and 18 at Imperial National Wildlife Refuge. We used a leave-one-out cross validation procedure to estimate errors. To generate the spatial models, we used interpolation from hand measurements of water depth in impoundment 16 (56 points) and 18 (58 points). The error bars in the bottom panel represent 1 SD and the numbers above the bars are the observed mean water depth. The upper and lower bounds of the boxes in the top panel represent the 75th and 25th percentiles of error, respectively. The upper and lower whiskers in the top panel represent the 90th and 10th percentiles of error, respectively. The black line in the box in the top panel represents the median error.

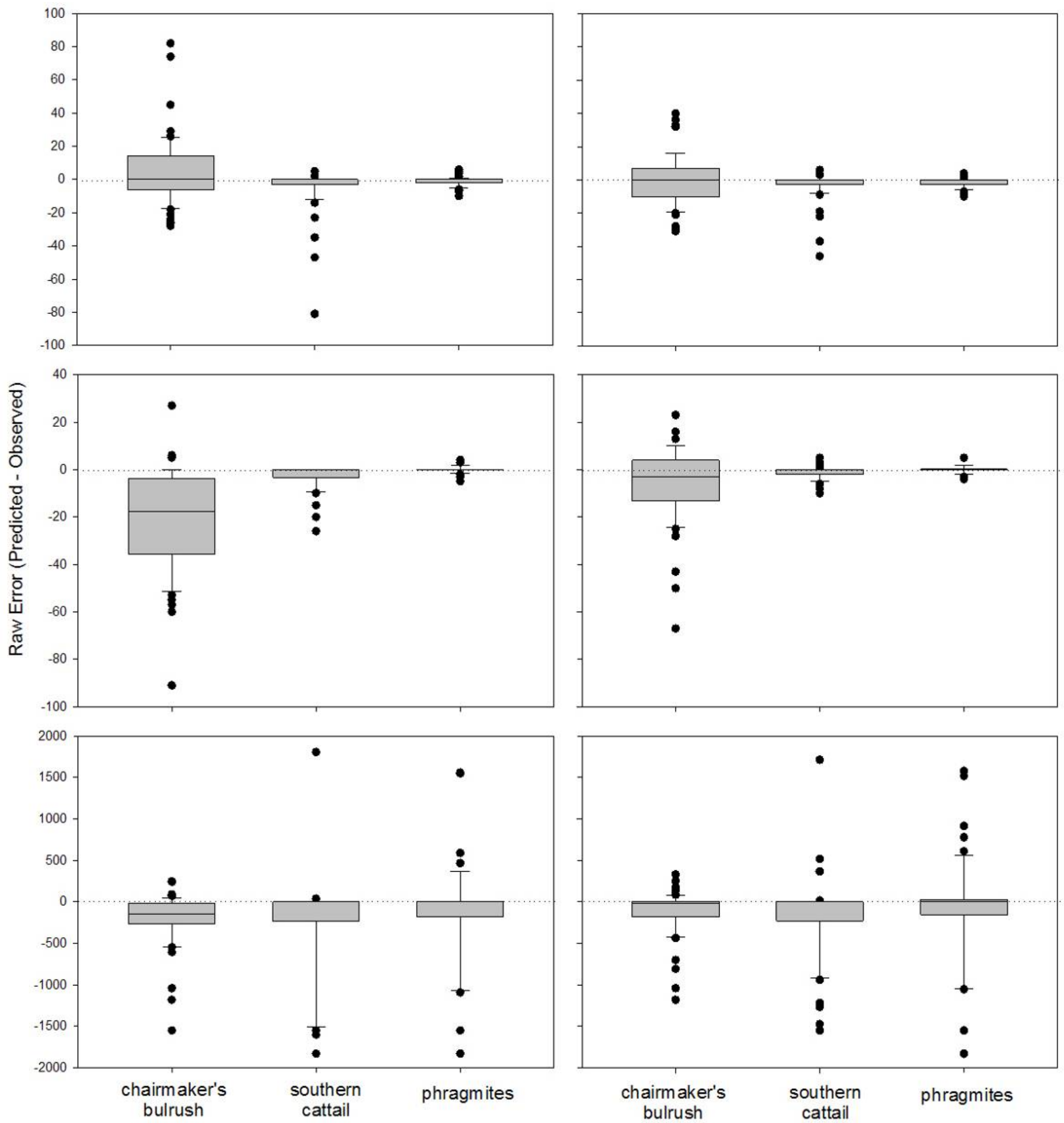

Figure 7. A comparison of raw error in spatial vegetation models for impoundment 16 that: (left) did not account for changes in vegetation between the date we collected the vegetation data used to build the models and the date we collected the vegetation data used to validate the models, and (right) accounted for the changes in vegetation between the 2 dates. The top panels are error in standing dead stem density (stems/0.25 m^2), the middle panels are error in standing live stem density (stems/0.25 m^2), and the bottom panels are error in mean standing stem height (mm). We accounted for the changes in vegetation using the growth rate in each vegetation variable between the date we collected the data to build the spatial models and a subsequent date that was later than the date we collected the data to validate the models. This comparison tests the validity of the spatial vegetation models we built to account for changes in vegetation between the date we collected the vegetation data and the date of the bird surveys. The upper and lower bounds of the boxes represent the 75^{th} and 25^{th} percentiles of error, respectively. The upper and lower whiskers represent the 90^{th} and 10^{th} percentiles of error, respectively. The black line in the box represents the median error.

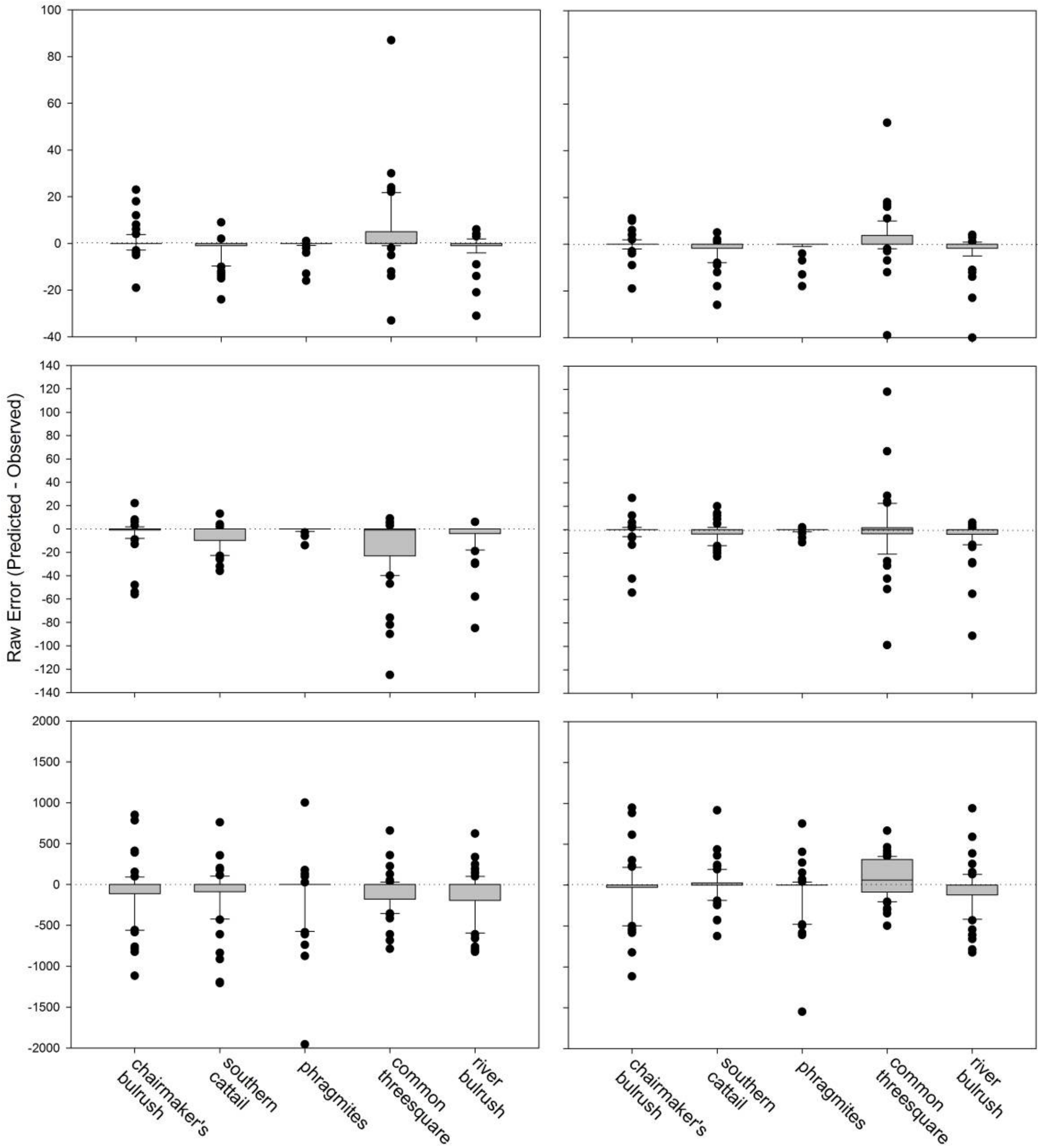

Figure 8. A comparison of raw error in spatial vegetation models for impoundment 18 that: (left) did not account for changes in vegetation between the date we collected the vegetation data used to build the models and the date we collected the vegetation data used to validate the models, and (right) accounted for the changes in vegetation between the 2 dates. The top panels are error in standing dead stem density (stems/0.25 m^2), the middle panels are error in standing live stem density (stems/0.25 m^2), and the bottom panels are error in mean standing stem height (mm). We accounted for the changes in vegetation using the growth rate in each vegetation variable between the date we collected the data to build the spatial models and a subsequent date that was later than the date we collected the data to validate the models. This comparison tests the validity of the spatial vegetation models we built to account for changes in vegetation between the date we collected the vegetation data and the date of the bird surveys. The upper and lower bounds of the boxes represent the 75^{th} and 25^{th} percentiles of error, respectively. The upper and lower whiskers represent the 90^{th} and 10^{th} percentiles of error, respectively. The black line in the box represents the median error.

