



# Predicting Shifts in the Geographical Distribution of Two Estuarine Plant Species from the Subtropical and Temperate Regions of South Africa

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Received: 1 November 2017 / Accepted: 23 August 2019 / Published online: 21 November 2019  
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## Abstract

Climate suitability maps are useful to determine changes in the distribution of species. The aim of this study was to predict the future distribution of two estuarine species (*Bassia diffusa* and *Hibiscus tiliaceus*) from two biogeographical regions under climate change. The Bioclim and Maxent modelling algorithms were used to calculate current climate suitability and were projected onto future climate data to develop climate suitability maps. The trained area under a receiver operating characteristic curve (AUC) values ranged from 0.723 to 0.936 for both species under the current climatic conditions, and from 0.695 to 0.933 for future conditions. Distribution range contraction for *Bassia diffusa* is predicted along its eastern distribution limit (South-East coast) in South Africa, suggesting extirpation in 42 out of 62 estuaries. This may allow mangroves to expand into areas where *B. diffusa* will be lost. Low suitability was predicted for *H. tiliaceus* in warm temperate estuaries which may limit further expansion. Future climate change scenarios in this region predict that temperature will not increase above the minimum temperature tolerance of *H. tiliaceus*. This approach can be applied to determine the potential range shifts of other estuarine species, supporting the development of proactive strategies to reduce climate change impacts on biodiversity.

**Keywords** Species distribution modelling · Climate change · Salt marsh · Coastal swamp forest · Model performance · Maxent · Bioclim

## Introduction

The impact of human-induced sea-level rise has been deemed to be one of the greatest threats to coastal ecosystems (Reed 1990; Nicholls et al. 1999; Wasson and Woolfolk 2011; Li et al. 2014). This could explain the increase in literature regarding the impact of sea-level rise on coastal ecosystems (e.g. Morris et al. 2002; Mori et al. 2010; Semeniuk 2013; Tabot

and Adams 2013; Wasson et al. 2013; Jain et al. 2014; Osland et al., 2016; Raposa et al. 2017). The consensus among these authors is that drowning and/or large-scale shifts in communities and ecosystems can be anticipated. However, this perception of the overwhelming effect of sea-level rise has overshadowed the concurrent changes in macroclimate associated with climate change (Osland et al., 2016; Gabler et al. 2017). Thus, the effects of macroclimatic change on coastal wetland plant community structure has been largely unexplored. The distribution of estuarine plant communities can be explained by a variety of environmental gradients at several spatial scales (Odum 1988; Veldkornet et al. 2016). At a biogeographic scale (macroecology) temperature and rainfall have been deemed the most important factors affecting estuarine species distribution (e.g. Ewanchuk and Bertness 2004 [for salt marshes]; Saintilan 2009 [for mangroves]; Harrison and Whitfield 2006 [estuarine fish species]).

Globally, these coastal wetlands can be divided into three bioclimatic zones (see Osland et al., 2016), where a single or small number of species play an important functional role and

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**Electronic supplementary material** The online version of this article (<https://doi.org/10.1007/s13157-019-01218-y>) contains supplementary material, which is available to authorized users.

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their abundance and performance are greatly influenced by macroclimatic drivers (Alongi, 2015; Gabler et al., 2017; Osland et al. 2016). The tropics and subtropics form the hot and wet climatic zone and is often dominated by swamp and mangrove forest (Giri et al. 2011). In the cool temperate climatic zone (cold and wet conditions) salt marshes of the graminoid type are most abundant (Pennings and Bertness 1999; Gabler et al., 2017; Osland et al., 2016). In dry climatic zones (arid and semi-arid climates) salt marshes are dominated by succulent plants. Between each of these regions are areas of transition where a combination of the vegetation types could occur (Gabler et al., 2017; Osland et al., 2016). Understanding how variation in climate will influence the distribution of species is necessary to accurately predict how climate change will impact natural communities and ecosystems (Bertness and Ewanchuk 2002).

Species distribution modelling (environmental niche modelling, niche modelling or climate envelope modelling) can be a powerful tool to assess the effect of macroclimatic changes on coastal habitats. Species distributional modelling (SDM) alerts scientists and decision makers to the potential risks that species may face and provides a means to determine potential changes to the distribution range of species. This can be used to support the development of proactive strategies to reduce climate change impacts on biodiversity (Guisan and Thuiller 2005; Bellard et al. 2012; Wróblewska and Mirski 2017).

Although scarce, SDM has been used to understand the global and local distribution range shifts of coastal and estuarine plant species. For example, at the global scale, Zhu et al. (2013) used SDM to determine potential invasion of the estuarine macrophyte, *Spartina alterniflora* Loisel. Their results suggest that climate (changes in rainfall and temperature) might be the main factors at a broad scale and that it might provide more suitable climate space for *S. alterniflora* in the high latitudes of the northern hemisphere. At a regional scale, Quisthoudt et al. (2013) predicted the distribution of the mangrove species in South Africa under different climate change scenarios. Using three modelling techniques (generalized linear models, generalized additive models and gradient boosting machines) and the minimum air temperature of the coldest month, water-balance and growing-degree days, it was suggested that climate change will create climatically suitable sites for the mangrove forests, specifically the species *Avicennia marina* (Forssk.) Vierh. and *Bruguiera gymnorhiza* (L.) Lam., beyond their current limits in that country.

