

INFLUENCE OF CLIMATE CHANGE ON THE POTENTIAL GLOBAL DISTRIBUTION OF *ERYTHRINA CRISTA-GALLI* L. (FABACEAE) OUTSIDE ITS NATURAL LIMITS

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ABSTRACT

Exotic species are potentially dangerous for the conservation of native biota because they escape predators, competitors and pathogens that usually are not displaced with the species to the areas in which they begin to colonize. The modeling of the potential distribution of occurrence of a native species can be an important tool for the recognition of environments colonized by an exotic, introduced and naturalized species. *Erythrina crista-galli* L. (Fabaceae) is a pioneer species, native of Brazil, Uruguay, Argentina, Bolivia and Paraguay. Due to its ecological characteristics, it has the capacity to expand its distribution to new available. This work aimed to identify the potential areas of distribution of *Erythrina crista-galli* L. outside South America, evaluating the favorable areas of 22,000 years BP until today as a way to verify the tendency of expansion or reduction of these territorial spaces outside its natural limits. The results indicate that the algorithm used in modeling the distribution for the species is highly efficient in pointing out areas in which the naturalization of the species could occur, increasing its distribution to new intercontinental frontiers. In these areas *E. crista-galli* could, due to its ecological characteristics, impact these local ecosystems. The study also indicates what would be the trend of dynamics of these potential areas in relation to the climatic changes that have occurred since the last glacial maximum.

Key words: exotic species; Corticeira-do-banhado; modeling.

RESUMO

Espécies exóticas são potencialmente perigosas para a conservação da biota nativa, uma vez que escapam de predadores, competidores e patógenos que normalmente não são deslocados com a espécie para as áreas nas quais estas passam a colonizar. A modelagem da distribuição potencial de ocorrência de uma espécie nativa pode ser uma importante ferramenta para o reconhecimento de ambientes colonizáveis por uma espécie exótica, introduzida e naturalizada. *Erythrina crista-galli* L. (Fabaceae) é uma espécie pioneira e com grande potencial paisagístico nativa no Brasil, Uruguai, Argentina, Bolívia e Paraguai. Por suas características ecológicas possui capacidade de ampliação de suas áreas de distribuição para ambientes exóticos. O objetivo deste trabalho foi apontar áreas potenciais de distribuição de *Erythrina crista-galli* L. fora da América do Sul, avaliando-se as áreas favoráveis de 22.000 anos AP até a atualidade como forma de verificar a tendência de expansão ou redução destes espaços fora de seus limites naturais. Os resultados indicam que o algoritmo utilizado na modelagem da distribuição para a espécie é altamente eficiente em apontar áreas nas quais a naturalização da espécie poderia ocorrer, ampliando sua distribuição para novas fronteiras intercontinentais. Nestas áreas *E. crista-galli* poderia, devido às suas características ecológicas, impactar esses ecossistemas locais. O estudo ainda indica qual seria a tendência de dinâmica destas áreas potenciais em relação às mudanças climáticas ocorridas desde o último máximo glacial.

Palavras chave: espécies exóticas; Corticeira-do-banhado; modelagem.

INTRODUCTION

The accidental or purposive introduction of exotic species due to their economic, food or ornamental characteristics is frequent in human history, however, it is one of the most important factors in the reduction of biodiversity in natural environments (Ricklefs 2003). *Schinus terebinthifolius*, for example, is a native

plant in the Pampa Biome and was introduced in Florida around 1898 and 1900 and, finding favorable climate, covers large areas and causes significant changes in local biodiversity (Williams *et al.* 2007, Ricklefs 2003).

Erythrina crista-galli L. (Fabaceae) is a native species of the same Biome, distributed naturally in southern Brazil (Figure 1), throughout the Uruguayan territory and in part of northern Argentina.



Figure 1. *Erythrina crista-galli* L. (Fabaceae); (A) and (B), adult specimens, aspect during the autumn-winter (Photographs: author, Aceguá City, Rio Grande do Sul State, Brazil). (C) aspect of fruit and seeds.

The species is still distributed on the part of the Paraguayan and Bolivian territory. In Argentina and Uruguay, the species is considered the national tree (Lorenzi 1992, Lozano and Zapater 2010, Nesom 2015).

In Brazil, the species occurs in the three southern States: Rio Grande do Sul, Santa Catarina and Paraná (Reflora 2019). However, the plant can be distributed in other regions as the central areas of the country, also occurring in the Distrito Federal and in the States of Mato Grosso do Sul, Mato Grosso, Minas Gerais, Rio de Janeiro and São Paulo State (Martins 2014).

