Potential effects of climate change on the risk of accidents with poisonous species of the genus*Tityus* (Scorpiones, Buthidae) in Argentina

Pablo Martinez Corresp., [1] , **Mayane A Andrade** [1] , **Claudio Juan Bidau**

[1] PIBi Lab – Laboratorio de Pesquisas Integrativas em Biodiversidade, Universidade Federal de Sergipe, Sergipe, Brasil

Corresponding Author: Pablo Martinez
Email address: pablo_sc82@hotmail.com

BACKGROUND: The knowledge of the factors that affect the geographic distribution of species permits us to infer where they can be found. Human beings, through the expansion of their own distribution area and their contribution to climate alteration have modified the geographic distribution of other biological species. As a consequence, the temporal pattern of co-occurrence of human beings and venomous species (scorpions, spiders, snakes) is being modified. Thus, the temporal pattern of areas with risk of accidents with such species tends to become dynamic along time. The aim of this work was to analyze the areas of occurrence of species of *Tityus* in Argentina and assess the impact of global climate change on their area of distribution constructing risk maps.

METHODS: Using data of occurrence of the species and climatic variables, we constructed models of species distribution (SMDs) under current and future conditions. We also created maps that allow the detection of temporal shifts in the distribution patterns of each *Tityus* species. Finally, we constructed risk maps for the analyzed species.

RESULTS: Our results predict that climate change will have an impact on the distribution of *Tityus* species which will clearly expand to more southern latitudes, with the exception of *T. argentinus*. *T. bahiensis*, widely distributed in Brazil, showed a considerable increase of its potential area (ca. 37%) with future climate change. The species *T. confluens* and *T. trivittatus* that cause the highest number of accidents in Argentina, showed significant changes of their distributions in future scenarios. The former fact is worrying because Buenos Aires province is the more densely populated federal district in Argentina thus liable to become the one most affected by *T. trivittatus*.

DISCUSSION: Then, these alterations of distributional patterns can lead to amplify the accident risk zones of venomous species, becoming an important subject of concern for public health policies.

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Pablo Ariel Martinez[1*], Mayane Alves Andrade[1], Claudio Juan Bidau[2]

[1] PIBi Lab – Laboratorio de Pesquisas Integrativas em Biodiversidade, Universidade Federal de Sergipe, São Cristóvão, Sergipe, Brasil

[2] Olaguer 444, Lomas del Mirador, Buenos Aires, Argentina.

*Corresponding author: Pablo Martinez, pablo_sc82@hotmail.com

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INTRODUCTION

The understanding of the factors that shape the distribution of species is a central objective of ecological and biogeographic studies (Brown et al. 1996). The Grinnellian niche that is, the climatic conditions where a given organism can persist is considered the principal determinant of the distribution of species (Soberón 2007, Higgins et al. 2012). Thus, knowledge about the factors that determine the geographic distribution of a given species provides information not only about where to find it but also where and how it can interact with the rest of the species (Ehrlén & Morris 2015).

The *Spatial Distribution Models* (SDM) are strong tools to infer from present-day climate, the occurrence of a given species within the geographic space (Elith & Leathwick 2009, Peterson 2011). However, man is currently altering the planet's climatic conditions in unprecedented ways (IPCC 2013). In this scenario, SDMs allow us to project the patterns of distribution into hypothetical future climatic conditions thus helping to understand how species will respond to eventual climate change (e.g. Wiens et al. 2009, Loyola et al. 2012, Porfirio et al. 2014).

In the last decades, humans have exerted enormous pressure on natural systems through the expansion of its own distribution because of urban growth, increasing exploitation of natural resources, and conversion of natural habitats into agroecosystems (Lawler et al. 2013, Venter et al. 2016). This strong impact on biodiversity not only leads to the loss of species of medicinal, commercial and evolutionary value, but to an increasing contact between man and wild species (Conover 2002). One of the central concerns is the contact between human beings and poisonous species such as snakes, spiders and scorpions which is progressively becoming a relevant area of the public health administration of many countries (Kasturiratne et al. 2008; Ediriweera et al. 2016). Furthermore, the geographic distributions of poisonous species are being modified as a consequence of global climate change (e.g. spiders: Saupe et al. 2011; snakes: Nori et al. 2013;