The estuarine environment provides several advantages when assessing the potential effects of climate change on species distribution, this owing to species-specific biology and distributional patterns (Kadereit et al. 2005). First, the distribution of species along a tidal inundation gradient occurs in a predictable manner and follows the assumptions of ecological

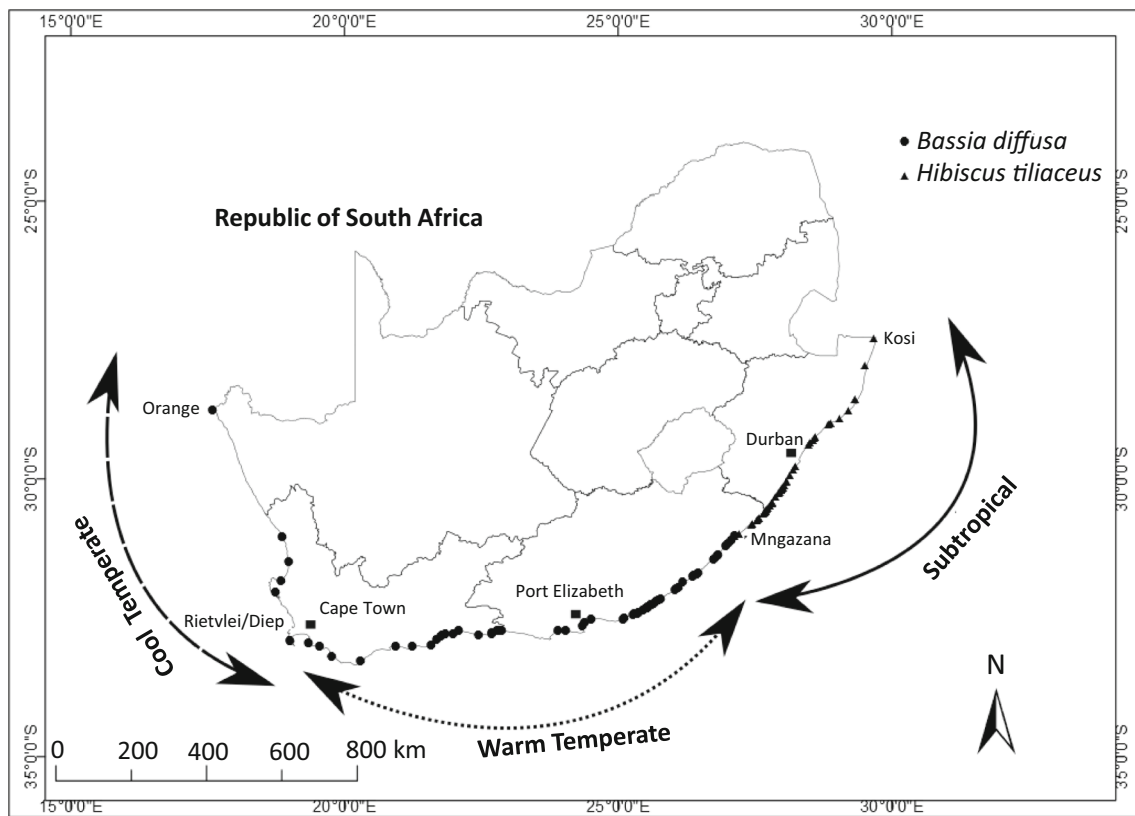
niche theory (He and Bertness 2014). Secondly, estuarine species, in contrast to inland species, show a linear distribution range which limits the spatial options for migration (Kadereit et al. 2005). The South African coastline is an excellent location to study the global importance of macroclimatic controls upon coastal wetland ecosystems. The country has all three of the global coastal wetland climatic zones (Adams et al. 2016). The region is expected to experience changes in climate across the different biogeographical regions (Cai et al. 2007). Increases in temperature and rainfall are expected for the Subtropical region (eastern coastline of South Africa); whereas less rainfall is projected for the cool temperate regions (western coastline) (Schulze et al. 2005; Boström et al. 2011). These changes will affect the primary inputs into estuaries (flow, sediment, and nutrients), which will ultimately affect the microclimatic conditions of species. Climate change (increase in temperature and rainfall) will favour the southward expansion of swamp and mangrove forest, to the detriment of salt marshes.