The potential for colonization of poor soils of *Erythrina crista-galli*, although it is a predominantly associated with humid environments, derives from pioneering behavior (Lorenzi 1992, Roderjan *et al.* 2002). In the natural areas of southern Brazil, populations are affected by agricultural activities (Corrêa 1984, Reitz *et al.* 1988, Lorenzi 1992 and Paz and Bassagoda 2002), occurring in areas frequently used for rice cultivation, soybeans and other cultures. However, due to its landscaping potential the species is naturalized in other regions of the globe, known as “Coral Tree” or “Cockspur coral-tree” (Flora of Mozambique 2019). These arrival area may include populations in natural areas or integrating parks, public areas and gardens, the most representative of these areas being the southern and southeastern region of Africa (Flora of Zimbabwe 2019, Flora of Mozambique 2019, African Plants Database 2019), eastern Australia and New Zealand (Bean 2008, Queensland Govt 2015, Atlas of Living Australia 2019) and southern United States (Tull 1999, Allen *et al.* 2002, Nesom 2015).

Predictions of occurrence of a species based on climate databases for a past period are relatively inaccurate since there are no models for many time intervals. These scarce data do not allow for making very robust inferences about the consequences of climate change on the history of species distribution. However, data from the last maximum glacial when compared to current distributions may help in understanding how such movements may have occurred since then (Waltari and Guralnick 2009, Nogués-Bravo 2009). Furthermore, this natural dynamics of increasing or reducing distribution areas of a species in the time interval studied can serve as important predictions of the areas available for the species in view of future climate change scenarios that accompany the warming trend since 22,000 years before the present.

Recognizing the potential distribution area of a species based on the knowledge of some populations is very useful for the conservation of species in environments where it is natural, as defined by Lemos *et al.* (2014) for *Schinus molle* L. In natural environments and in new occurrence frontiers, such data on the potential distribution also allows inferences to be made about the studied ecosystems. Thus, this type of evaluation can provide useful data for the management of species where they were introduced, since the success of the establishment of a displaced species, accidentally or intensely, responds to climatic and environmental variables that the species is subject to (Begon *et al.* 2007, Brito 2009, Cahill *et al.* 2012, Alexandre *et al.* 2013).

The main factors local extinctions in future scenarios will be given by the intolerance of native species to adapt to changing environmental factors (Cahill *et al.* 2012). On the other hand, exotic species introduced may benefit more in colonized areas than native species (Ricklefs 2006). In a climate change scenario, such an advantage of exotic organisms can stand out over the natives, further impacting the conservation of natural environments.

The objective of this work was to identify the occurrence areas of *Erythrina crista-galli* L. where the species was introduced and naturalized, establishing a relation between the areas available in these places in the past and currently. The trend of warming since 22,000 years can point to the consequences of climatic variations on these distribution areas.

MATERIAL AND METHODS

Register of Populations

Location data of 26 natural populations of *Erythrina crista-galli* L. recorded in Brazil and 44 populations recorded in Argentina, by Lozano and Zapater (2010) were employed as presence records.

In Brazil, records were taken by the author, adding the records obtained from the works of Gratieri-Sossella (2005), Costa and Morais (2008), Lazarotto *et al.* (2011), Hirsch and Gava (2013) and the Universidade Federal do Rio Grande do Sul (UFRGS) database for the “Flora Digital do Rio Grande do Sul e Santa Catarina” platform.

For Argentina, were considered the records made by Lozano and Zapater (2010).

Erythrina crista-galli L. distribution modeling

Erythrina crista-galli L. distribution potential maps were produced using the Maxent algorithm (Maximum Entropy Modeling of Species Geographic Distributions, version 3.3.3k, Oct 2011) (Phillips *et al.* 2006), using the latitude-longitude coordinate system and the basic parameters suggested by the software with the incorporation of 70 (seventy) population occurrence points (Table 1).

Diva-GIS® software, version 7.5 (Jan 2012) (Hijmans 2012) was used for the subsequent generation of the distribution maps based on the predictions generated by MaxEnt.

Table 1. Sample points (Pt) of *E. crista-galli* populations in Brazil and Argentina considered in the study.