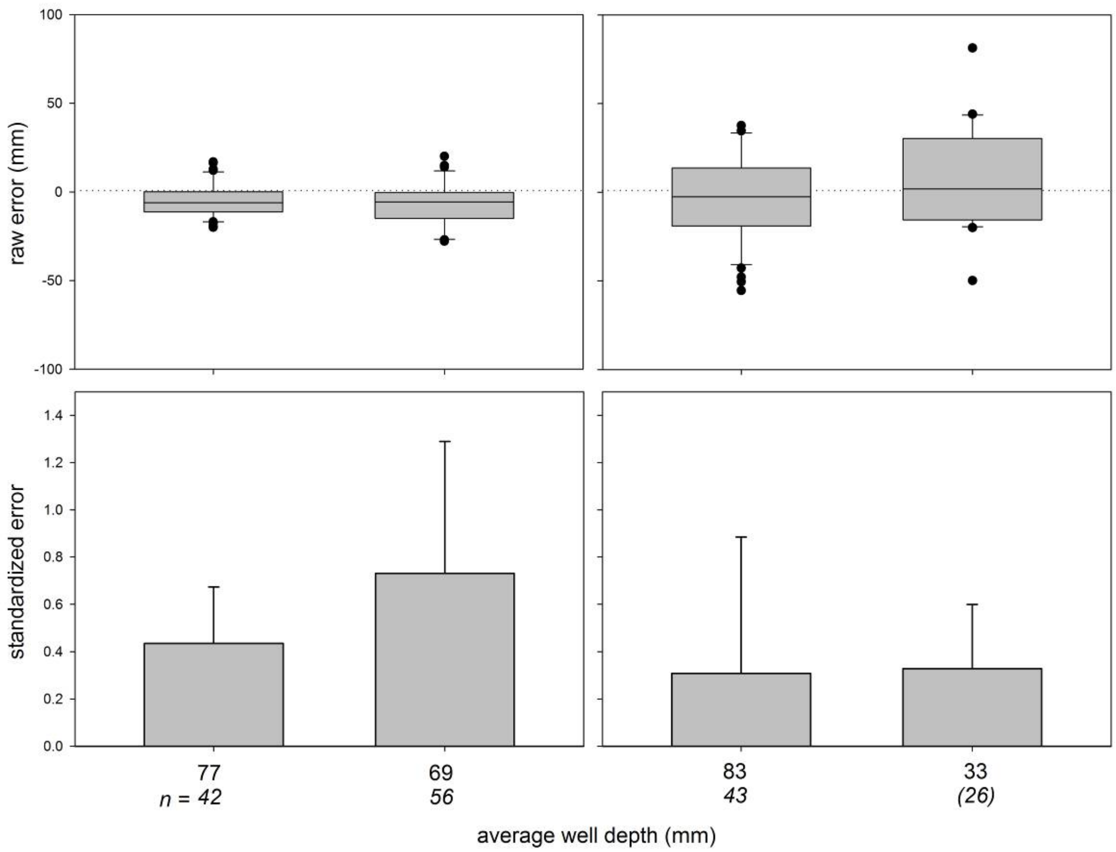

Figure 9. The raw error (observed – predicted) and standardized error ((observed – predicted / observed mean) associated with water depth models in impoundment 16 (left) and 18 (right) at Imperial National Wildlife Refuge. We created water depth models by adjusting the bathymetric model for each impoundment based on the difference between the pooled piezometer measurements on the date the data was collected to produce the bathymetric model and the date of the water depth model. The error bars in the bottom panel represent 1 SD. The upper and lower bounds of the boxes in the top panel represent the 75th and 25th percentiles of error, respectively. The upper and lower whiskers in the top panel represent the 90th and 10th percentiles of error, respectively. The black line in the box in the top panel represents the median error.

Vegetation Monitoring and the Success of Wetland Restoration Efforts

Chairmaker's bulrush dominated impoundment 16, but southern cattail and phragmites were also common (Fig. 10). Common threesquare dominated impoundment 18, but chairmaker's bulrush, southern cattail, phragmites, and river bulrush were also common (Fig. 10). The proportion of vegetated area occupied by each plant species remained relatively constant throughout the study period in both impoundments (Fig. 10), but stem density and overhead cover increased in impoundment 18 as wetland plants matured.

The emergent wetland plants planted in impoundment 18 were all present in the impoundment 24 months after planting, but the magnitude of success varied among species (Figs. 11 and 12). Common threesquare became established in 96% of the area where it was planted and also colonized 82% of the area where it was not planted. Chairmaker's bulrush, although planted in the same areas as common threesquare, became established in only 44% of the area where it was planted. Chairmaker's bulrush did, however, colonize 55% of the area where it was not planted. Creeping spikerush only became established in 21% of the area where it was planted and colonized only 7% of the area where it was not planted. However, creeping spikerush often formed mats of fallen dead vegetation. Hence, our sampling design may have underestimated the areal extent of this species. Hardstem bulrush was present in 1 small patch in the eastern edge of the impoundment (where it was planted), but was not captured by our vegetation surveys (it remained restricted to where it was planted and did not colonize other areas). Southern cattail, phragmites, and river bulrush were not planted in impoundment 18, but colonized 78%, 31%, and 34% of the impoundment, respectively (Figs. 11 and 12). We expected southern cattail and phragmites to colonize impoundment 18 because these species are common in adjacent impoundments (and probably had seed present in the soil). In contrast, river bulrush is rare in wetlands on the lower Colorado River. Hence, we suspect that river bulrush was introduced to impoundment 18 via a contaminated nursery plug used to plant one of the other species.

Our data suggests that each plant species varied in respect to water depth tolerance (Fig. 12). Common threesquare (both planted and naturally colonized) thrived in all areas of impoundment 18 regardless of water depth. We observed common threesquare in average water depths ranging from -106 to 346 mm. Chairmaker's bulrush was more successful when planted in shallow water, and plantings did not succeed in average water conditions >263 mm. Similarly, naturally colonized chairmaker's bulrush occupied a higher proportion of the area available if shallow surface water was present and did not naturally colonize areas where the average water conditions were >203 mm. We observed chairmaker's bulrush in average water depths ranging between -106 to 263 mm. Planted creeping spikerush was most successful in areas where the average water depth was between 101 to 200 mm, and did not succeed in average water conditions <-74 mm. However, creeping spikerush naturally colonized areas where average water depth ranged from -105 to 264 mm. Each of the 3 plant species that were not planted in impoundment 18 grew in almost all water depths, but occupied a higher portion of available area if the water depth was shallow. Phragmites and river bulrush did not grow in water depths >250 and >227 mm, respectively. Southern cattail grew in all available water depths. Phragmites was the only unwanted invasive plant to become established in any substantial quantity in impoundment 18. Phragmites was established in the northwestern corner of the impoundment prior to the beginning of the project. Hence, we were unable to control the spread of phragmites. Phragmites spread into areas where other species were not planted or where the water was too deep for planted species to survive (Fig. 12).

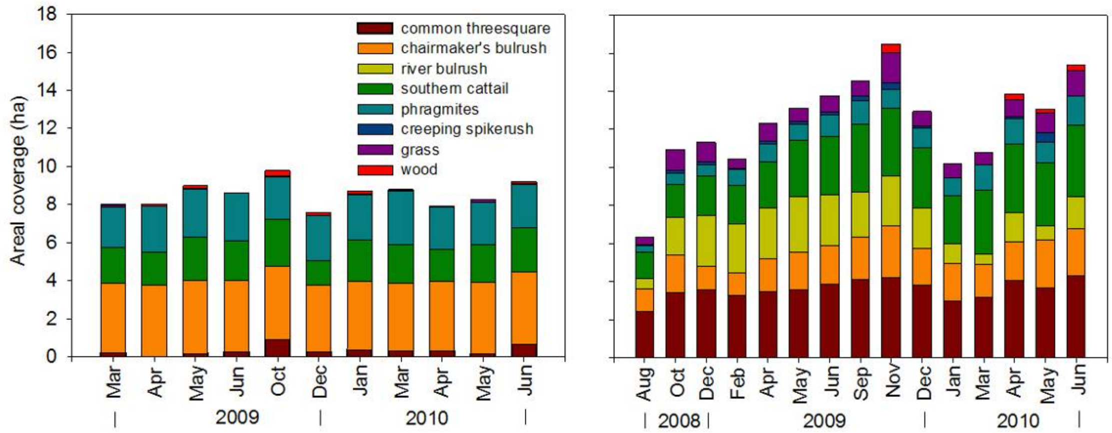

Figure 10. Areal coverage of each of 8 plant species in impoundment 16 (left) and 18 (right) at Imperial National Wildlife Refuge. We used interpolated models of vegetation stem density to estimate the areal extent of each species. The total areal extent in each bar may total to more than the total vegetated area in the impoundment because many locations have >1 species present. The dates on the x-axis of the 2 panels indicate the occasions when we sampled vegetation at 56 and 58 0.25m^2 sampling plots in impoundment 16 and 18, respectively.