The aim of this study was to predict the potential shifts in the distribution of two estuarine species *Bassia diffusa* (Thunb.) Kuntze (a functionally important salt marsh species) and *Hibiscus tiliaceus* L. (a functionally important coastal swamp forest species) from two estuarine biogeographical regions under different climate change scenarios. We hypothesize that future climate (2050) will result in distribution range contraction for *B. diffusa* and distribution range expansion for *H. tiliaceus* in responses to changes in temperature and rainfall. These species and their conspecifics form important components of estuarine communities locally and globally (Saintilan et al. 2014; Osland et al., 2016). Understanding the resilience of these species to climate change (temperature and rainfall changes) is crucial to develop proactive management strategies.

## Materials and Methods

### South African Estuarine Temperatures and Biogeography

The South African coastline can be grouped into three bioclimatic regions (Harrison and Whitfield 2006; Teske et al. 2011; James et al. 2016). According to Harrison and Whitfield (2006), the west coast (from the Orange River Estuary to Cape Point) of South Africa is classified as the cool temperate zone. The warm temperate zone extends approximately from Cape Point to the Mbashe Estuary. The subtropical zone extends from the Mbashe Estuary to Kosi Bay along the east coast (Fig. 1). Cool temperate estuaries are characterised by high salinity and low turbidity as a result of low rainfall and runoff, high seawater input and evaporative loss. Subtropical estuaries have lower salinity and higher turbidity due to relatively high runoff (Harrison 2002). Recently, James et al.,



**Fig. 1** The distribution of *Bassia diffusa* (black circles) and *Hibiscus tiliaceus* (black triangles) along the South African coast. Major coastal towns are represented with black squares

(2016) showed that temperatures in cool temperate estuaries can fluctuate between 24 °C to 14 °C during summer, whereas subtropical estuaries can vary between 26 °C and 24 °C. The authors also noted that water temperature shows variation depending on the estuary type. Temperatures in permanently open estuaries correspond with that of seawater temperatures, whereas estuarine lakes often have higher temperatures due to their shallow nature (James et al. 2016).

Using the South African Estuarine Botanical database, which records the presence and absence of estuarine plant species, Adams et al. (2016) defined plant communities in the three biogeographical regions (based on the Harrison and Whitfield 2006 classification). Their study showed that 37 species were restricted to the warm temperate region and 20 taxa, such as *Acrostichum aureum* L., *Barringtonia racemosa* (L.) Sprengel., *Ceriops tagal* (Perr.) C.B.Rob., *Hibiscus tiliaceus*, and *Lumnitzera racemosa* Wild. were restricted to the subtropical region. Some species that were shared between the warm temperate and subtropical region were the mangroves and seagrass (e.g. *Halophila ovalis* (R. Brown) J. D Hooker). The separation of species between different regions were attributed to differences in rainfall (reducing water and sediment salinity), temperature as well as stronger competition (through greater biomass accumulation and shading) of mangrove species over salt marsh species (Saintilan 2009; Adams et al. 2016).

### Study Species and Location Data

In this study, we modelled two species, *Bassia diffusa* (Amaranthaceae) and *Hibiscus tiliaceus* (Malvaceae). The distribution data for the species were obtained from the South African Estuarine Botanical Database (Adams et al. 2016). The database has been updated from scientific publications, site visits, graduate research projects, environmental flow requirement studies and any other initiatives that included macrophyte mapping and a detailed assessment of species composition. An earlier version of the database was developed to determine the conservation and biodiversity importance of South Africa's estuaries (van Niekerk and Turpie, 2012). This would provide continuous input to the estuaries component of the National Biodiversity Assessment undertaken by the South African National Biodiversity Institute (SANBI). The database was regularly updated from 2009 to 2015 (the version used in this study). Estuaries were either updated from site visits, where only the presence of species was recorded, or from literature sources.

The species *Bassia diffusa* (Amaranthaceae) is a low growing decumbent often straggling shrub (subshrub) about 10–25 cm in height (Plate 4) (Brenan 1988). This species was selected in this study because it forms an important component of temperate salt marsh habitats. Adams et al. (2016)

found *B. diffusa* to occur in Permanently Open and Temporarily Open/Closed estuaries. In subtropical estuaries, such as the Mngazana Estuary the supratidal zone is characterised by salt marsh plants at the spring high water mark with mangrove forest extending to the low water mark. Here, *B. diffusa* occupies a meter-wide zone, forming dense stands, approximately 25 cm in vertical height (Colloty and Adams 2000). Distributional data for *B. diffusa* were obtained from the Estuarine Botanical Database, where the species has been recorded in 62 South African estuaries (from the Orange River Estuary to Mngazana Estuary and is one of the most widely distributed species in the family Amaranthaceae (Adams et al. 2016) (Fig. 1).

*Hibiscus tiliaceus* is an evergreen, sprawling tree that typically grows to 3–10 m in height with a sprawling form (Elevitch and Thomson 2006). This species was selected in this study because it forms an important component of coastal swamp forest habitats in subtropical estuaries. The species, *Hibiscus tiliaceus*, is indigenous throughout the tropics and subtropics but has become naturalised in tropical and subtropical America, Africa, Asia, Australia, and throughout the Pacific islands (Elevitch and Thomson 2006). Distribution data for *H. tiliaceus* were obtained from the Estuarine Botanical database. The species occurs in 51 South African estuaries from Mngazana Estuary to Kosi Bay Estuary (Adams et al. 2016) (Fig. 1).