Pt	Coordinates		Ctry	Sources	Pt	Coordinates		Ctry	Sources
	Lat	Long				Lat	Long		
1	-28.260071	-52.361221	BRA	(1) (4)	36	-31.692408	-60.633124	ARG	(3)
2	-29.716323	-53.713077	BRA	(1) (2) (5)	37	-31.862346	-60.601139	ARG	(3)
3	-29.694603	-53.840778	BRA	(1) (6)	38	-31.477548	-62.074979	ARG	(3)
4	-29.682794	-51.109397	BRA	(1) (7a)	39	-30.831791	-59.713462	ARG	(3)
5	-28.775219	-51.514907	BRA	(1) (7b)	40	-29.737760	-59.653283	ARG	(3)
6	-30.907583	-51.499180	BRA	(1) (7c)	41	-29.093638	-58.756493	ARG	(3)
7	-30.050336	-51.178270	BRA	(1) (7d)	42	-29.011117	-59.606084	ARG	(3)
8	-31.317860	-53.511927	BRA	(1) (7e)	43	-29.052386	-56.616784	ARG	(3)
9	-30.095233	-51.714094	BRA	(1) (7f)	44	-28.210029	-55.798660	ARG	(3)
10	-30.160038	-51.331176	BRA	(1) (7g)	45	-25.671690	-54.351210	ARG	(3)
11	-31.759968	-52.404510	BRA	(1) (7h)	46	-26.434942	-54.555741	ARG	(3)
12	-32.256955	-53.079653	BRA	(1) (7i)	47	-26.786605	-54.162412	ARG	(3)
13	-29.459628	-51.998258	BRA	(1) (7j)	48	-27.444782	-55.625596	ARG	(3)
14	-30.563205	-52.563167	BRA	(1) (7k)	49	-27.221157	-55.499731	ARG	(3)
15	-32.072408	-52.162877	BRA	(8)	50	-27.667955	-56.427987	ARG	(3)
16	-31.812734	-54.121973	BRA	(9a)	51	-27.416853	-58.473297	ARG	(3)
17	-31.808744	-54.158668	BRA	(9b)	52	-27.081162	-58.866625	ARG	(3)
18	-31.476646	-54.137924	BRA	(9c)	53	-27.862858	-58.945291	ARG	(3)
19	-31.295393	-54.172038	BRA	(9d)	54	-28.182296	-58.662094	ARG	(3)
20	-31.213223	-54.286093	BRA	(9e)	55	-28.583709	-58.961024	ARG	(3)
21	-31.251639	-54.078156	BRA	(9f)	56	-28.597524	-58.772226	ARG	(3)
22	-30.871171	-55.509581	BRA	(9g)	57	-28.621747	-58.691439	ARG	(3)
23	-30.813042	-55.307651	BRA	(9h)	58	-26.331422	-61.317171	ARG	(3)
24	-30.525303	-55.072467	BRA	(9i)	59	-24.954779	-58.537630	ARG	(3)
25	-30.252451	-54.960138	BRA	(9j)	60	-24.465745	-65.184359	ARG	(3)
26	-31.354053	-53.941534	BRA	(9k)	61	-24.255573	-65.162386	ARG	(3)
27	-34.694288	-58.248550	ARG	(3)	62	-24.755405	-64.371371	ARG	(3)
28	-34.653629	-58.336441	ARG	(3)	63	-27.236617	-65.807715	ARG	(3)
29	-34.558689	-58.414673	ARG	(3)	64	-28.117198	-65.574660	ARG	(3)
30	-34.521429	-58.499485	ARG	(3)	65	-28.235840	-63.866807	ARG	(3)
31	-34.350052	-58.491004	ARG	(3)	66	-27.850627	-64.208617	ARG	(3)
32	-33.057659	-58.417885	ARG	(3)	67	-28.567050	-66.186156	ARG	(3)
33	-31.886730	-58.243402	ARG	(3)	68	-28.300851	-65.822200	ARG	(3)
34	-30.760964	-57.880310	ARG	(3)	69	-28.513447	-65.805720	ARG	(3)
35	-30.810593	-59.697575	ARG	(3)	70	-25.135125	-64.219863	ARG	(3)

(1) The approximate position of the point was taken according to the description of the study area. (2) One more point is no longer included by the lack of precision in the description. (3) Average position of the given point per map presented from LOZANO and ZAPATER 2010. (4) GRATIERI-SOSSELLA 2005. (5) COSTA and MORAIS 2008. (6) LAZAROTTO *et al.* 2011. (7) UFRGS 2016. (7a) Novo Hamburgo, RS (Parque Henrique Luís Roessler); (7b) Nova Prata, RS (Parque Termal); (7c) Arambaré, RS (Restinga); (7d) Porto Alegre, RS (Jardim botânico); (7e) Pinheiro Machado, RS (Torinhas); (7f) Arroio dos Ratos, RS (Floresta); (7g) Guaíba, RS (source of Arroio Passo Fundo); (7h) Pelotas, RS (exit to Capão do Leão); (7i) Arroio Grande, RS, Reserva Biológica do Mato Grande; (7j) Lajeado, RS, Jardim botânico; (7k) Encruzilhada do Sul, RS (Rural property). (8) HIRSCH and GAVA 2013. Midpoint (FURG). (9) Data of the author. (9a) Aceguá, RS (point 1); (9b) Aceguá, RS (point 2); (9c) Bagé, RS (Rio Negro); (9d) Bagé, RS (Pirai); (9e) Bagé, RS (landmark Bagé-Dom Pedrito); (9f) Bagé, RS (Olhos D'água); (9g) Santana do Livramento, RS (point 1); (9h) Santana do Livramento, RS (point 2); (9i) Rosário do Sul, RS (point 1); (9j) Rosário do Sul, RS (point 2); (9k) Hulha Negra, RS.