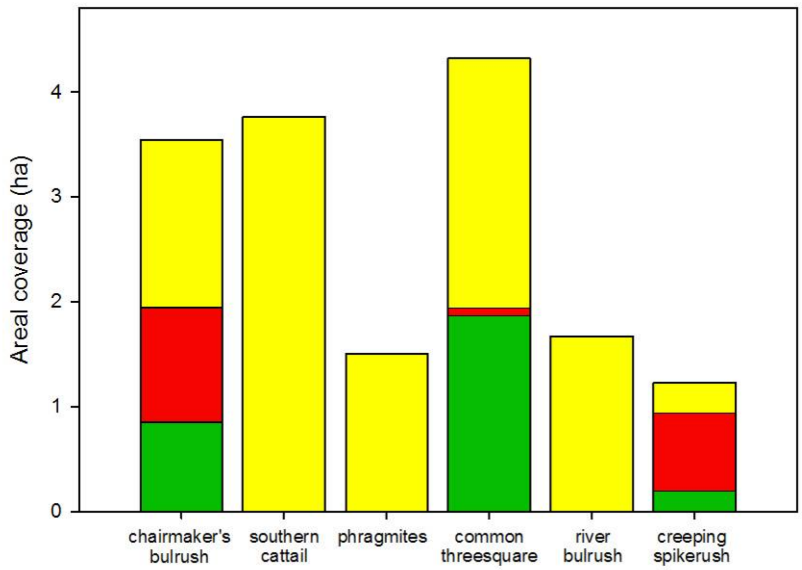

Figure 11. Areal coverage of emergent wetland-plant species in impoundment 18 at Imperial National Wildlife Refuge in June 2010 (May 2010 for creeping spikerush). Three conditions are represented for each species: (green) areas where the species was planted and present (i.e., successful plantings); (red) areas where the species was planted, but absent (i.e., unsuccessful plantings); and (yellow) areas where the species was not planted but present (i.e., naturally colonized). We estimated areal extent of occupancy for each species based on an interpolation from 58 point measurements of stem density for each species. We used a planting plan surface to determine the area planted with each species.

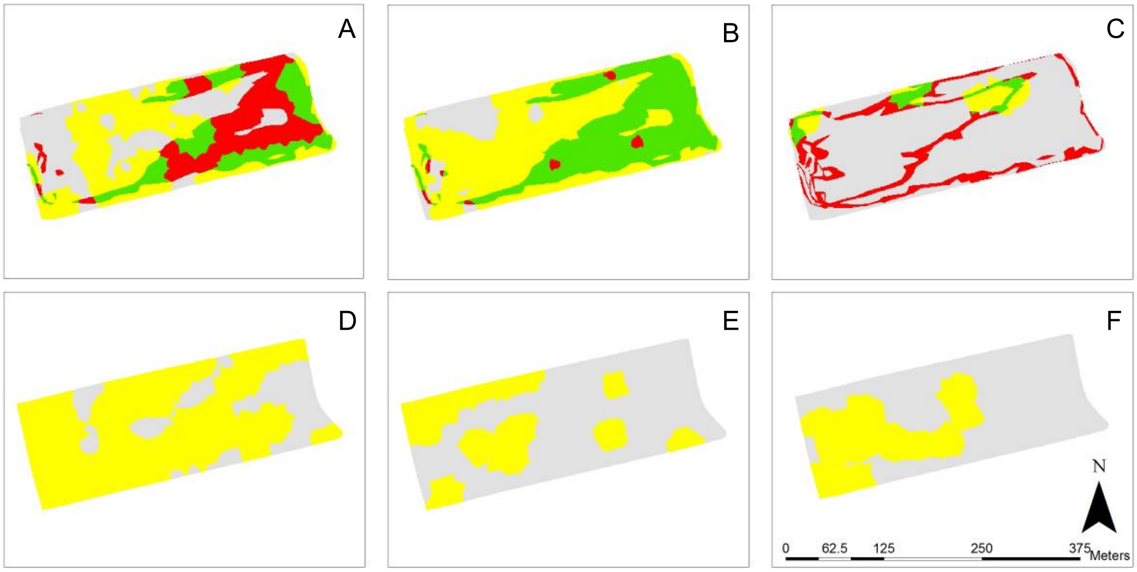

Figure 12. Aerial coverage of the following species in impoundment 18 during the June 2010 (except May 2010 for creeping spikerush) vegetation sampling visit: (A) chairmaker's bulrush, (B) common threesquare, (C) creeping spikerush, (D) southern cattail, (E) phragmites, and (F) river bulrush. Four conditions are represented for each species: (green) areas where the species was planted and present (i.e., successful plantings); (red) areas where the species was planted, but absent (i.e., unsuccessful plantings); (yellow) areas where the species was not planted but present (i.e., naturally colonized); and (grey) areas where the species was not planted and absent. We determined occupnacy for each plant species based on an interpolation from 58 point measurements of stem density for each species. We used a planting plan surface to determine the area planted with each species.

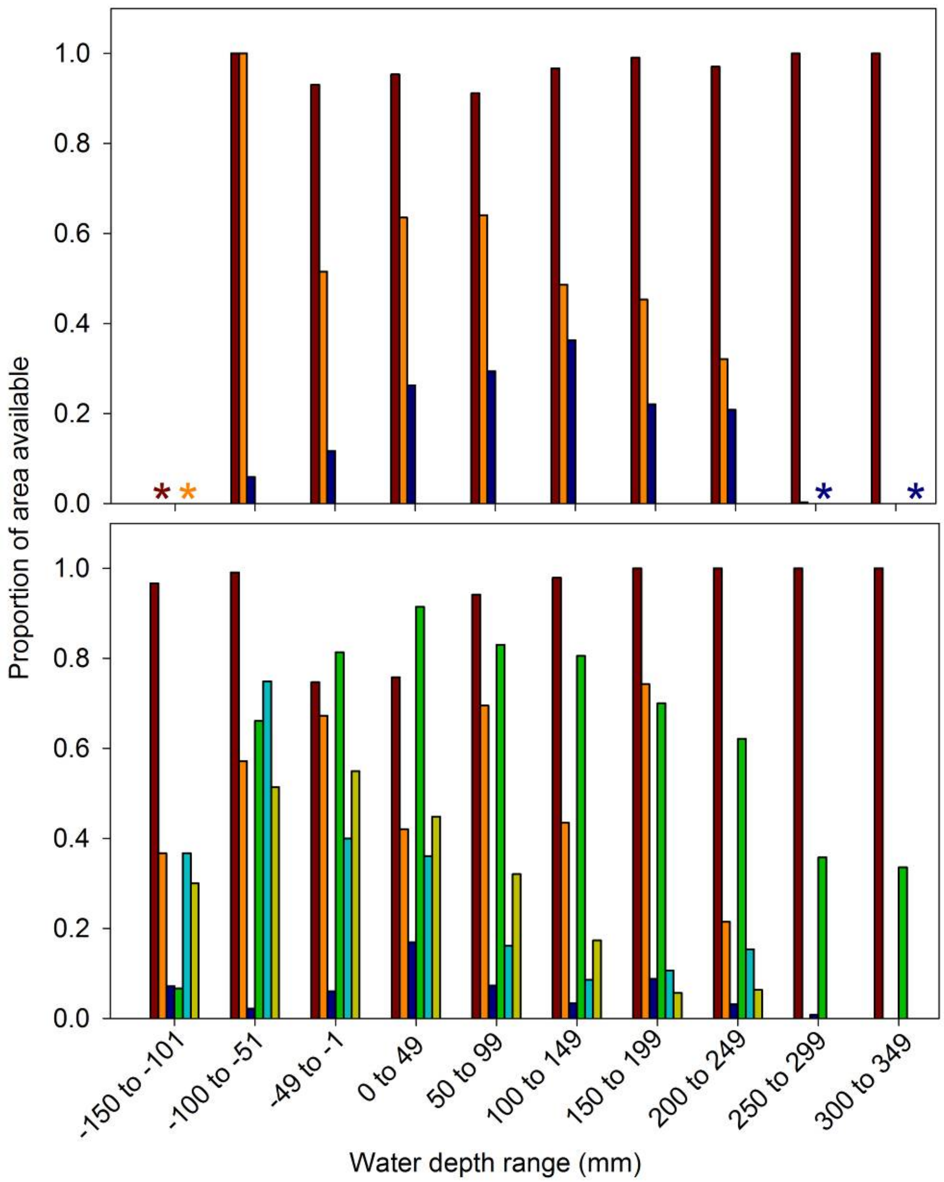

Figure 13. The proportion of available area in each water depth category where 6 emergent wetland plant species were present in impoundment 18: common threesquare (red), chairmaker's bulrush (orange), creeping spikerush (dark blue), southern cattail (green), phragmites (light blue), river bulrush (yellow). The top panel shows the proportion of area where the plants were planted, and the bottom panel shows the proportion of area where the plants were not planted. Asterisks in the top panel demark areas where the species was not planted. We used the final planting plan for impoundment 18 to determine whether the plants were planted in each 1-m^2 cell of impoundment 18. We used spatial interpolation models to determine if the plants were present in each 1-m^2 cell in impoundment 18. We used the bathymetric model and the pooled piezometer measurements from the entire study period from impoundment 18 to determine the average water depth conditions throughout the study period in each 1-m^2 cell.

