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Ecological Niche Model used to examine the distribution of an invasive, non-indigenous coral

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ABSTRACT

All organisms have a set of ecological conditions (or niche) which they depend on to survive and establish in a given habitat. The ecological niche of a species limits its geographical distribution. In the particular case of non-indigenous species (NIS), the ecological requirements of the species impose boundaries on the potential distribution of the organism in the new receptor regions. This is a theoretical assumption implicit when Ecological Niche Models (ENMs) are used to assess the potential distribution of NIS. This assumption has been questioned, given that in some cases niche shift may occur during the process of invasion. We used ENMs to investigate whether the model fit with data from the native range of the coral *Tubastraea coccinea* Lesson, 1829 successfully predicts its invasion in the Atlantic. We also identified which factors best explain the distribution of this NIS. The broad native distributional range of *T. coccinea* predicted the invaded sites well, especially along the Brazilian coast, the Caribbean Sea and Gulf of Mexico. The occurrence of *T. coccinea* was positively related to calcite levels and negatively to eutrophy, but was rather unaffected to other variables that often limit other marine organisms, suggesting that this NIS has wide ecological limits, a trait typical of invasive species.

1. Introduction

A non-indigenous, invasive species can be considered to be an organism that has been able to colonize new areas, establish populations outside its native habitat and cause ecological, economic and/or social impacts in the invaded region (Lockwood et al., 2007). Despite the potentially huge economic and ecological losses invasive species cause (Pimentel et al., 2001; Aguin-Pombo, 2012), only a small fraction of non-indigenous species (NIS) actually establish a viable population outside their native range (that is, being able to sustain a population without immigration of new individuals). Among those that do become established, even fewer become invasive (expanding their range, becoming highly abundant and modifying the receptor community). Impacts on the local environment due to the successful spreading and dominance of a NIS may include the substitution of local species, change in community structure and modification of ecosystem's functions (Williamson, 1996; Lockwood et al., 2007). Although it is unlikely that a given species is successful in invading, the increase in human activities today has increased propagule pressure and modified local natural communities, two processes which favour successful biological invasions (Westphal et al., 2008; Barbosa et al., 2010).

The environmental envelope of a species, also called its niche (Grinnell, 1917; Hutchinson, 1957) limits its geographic distribution (Brown and Pavlovic, 1992; Peterson, 2003). In the case of a NIS, the environmental requirements of the species define the boundaries of its potential distributional range in the new region. Identifying the key factors that limit dispersion and establishment of an introduced species is extremely useful in order to evaluate risk, anticipate the process of invasion and where necessary deal with its consequences (Peterson, 2003). Ecological Niche Models (ENMs *sensu* Peterson and Soberón, 2012) emerged in the last decade (Corsi et al., 2000; Peterson and Shaw, 2003) as a tool that can be used for predicting potential NIS distributions (Jiménez-Valverde et al., 2011). Since biogeography and species composition studies of marine habitats are still limited in geographic scope compared to the terrestrial realm (but see Murase et al., 2009; Briggs and Bowen,

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2013) ENMs can be especially insightful when applied to marine systems. Additionally, community loss and other impacts of invasive species on coral and rocky reefs are under-studied when compared to terrestrial systems (Campbell, 2009). Thus ENMs are valuable in elucidating distributional aspects of reef species and improving our understanding of these sensitive environments (Wilkinson, 2004; Selkoe et al., 2009).

The orange cup-coral *Tubastraea coccinea*, Lesson 1829 is a non-zooxanthellate scleractinian coral native to Indo-Pacific coral reefs. It is the first known scleractinian to have invaded the Atlantic (first reported during the early 1940's in the Caribbean) and it has since spread through the Caribbean Sea, the Gulf of Mexico, including Texas and Florida coasts (USA), and Brazil (Fig. 1) (Cairns, 2000; Castro and Pires, 2001; de Paula and Creed, 2004; Sammarco et al., 2013). The species is also present in West Africa (Laborel, 1974; Fenner, 2001). In the West Atlantic coast it was introduced by fouling external surfaces of relocated oil/gas platforms (Sammarco et al., 2004). Recent studies have shown it to be harmful to native indigenous coral species, being capable of causing necrosis in the endemic *Mussismilia hispida* (Creed, 2006).

In the present study the aim was not only to generate distributional maps for this NIS but also investigate whether the models could identify what forces are driving the range expansion of *T. coccinea*. This is particularly critical since a recent study has shown that the potential distribution of *T. coccinea* largely overlaps with endemic reef forming coral species negatively impacted by the orange cup-coral (Riul et al., 2013). Predicting the potential impact of the invasive species on the receptor communities is imperative and crucial to focus ongoing managing initiatives. As both native and invaded area occurrence records are extensively available for this species, we also tested the model's predictive ability by evaluating its performance under two different scenarios: 1) feeding the model with all available records (both native and invaded occurrences); 2) feeding the model with only occurrence data from the native habitat.