### Predictor Variables and Modelling Approach

The purpose of this study is not to explore environmental factors that limit the distribution of the species but to generate spatial predictions of its potential distributions. The assumption of this study is that modelling of the climate envelope, or niche, assumes that the current species or community distribution is in equilibrium with its environment (Phillips et al. 2006). Within the estuarine environment, the important variables affecting species geographical distribution are related to temperature and rainfall (Zhu et al. 2013; James et al. 2016). For this reason, sea-surface temperature (SST), annual mean temperature, mean diurnal range (mean of monthly (max temp - min temp), minimum temperature of the coldest month, annual precipitation, precipitation of wettest month and precipitation of driest month for the entire South African coastline were used as environmental variables. Climate (present and future) information was obtained from the WorldClim database (version 1.4; Hijmans et al. 2005; <http://www.worldclim.org>). These climatic layers (19) are based on weather conditions recorded over 50 years from 1950 to 2000 on a grid of 30" resolution. Data layers (vector layers) were downscaled based on the Model for Interdisciplinary Research on Climate MIROC (Hasumi and Emori 2004). The future climate data is based on the IPCC5 climate projections from global climate models (GCMs) for 85 representative concentration pathway (RCP). These are the most recent GCM climate projections that are used in the Fifth

Assessment IPCC report. The GCM output was downscaled and calibrated (bias corrected) using WorldClim 1.4 as baseline 'current' climate. The 30 s spatial resolution data set was selected. Sea-surface temperature data were obtained from R Schlegel and A Smit (University of the Western Cape). In total, 129 in situ temperature time series of up to 43 years are used in their investigations of the thermal characteristics of coastal seawater. These data were collected with handheld thermometers or underwater temperature recorders (UTRs) and are recorded at precisions from 0.58 to 0.0018 °C (Schlegel and Smit, 2016). A uniform rate of temperature increase of 0.1 °C per decade for the whole coastline was used. This is in line with the global average (IPCC, 2013) and decadal trends calculated by Schlegel and Smit (2016) for the South African coastline. An initial study was performed using six models from three modelling classes: Bioclim, Domain, generalized linear models (GLMs), generalized additive models (GAMs), Maxent and Random Forest. The first two are in the profile model class, GLMs and GAMs are regression models and Maxent and Random Forest are machine learning models (Franklin 2010). Domain, GLM, GAM, and Random Forest were removed from the study as they failed to predict the current distribution of the species. In this study, the Bioclim and Maxent modelling algorithms were used. These models were used to calculate current climate suitability and then projected onto future climate data to develop climate suitability maps for 2050. In order to reduce sampling bias and to facilitate the comparison of outputs from different modelling algorithms, the 'probability of occurrence' maps was reclassified to binary data ('present' or 'absent') using the maximum sensitivity plus specificity threshold criterion (Liu et al. 2005). A mask of the estuarine functional zone (EFZ, Veldkornet et al. 2015) was used to sample background data (1000 background points) from the climate layers; some of the modelling methods require data of absences (known as background or "pseudo-absences"). Model evaluation requires training and testing data. Both models were evaluated by Split 1/3 of the presence and background data for testing and 2/3 for training. Model performance was evaluated for each combination using a standard statistical measure of predictive ability, namely the trained area under the receiver operating characteristic curve (AUC), Cohen's kappa (the threshold at which kappa is highest) and sensitivity plus specificity. All analysis was done using the dismo package in R (Hijmans et al., 2013).

### Results

Models of climate and the sea-surface temperature had good predictive performance for the current and future distribution of the species. Predictive models performed better than random for *Bassia diffusa* and *Hibiscus tiliaceus*. The model evaluation results are presented in Table 1. The training AUC values ranged from 0.723 to 0.936 for both species under the current climatic conditions, and from 0.695 to