The quality of the model was evaluated using the Receiver Operating Characteristics (ROC) parameter that describes the sensitivity and specific aspects of the model (Phillips *et al.* 2006), while the Area Under the Curve (AUC) was used to measure the sensitivity of the prediction. AUC rates ranging from 0 to 1, indicate that the closer to 1, the better the modeling performance, while values below 0.5 indicate low performance (Peterson *et al.* 2008). According to Araújo *et al.* (2005) the quality assessment of the model based on AUC data are made by values where $AUC > 0.90$ are considered “excellent”, $0.80 > AUC \leq 0.90$ are “good”, between 0.70 and $AUC \leq 0.80$ are “acceptable”, $0.60 > AUC \leq 0.70$ are “bad” “results and those obtained between $0.50 > AUC \leq 0.60$ are considered” invalid “.

For the present data we used data from 20 (twenty) global environmental variables of the average period between 1950-2000. The variables were “BioClim”, containing 19 conditions (Table 2) plus the variable “altitude”. These climatic data were all obtained from WorldClim (Global Climate Data) (Hijmans, 2005), and it is possible to later identify the most influential variables in the distribution of the species.

The base of maps used with the territorial limits of the countries was obtained from the Global Administrative Areas (GADM), version of 2.8 (Nov 2015), using the datum WGS84 (GAA 2016) with spatial resolution of 2.5 arc-seconds, or approximately 5 km².

For the representation of the probability of occurrence index, were allowed 6 (six) frequency intervals. For the calculation of the area of distribution, in relation to each of the frequency ranges, was used the image editing software ImageJ (Rasband 2016), version 1.50i (2016), plotting the appropriate scale in kilometers.

The AUC of the generated model revealed high sensitivity ($AUC=0.994$), demonstrating “excellent” performance of the evaluation (Araújo *et al.* 2005).

Contribution of environmental factors in the distribution of *Erythrina crista-galli* L.

Data extracted from the Maxent algorithm allows to verify the most relevant environmental factors in the distribution of *Erythrina crista-galli* L. on the global scale (Table 2).

It is observed that practically half of this distribution is given by only two environmental factors: (a) isothermality (factor that considers the coefficient of variation between the average daytime amplitude (mean monthly temperature (max-min)) and variation (or amplitude) of the annual average temperature] and (b) the average precipitation of the warmer quarter.

It should be noted that the first five environmental variables in the table above (20% of the factors tested) explain practically 90% of the occurrence of *E. crista galli*, thus, the distribution of the species is strongly influenced by these factors.

DISTRIBUTION OF ECOLOGICAL NICHES IN THE OCCURRENCE CENTER IN SOUTH AMERICA

The distribution maps generated by the model, although it has only incorporated data of population located in the Brazil and Argentina, show a natural distribution of the species as described in the literature. Mello *et al.* (2019) specifically considering the distribution of the species in the south of South America, makes considerations about the climatic influence and the conservation of *E. crista galli*. As in this work the

Table 2. Percentage contribution and importance of exchange of environmental factors in the distribution of *Erythrina crista-galli* L. Highlights are the environmental factors that, together, add up to a significant part of the species contribution.

Environmental variable	Contribution (%)
BIO3 = Isothermality (BIO2/BIO7) (* 100)	30.5
BIO18 = Precipitation of Warmest Quarter	21.2
BIO4 = Temperature Seasonality (standard deviation *100)	20.4
BIO14 = Precipitation of Driest Month	12.2
Bio1 = Annual Mean Temperature	5.4
Altitude	2.1
BIO6 = Min Temperature of Coldest Month	1.9
BIO11 = Mean Temperature of Coldest Quarter	1.6
BIO16 = Precipitation of Wettest Quarter	1.4
BIO15 = Precipitation Seasonality (Coefficient of Variation)	0.8
BIO19 = Precipitation of Coldest Quarter	0.7
BIO17 = Precipitation of Driest Quarter	0.6
BIO2 = Mean Diurnal Range (Mean of monthly (max temp - min temp))	0.6
BIO5 = Max Temperature of Warmest Month	0.5
BIO8 = Mean Temperature of Wettest Quarter	0.2
BIO13 = Precipitation of Wettest Month	0.1

objective is to demonstrate the distribution to potential areas of the species in foreign continents, in relation to the South American continent, more details on the modeling of its distribution can be obtained in that work.