2. Materials and methods

Ecological Niche Modelling consists of combining geographical coordinates of occurrence for the species with environmental variables which potentially explain their presence. A chosen algorithm generates a model of environmental suitability comparing the overall region of interest with the environmental conditions of the points of occurrence (*e.g.*, Anderson and Raza, 2010). The output of the model is a projection of a probability surface representing habitat suitability onto the geographical space (Verbruggen et al., 2009). We chose maximum entropy as our correlative modelling algorithm and used the Maxent 3.3.3a software (Computer Sciences Department – Princeton University, 2004) to examine the potential distribution of the orange cup-coral. This presence-background technique (Phillips et al., 2006; Phillips and Dudík, 2008) has performed well in comparative studies of different methods (Elith et al., 2006; Hernandez et al., 2006; Ortega-Huerta and Peterson, 2008; Wisz et al., 2008), and has already been successfully used to model coral populations and other marine organisms (Verbruggen et al., 2009; Magris and Déstro, 2010; Bučas et al., 2013; Georgian et al., 2014).

2.1. Species occurrence records

We collected 132 occurrence records for *T. coccinea* (17 for Brazil, 49 for the Caribbean and Gulf of Mexico and 66 independent points for its native range in the Indo-Pacific region) from the literature obtained from a range of online databases (*e.g.*, Web of Knowledge, ScienceDirect, PubMed and Scielo). We also used the Ocean Biogeographic Information System (OBIS – http://www.iobis.org/ last accessed in May 2012), Global Biodiversity Information Facility (GBIF – http://www.gbif.org last accessed in May 2012) and the Cria speciesLink (http://www.splink.org.br) databases. As *T. coccinea* is synonymous with *Tubastraea aurea* (Cairns, 2000; Glynn et al., 2008) and often wrongly cited (the genus) as

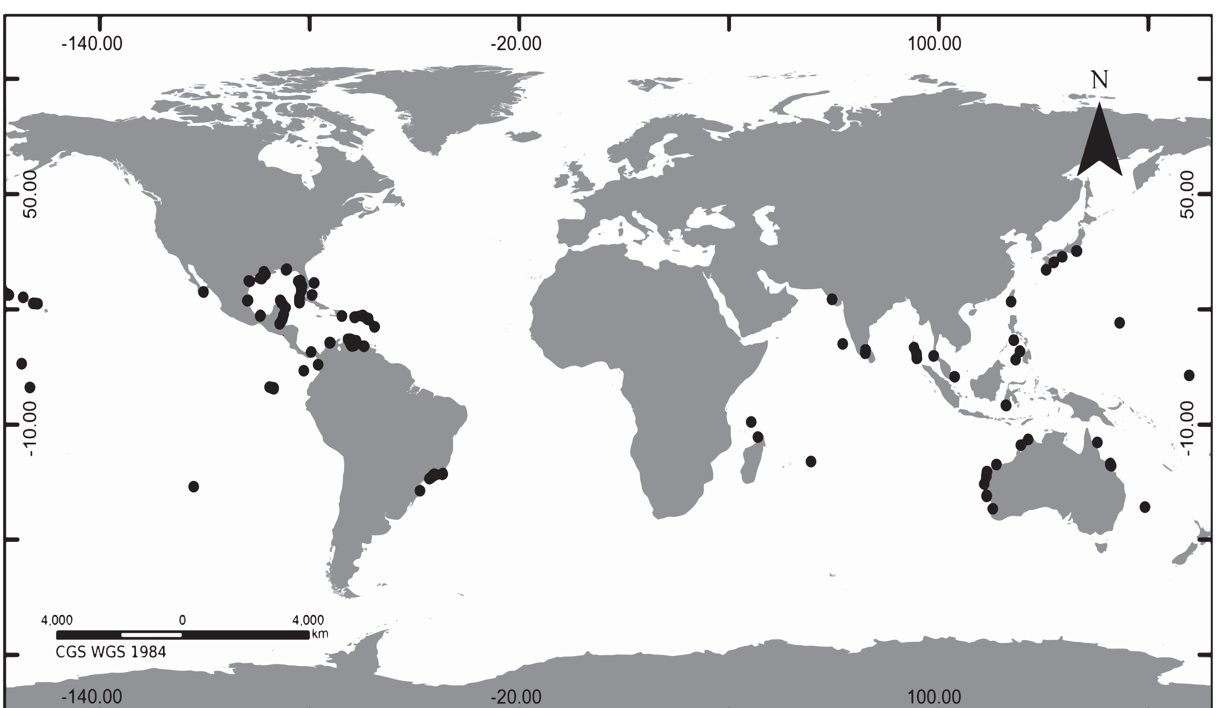

Fig. 1. Global distribution of the scleractinian *Tubastraea coccinea* represented by black dots.