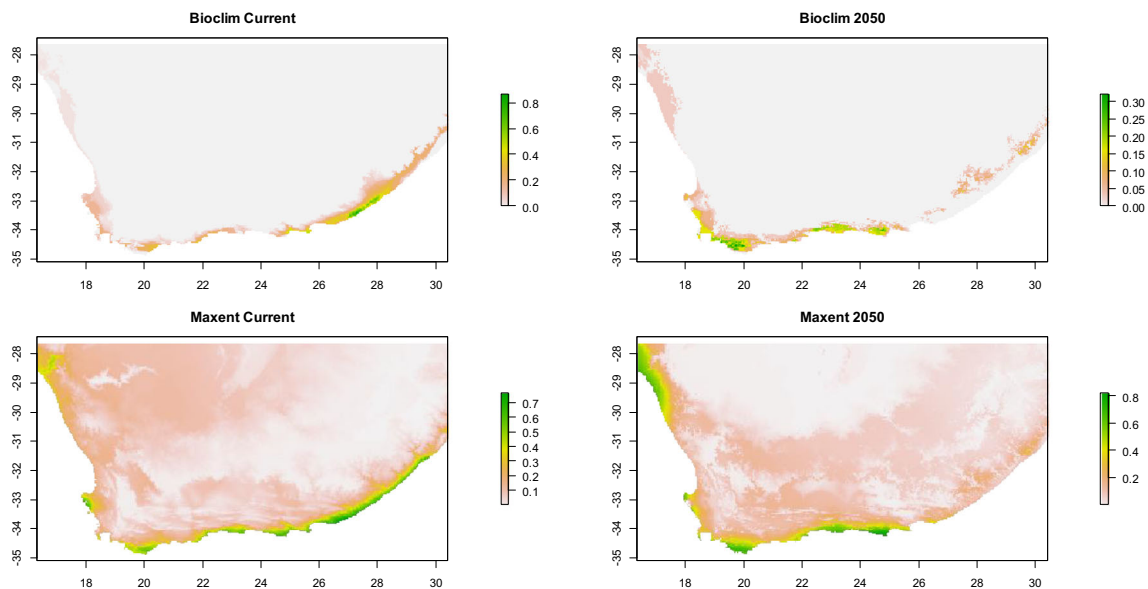
**Table 1** Model fit metrics for the distribution of each species

Model	Species	Variable	AUC <sub>tr</sub>		Kappa		Sens+Spec	
			Present	Future	Present	Future	Present	Future
Maxent	<i>Bassia diffusa</i>	Climate	0.739	0.695	0.565	0.541	0.397	0.352
		SST	0.723	0.732	0.531	0.572	0.359	0.351
	<i>Hibiscus tiliaceus</i>	Climate	0.904	0.944	0.020	0.010	0.020	0.017
		SST	0.852	0.885	0.516	0.449	0.403	0.267
Bioclim	<i>Bassia diffusa</i>	Climate	0.747	0.802	0.258	0.247	0.161	0.159
		SST	0.815	0.695	0.311	0.087	0.262	0.087
	<i>Hibiscus tiliaceus</i>	Climate	0.936	0.933	0.166	0.142	0.020	0.024
		SST	0.878	0.817	0.020	0.108	0.020	0.027

Bioclim and Maxent were applied to *Bassia diffusa* and *Hibiscus tiliaceus* occurrence data. Model fit metrics included trained area under the receiver operator curve (AUC<sub>tr</sub>), Cohen's kappa and sensitivity plus specificity (Sens+Spec)

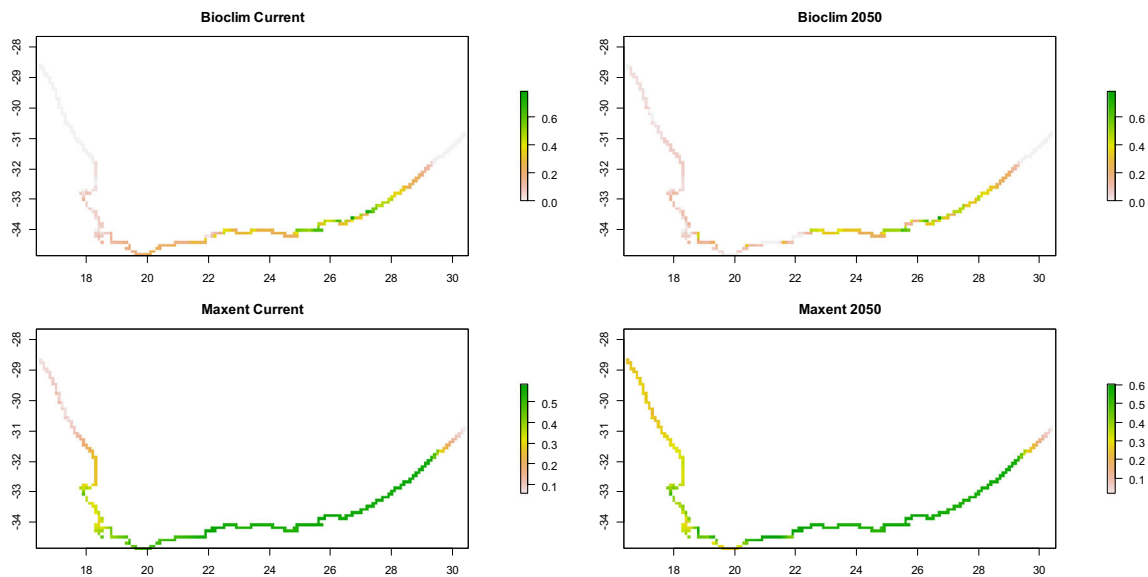
0.933 for future conditions. These values indicate good to excellent model performance (Swets 1988). The training AUC for climate models and sea-surface temperature were generally greater for *Hibiscus tiliaceus* compared to *Bassia diffusa* for current and future predictions. Altered conditions, from the present conditions relative to future climate conditions, are presented in Fig. 1A-4A (supplementary material). Generally, an increase in ambient and sea-surface temperature and a decrease in precipitation is predicted for the area in which the salt marsh species *B. diffusa* occurs. An increase in temperature (ambient and sea-surface) and precipitation is predicted for the coastal swamp forest species *H. tiliaceus*. Based on the Maxent permutation test, the annual temperature is the most important variable for *Bassia diffusa*; whereas annual precipitation is the most important variable for *Hibiscus tiliaceus*.

