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# A Bayesian network approach to predicting nest presence of the federally-threatened piping plover (*Charadrius melodus*) using barrier island features[☆]

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ABSTRACT

Sea-level rise and human development pose significant threats to shorebirds, particularly for species that utilize barrier island habitat. The piping plover (*Charadrius melodus*) is a federally-listed shorebird that nests on barrier islands and rapidly responds to changes in its physical environment, making it an excellent species with which to model how shorebird species may respond to habitat change related to sea-level rise and human development. The uncertainty and complexity in predicting sea-level rise, the responses of barrier island habitats to sea-level rise, and the responses of species to sea-level rise and human development necessitate a modeling approach that can link species to the physical habitat features that will be altered by changes in sea level and human development. We used a Bayesian network framework to develop a model that links piping plover nest presence to the physical features of their nesting habitat on a barrier island that is impacted by sea-level rise and human development, using three years of data (1999, 2002, and 2008) from Assateague Island National Seashore in Maryland. Our model performance results showed that we were able to successfully predict nest presence given a wide range of physical conditions within the model's dataset. We found that model predictions were more successful when the ranges of physical conditions included in model development were varied rather than when those physical conditions were narrow. We also found that all model predictions had fewer false negatives (nests predicted to be absent when they were actually present in the dataset) than false positives (nests predicted to be present when they were actually absent in the dataset), indicating that our model correctly predicted nest presence better than nest absence. These results indicated that our approach of using a Bayesian network to link specific physical features to nest presence will be useful for modeling impacts of sea-level rise or human-related habitat change on barrier islands. We recommend that potential users of this method utilize multiple years of data that represent a wide range of physical conditions in model development, because the model performed less well when constructed using a narrow range of physical conditions. Further, given that there will always be some uncertainty in predictions of future physical habitat conditions related to sea-level rise and/or human development, predictive models will perform best when developed using multiple, varied years of data input.


## 1. Introduction

Many shorebird species are threatened by the impacts of sea-level rise and human development on their habitats, particularly their low-lying habitats found on barrier islands. Barrier islands are long, narrow landforms that fringe mainland coasts, and are bounded on one side by an ocean, gulf, or sea, and on the other side by a lagoon that abuts the mainland (Davis and FitzGerald, 2004). Along the US Atlantic Coast, barrier islands stretch from Maine to Florida, or some 3700 km and encompass an area of 6800 km$^2$ (Zhang and Leatherman, 2011). These barrier islands provide vital


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breeding habitat for many shorebird species, including the piping plover (*Charadrius melodus*), a shorebird that was federally listed as threatened along the US Atlantic Coast under the US Endangered Species Act in 1986 (US Fish and Wildlife Service, 1985).

Piping plover nest site selection is driven by the need to select habitat features that maximize access to reliable food sources and minimize flooding from overwash or storms, predation, and intraspecific/interspecific competition for food resources. A balancing of these selective forces results in plovers typically nesting on flat, open, low-lying dry sand or pebble beaches (Houghton, 2005) with clumped sparse vegetation (Cohen, 2005; Cohen et al., 2008), adjacent to moist substrate habitat (MOSH) where plovers feed (Cohen, 2005), near dunes (Burger, 1987; Powell and Cuthbert, 1992), and away from the high tide boundary (Cohen, 2005).

Piping plovers select nest sites based on the proximity to MOSH where they feed. On barrier islands, MOSH is most commonly associated with bayside or sound-side low wave energy beaches (Cohen, 2005; Cohen et al., 2009; Keane, 2002) but is generally characterized by habitat features such as intertidal mud flats or sand flats, and ephemeral pools that are rich in preferred prey resources (Elias and Fraser, 2000; Fraser et al., 2005; Keane, 2002; Patterson et al., 1991). Access to a reliable food source is such a vital determinant of nest site selection that piping plovers preferentially nest adjacent to MOSH (Loegering and Fraser, 1995) even when presented with physical barriers that prevent chicks from accessing the MOSH (Fraser et al., 2005; Keane, 2002; Loegering and Fraser, 1995; Patterson et al., 1991).

Piping plovers select bayside or sound-side habitat for nesting not only because of its likely greater proximity to MOSH, but also for the increased protection from flooding, as bayside habitat is farther from oceanfront wave action than ocean-side habitat, and is often separated from the oceanfront by dunes. Plovers that nest on ocean-side beaches typically place nests above the daily and spring high-tide flood levels and close to dunes to avoid overwash events (Maslo et al., 2011). The areas of bare sandy, pebble, or gravel substrate pocketed with clumps of vegetation that typically characterize plover nesting sites offer camouflage from predators for adults and their eggs and chicks (MacIvor, 1990; Maslo et al., 2011; Patterson et al., 1991).

