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Predicting habitat associations of five intertidal crab species among estuaries

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ABSTRACT

Intertidal crab assemblages that are active on the sediment surface of tropical estuaries during tidal exposure play an important role in many fundamental ecosystem processes. Consequently, they are critical contributors to a wide range of estuarine goods and services. However, a lack of understanding of their spatial organization within a large landscape context prevents the inclusion of intertidal crabs into generally applicable ecological models and management applications. We investigated spatial distribution patterns of intertidal crabs within and among eight dry tropical estuaries spread across a 160 km stretch of coast in North East Queensland, Australia. Habitat associations were modelled for five species based on photographic sampling in 40–80 sites per estuarine up- and downstream component: *Uca seismella* occurred in sites with little structure, bordered by low intertidal vegetation; *Macrophthalmus japonicus* occupied flat muddy sites with no structure or vegetation; *Metopograpsus frontalis* and *Metopograpsus latifrons* occupied sites covered with structure in more than 10% and 25% respectively. Finally, both *Metopograpsus* spp. and *Metopograpsus thukuhar* occupied rock walls. Habitat associations were predictable among estuaries with moderate to high sensitivity and low percentages of false positives indicating that simple, physical factors were adequate to explain the spatial distribution pattern of intertidal crabs. Results provide a necessary first step in developing generally applicable understanding of the fundamental mechanisms driving spatial niche organization of intertidal crabs within a landscape context.

1. Introduction

Tropical estuaries are among the economically most valuable ecosystems of the world because they support high productivity and a diversity of ecosystem goods and services used by humans (Costanza et al., 1997; Ronnback, 1999). For instance, they provide food, firewood and medicines, prevent coastal erosion, trap pollutants and provide nurseries for many commercially important fish (Alongi, 2002). However, the ecological functioning of tropical estuaries, and accordingly their ability to provide goods and services, is jeopardized by growing urbanization and the increasing impacts of climate change (Lovelock and Ellison, 2007; Alongi, 2008). As a result, large areas of tropical estuaries have disappeared (Valiela et al., 2001) and the condition of remaining areas is deteriorating (Alongi, 2002; Duke et al., 2007). Impacts are likely to continue because many more major urban and economic centers are expected to develop on tropical estuaries over the next few decades (Seto, 2011). Consequently, a generally applicable understanding of the ecological functioning of tropical estuaries relevant to the large, estuary wide, scale at which the effects of climate change and urbanization are likely to be felt, is critical as a basis for their future sustainable use (Fausch et al., 2002).

Intertidal crabs that are active on the sediment surface of tropical estuaries during tidal exposure are a highly abundant fauna that is intimately involved in many ecological processes via trophic interactions and ecosystem engineering (Kristensen, 2008; Amaral et al., 2009). For example, they influence sediment composition (Botto and Iribarne, 2000; Escarpa et al., 2004), productivity (Koch and Wolff, 2002; Werry and Lee, 2005), vegetation structure (Bosire et al., 2005), faunal composition (Dye and Lasiak, 1986; Botto et al., 2000) and energy fluxes (Wolff et al., 2000). Consequently, shifts in intertidal crab assemblages are likely to influence the wider estuarine community and affect ecosystem functioning. These

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influences can be far reaching as alternating tidal inundation and exposure enables interactions between the resident crab fauna and transient estuarine components. For example, aquatic crabs, fish (Cannicci et al., 1996a; Sheaves and Molony, 2000) and birds (Botto et al., 2000) move in and out of the intertidal during different tidal periods (Sheaves, 2005), and nutrients and various other materials are deposited or exported by the tides (Bouillon et al., 2008). The extensive linkage of intertidal crabs to ecosystem processes makes them useful model species to study the functioning of tropical estuaries.

Many of the intertidal crabs dominating within tropical estuaries, including Ocypodoidea and Grapsidoidea, have limited home ranges (Cannicci et al., 1996b, 1999a; Guest and Connolly, 2004; Guest et al., 2006; Zeil and Hemmi, 2006) making them potentially highly suitable to detect environmental change at small scales of a few meters. For example, many fiddler crabs (Ocypodoidea) such as *Uca lactea* and *Uca vomeris* have burrow centred spatial strategies with territories rarely exceeding a few square meters (Zeil, 1998; Takeda, 2003; Yamaguchi and Tabata, 2005; Zeil and Hemmi, 2006). Similarly tree associated intertidal crabs such as *Selatium elongatum* and *Sesarma leptosome* (Grapsoidea) remain within defined areas generally within 10 m (Cannicci et al., 1996b, 1999a). In fact, *Metopograpsus thukuhar*, common throughout the Indo-Pacific, maintains its activity within the root apparatus of a single tree (Fratini et al., 2000). The potential of intertidal crabs to act as bio-indicators of ecosystem condition has been demonstrated by changes in diverse attributes. For example, changes in behaviour, survival, biomass, species richness and burrow morphology were demonstrated in response to sewage pollution in tropical estuaries (Bartolini et al., 2009; Penha-Lopes et al., 2009; Cannicci et al., 2009). Meanwhile, organic pollutants and heavy metals are known to influence physiological processes, resulting in changes to molting, reproduction and population structure of crabs (MacFarlane et al., 2000; Rodriguez et al., 2007). Finally, composition of intertidal crab communities has been used as a condition indicator of degraded areas and for measuring the success of rehabilitation programs (Macintosh et al., 2002; Ashton et al., 2003a; Nordhaus et al., 2009).