Bird Surveys and the Response of Birds to Adaptively Managed Water Depths

We completed 11 surveys for wetland-dependent birds in impoundment 16 during the 2009 breeding season (Table 5, Fig. 3). We detected a maximum of 3 black rails and 21 clapper rails during these surveys. We detected $\geq$1 black rail on 36% and $\geq$1 clapper rail on 90% of these 11 surveys. We detected our first black rails in impoundment 16 in 2009 only a week after we recommended that INWR lower the water levels at the beginning of the breeding season (Fig. 3). We detected black rails in impoundment 16 on 2 subsequent surveys, but failed to detect black rails once the water levels rose again in early May (Fig. 3). We detected 2 black rails in late July, when we were unable to assess water level trends because we were recalibrating the piezometers. Staff gauge measurements, however, suggested that the water levels in impoundment 16 were low during the time of this survey relative to water levels in previous months. We detected fewer clapper rails later in the breeding season, but this is expected as clapper rail detection probability declines later in the breeding season (Conway et al. 1993).

We completed 7 bird surveys in impoundment 18 during the 2009 breeding season (Table 5, Fig. 3). We detected a maximum of 3 black rails and 3 clapper rails during these surveys. We detected $\geq$1 black rail on 14% and $\geq$1 clapper rail on 86% of these 7 surveys. We detected the first black rails (3 birds) on 20 April 2009 and the first clapper rail (1 bird) on 26 March 2009 in impoundment 18; less than 1 year after BOR planted vegetation in the impoundment. We also detected least bittern (Table 5), American bittern, Virginia rail, sora, pied-billed grebe, and common moorhen on $\geq$1 of the 7 surveys in impoundment 18.

INWR staff automated the water delivery system for both impoundments in February 2010. This substantially reduced the variation in water depth and allowed staff to more accurately manage water depths at the levels we recommended from our habitat suitability modeling (Fig. 3). We consistently detected more black rails, but fewer clapper rails (compared to numbers detected in 2009) in impoundment 16 during the 2010 breeding season. We completed 11 bird surveys in impoundment 16 during the 2010 breeding season (Table 5, Fig. 3). We detected a maximum of 7 black rails and 16 clapper rails during these surveys. We detected $\geq$1 black rail on 76% and $\geq$1 clapper rail on 91% of the 11 surveys. We consistently detected more black rails and more clapper rails (compared to numbers detected in 2009) in impoundment 18 during the 2010 breeding season. We completed 11 bird surveys in impoundment 18 during the 2010 breeding season. We detected a maximum of 5 black rails and 13 clapper rails during these surveys. We detected $\geq$1 black rail and $\geq$1 clapper rail on 91% of these 11 surveys. These data suggest that impoundment 18 was providing similar habitat for both species compared to impoundment 16 in only second breeding seasons after BOR planted vegetation in the impoundment.

Table 5. The total number of individual Lower Colorado River Multi-species Conservation Program focal species detected during breeding season point-count surveys at impoundment 16 and 18 at Imperial National Wildlife Refuge.

Impoundment 16				Impoundment 18			
	# of birds detected				# of birds detected		
Date	Black rail	Clapper rail	Least bittern	Date	Black rail	Clapper rail	Least bittern
20-Feb-09	0	10	1	26-Mar-09	0	1	0
17-Mar-09	0	2	0	13-Apr-09	0	1	0
19-Mar-09	0	9	0	28-Apr-09	0	1	0
09-Apr-09	0	21	0	14-May-09	0	2	0
20-Apr-09	3	11	3	25-May-09	0	3	0
24-Apr-09	1	8	0	15-Jun-09	0	2	0
01-May-09	1	4	0	07-Jul-09	3	0	1
12-May-09	0	12	0	12-Mar-10	0	3	0
25-May-09	0	1	0	30-Mar-10	2	7	1
11-Jun-09	0	0	0	31-Mar-10	2	4	2
06-Jul-09	2	5	1	15-Apr-10	1	13	1
02-Mar-10	0	16	0	30-Apr-10	1	5	2
23-Mar-10	0	1	0	14-May-10	3	1	0
24-Mar-10	0	8	1	24-May-10	2	8	1
05-Apr-10	2	5	0	08-Jun-10	2	2	0
16-Apr-10	1	2	1	28-Jun-10	4	3	0
03-May-10	2	11	1	13-Jul-10	5	1	1
17-May-10	4	6	1	26-Jul-10	3	0	1
28-May-10	7	8	0				
16-Jun-10	2	0	0				
12-Jul-10	5	2	0				
27-Jul-10	4	2	0				

Determining the Habitat Preferences of Black and Clapper Rails

We found that 5 and 6 principal components best summarized the 24 vegetation variables in the dataset for black rails and clapper rails, respectively (Tables 6 and 7). We named the components in the black rail dataset as follows based on the variables that loaded highest for each component: chairmaker's bulrush, common threesquare, southern cattail, river bulrush, and upland. We named the components in the clapper rail dataset as follows: chairmaker's bulrush, southern cattail, river bulrush, total stem density, phragmites, and upland. We excluded impoundment as a random variable in our vegetation models for both species prior to determining the importance of each variable in predicting rail occupancy. The model without impoundment (16 vs 18) as a random variable had a lower AICc value than the model that included impoundment as a random variable ($\Delta AICc_{black\ rail} = 2.14$, $\Delta AICc_{clapper\ rail} = 2.05$). We chose to use a quadratic water depth term in each model including water depth because a model with a quadratic water depth term had a lower AICc value than a model with the linear water depth term ($\Delta AICc_{black\ rail} = 1.84$,

$\Delta AICc_{clapper\ rail}$ = 11.59). The final model-averaged model including all the data had good model fit (HL-GOF $P_{black\ rail}$ = 0.063, HL-GOF $P_{clapper\ rail}$ = 0.378) and had a moderate discrimination ability ($AUROC_{black\ rail}$ = 0.719, $AUROC_{clapper\ rail}$ = 0.732). The final model-averaged model created from the data where we removed rail observations with extreme water depth values (i.e., those with the largest absolute Z-score) suggested slightly better model fit (HL-GOF $P_{black\ rail}$ = 0.370, HL-GOF $P_{clapper\ rail}$ = 0.732) and moderate discrimination ability ($AUROC_{black\ rail}$ = 0.727, $AUROC_{clapper\ rail}$ = 0.800).

Three of the vegetation components had more predictive power than a random variable (i.e., a variable weight > 0.26) in explaining the probability of black rail occupancy (Table 8): chairmaker's bulrush, southern cattail, and river bulrush. When we added water depth to the important vegetation variables, the interaction between river bulrush and water had the most predictive power, followed by the main effect of river bulrush, chairmaker's bulrush, water depth and southern cattail (Table 8). The 2-way interactions of water with both chairmaker's bulrush and with southern cattail had low variable weight suggesting they were not important in predicting the probability of black rail occupancy. The probability of black rail occupancy was negatively associated with river bulrush, however black rails do appear to use river bulrush if the water depth is optimal (i.e., near 0; Fig. 14). The probability of black rail occupancy was positively associated with stem density and height of chairmaker's bulrush, and slightly negatively associated with stem density and height of southern cattail (Fig. 15). The optimal water depth (i.e., the range of water depths that produced a <10% decrease in the maximum probability of occupancy) for black rails was between -24 and 158 mm when we included black rail observations with extreme water depths (i.e., those with the largest absolute Z-score) and between -44 and 40 mm when we eliminated black rail observations with extreme water depths (Fig. 16).

All 6 of the vegetation components had more predictive power than a random variable (i.e., a variable weight > 0.30) in explaining the probability of clapper rail occupancy (Table 8). However, chairmaker's bulrush had a variable weight of only 0.33, hence we removed chairmaker's bulrush from all subsequent analyses. The interaction between river bulrush and water depth had the most predictive power, followed by phragmites, the main effect of river bulrush, southern cattail, and water. Upland, total stem density, and the interaction between water and variables other than river bulrush had little predictive power. The probability of clapper rail occupancy was negatively associated with river bulrush. However, clapper rails did seem to use river bulrush if the water depth was optimal (33 mm; Fig. 17). The probability of clapper rail occupancy was positively associated with both southern cattail and phragmites (Fig. 18). However, in a post-hoc analysis of this relationship, we found that a quadratic term had a lower AICc value than the linear term for both southern cattail ($\Delta AICc$ = 6.03) and phragmites ($\Delta AICc$ = 8.93). The quadratic relationship suggests that clapper rails are associated with moderately dense and tall (i.e., early successional) southern cattail and phragmites, but are less likely to occupy highly dense stands of either species (Fig. 19). The optimal water depth for clapper rails was between -170 and 103 mm when we included clapper rail observations with extreme water depths and between 0 and 65 mm when we eliminated clapper rail observations with extreme water depths (Fig. 16). The optimal water depth to support black rails and clapper rails simultaneously was between 0 and 40 mm (Fig. 16).

Table 6. The results of a principal components analysis (PCA) used to reduce the number of variables and reduce multicolinearity for subsequent logistic regression analyses. We generated the data for the PCA from vegetation surveys at black rail use and random points. We used a varimax rotation to rotate the components and parallel analysis to select the number of components. The eigenvalues reported are adjusted based on the parallel analysis. We named components based on the variables with the highest component weights.