Based on known occurrences of the two species (*Bassia diffusa* and *Hibiscus tiliaceus*) and current climate data, we generated geographic distribution maps predicting areas of range contraction and/or expansion. Changes in habitat suitability were predicted for both species based on climate and sea-surface temperature data (Figs. 2 and 3). For *Bassia diffusa*, both models (Bioclim and Maxent) showed lower habitat suitability under future climate scenarios. Potential loss of geographic range is predicted along the eastern limit (South-East coast) of its distribution. This includes a total of 42 out of the total 62 estuaries where the species currently occurs. Both models predicted an increased probability of occurrence for the species along the west coast of South Africa for sea-surface temperature. There were differences in the predicted distribution of *Hibiscus tiliaceus*. Based on the Bioclim model, an extreme range retraction is predicted. The Maxent



**Fig. 2** Habitat suitability models of *Bassia diffusa* under current and future climate scenarios for climate variables. Higher values (in green) indicate a greater habitat suitability/predictability





**Fig. 3** Habitat suitability models of *Bassia diffusa* under current and future climate scenarios for sea-surface temperature. Higher values (in green) indicate a greater habitat suitability/predictability

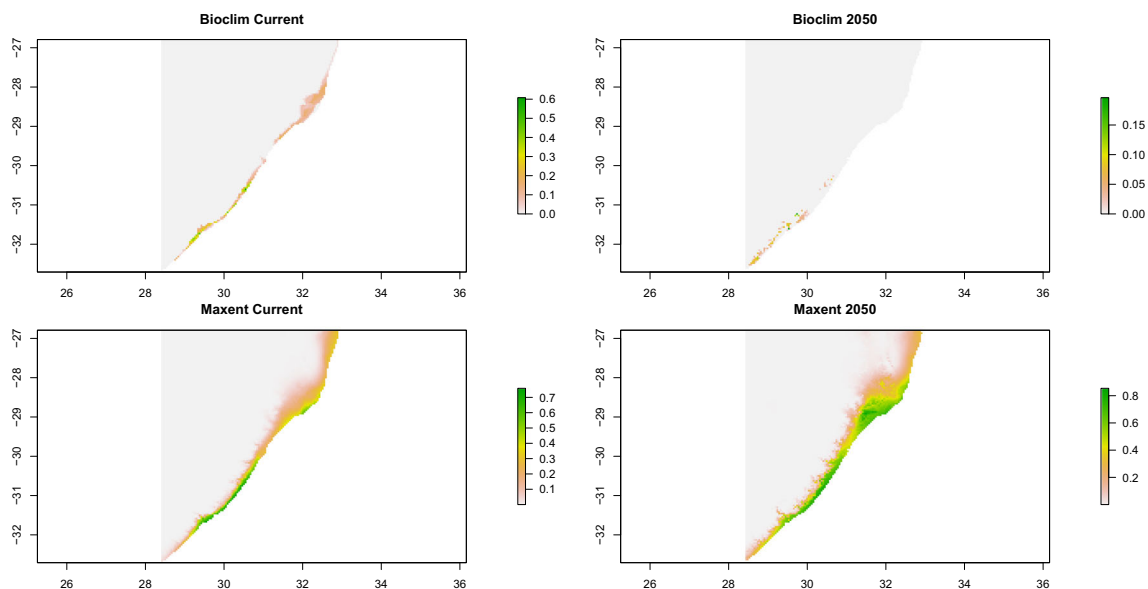
model predicted very little change in the distribution of *H. tiliaceus* with a possible increase along the limits of its range (Fig. 4). This is also reflected in the models of sea-surface temperature (Fig. 5).