Associations between intertidal crabs and environmental properties such as organic matter content, vegetation and tidal height have been demonstrated in tropical estuaries (Weis and Weis, 2004; Koch et al., 2005; Arruda Bezerra et al., 2006; Ravichandran et al., 2007; Takeda, 2010). Modelling of the associations between intertidal crabs and environmental parameters identified distinct habitats within the landscape of the low intertidal banks, the area between mean low tide at spring and the edge of the mangrove forest, of a tropical estuary in Northeast Australia (Vermeiren and Sheaves, 2014b). In particular, *Uca seismella* was associated with habitats with low intertidal vegetation and almost no structural complexity. Meanwhile, *Metopograpsus frontalis* was associated with habitats with at least 4% of the substratum containing structure, and *Metopograpsus latifrons* with habitats with at least 22% of the substratum containing structure. Finally, no discrete habitat was identified for *Uca coarctata,* although areas with higher abundance were identified as low intertidal banks with pneumatophores and at least some canopy overhang.

Despite evidence of distinct habitat associations, a lack in understanding of the applicability of these associations among tropical estuaries makes it hard to integrate the strong ecological role and bio-indicator potential of intertidal crabs into generally applicable models and management applications for these estuaries. For example, an association pattern was established between the families Grapsidae and Sesarmidae and mangrove trees using five transects across two estuaries 140 km apart (Dahdouh-Guebas et al., 2002). Nonetheless, in this case differences between estuaries or sites were not addressed (Dahdouh-Guebas et al., 2002). Consequently, the predictability of Grapsidae and Sesarmidae spatial distribution relative to mangrove tree spatial distribution among estuaries remains unquantified. Likewise, relative numbers of crabs from the superfamilies Ocypodoidea and Grapsoidea in floristically similar sites between two estuaries were comparable for each of four locations along the East African Coast (Hartnoll et al., 2002). Although this similarity in numbers indicates predictability in abundance between comparable sites, the limited taxonomic resolution (superfamily level only) provides little information on species composition.

Predictive habitat modelling has been used successfully to develop generally applicable ecological models of organism habitat associations in ecological, management and conservation contexts (Guisan and Zimmermann, 2000; Wintle et al., 2005). The technique relies on the statistical modelling of patterns of association between species and environmental parameters. Subsequent testing of the statistical model as a hypothesis in other systems allows the results regarding organism habitat associations to be interpolated among systems with similar environmental context and geographical region, rather than be limited only to the studied systems (Guisan and Zimmermann, 2000). This is cost effective and logistically efficient as only a limited number of surveys are needed compared to extensive and often financially prohibitive long-term monitoring projects. Photographic sampling allows for the rapid large scale sampling of intertidal crabs spatial distribution patterns necessary for this modelling (Vermeiren and Sheaves, 2014a). The method is particularly suited for a range of intertidal crabs active on the surface of the low intertidal banks of tropical estuaries during tidal exposure because of the restricted home-ranges of many of these crabs. Additionally, many of the species occurring throughout the area studied in this manuscript have easily identifiable colour patterns which allows their identification out of a list of detailed species ID collected during pilot work. Consequently, predictive habitat modelling and photographic sampling provide a useful methodological combination to address patterns of crab-habitat associations among estuaries.

This study aimed to investigate the spatial distribution patterns of intertidal crabs within and among estuaries, thereby gaining increased ecological knowledge of this key faunal component at scales relevant to dominant anthropogenic threats. Specifically, the null-hypothesis was tested that intertidal crabs do not occur within habitats that are predictable among estuaries. Therefore, associations between crabs and habitats were statistically modelled within a set of training-estuaries. Subsequently, the predictions of these statistical models were tested among a different set of test-estuaries. Results provide statistical models capable of providing predictions regarding habitat associations of intertidal crabs for estuaries within the studied region. Families with representative species included in this study were Grapsidae, Ocypodidae & Macrophthalmidae, all of which could be sampled with the photographic technique.

2. Methods

2.1. Study area

Sampling was conducted in eight estuaries distributed along a 160 km long region of North Queensland, Australia (Fig. 1). A dry tropical climate occurs in this region which is characterized by highly seasonal rainfall, with nearly 80% of the average annual rainfall of 115 cm occurring during the summer wet season from December to March (Bureau of Meteorology, Queensland government, data for Townsville between 1940–2011). Sampling was conducted in the pre-wet (September–October) and post-wet