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# Linking multi-temporal satellite imagery to coastal wetland dynamics and bird distribution

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ABSTRACT

Ecosystems are characterized by dynamic ecological processes, such as flooding and fires, but spatial models are often limited to a single measurement in time. The characterization of direct, fine-scale processes affecting animals is potentially valuable for management applications, but these are difficult to quantify over broad extents. Direct predictors are also expected to improve transferability of models beyond the area of study. Here, we investigated the ability of non-static and multi-temporal habitat characteristics to predict marsh bird distributions, while testing model generality and transferability between two coastal habitats. Distribution models were developed for king rail (*Rallus elegans*), common gallinule (*Gallinula galeata*), least bittern (*Ixobrychus exilis*), and purple gallinule (*Porphyrio martinica*) in fresh and intermediate marsh types in the northern Gulf Coast of Louisiana and Texas, USA. For model development, repeated point count surveys of marsh birds were conducted from 2009 to 2011. Landsat satellite imagery was used to quantify both annual conditions and cumulative, multi-temporal habitat characteristics. We used multivariate adaptive regression splines to quantify bird–habitat relationships for fresh, intermediate, and combined marsh habitats. Multi-temporal habitat characteristics ranked as more important than single-date characteristics, as temporary water was most influential in six of eight models. Predictive power was greater for marsh type-specific models compared to general models and model transferability was poor. Birds in fresh marsh selected for annual habitat characterizations, while birds in intermediate marsh selected for cumulative wetness and heterogeneity. Our findings emphasize that dynamic ecological processes can affect species distribution and species–habitat relationships may differ with dominant landscape characteristics.



## 1. Introduction

Knowledge of species distributions are fundamental for conservation and management of animal populations. Over broad spatial scales, species distribution models (SDMs) are important tools for spatial interpolation and extrapolation of survey data using statistical species–habitat relationships (Guisan and Zimmermann, 2000). Generally, SDMs use static habitat characteristics (e.g., elevation, land-cover, climate) to correlate with species distribution. However, disturbances are fundamental to ecosystems (Pickett and White, 1985), and SDMs may benefit from the inclusion of ecological processes such as flooding, grazing, extreme weather events, and fires. These events may have cumulative properties or may result in dynamic habitats. The characterization of fine-scale ecological processes is inherently more direct, or mechanistic, in SDMs (e.g., related to prey availability, refuge from predators), compared to more correlative models (e.g., climate, elevation) (see Dormann et al., 2012). Yet only a few SDMs have investigated multi-temporal ecological processes or dynamic habitats. For example, Mueller et al. (2008) used satellite imagery to quantify changes in ungulate distribution related to the Normalized Difference Vegetation Index (NDVI), which was indicative of seasonal forage quality in African grasslands.

Models informed by satellite imagery have concentrated on land-cover classifications or variants of the NDVI (Leyequien et al., 2007; Pettorelli et al., 2011), but these applications use only a minor fraction of available reflectance data from imagery. Recent studies have included other indices, such as texture (Bellis et al., 2008) and raw satellite imagery bands (Shirley et al., 2013), although reflectance data is difficult to interpret when no a priori meaning is identified (see Meiman et al., 2012). An approach that characterizes ecologically meaningful remote sensing variables is therefore needed to bridge the gap between ecological and geographical

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perspectives (Cord et al., 2014). Satellite imagery is readily available at a relatively fine-scale (30 m for Landsat Thematic Mapper), and its high temporal resolution has the potential to measure direct habitat characteristics, including disturbance regimes, related to animals. Furthermore, the generality and specificity of direct remote sensing models is unknown.

The projection of SDMs outside the area of their development, or spatial transferability, is increasingly needed to extend predicted distributions over broad spatial extents (Franklin, 2010). A major factor affecting transferability, and generality, of SDMs is the type of predictor variables. Indirect, direct, and resource gradient predictors have been recognized (Austin and Smith, 1989; Guisan and Zimmermann, 2000), but we note that predictor types are not always straightforward (e.g., water may be consumed by an animal or may be needed for prey species). Here, we clump direct and resource predictors into the same category of being "direct." Direct, ecologically meaningful resource predictors of species are expected to be more transferable in comparison to factors with no direct effect on an organism's physiology (Guisan and Zimmermann, 2000; Randin et al., 2006; Vanreusel et al., 2007), such as topography or land-cover. Therefore, remote sensing based habitat characterizations of foraging habitat and vegetative cover, representing direct variables for wildlife species, are expected to produce transferable models. However, SDM transferability can also be affected by the truncation of abiotic predictors within a region (Sundblad et al., 2009) or with differing dominant landscape characteristics. For example, SDMs of marbled murrelet (*Brachyramphus marmoratus*) had weakened transferability due to differing degrees of fragmentation between regions (Zharikov et al., 2007).