Distribution of ecological niches in the African continent

For the southern African continent (Figure 2. A and B), where *Erythrina crista-galli* L. is naturalized, it is observed that in the last studied period the species had an extensive area available, with more expressive spots north South Africa and southern Zimbabwe.

Currently the ecological niches available for the species are restricted almost exclusively to the southern half of Zimbabwe, north and east of South Africa.

On the island of Madagascar alone, the total area available for the species decreased from 12,156 km² during the maximum glacial period to just over 3,620 km² today.

Distribution of ecological niches in the Australian continent and New Zealand

One of the points used to evaluate the efficiency of the model in the indication of the potential distribution of *Erythrina crista-galli* L. was obtained from the Australian continent.

Information from the Atlas of Living Australia was used, where 50 of the 181 points (27%) indicated by their database were plotted. The generated map allowed to compare the efficiency of the model in which

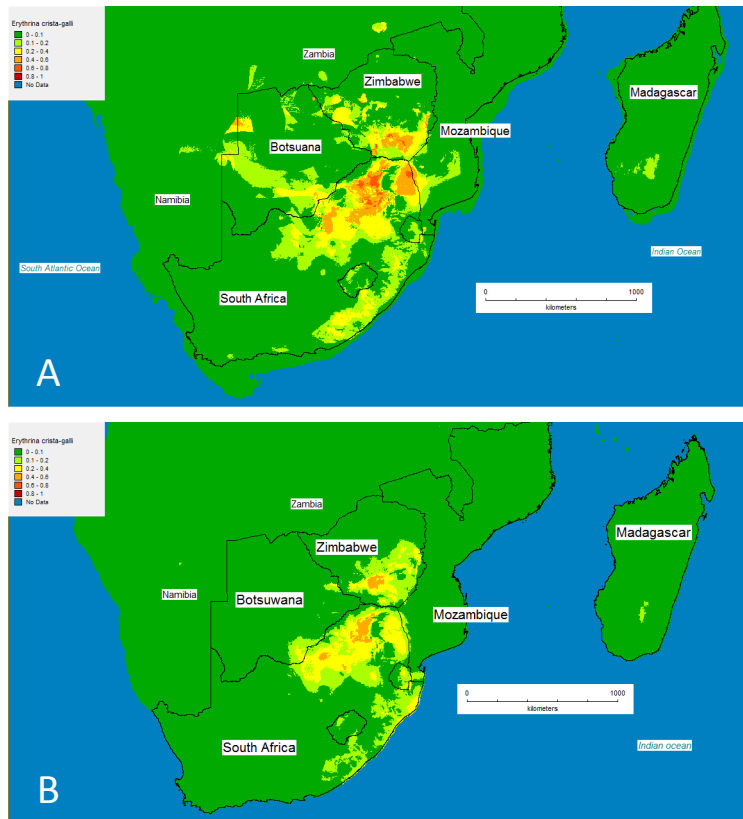


Figure 2. (A) Distribution map of *Erythrina crista-galli* L. (Fabaceae) 22,000 years ago BP and (B) current distribution of ecological niches for the African continent (South Africa, Lesotho, Swaziland, Mozambique, Zimbabwe, Botswana, Madagascar and Namibia). The areas of the model that advance over the present boundaries of the continents towards the oceans represent the reduction of sea level 22,000 years ago BP, due to the glaciation. In these maps the different colors of the legend represent the classes of probability of occurrence of the species, given the meeting of favorable environmental characteristics for the species.

plants in the Australian continent were not informed with the points of existence of individuals registered by the Atlas. For the selection of these 50 points were excluded those very close to each other to allow a greater possible distribution.

These data showed that the populations of *Erythrina crista-galli* on that continent occur on the Australian east coast and north of New Zealand. Such distribution is found in the sites provided by the model for the existence of niches available for the species in that continent (Figure 3), where the species is naturalized.

The Atlas of Living Australia provides species-based data from biological collections, museums, herbaria, and collector records. Graham *et al.* (2004), does not indicate the use of data from museums and collections for this purpose, as it considers that they may result in biased or incorrect distributions due to the low reliability it claims these data have. Raxworthy *et al.* (2003), however, argue that data from museums and collections may be central to understanding species distribution in regions where recent records are scarce, usually due to lack of inventories (Schmidt 2007). However, data from sources such as those cited can be extremely useful for validation of models such as this one.