Yañes-Arenas et al. 2015). As a consequence, alterations of the temporal patterns of co-occurrence of venomous species and human beings occur and accident risk areas will present special spatial dynamics along time. Thus being, it is essential that public health decision-making takes into consideration this worldwide phenomenon. Considering poisonous animals, accidents with scorpions are among the most alarming from an epidemiological point of view (Day et al., 2004; Chippaux & Goyffon, 2008). It has been estimated that about 1.5 million cases of envenomation by scorpion stings occur annually worldwide with a 3% risk of a fatal outcome (Chippaux & Goyffon, 2008). Accidents tend to be more frequent in adults (however, see Roodt et al. 2003) but in children the rate of lethality can be up to ten times higher (Chippaux & Goyffon, 2008; Khattabi et al. 2011). The number of different described species is variously given by different authors between 1300 and 1900 species distributed in 13-18 families (Polis, 1990; Williams, 2008; Stockman & Ythier, 2010). However, only 30 are considered potentially dangerous for humans (Chippaux & Goyffon 2008). Of the 50 species known in Argentina, *Tityus* C.L. Koch is the only genus of medical relevance (De Roodt et al. 2003, de Roodt 2014, de Roodt et al. 2014). *Tityus* comprises more than 140 Neotropical species (Fet et al., 2000) of which only six inhabit Argentina: *T. argentines* Borelli, *T. bahiensis* (Perty), *T. confluens* Borelli, *T. paraguayensis* Kraepelin, *T. trivittatus* Kraepelin and *T. uruguayensis* Borelli. Of these, only *T. confluens, T. trivittatus* and *T. bahiensis* can produce fatal accidents (Ojanguren-Affilastro 2005).

The aim of this work is to analyze using SDMs the potential areas of occurrence of *Tityus* species in Argentina, and to estimate the potential impact of future climate change on the distributional patterns of the species. Finally, we establish risk maps for all affected Argentine provinces for present-day conditions and the future.

MATERIALS AND METHODS

Obtention of data: occurrence and climatic variables

Six *Tityus* species are recognized for Argentina (see Introduction). However, in 2000, the presence of a seventh species (*T. serrulatus* Lutz & Mello) was recorded in Corrientes province (Camargo & Richiardi, 2000). This species is widely distributed in Brazil and is considered one of the most dangerous in the world (Pucca et al. 2015). Thus, we obtained data of occurrence of all seven species with proven or possible existence in Argentina. Occurrence data were obtained from the Global Biodiversity Information Facility (GBIF, www.gbif.org) databases and from the excellent monograph by Ojanguren-Affilastro (2005). All data were carefully examined to eliminate doubtful or duplicated occurrence records. For *T. uruguayensis* and *T. paraguayensis* the number of records (< 10) was insufficient for performing SDM. Such a low number of occurrences affects the reliability of the SDM (Stockwell & Peterson, 2002). Thus, the latter two species were not included in our analyses. Robust data were effectively obtained for *T. argentinus* (n=43), *T. bahiensis* (n=25), *T. confluens* (n=55), *T. trivittatus* (n=60), and *T. serrulatus* (n=73).

We obtained data of 19 climatic variables for the present (1950-2000) from the WorldClim database (Hijmans et al. 2005) . These variables are derived from temperature and rainfall information. All climatic variables were used at a resolution of 2.5min (~5km). Because the variables to be input in the model must be independent we analyzed their colinearity using Pearson's correlation analysis. Of the original 19 variables we selected those six with the highest biological relevance that showed a low correlation (r<0.75) in the study area (South America): Bio7- Annual thermal amplitude; Bio11 – Mean temperature of the coldest season; Bio15 – Precipitation seasonality; Bio16 – Precipitation of the rainiest season; Bio17 - Precipitation of the driest season; and Bio18 – Precipitation of the warmest season.

For the projection of our models into the future, we used analog climate layers from general circulation models (GCM). For projections into 2070 we used the CCSM4, GISSE2-R and MIROC5. We also made projections into an intermediate scenario, RCP6.0, that establishes that carbon emissions will cause a mean temperature rise of 2.2ºC (1.4-3.3) by 2080-2100 (IPCC, 2013).

Models of Species Distribution and Risk Maps

The SDMs of *Tityus* species were performed with maximum entropy algorithm in Maxent software (Phillips et al. 2006). We chose this algorithm because it only uses presence points and shows a higher performance than other algorithms (Elith et al., 2011). The performance of the model was assessed by the Area Under Curve method (AUC) (Peterson et al. 2008). AUC evaluates the model through the relationship between the correctly predicted presences (sensibility) and the erroneously predicted absences (1 minus specificity). The group of data was also divided using 75% as training data and 25% to evaluate the model's robustness. Then the whole dataset was used to develop the model.

We first constructed the models under the current climatic conditions, and then we projected them for the future climate GCM, GISSE2-R, and MIROC5 (year 2070) in the RCP6.0 scenario. The continuous probability maps of occurrences generated by Maxent were transformed into binary maps, where absence (0) is considered below a certain threshold, and above the threshold, presence (1). To define the threshold we used the minimum 10% to establish the lowest probability of the adequate climate (Tania Escalante et al. 2013). The binary maps of present and future were combined in the DIVA-GIS software (http://www.diva-gis.org/). We finally generated a map where changes in the temporal patterns of distribution of each scorpion species can be detected (Stability, Expansion, and Retraction).