	Chairmaker's bulrush	Common threesquare	Southern cattail	River bulrush	Upland
Adjusted eigenvalue	5.2	2.2	1.6	1.4	1.3
Percent variation explained	20.2	12.1	11.1	10.9	8.5
Variable	**Component weight**				
Chairmaker's bulrush mean height	.868	-.180	-.095	-.164	-.052
Chairmaker's bulrush standing live stem density	.749	.194	-.153	-.054	-.104
Weighted mean height	.737	-.337	.350	-.212	-.086
Chairmaker's bulrush standing dead stem density	.713	.023	-.186	-.110	-.109
Phragmites mean height	.666	-.354	.085	-.159	.350
Common threesquare mean height	-.660	.525	-.047	.191	-.044
Phragmites standing dead stem density	.558	-.192	.009	-.095	.266
Fallen dead vegetation stem density	.485	-.009	-.235	.036	-.135
Total standing stem density	.327	.903	.076	.172	-.077
Common threesquare standing live stem density	-.351	.706	-.079	.074	-.160
Common threesquare standing dead stem density	-.345	.529	-.244	-.130	.009
Grass standing live stem density	-.051	.463	.132	.013	.243
Fallen dead vegetation mean height	.411	-.444	-.010	.024	-.209
Southern cattail standing dead stem density	-.030	-.046	.872	-.075	-.012
Southern cattail mean height	-.046	-.089	.860	-.003	.083
Southern cattail standing live stem density	-.247	.183	.803	.077	.082
River bulrush standing dead stem density	-.114	.012	-.038	.924	-.021
River bulrush standing live stem density	-.065	.025	-.021	.920	-.032
River bulrush mean height	-.398	.103	.040	.601	.192
Phragmites standing live stem density	.086	-.159	.136	-.083	.720
Woody vegetation standing live stem density	-.062	.101	-.064	.016	.705
Number of plant species present	-.299	.264	.186	.345	.607
Grass standing dead stem density	-.015	.043	.001	.325	.356

Table 7. The results of a principal components analysis (PCA) used to reduce the number of variables and reduce multicolinearity for subsequent logistic regression analyses. We generated the data for the PCA from vegetation surveys at clapper rail use and random points. We used a varimax rotation to rotate the components and parallel analysis to select the number of components. The eigenvalues reported are adjusted based on the parallel analysis. We named components based on the variables with the highest component weights.

	Chairmaker's bulrush	Southern cattail	River bulrush	Total stem density	Phragmites	Upland
Adjusted eigenvalue	5.1	2.6	1.7	1.7	1.3	1.0
Percent variation explained	16.7	10.7	10.2	9.5	9.5	6.5
Variables	**Component weights**					
Chairmaker's bulrush mean height	.848	-.049	-.255	-.052	.195	.003
Chairmaker's bulrush standing live stem density	.809	-.124	-.115	.146	-.168	.138
Weighted mean height	.682	.404	-.227	-.143	.335	-.185
Chairmaker's bulrush standing dead stem density	.652	-.189	-.192	.082	.216	-.089
Common threesquare mean height	-.637	-.143	.137	.446	-.255	.058
Fallen dead vegetation density	.543	-.235	.024	-.031	.033	-.101
Common threesquare standing dead stem density	-.425	-.294	-.120	.401	-.073	-.070
Southern cattail standing dead stem density	-.062	.862	-.083	-.076	-.039	-.091
Southern cattail mean height	-.042	.854	.036	.003	.094	.047
Southern cattail standing live stem density	-.196	.769	.179	.062	-.140	.221
River bulrush standing dead stem density	-.087	.005	.836	-.038	-.072	-.072
River bulrush standing live stem density	-.052	-.036	.835	.060	-.052	-.035
River bulrush mean height	-.318	.122	.771	.121	-.002	.156
Total stem density	.360	.021	.047	.898	-.146	.041
Common threesquare standing live stem density	-.288	-.172	.062	.774	-.172	-.098
Grass standing live stem density	-.021	.082	.051	.554	-.002	.034
Phragmites standing dead stem density	.311	-.031	-.053	.002	.781	-.092
Phragmites mean height	.446	.111	-.111	-.122	.753	-.007
Phragmites standing live stem density	-.069	.141	.109	.017	.683	.390
Fallen dead vegetation mean height	.284	-.063	.038	-.263	.397	-.263
Woody vegetation standing dead stem density	-.022	-.032	-.024	-.042	.130	-.010
Woody vegetation standing live stem density	-.042	-.039	-.043	-.019	.179	.725
Grass standing dead stem density	.059	.055	-.019	-.041	-.183	.580
Number of plant species present	-.327	.201	.414	.206	.045	.536

Table 8. The relative importance of variables used to explain the probability of occupancy of black rails and clapper rails in impoundment 16 and 18 on Imperial National Wildlife Refuge. All the variables (except water) are principal components from a principal components analysis (PCA). We determined which vegetation components were important in predicting the probability of occupancy for each species by comparing the variable weight to the weight of a variable with no predictive power. We then ranked the importance of each important vegetation component when combined with water and the interaction with water. We standardized variable weights in the vegetation and water models by the number of models that each variable appeared in.

Black Rail			**Clapper Rail**		
	Variable Weight			**Variable Weight**	
Variable	**Vegetation Only**	**Vegetation and Water**	**Variable**	**Vegetation Only**	**Vegetation and Water**
River bulrush * water depth	--	0.0673	River bulrush * water depth	--	0.0065
River bulrush	0.8808	0.0416	Phragmites	1.0000	0.0056
Chairmaker's bulrush	0.8999	0.0347	River bulrush	1.0000	0.0056
Water depth	--	0.0313	Southern cattail	1.0000	0.0056
Southern cattail	0.4769	0.0197	Water depth	--	0.0040
Chairmaker's bulrush * water depth	--	0.0106	Upland	0.5410	0.0034
Southern cattail * water depth	--	0.0044	Phragmites * water depth	--	0.0033
Common threesquare	0.2116	--	Total stem density	0.5077	0.0023
Upland	0.2406	--	Upland * water depth	--	0.0018
			Southern cattail * water depth	--	0.0018
			Total stem density * water depth	--	0.0006
			Chairmaker's bulrush	0.3350	--

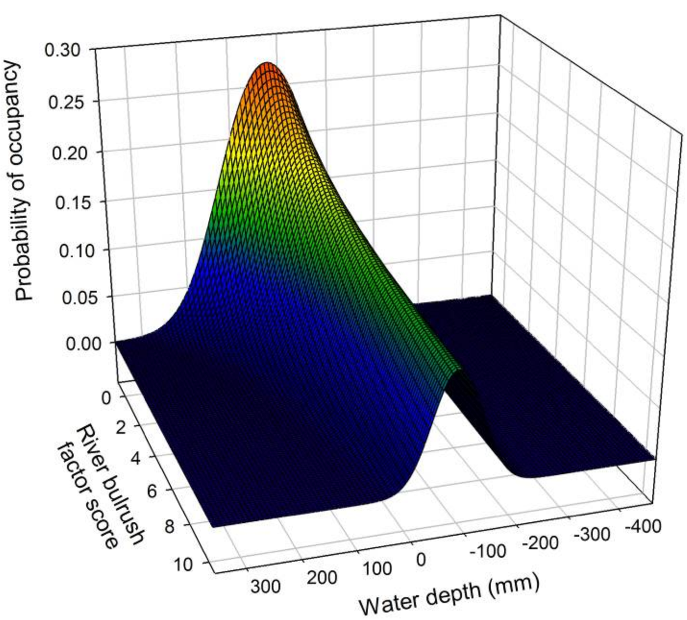

Figure 14. The probability of black rail occupancy given water depth, the factor score for river bulrush, and all other variables held at their mean values for occupied locations. River bulrush stem density weighted highest in the river bulrush factor. Hence, an increasing factor score can be conceptualized as increasing stem density of river bulrush.

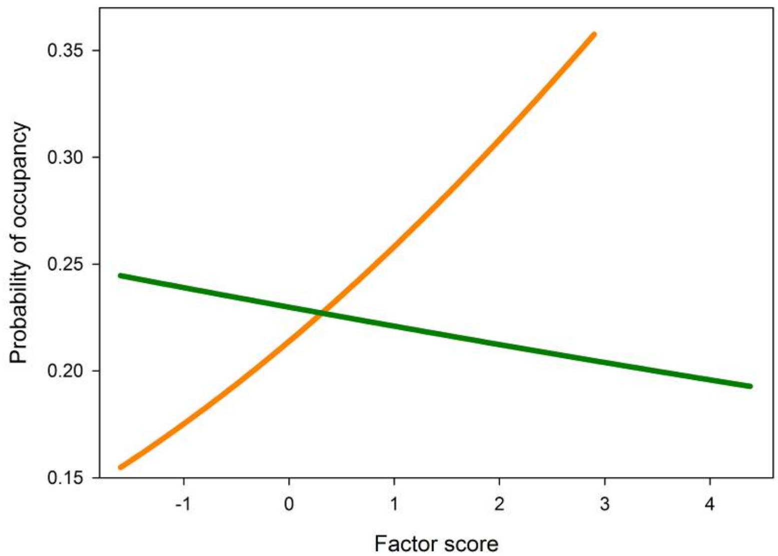

Figure 15. The probability of black rail occupancy given the factor score for chairmaker's bulrush (orange) and southern cattail (green) with the values for all other vegetation variables in the model held at their mean value and water depth at -1 mm. Both standing stem height and stem density weighted highly on the factor score for both plant species. Hence, an increasing factor score can be conceptualized as an increase in either stem density or stem height for each species.