## Discussion

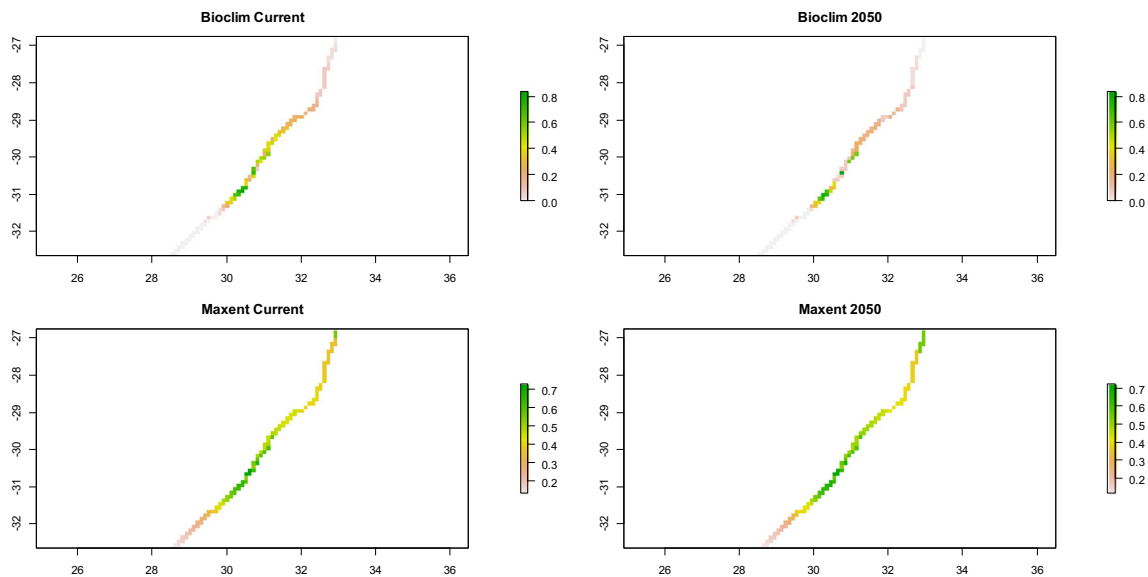
The purpose of species distribution modelling is to identify areas that are suitable for the species without considering biotic interactions, dispersal abilities and small-scale environmental changes (Guisan and Thuiller 2005; Bellard et al.

2012). In this study, shifts in species distribution under climate change were identified for two species from different biogeographical regions by the consensus of multiple models. The results from this study support the hypothesis that with future climate change there will potentially be a range contraction for the salt marsh species *Bassia diffusa* and a range expansion for the coastal swamp forest species *Hibiscus tiliaceus*.

It is anticipated that macroclimatic change will transform coastal wetland ecosystems within this century (Harley et al. 2006; Quisthoudt et al. 2013; Osland et al., 2016; Gabler et al. 2017). Generally, a southward expansion of mangrove and coastal swamp forests is expected at the detriment of salt



**Fig. 4** Habitat suitability models of *Hibiscus tiliaceus* under current and future climate scenarios for climate variables. Higher values (in green) indicate a greater habitat suitability/predictability



**Fig. 5** Habitat suitability models of *Hibiscus tiliaceus* under current and future climate scenarios for sea-surface temperature. Higher values (in green) indicate a greater habitat suitability/predictability

marsh habitats (Quisthoudt et al. 2013; Saintilan et al. 2014). Previous studies have focused on mangrove expansion, with little information on what will happen to coastal salt marshes. The modelling results show potential range contraction along the southeast coast of South Africa for the salt marsh species, *Bassia diffusa*. The region within the current distribution will experience increases in ambient and sea-surface temperature, and a reduction in rainfall (Mori et al. 2010; Smit et al. 2013; James et al. 2016). We speculate that these new conditions will be outside the natural ecological requirements for the species. Kadereit and Freitag (2011) suggested that the earliest Camphorosmeae, the tribe to which the species belongs, were coastal halophytes of a warm temperate climate. Most extant species in this tribe are xerophytes or halophytes in semi-deserts or arid salt marshes. This also reflects the terrestrial year-round and winter rainfall region.

There is a lack of information on the physiological or eco-physiological responses of *Bassia diffusa* to temperature-driven variables, thus drawing conclusions of species-response to climate change may be virtually impossible. However, with an increase in rainfall, an increase in flooding/inundation is expected and consequently longer periods of submergence of the species. The response of *Bassia diffusa* to submergence has been determined. Tabot and Adams (2013) found that the species, found along the upper intertidal zone, is not tolerant of long-term submergence (> seven days). The survival of this species in the upper intertidal zone of salt marshes depends on adaptations to submergence and therefore with sea-level rise, upper intertidal species will be submerged more frequently; above their current tolerance (Tabot and Adams 2013). Therefore, the compounding effect of sea-level rise and changes in temperature and rainfall could lead to a complete extirpation of *B. diffusa* in estuaries.

Therefore, the species may be more restricted to semi-arid and arid climates along the south and west coast. The area currently occupied by *Bassia diffusa* is also representative of temperate climates globally. In temperate climates, an increase in temperature and decreasing intensity and frequency of frost may result in transitions in the distribution of temperature sensitive higher plants (Saintilan et al. 2014; Gabler et al. 2017). The loss of *B. diffusa* (i.e. salt marsh habitats in temperate regions) may also provide suitable habitat for the establishment of mangrove seedlings in these estuaries along the southeast coast. Distributional shifts of mangroves species have been modelled in South Africa and predictions suggested the southward movement of mangroves into salt marsh habitats (Quisthoudt et al. 2013). Results from this study, therefore, provide empirical evidence that salt marshes are vulnerable to mangrove expansion. This is due to increases in winter temperature and changing rainfall regimes that will ultimately lead to changes in the coverage of foundation plant species within salt marshes (Osland et al. 2013; Saintilan et al. 2014).