Despite our extensive knowledge on the relationship between piping plover nest site selection and physical features of barrier islands, there has been little work done to explicitly link how sea-level rise or human-induced alterations in barrier island geomorphology affect the physical habitat features selected by nesting piping plovers. Barrier islands' positions between the ocean and mainland make them particularly attractive for commercial and residential real estate while their generally low elevations make them highly vulnerable to the effects of sea-level rise; these conflicting attributes often result in the demand for shoreline protection measures that may actually degrade habitats and resilience in the long-term (Feagin et al., 2005; Houston, 2008; Schlacher et al., 2007; Weinstein et al., 2007). Recent studies on the effects of sea-level rise on barrier islands have emphasized the need for further research on the uncertainty that these anthropogenic factors introduce into the complex process of modeling sea-level rise effects on habitats and species (Chu-Agor et al., 2012; Convertino et al., 2011; Seavey et al., 2011).

Piping plovers respond rapidly to physical changes in their environment (Cohen et al., 2009; Kumer, 2004; Schupp et al., 2013) and are thus an ideal indicator species to model the effects of sea-level rise and human development on barrier island habitat and shorebirds, as has been done in previous studies (Aiello-Lammens et al., 2011; Seavey et al., 2011). The models used in these previous studies delineated general shorebird habitat based on historical nesting locations, and applied sea-level rise and/or human development scenarios to those known nesting habitats. To accurately predict how sea-level and human development driven changes in barrier island physical features will impact piping plovers, we need to link piping plover habitat selection to those physical features that will be altered by these processes. Our objective in this paper was to develop and test a model that links piping plover nest presence or absence to these physical features of their nesting habitat using data readily available across the breeding range via remote sensing tools and minimal on-the-ground effort for beach managers.

We used a Bayesian network (BN) modeling framework to accomplish our objective. A BN is a type of directed graphical model with nodes that represent variables and arcs (i.e. arrows) that represent conditional dependencies among variables. The graphical structure of BN's provide a clear representation of the links among variables that facilitates their use as a resource management tool across multiple disciplines and stakeholder groups (Uusitalo, 2007). The conditional probability distributions for each variable are derived using Bayes' Theorem, and thus BNs can be readily updated as new information becomes available and are easily adapted to a variety of circumstances. Furthermore, the conditional probability distributions can be derived and updated using various forms of data, including data with missing observations, thus allowing uncertainty to be propagated through the network (Koller, 2009). Our ultimate aim in developing this model was to provide a tool for managers to predict piping plover nest presence or absence under various scenarios of sea-level rise and human development. The BN's explicit graphical representation, flexibility, adaptability, and incorporation of uncertainty provided us with the ideal framework with which to build such a model.

In this paper we present how we constructed a BN (Koller, 2009; Pearl, 1988) to link piping plover nest presence to the physical features of a barrier island in Assateague Island National Seashore (ASIS), MD, based on data collected in 1999, 2002, and 2008. We then assess how well the model predicted nest presence or absence within and across years, and how varying ranges of the specific physical features influenced the likelihood of predicting plover nest presence or absence. Finally, we discuss how this model can be simplified and applied to other coastal sites and used to predict future changes in piping plover populations related to sea-level rise and human development.

## 2. Methods

### 2.1. Study site and model variables

The study area encompassed the northern 10 km of ASIS, hereafter 'the North End'. ASIS is located on Assateague Island, Maryland, a 58-km barrier island off the coasts of Maryland and Virginia, US (38°05′ N, 75°12′ W, Fig. 1). Assateague Island supports a mosaic of habitats ranging from marsh and mudflats on the bayside, to coniferous and deciduous forest in the interior, and dunes and sandy beach on the ocean-side. As a barrier island, Assateague Island has low elevations with a mean cross-shore elevation of approximately 4 m above mean sea level (all elevations in this study referenced to North American Vertical Datum 1988 mean sea level, 0.34 m NAVD88) and narrow widths ranging from approximately 220–4500 m. The North End is particularly low lying and narrow, with a mean cross-shore elevation of approximately 1 m above mean sea level and widths ranging from approximately 260–700 m, and has held more than 90% of the total Maryland piping plover nesting population since the National Park Service (NPS) began monitoring plover nesting populations here in 1992.

The North End's particularly low elevation and narrow width compared to the rest of Assateague Island make this area especially vulnerable to storm damage. Severe winter storms in late January and early February 1998 washed over the entire width of the island