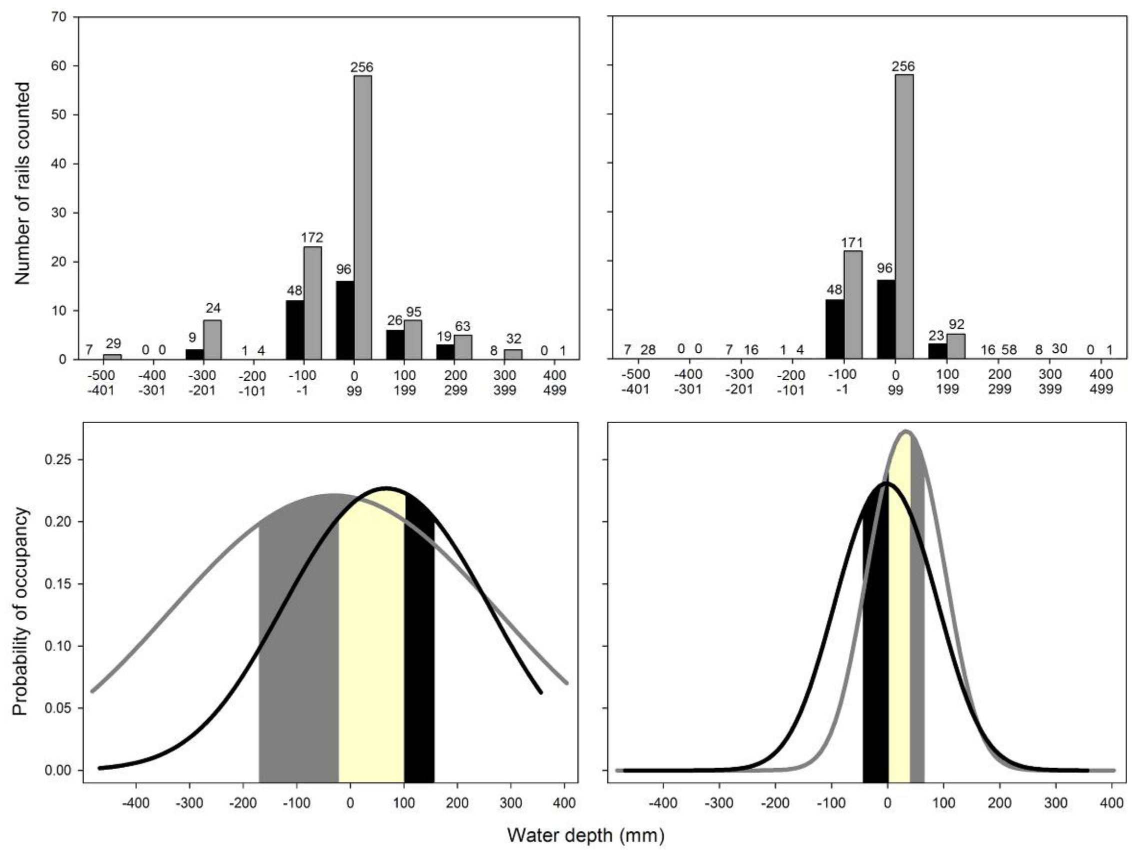

Figure 16. The influence of water depth on black rail (black) and clapper rail (gray) occupancy including all rail observations (left panels) and after removing 20% of rail detections with the most extreme water depths (right panels). The top panels show the number of rails counted in each 100 mm water depth bin. The numbers above the bars are the total number of sites (occupied and random) available in each water detph bin. The 2 bottom panels are the probability of occupancy (from logistic regression) given water depth, with all vegetation variables held at the mean value for occupied locations. The shaded areas in the bottom panels represents the optimal water depth for black rails (black), clapper rails (gray), and the overlap of the optimal water depths for both species (yellow). We considered the water depth optimal where the probability of occupancy was within 10% of the maximum probability of occupancy for both species.

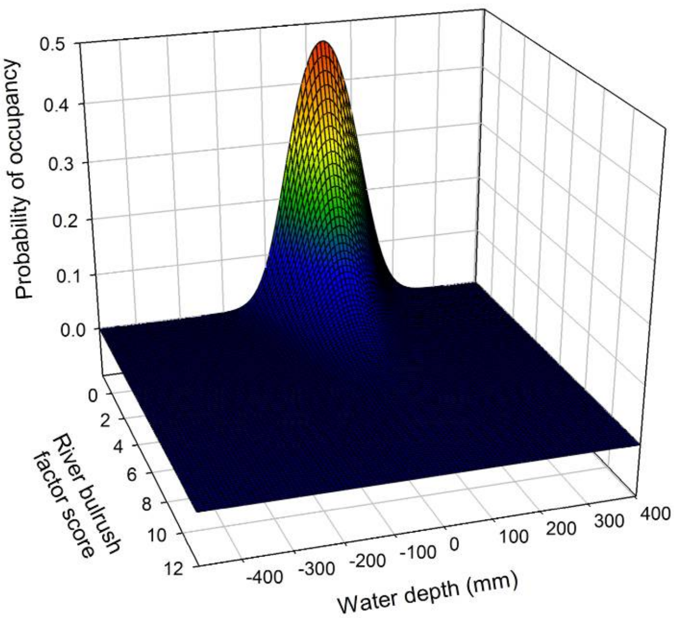

Figure 17. The probability of clapper rail occupancy given water depth, the factor score for river bulrush, and all other variables held at their mean values for occupied locations. River bulrush stem density weighted highest in the river bulrush factor. Hence, an increase in the factor score can be conceptualized as an increase in the stem density of river bulrush.

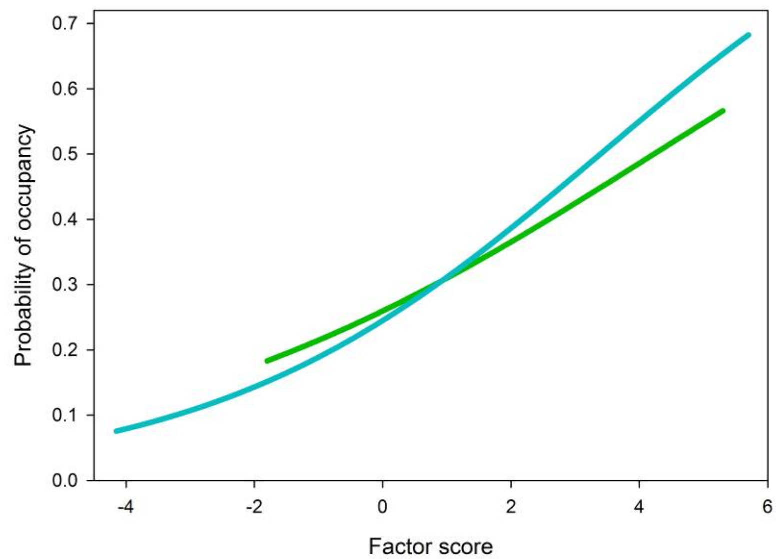

Figure 18. The probability of clapper rail occupancy given the factor score for phragmites (teal) and southern cattail (green) with the values for all other vegetation variables in the model held at their mean value and water depth at 33 mm. Standing stem height and stem density weighted highly on the factor score for both plant species. Hence, an increase in the factor score can be conceptualized as an increase in either stem density or stem height for each species.

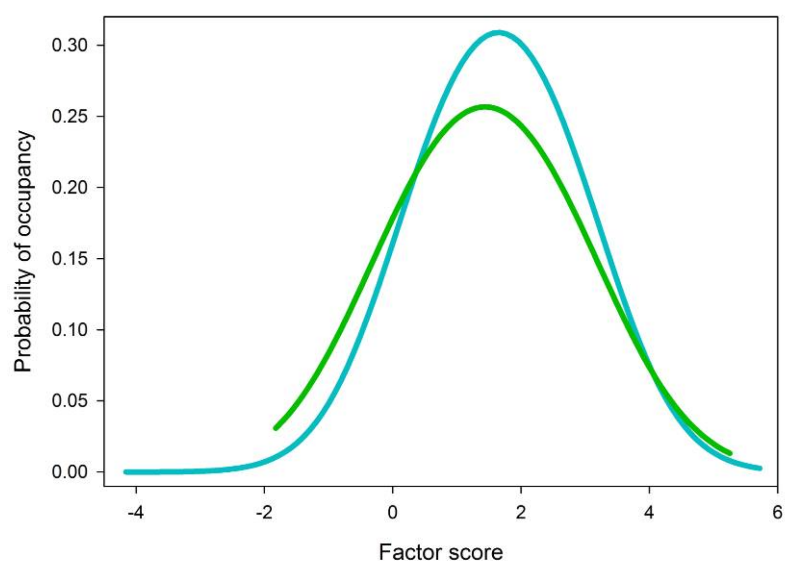

Figure 19. The probability of clapper rail occupancy given the factor score for phragmites (teal) and southern cattail (green) modeled as quadratic terms, with all other vegetation variables held at their mean values for occupied locations. The factor score for both phragmites and southern cattail is positively correlated with the height and density of the species. Hence, this graph suggests that clapper rails prefer earlier successional phragmites and southern cattail (i.e., phragmites and southern cattail that is moderately dense and tall).

DISCUSSION

We were able to determine the effectiveness of wetland restoration efforts and the habitat preferences of both black rails and clapper rails while minimizing some of the drawbacks of traditional vegetation monitoring methods by using interpolation from point measurements of vegetation and water. Our vegetation models characterized the structure and composition of the vegetation in both impoundments with moderate accuracy and allowed us to predict the vegetation at every location throughout the 2 impoundments (not merely within the sampling plots that we monitored). Our models also provided a good representation of the bathymetry of each impoundment, which allowed us to estimate local water depths with moderate accuracy. In fact, the errors presented here are likely overestimates of error due to the nature of the leave-one-out cross validation approach that we used. Leave-one-out cross validation is the most common method used to evaluate interpolation models. However, the method overestimates error because the network of interpolation points is weakened by removing a point (Willmott and Matsuura 2005). For example, if a small patch of common threesquare is only represented by one point, and that point is removed during the cross validation, the interpolation will falsely predict that common threesquare is absent at the point location. The method is particularly biased when the data is highly variable among points, such as with our data. For these reasons, the errors presented here are larger than the errors present in the final models (because we used all of the points in the final spatial models, but had to leave points out to document the predictive ability of the models).