We developed SDMs for four marsh birds (i.e., rails, bitterns, gallinules) in coastal Louisiana and Texas, USA. Over broad extents, the general distribution of the waterbird guild has been linked to coarse land-cover (10 km) (Virkkala et al., 2005), fine-scale land-cover (10 m) (Heinanen et al., 2012), and annual precipitation patterns (Forcey et al., 2011). Meanwhile, localized field studies have shown marsh birds select for water depth (Lor and Malecki, 2006; Tozer et al., 2010) and open water-vegetation edge (Rehm and Baldassarre, 2007; Rush et al., 2009). Here, we used satellite imagery with a broad spatial extent to characterize fine-scale, dynamic wetland patterns and processes related to marsh bird food availability and vegetative cover. Few predictors were static over the course of study, and several variables invoked a cumulative multi-temporal imagery to characterize habitat. Here, we define *multi-temporal* habitat variables as those derived from multiple dates of imagery to characterize an accumulation of ecological information (e.g., flooding regime). *Single-date* habitat characteristics were derived from a single image during each year in which bird surveys were conducted. Marsh bird distributions were modeled in fresh and intermediate (oligohaline) coastal marsh types where flooding and salinity regimes differ. The geographic range of all bird species extended beyond the study area extent. Our objectives were: (1) develop SDMs for the resident king rail (*Rallus elegans*) and common gallinule (*Gallinula galeata*) as well as the migratory breeders, least bittern (*Ixobrychus exilis*) and purple gallinule (*Porphyrio martinica*); (2) compare selection of annual, single-date habitat measures with selection of multi-temporal wetland characteristics (i.e., flooding regime); (3) compare marsh type-specific models with general species models, and test the transferability of models between the two marsh types. We hypothesized multi-temporal habitat characteristics would rank higher and be selected more often than single-date habitat measures because multi-temporal imagery characterizes valuable information on wetland dynamics, such as flooding duration and frequency. We also hypothesized models would be transferable because marsh birds select for a limited number of habitat features (e.g., open water-vegetation edge) characterized directly in our study, and the assumption is species–habitat relationships are unvarying in all marshes.

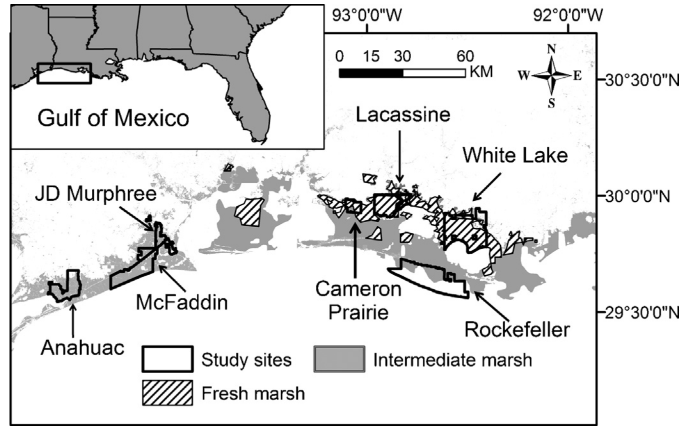


**Fig. 1.** Extent of the study area in Louisiana and Texas, USA. Study sites are named.

## 2. Methods

### 2.1. Study area

Study sites were in the Chenier Plain of Louisiana and Texas, USA (Fig. 1), which is characterized by sand ridges that restrict tidal influence (McBride et al., 2007). Fresh marsh sites included Lacassine National Wildlife Refuge (NWR), White Lake Conservation Area, and part of Cameron Prairie NWR. Dominate vegetation species were *Panicum hemitomon*, *Typha* spp., and *Sagittaria lancifolia*. Rockefeller State Wildlife Refuge, JD Murphree Wildlife Management Area, McFaddin NWR, part of Cameron Prairie NWR, and Anahuac NWR were intermediate marshes. The classification of intermediate marsh followed Visser et al. (2000), which included three oligohaline marsh communities. Dominate vegetation included *Spartina patens*, *Phragmites australis*, *Schoenoplectus* spp., *Typha* spp., and *Paspalum vaginatum*. Water levels are primarily determined by rainfall, seasonal wind-driven tides, and water-level management. Rainfall in winter months (November–February) typically floods marshes, and then flooding recedes during the late spring and summer with the exception of permanent ponds, canals, and impoundments. Fresh marsh in the region has been altered for the purpose of navigation, prevention of floods and salt water intrusion, and to hold water in the basin for rice growers (Gunter and Shell, 1958). Intermediate marshes are also affected by hydrological modifications, but they are not as strongly modified for agricultural purposes. Both marsh types are often managed to hold water during the winter for waterfowl, particularly in fresh marsh. The result is generally deeper water levels in fresh marsh compared to intermediate marsh (Pickens and King, 2014). In Louisiana, Snedden and Steyer (2013) reported fresh marsh dominated by *P. hemitomon* and *S. lancifolia* were flooded for 62% of the year, while intermediate marshes dominated by *S. patens* were flooded for 45–55% of year. However, the difference in flooding duration may be greater, as Nyman et al. (2009) showed *S. patens* marshes were flooded for only 21–32% of the year. Meanwhile, impounded fresh marsh sites dominated by *Typha* spp. are likely to be flooded 100% of the year.

### 2.2. Marsh bird surveys

Bird surveys were conducted from early March to mid-June of 2009–2011. March was the start of the resident breeding bird season and migratory breeding birds arrived by late April. Over 100