On the Australian mainland and New Zealand (Figure 4. A and B) a very significant reduction in the niches available over time can also be observed. A significant area between the State of Queensland (QLT) and the Northern Territory (NT) would have been, over time, ecological spaces available that would have been lost with the global warming trend of 22,000 years BP to the present day.

In general, a migration of these niches to the eastern parts of the continent seems to occur, reaching the coastal portions between the states of Queensland, New South Wales (NSW) and Victoria (VIC), where a large number of current occurrences for the species are recorded. This retreat towards the east would have shortened its distribution by the Australian territory in at least 400km to the west of the coast. In New Zealand the available areas were concentrated in the northern part in general, also with more favorable areas linked to the coast. After the climatic changes of the studied period, the model shows that these ecological spaces would extend a little more to a strip to the south-southeast of New Zealand.

Distribution of ecological niches in the American continent

The areas of possible distribution of ecological niches to *Erythrina crista-galli* in Mexico and the United States, which are the most significant areas of this distribution in the northern hemisphere, also shows that areas in the past follow the trend of all environments already cited, becoming less representative at present than in the last 22,000 years BP (Figure 5. A and B).

For these environments, the most available areas for the occurrence of the species were located where today is Mexico and the coastal areas of the American State of Florida. In this extensive area the most favorable sites for the development of the plant would be the central region of Mexico. At present, however, the niches are spread over scattered regions in Mexico, and the coastal areas of the States of Texas, Louisiana, and Mississippi, a more restricted part of the coast of State of Alabama and east Florida, still occurring in a significant spot of around 300km between southeastern Alabama and west-central Georgia.

CONCLUSIONS

The modeling of the potential distribution for *Erythrina crista-galli* L. for different continents is really related to sites where the species is registered by different studies and is naturalized, which shows the efficiency of the model.

The distribution of the species in non-natural environments, approximates the parallel 30° north (North America) and south (África and Australia).

From 22,000 years ago to the present, the global warming trend has led to a reduction in the areas available to the species in all territorial spaces in which *Erythrina crista-galli* is found as an exotic species.

The naturalization of the species in new environments, although without a tendency to increase in the long term, may constitute a risk to the native species. Potential distribution maps can provide important information for species management actions, highlighting special attention for those areas where the model shows more concentration of environmental factors important for species establishment.

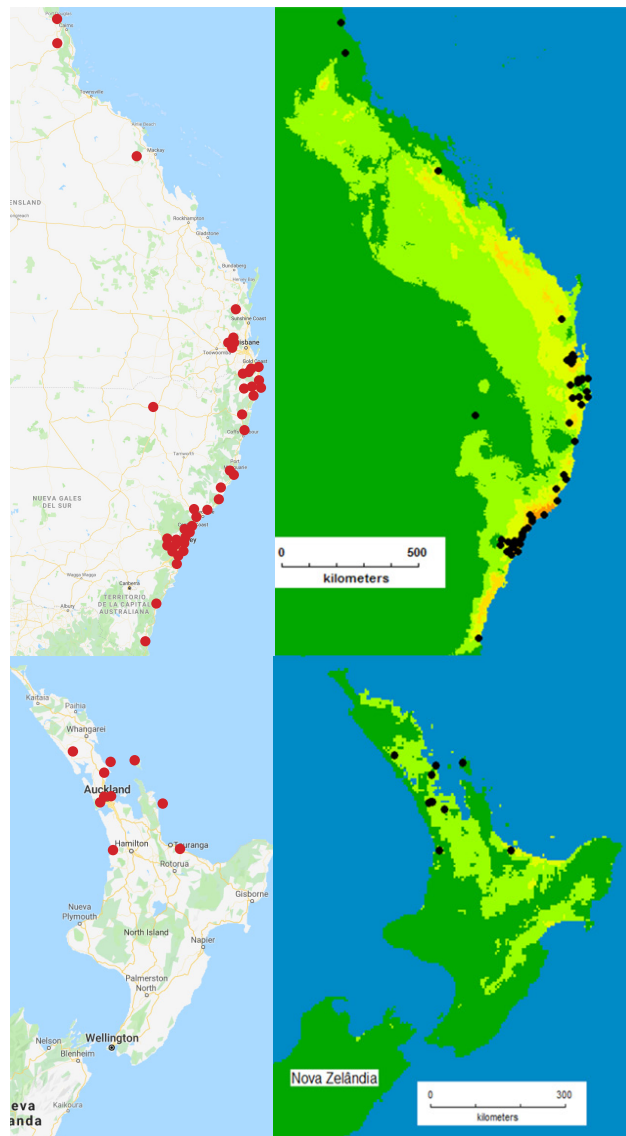


Figure 3. (A) Map of *Erythrina crista-galli* L. (FABACEAE) records for Australia and New Zealand with data from the Atlas of Living Australia (accessed August, 25, 2018) (red dots) and (B) distribution of areas based on the modeling of niches for that continent with the plot of 60 points (black dots on the map), 50 points in Australia and 10 in New Zealand.