Subtle changes in habitat suitability are predicted for *Hibiscus tiliaceus*. These changes can be explained by increases in temperature and rainfall brought on by an increased prevalence of the Agulhas Current. Cai et al. (2007) and Rouault et al. (2009) indicate that the increase in Agulhas Current transport will lead to an associated stronger Agulhas Leakage with more warm Indian Ocean water passing the southern and western coasts of South Africa. Excluding biotic and other abiotic variables, these conditions are ideal for the persistence of this species. *Hibiscus tiliaceus* favours environments with uniform rainfall (900–2500 mm) patterns and can tolerate a minimum temperature of 14 °C (Elevitch and Thomson 2006). The low suitability and potential distribution of *H. tiliaceus* into warm temperate estuaries could be due to

the fact that under future climate scenarios the temperature will not increase above the minimum temperature tolerance of the species. Globally, the area occupied by *H. tiliaceus* is representative of tropical areas, where woody plants are the functional important species (Osland et al., 2016). Osland et al. (2016) apply the term tropicalization as the poleward movement of tropical marine organisms (such as *Hibiscus tiliaceus*). This is in response to a reduction in the frequency and intensity of extreme winter events. Our study indicates tropicalization with climate change. This is anticipated on multiple continents, which will greatly affect ecosystem structure and function (Osland et al. 2014; Saintilan et al. 2014).

Sea-surface temperature predictions showed little change under climate change, probably because the assumption is that there will only be an increase of 0.1 °C per decade (Smit et al. 2013). The time frame used in this study (approximately 50 years) may have been too short to accurately detect changes in sea-surface temperature and the consequent biological responses. It was expected that the response of *Bassia diffusa* to sea-surface temperature would be similar to that found by James et al. (2016) for a group of mugilid fish species restricted to the temperate regions of the coastline. Their results predicted an increase in habitat suitability further north of its current distribution for 2100. Nonetheless, results from the current study did show subtle changes in species distribution, in response to sea-surface temperature, which is worth noting because results from this study have implications for estuarine conservation and management.

Coastal salt marshes provide several ecosystem services such as nursery functions, freshwater flows to the marine environment, carbon sequestration, flood regulation, storm protection, safe bathing areas, and estuarine plants as food, fuel and building resources (Tabot and Adams 2013; González-Alcaraz et al. 2014). The conservation of these habitats is therefore of paramount importance. The aim of estuarine conservation in South Africa to conserve or maintain a representative proportion (20% of each habitat type) of functionality (Turpie et al., 2012). These species in the current study form important components of estuarine communities with *Bassia diffusa* being a widely distributed upper intertidal species that forms an integral part of salt marsh ecosystem functioning, and *Hibiscus tiliaceus* an important species in coastal swamp forests of subtropical estuaries where a significant proportion of these habitat types have already been lost. Climate change will lead to a significant altering in species distribution (particularly for *Bassia diffusa*). The estuaries along the south-east coast of South Africa may shift from a salt marsh to a mangrove dominated salt marsh (Saintilan et al. 2014).

Climate change vulnerability assessments need to include the multiple interacting components of climate change. This will change the current conservation priority setting parameters to maintain estuarine representativeness. In South Africa, the ability to predict the response of estuaries to climate

change, and to plan for adaptation, is still hindered by a lack of good predictive tools and the lack of a fundamental understanding of many of the effects of climate variability on the physical, chemical and biological characteristics of the aquatic domain (van Niekerk et al. 2012). A way to ensure resilience is the inclusion of potential climate change threats (and future projects) in the determination and implementation of the Estuarine Ecological Water Requirements and the protection/rehabilitation of the estuarine functional zone.

## Conclusion

This study strongly indicates that climate change may affect the distribution of species from different climatic zones along the South African coastline. For *Bassia diffusa*, a range retraction along the southeast coast is predicted, which may create colonization opportunities for mangrove species. In contrast, *Hibiscus tiliaceus* may see an increase in habitat suitability in areas where higher rainfall and temperature is predicted. The modelling approaches of this study can also be applied to similar environments globally. This is particularly true for regions such as Australia, New Zealand, South America, western North America, the Middle East and Asia where climatic gradients affect the mangrove and marsh salt marsh interactions (i.e. changes from temperate to tropical regions). Using species distribution modelling (SDM), we have identified potential future risks to species. SDM, in combination with predictions of sea-level rise, can be used to determine the potential range expansion and contraction of coastal wetland globally, that can ultimately be used to support the development of proactive strategies to reduce climate change impacts on biodiversity.

**Acknowledgements** This study was funded by the National Research Foundation (Thuthuka Grant held by AR) and the South African Network for Coastal and Oceanic Research (SANCOR). DAV is an NRF-SANCOR postdoctoral fellow. AJ Smit (University of the Western Cape) is thanked for providing the sea-surface temperature dataset. The associate editor and reviewer are thanked for improving the quality of the manuscript.

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