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Coastal urbanization and the integrity of estuarine waterbird communities: Threshold responses and the importance of scale

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ABSTRACT

Estuarine ecosystems are becoming increasingly altered by the concentration of human populations near the coastline, however a robust indicator of this change is lacking. We developed an index of waterbird community integrity (IWCI) and tested its sensitivity to anthropogenic activities within 28 watersheds and associated subestuaries of Chesapeake Bay, USA. The IWCI was used as a tool to gain insight into how human land use affects estuarine ecosystem integrity. Based on Akaike's information criteria (AIC), a single variable model including percent developed land in estuarine watersheds was thirteen (2002) and twenty-six (2003) times more likely than models including percent agriculture and forest cover to fit the IWCI data. Consequently, we examined how suburban, urban, and total development shaped IWCI scores at three spatial scales: (1) watershed; (2) inverse-distance-weighted (IDW) watershed (land cover near the coastline weighted proportionally greater than that farther away); (3) local (land cover within 500 m of the coastline). Suburban, urban, and total development were all significant predictors of IWCI scores. Relationships were stronger at the IDW and local scales than at the whole watershed scale. Nonparametric changepoint analysis revealed a >80% probability of a threshold in IWCI scores when as little as 3.7% (2002) and 3.5% (2003) of the IDW land cover within the watershed was urban. Our results indicate that, of the landscape stressors we examined, development near estuarine coastlines is the primary stressor to estuarine waterbird community integrity, and that estuarine ecosystem integrity may be impaired by even extremely low levels of coastal urbanization.

1. Introduction

Estuaries are one of the most biologically productive and threatened ecosystems in the world (Kennish, 2002). Although estuarine structure and function can be compromised by a variety of factors, degradation can often be traced to stressors arising from human development of coastal landscapes. For example, coastal development can alter benthic

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(Hale et al., 2004; King et al., 2005a), fish (Sanger et al., 2004) and marsh bird (DeLuca et al., 2004) communities. Furthermore, eutrophication of coastal waters, frequently the result of anthropogenic nutrient influxes (Nixon, 1995), can disturb estuarine food web structure, potentially compromising both ecological and economic integrity (Baird et al., 2004; Keats et al., 2004). With 75% of the world's population expected to live within 60 km of the coast by 2020 (Roberts and Hawkins, 1999), refining our understanding of how modernizing coastal landscapes shape estuarine condition will be crucial for planning long term, sustainable land use strategies.

Anthropogenic disturbances span local and regional political boundaries and pose difficult conservation dilemmas. Because planning goals, policies, and laws often differ across such borders, cooperation among stakeholders can be the primary obstacle to implementing effective management initiatives (Brody et al., 2004). Two approaches can help ameliorate this situation. First, information about the critical scale at which human activities disrupt ecosystems should be an integral part of land use planning because the scale of disturbance will also determine the scale at which action should be taken (e.g. community, county, state, etc.) (Lovell et al., 2002; Jackson et al., 2004). Second, identifying quantitative thresholds in the response of biota to disturbances can provide conservation planners with simple, numerical targets that can be easily communicated to nonscientists (With and Crist, 1995; DeLuca et al., 2004; Guénette and Villard, 2005). Thus, understanding the scale at which disturbances are influencing ecosystems is particularly important to identifying the numerous political and management agencies that could potentially be involved with conservation actions. Such methods can facilitate the process of conveying sound scientific findings into practical conservation practices.

Bird communities have proven to be effective indicators of ecological condition in research where land cover modifications were hypothesized to affect ecosystem integrity (O'Connell et al., 2000; Bryce et al., 2002; Hausner et al., 2003; Glennon and Porter, 2005). DeLuca et al. (2004) previously demonstrated that even low levels of development near coastal marshes resulted in a threshold response beyond which marsh ecosystem integrity significantly declined. The present study expands on the methods developed for calculating indices of community integrity in DeLuca et al. (2004) and applies them to an aquatic ecosystem. This application enabled us to pursue several novel inquiries from those presented in DeLuca et al. (2004). First, the waterbird community is more directly dependent upon estuarine condition than marsh or near-shore terrestrial bird communities. For example, the presence of breeding terrestrial birds is typically tied to territory locations that may be dependent upon factors other than the current integrity of the site. Such factors include previous breeding success, patch size, social systems, and vegetation structure. Conversely, due to the lack of territoriality of most breeding waterbirds, their presence is more likely related to the current state of food resources at that location. Thus, an index based on the waterbird community is likely to reflect conditions at lower trophic levels and abiotic conditions at survey locations (Takekawa et al., 2006). Second, because waterbirds are part of the aquatic food web of estuaries, this community offers a reliable method to assess the importance of scale within a watershed framework. Disturbances within the watershed have the potential to alter aquatic systems via direct hydrological connectivity. Finally, relatively recent innovations in GIS modeling (i.e. inverse-distance weighting) enabled us to conduct a detailed analysis accounting for local and watershed scales simultaneously, resulting in a refined resolution of the scale at which human disturbance affects waterbirds.

We developed an index of waterbird community integrity (IWCI) and used it as a tool to evaluate whether coastal anthropogenic landscape disturbances alter estuarine ecosystems. We first determined which land cover types were significant stressors to the IWCI and then evaluated how these land cover types affected the IWCI at three geographic scales: watershed, inverse-distance-weighted (IDW) watershed (emphasizing land cover near the shoreline to account for within-watershed spatial arrangement), and local (within 500 m of the subestuary). Finally, we tested the hypothesis that nonlinear relationships between land cover and IWCI scores represented ecological thresholds.

2. Study site and methods

2.1. Study area

Field work was conducted in subestuaries of Chesapeake Bay, USA (39° 23′ N; 36° 48′ N–76° 45′ W; 75° 44′ W). The periphery of Chesapeake Bay is dominated by subestuaries which are small, shallow estuarine embayments, many of which are fed by third through fifth order streams. Chesapeake Bay is one of the largest and most productive estuaries in the world. It is characterized by 7400 km of tidal shoreline, shallow waters, approximately 101,000 ha of estuarine wetlands, and diverse floral and faunal communities (Tiner and Burke, 1995; Lippson and Lippson, 1997). Land cover within the Chesapeake Bay watershed is varied, but spatially aggregated. Industrial and high-density urban development are concentrated on the western shore of the bay near Baltimore, Maryland and Portsmouth, Virginia. Forest cover is highest in the vicinity of the Patuxent River on the western shore, but declines as it becomes increasingly interspersed with urban/suburban development to the north and low-density agriculture to the south. Commercial agriculture dominates the eastern shore of the bay and consists of row crops, poultry farms, and pasture.

2.2. Site selection and classification

We selected 28 subestuaries (Fig. 1) based on land cover characteristics, geomorphology, and hydrology of surrounding watersheds. Watershed boundaries were delineated using techniques described by King et al. (2005a). We used National Land Cover Data (USEPA, 2000) to select watersheds that best represented land cover types present in the study area, while minimizing confounding effects of spatial distribution unrelated to land cover (King et al., 2005b). We required that watersheds contain a third through fifth order stream that drained to a well-defined subestuary. These conditions were necessary because we wished to maximize hydrological connectivity between watershed land cover and biological processes in