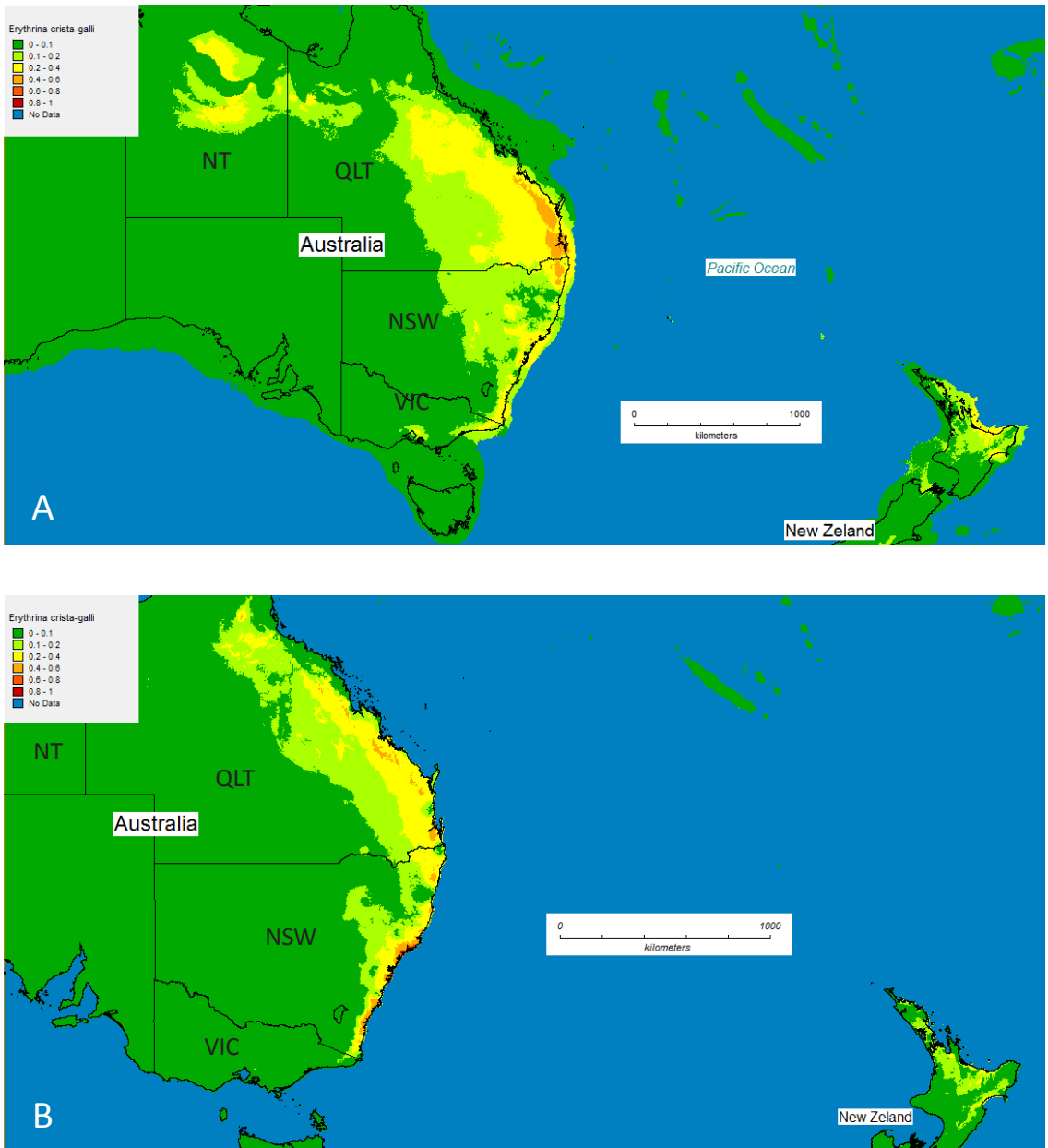


Figure 4. (A) Map of the distribution of *Erythrina crista-galli* L. (Fabaceae) 22,000 years ago BP and (B) current distribution of ecological niches for the species to the Australian continent. (QLT) = State of Queensland, (NT) = Northern Territory, (NSW) = New South Wales and (VIC) = Victoria. The areas of the model that advance over the present boundaries of the continents towards the oceans represent the reduction of sea level 22,000 years ago BP, due to the glaciation. In these maps the different colors of the legend represent the classes of probability of occurrence of the species, given the meeting of favorable environmental characteristics for the species