California black rails were most likely to occupy locations in impoundments 16 and 18 with high densities of chairmaker's bulrush, low densities of river bulrush, and shallow water depths (i.e., saturated soil). We also observed a slight negative association between black rails and southern cattail, but our data does not suggest that black rails avoid cattail completely. Indeed, black rails are known to occupy sites where cattail is present (Flores and Eddleman 1995, Conway and Sulzman 2007), but do not use cattail in proportion to its availability suggesting the possibility of interactions between cattail and other habitat characteristics (Flores and Eddleman 1995). Many past studies have suggested that California black rails on the lower Colorado River prefer areas with chairmaker's bulrush and shallow water depths (Repking and Omhart 1975, Evens et al. 1993, Flores and Eddleman 1995, Conway and Sulzman 2007). However, only 1 study has used methods that quantify vegetation and water depth at the locations within the wetland where black rails were detected (Flores and Eddleman 1995). The other studies simply quantified the vegetation and water depth at the wetland scale (Repking and Omhart 1975) or within a predefined radius of the survey point (Evens et al 1991, Conway and Sulzman 2007). Hence, the association of black rails with chairmaker's bulrush and shallow water in these studies could be the result of (1) the location of survey points on the interface of the upland and the wetland, and (2) the movement of black rails towards the survey point in response to the call broadcast (Flores and Eddleman 1995). Although our survey points were also located on the upland edge of the wetland and rails likely moved in response to call broadcast, the distribution of water depths and chairmaker's bulrush in each impoundment was not correlated with the upland edge (Fig. 12). Hence, our results are not subject to these biases, and yet still suggest a strong association with chairmaker's bulrush and shallow water. Furthermore, other studies have suggested that water depth best explains the probability of occupancy for black rails and that the association with chairmaker's bulrush has been overemphasized (Flores and Eddleman 1995). We found that chairmaker's bulrush and water depth are both important in explaining the probability of occupancy for black rails, and that they have similar power to discriminate between occupied and random locations. Our study is the first to use methods that could parse the influences of chairmaker's bulrush and water depth as important habitat characteristics for black rails.

Many studies have also suggested that stable water depths are imperative for black rails (Repking and Omhart 1975, Evens et al. 1991, Flores and Eddlman 1995), but these studies inferred this relationship from black rail abundance in relation to the proximity of a dam (Repking and Omhart 1975), from the type of wetland (i.e., seep, slough, or riverine) where black rails were most abundant (Evens et al. 1993), or from black rail's preference for shallow water (Flores and Eddleman 1995). These studies did not compare black rail abundance within (1) different wetlands with similar vegetation but different temporal ranges in water depth, or (2) the same wetland with different temporal ranges in water depth among years. We were able to compare the same 2 wetland impoundments with different temporal ranges in water depth among years, because INWR staff automated the irrigation of both impoundments in February 2010, which significantly stabilized temporal ranges in water depth. Our data suggests that black rails prefer more stable water depths. However, this result is difficult to decouple from the decrease in water depth that occurred simultaneously with the stabilization of water depth.

Yuma clapper rails were most likely to occupy locations with low densities of river bulrush, moderate densities of phragmites and southern cattail, and 0 to 65 mm of water. Yuma clapper rails are known to be strongly associated with southern cattail on the lower Colorado River (Eddleman and Conway 1998), and are often found in areas dominated by phragmites as long as there is southern cattail present or nearby (Smith 1975, Todd 1986, Hinojosa-Huerta et al. 2001). Moreover, clapper rails are known to be more abundant in early successional marshes, where the vegetation is not too dense (Conway et al. 2010). The optimal water depth identified in our study is shallower than those reported by previous authors (<300 mm, Gould 1975, Todd 1986; <150 mm, Powell 1984; $\bar{x}$ = 258 mm, Eddleman 1989), but similar to the 30 to 80 mm range reported by Smith (1974). The deepest water areas in impoundment 18 were sparsely vegetated, precluding the occupancy of clapper rails and impoundment 16 had few deep water areas. Moreover, the water depth in each impoundment can only get so deep before overflowing the dikes. Hence, the shallow optimal water depth is likely a result of the lack of deep water areas with sufficient vegetation within the 2 impoundments. However, shallow water areas, such as those in impoundment 16 and 18 are important breeding areas for clapper rails (Conway et al. 1993). Moreover, Yuma clapper rails are thought to be tolerant of shallow water as long as the soil does not become dry (Todd 1986). Yuma clapper rails also appear to be tolerant of highly fluctuating water depths. Water depths in impoundment 16 varied greatly in 2009 when clapper rails were most abundant in that impoundment.

Impoundment 18 was a very successful wetland restoration for black rails and clapper rails. Clapper rails, black rails, and least bitterns were present in impoundment 18 within a year of planting, and were still relatively abundant in the impoundment 2 years after planting. However, we recommend some improvements for future marsh restoration efforts that attempt to create habitat for black rails and clapper rails. Most importantly, both rail species seem to be negatively associated with river bulrush. We do not know why both species avoided river bulrush, especially considering river bulrush is used by other wetland-dependent birds in Wisconsin (Manci and Rusch 1988). River bulrush is rare on the lower Colorado River and should not be planted so as to avoid the spread of this species to other wetlands. If possible, plantings should be screened for this species prior to being planted to ensure contaminated nursery samples are not planted in future wetland restorations. Similarly, we discourage planting common threesquare. Common threesquare is also rare on the lower Colorado River (Nadeau and Conway, unpublished data). Our data shows that common threesquare is capable of colonizing a larger range of water depths than chairmaker's bulrush. Hence, introduced common threesquare could outcompete chairmaker's bulrush in some situations. We do not know whether black rails would be negatively affected if chairmaker's bulrush were to be displaced by common threesquare, but it is wise to assume (until proven otherwise) that it could be detrimental to black rails. We recommend planting only chairmaker's bulrush and southern cattail in areas intended to support black rails and clapper rails. These 2 species are common emergent wetland plants on the lower Colorado River. Chairmaker's bulrush appears to be most successful when planted in areas where water depths average between 0 and 100 mm. Southern cattail appears to be most successful in areas where water depths average between 0 and 150 mm.

MANAGEMENT RECOMMENDATIONS

Our results suggest that a wetland can be managed simultaneously for both California black rails and Yuma clapper rails by (1) maintaining mostly shallow water depths (saturated soil to <40 mm), (2) maintaining stable water in shallow areas (where black rails are expected), and (3) promoting chairmaker's bulrush in shallow water areas (<30 mm) where black rails are most likely to occur and southern cattail in deeper water areas (>30 mm) where clapper rails are most likely to occur. We do not recommend planting species other than chairmaker's bulrush or southern cattail. In areas where water depths are likely to exceed 350 mm, we encourage planting California bulrush (*Schoenoplectus californicus*), which is tolerant of deep water and common on the lower Colorado River. We suggest planting any new marsh restoration sites immediately after water is added to the site to discourage the growth of phragmites and other invasive plants. We strongly encourage the use of automated irrigation procedures such as those implemented in impoundments 16 and 18 in 2010. Automated irrigation stabilizes water depth and reduces the time and money necessary to maintain water delivery. Furthermore, automated irrigation reduces the need for staff to coordinate irrigation among their many other tasks and among co-workers during vacation and holidays. Staff at INWR followed the irrigation schedule listed in Table 9. Note, however, that the length of each irrigation event will vary based on the number and size of the impoundments being irrigated. We propose a simple wetland design for future managed wetland impoundments including 3 components: (1) an area with shallow and stable water depths (-10 to 30 mm) at one end of the impoundment planted with chairmaker's bulrush; (2) a gradual slope planted with a mix of 30% chairmaker's bulrush and 70% southern cattail; and (3) an area with deep water (250 to 350 mm deep) planted with southern cattail. The design of such a wetland could take many shapes from (1) a mosaic of deep (some >40 mm) and shallow water pools, or (2) a wetland with a gently sloping gradient from shallow (0 mm) to deep (>40 mm). We recommend that all future marsh restoration efforts be designed so that we can learn from their outcomes. We also recommend the use of prescribed fire to maintain the early successional vegetation in restoration efforts based on the results of recent research (Conway et al. 2010).

Table 9. Automated irrigation schedule for the wetland impoundments at Imperial National Wildlife Refuge. This schedule was implemented in 2010.

Months	**Days/Week Irrigated**	**Length Of Irrigation Event**
January - March	3	6
April - May	4	6
June - October	4	8
November - December	3	6

LITERATURE CITED

Anderson, B. W. and R. D. Omhart. 1985. Habitat use by clapper rails in the lower Colorado River valley. *Condor* 87:116-126.

Arizona Game and Fish Department. 1996. Wildlife of special concern in Arizona. Nongame and Endangered Wildlife Program, Arizona Game and Fish Department, Phoenix, AZ, USA.

Bate (Nadeau), J. 2009. Applying Adaptive Management to Multi Species Habitat Conservation Planning: A Case Study Review. MS Thesis, University of Arizona, Tucson, AZ, USA.

Barton, K. 2010. MuMIn: Multi-model inference. R package version 0.13.17. http://CRAN.R-project.org/package=MuMIn

Bennett, W. W. and R. D. Omhart. 1978. Habitat requirements and population characteristics of the clapper rail in the Imperial Valley of California. University of California, Lawrence Livermore Laboratory, Livermore, CA, USA.