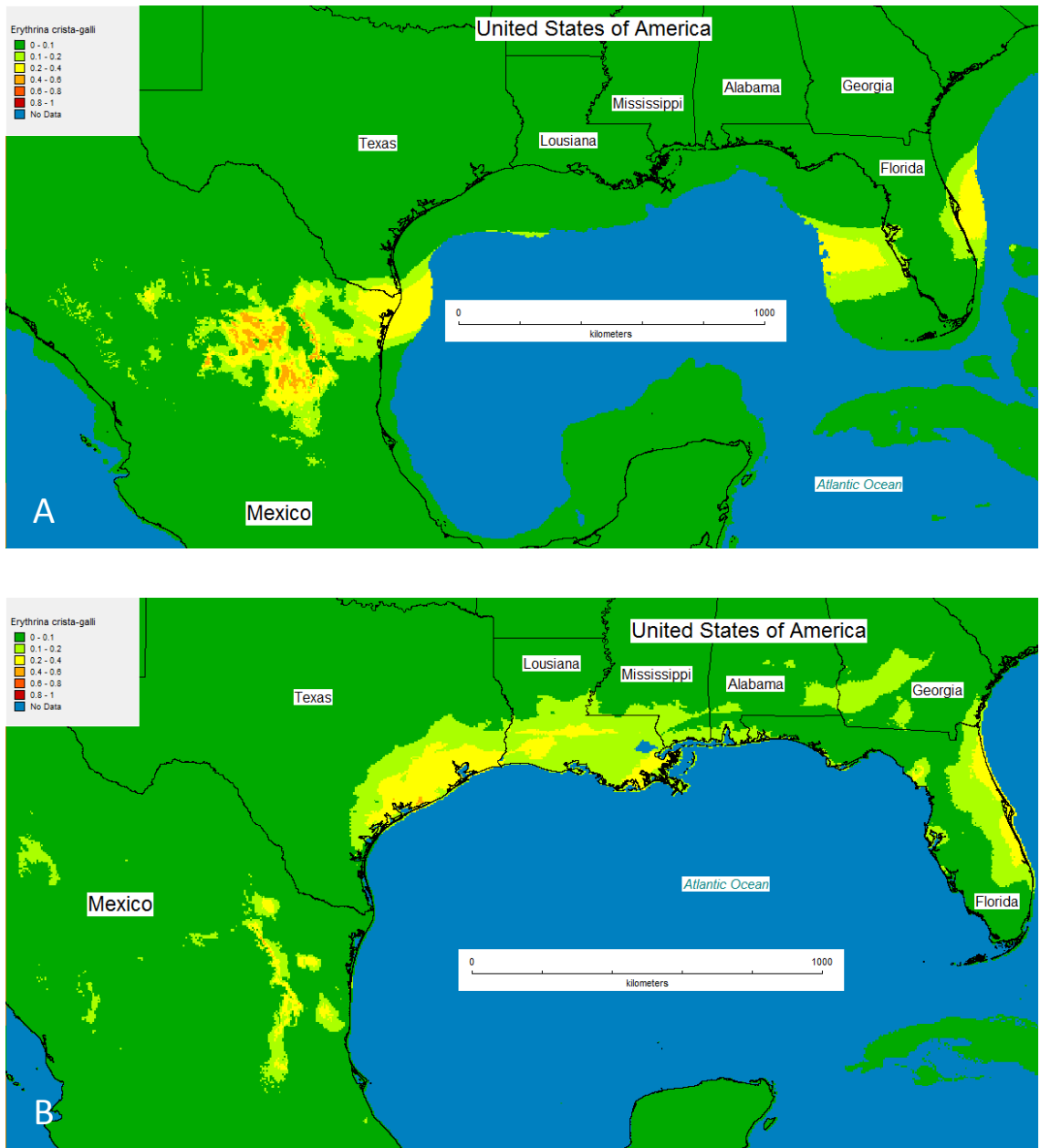


Figure 5. (A) Distribution map of *Erythrina crista-galli* L. (Fabaceae) 22,000 years ago BP and (B) current distribution of ecological niches for the species to Mexico and the United States of America. The areas of the model that advance over the present boundaries of the continents towards the oceans represent the reduction of sea level 22,000 years ago BP, due to the glaciation. In these maps the different colors of the legend represent the classes of probability of occurrence of the species, given the meeting of favorable environmental characteristics for the species.

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