Bolduc, F. and A. D. Afton. 2008. Monitoring waterbird abundance in wetlands: The importance of controlling results for variation in water depth. *Ecological Modeling* 216: 402-408.

Burnham, K. P. and D. R. Anderson. 2001. Model selection and multimodel inference: A practical information-theoretic approach. 2nd Edition. Springer, New York, NY, USA.

California Department of Fish and Game. 2006. State and federally listed endangered and threatened animals of California. Biogeographic Data Branch, California Department of Fish and Game, Sacramento, CA, USA.

Conway, C. J. 2009. Standardized North American Marsh Bird Monitoring Protocols, version 2009-2. Wildlife Research Report #2009-02. U.S. Geological Survey, Arizona Cooperative Fish and Wildlife Research Unit, Tucson, AZ, USA.

Conway, C. J., W. R. Eddleman, S. H. Anderson, and L. R. Hanebury. 1993. Seasonal Changes in Yuma Clapper Rail Vocalization Rate and Habitat Use. *Journal of Wildlife Management* 57:282-290.

Conway, C. J. and C. Sulzman. 2007. Status and habitat use of the California black rail in the southwestern U.S.A. *Wetlands* 27: 987-998.

Conway, C. J., C. Sulzman, and B. E. Raulston. 2002. Population trends, distribution, and monitoring protocols for the California black rail. Technical Report (Heritage Program IIPAM Grant # I99010), Arizona Game and Fish Department, Phoenix, AZ, USA.

Conway, C. J., C. P. Nadeau, and L. Piest. 2010. Fire helps restore natural disturbance regime to benefit rare and endangered marsh birds endemic to Colorado River. *Ecological Applications* 20: 2024-2035.

Dahl, T. E. 1990. Wetland losses in the United States 1780's to 1980's. U.S . Department of the Interior, Fish and Wildlife Service, Washington, D.C, USA.

Dahl, T. E. 2006. Status and trends of wetlands in the conterminous United States 1998 to 2004. U.S. Department of the Interior, Fish and Wildlife Service, Washington, DC, USA.

Diario Oficial de la Federacion. 2002. Norma Oficial Mexicana NOM-059-ECOL-2001, Proteccion ambiental-Especies nativas de Mexico de flora y fauna silvestres-Categoriosde riesgo y especificaciones para su inclusion, exclusion o cambio-Lista de especies en riesgo. Secretaria de Medio Ambiente y Recursos Naturales, 6 Marzo 2002.

Eddleman, W. R. and C. J. Conway. 1998. Clapper Rail (Rallus longirostris). *In* A. Poole and F. Gill (eds.) The Birds of North America, no. 340. The Academy of Natural Sciences, Philadelphia, PA, USA.

Eddleman, W. R., R. E. Flores, and M. L. Legare. 1994. Black rail (*Laterallus jamaicensis*). *In* A. Poole and F. Gill (eds.) The Birds of North America, no. 123. The Academy of Natural Sciences, Philadelphia, PA, USA.

Evens, J. G., G. W. Page, S. A. Laymon, and R. W. Stallcup. 1991. Distribution, relative abundance and status of the California black rail in western North America. *Condor* 93:952-966.

Flores, R. E. and W. R. Eddleman. 1991. Ecology of the California black rail in southwestern Arizona. Final report. Arizona Game and Fish Department, Phoenix, Arizona, USA.

Flores, R. E. and W. R. Eddleman. 1995. California Black Rail use of habitat in Southwestern Arizona. *Journal of Wildlife Management* 59:357-363.

Gibbs, J. P., F. A. Reid, and S. M. Melvin. 1992. Least Bittern (Ixobrychus exilis). *In* A. Poole and F. Gill (eds.) The Birds of North America. The Academy of Natural Sciences, Philadelphia, PA, USA.

Glorfeld, L. W. 1995. An improvement on horn's parallel analysis methodology for selecting the correct number of factors to retain. *Educational and Psychological Measurement* 55: 377-393.

Gould, G. 1975. Yuma clapper rail study-censuses and habitat distribution. Calif. Dep. of Fish and Game, Wildlife Management Branch Administrative Report No. 75-2, Sacramento, CA, USA.

Hinajosa-Huerta, O., S. DeStafano, and W. Shaw. 2001. Distribution and abundance of the Yuma clapper rail (Rallus longirostris yumanensis) in the Colorado River delta, Mexico. *Journal of Arid Environments* 49: 171-182.

Hosmer, D. W. and S. Lemesbow. 1980. Goodness of fit tests for the multiple logistic regression model. *Communications in Statistics - Theory and Methods* 9: 1043-1069

Kerlinger, P. and D. S. Wiedner. 1990. Habitat use and vocal behavior of black rails in South Jersey. *Records of New Jersey Birds* 16: 58-62.

Latta, M. J., C. J. Beardmore, and T. E. Corman. 1999. Arizona Partners-In-Flight Bird Conservation Plan. Technical Report 142. Arizona Game and Fish Department, Phoenix, AZ, USA.

Legare, M. L. and W. R. Eddleman. 2001. Home Range Size, Nest-Site Selection and Nesting Success of Black Rails in Florida. *Journal of Field Ornithology* 72: 170-177.

Lower Colorado River Multi-Species Conservation Program. 2004. Lower Colorado River Multi-Species Conservation Program Volume II: Habitat Conservation Plan, Final, J&S 00454.00, Sacramento, CA, USA.

Manci, K. M. and D. H. Rusch. 2005. Indices to distribution and abundance of some inconspicuous waterbirds on Horicon Marsh. *Journal of Field Ornithology* 59: 67-75.

Manolis*, T.* 1978*.* Status of the black rail in central California. *Western Birds 9: 151–158.*

Metz, C. E. 1978. Basic principles of ROC analysis. *Seminars in Nuclear Medicine* 8: 283-298

Nadeau, C. P and C. J. Conway. 2008. Restoration of managed marsh units to benefit California black rails and other marsh bird: an adaptive management approach. December 2008 Progress Report. University of Arizona, Tucson, AZ, USA.

Nadeau, C. P, and C. J. Conway. 2009. Restoration of managed marsh units to benefit California black rails and other marsh birds: an adaptive management approach. March 2009 Progress Report. University of Arizona, Tucson, AZ, USA.

Nadeau, C. P., C. J. Conway, and K. M. Morris. 2010. Restoration of managed marsh units to benefit California black rails and other marsh bird: an adaptive management approach. February 2010 Progress Report. University of Arizona, Tucson, AZ, USA.

Ogonowski, M. S., C. P. Nadeau, and C. J. Conway. 2009. Restoration of managed marsh units to benefit California black rails and other marsh birds: an adaptive management approach, August 2009 Progress Report. Wildlife Research Report #2009-03, USGS Arizona Cooperative Fish and Wildlife Research Unit, Tucson, AZ, USA.

Pearce, J. and S. Ferrier. 2000 Evaluating the predictive performance of habitat models developed using logistic regression. *Ecological Modeling* 133: 225-245.

R Development Core Team. 2010. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, http://www.R-project.org.

Remote Data Systems. 2011. Description of the RDS Ecotone WM 2.0 m Water Level Monitor - WM16k2030. Accessed 28 March 2011, http://www.rdsys.com/rds-ecotone-wm-water-level-monitors/rds-ecotone-wm-2.0m-water-level-monitor-wm16k2030/

Runde, D. E., P. D. Southall, J. A. Hovis, R. Sullivan, and R. B. Renken. 1990. Recent records and survey methods for the black rail in Florida. *Florida Field Naturalist* 18: 33-35.

Repking, C. F. and R. D. Ohmart. 1977. Distribution and density of *black rail* populations along the lower Colorado River. *Condor* 79:486-489.

Rush, S. A., E. C. Soehren, M. S. Woodrey, C. L. Graydon, and R. J. Cooper. 2009. Occupancy of select marsh birds within northern Gulf of Mexico tidal marsh: current estimates and projected change. *Wetlands* 29: 798-808.

Russell, S. M. 1966*. Status of the* Black Rail *and Gray-breasted Crake in British Honduras. Condor 68:105-107.*

Smith, P. M. 1975. Habitat requirements and observations on the clapper rail, *Rallus longirostris yumanensis.* M.S. Thesis, Arizona State University. Tempe, AZ, USA.

Sprecher, S. W. 2000. Installing Monitoring Wells/Piezometers in Wetlands. ERDC TN-WRAP-00-02, U.S. Army Research and Development Center, Vicksburg, MS, USA.

Todd, R. L. 1986. A saltwater marsh hen in Arizona: a history of the Yuma clapper rail (Rallus longirostris yumanensis). Arizona Game and Fish Department, Federal Aide Project W-95-R, Completion Rep., Phoenix, AZ, USA.

Tomlinson, R. E. and R. L. Todd. 1973. Distribution of two western clapper rail races as determined by responses to taped calls. *Condor* 75: 177-183.

U.S Fish and Wildlife Service. 1983. Yuma Clapper Rail Recovery Plan. U.S Fish and Wildlife Service, Albuquerque, NM, USA.

U.S. Fish and Wildlife Service. 2008. Birds of Conservation Concern 2008. United States Department of Interior, Fish and Wildlife Service, Division of Migratory Bird Management, Arlington, VA, USA.

Weske, J. S. 1969. An ecological study of the black rail in Dorchester County, Maryland. Thesis, Cornell University, Ithaca, NY, USA.

Willmott, C. J. and K. Matsuura. 2005. On the use of dimensioned measures of error to evaluate the performance of spatial interpolators. *International Journal of Geographical Information Science* 20: 89-102.