Finally, we created an accident risk map with the analyzed *Tityus* species. To do this, each species was weighted on the basis of its biological risk of accidents in Argentina and the dangerousness of its venom giving values of 0.5 to *T. argentinus*, 1.0 to *T. bahiensis*, 1.5 to *T. confluens* and 2 to *T. trivittatus* (*T. serrulatus* was not included in the risk map because it has a low probability of becoming established in Argentina; see Results). The risk maps of all species were multiplied by their respective risk values, stacked and added up.

RESULTS

The models for all five species showed an optimal performance with values of AUC exceeding 0.95: *T. argentinus*: 0.99; *T. bahiensis*: 0.98; *T. confluens*: 0.96; *T. serrulatus*: 0.96 y *T. trivittatus*: 0.97). The suitability maps of all species were concordant with the distribution patterns proposed in the literature (Appendix A, Fig. S1). In Argentina, *T. argentinus*, showed that the best climatic conditions for its occurrence correspond to Tucumán province, western Santiago del Estero, central Salta, and eastern Jujuy (Fig. 1a). *T. bahiensis* showed predominance in northeastern Argentina including the provinces of Misiones, Corrientes, northern Santa Fe, and eastern Chaco and Formosa (Fig. 1b). The highest suitability values for *T. confluens* corresponded to north-central Argentina (Fig. 1c). The best climatic conditions for *T. trivittatus* were observed in northeastern Argentina with the exception of Misiones province (Fig. 1d). Finally, *T. serrulatus* did not show favorable climatic conditions within the Argentine territory with the exception of a small region in the center of Tucumán province (Fig. 1e).

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From the future projections (RCP6.0-2070 scenario) we were able to show that models CCSM4, GISSE2-R, and MIROC5 were concordant and highly correlated between them (r>0.85) (Appendix A, Table S1). Thus, only the CCSM4 model are presented. The future projections show a clear trend of all species except *T. argentinus* to expand their distributions towards south (Fig. 1a-d). In the case of *T. argentinus*, its area of occupancy is expected to decrease with the largest area losses towards the eastern part of its original distribution (Table 1, Fig. 1a). In contrast, *T. bahiensis, T. confluens* and *T. trivittatus* show a clear future increase of their original distributions (Table 1, Fig. 1b-d).

The risk map for the present shows that the areas with a higher probability of serious accidents with scorpions correspond to central and northern Santa Fe province, eastern Chaco province, and northern Córdoba and Tucumán (Fig. 2a). Future projections predict intense changes in the zones at risk. The most alarming zones are central-southern Santa Fe, the whole Córdoba province, southern Corrientes, eastern Entre Ríos, southwestern Tucumán, and eastern San Luis (Fig. 2b).

DISCUSSION

Scorpions are a fascinating group of arthropods of great antiquity (ca. 450my) that have fascinated humans since antiquity, and although only about 30 species worldwide are really dangerous for humans due their highly toxic venoms, they tend to be considered agents of evil since antiquity (Cloudsley-Thompson 1990, Polis, 1990; Sissom, 1990). Nevertheless, those species that can put in risk human life are worthy of consideration from the medical point of view. Our study using SDMs revealed for the first time the potential geographic distributions of scorpions of the genus *Tityus* in Argentina. Envenomation accidents by scorpions stings are generally restricted to tropical and subtropical regions (Borges et al. 2012). However, our results predict that climate change with its steady increase in global warming, will have a notorious impact in the patterns of distribution of *Tityus* species that will clearly extend to more southern latitudes. A comparable situation has been observed in Argentine poisonous snakes where species of the genera *Crotalus* (rattlesnakes, *serpientes de cascabel*), *Bothrops* (*yararás*), and *Micrurus* (coral snakes, *coralillos*) accompanied climate change with a clear shift of their distributions towards south (Nori et al. 2013). This trend is expected for many tropical and subtropical species of vertebrates and invertebrates when a sustained increase in temperature allows the colonization of new previously limiting habitats leading to an expansion to higher latitudes (Parmesan et al. 1999, Vanderwal et al. 2013). These potential distributional changes may lead to and amplification of the accident risk zones of poisonous species. Then, the relationships of co-occurrence of human beings and venomous species in Argentina are expected to varya spatial ana temporally.

T. argentinus was the scorpion species for which less changes are predicted: new favorable climatic conditions are only expected in Catamarca province (Fig. 1a). Also, this species was the only one to show a potential reduction of ots geographic distribution (Table 1, Fig. 1a). Furthermore, *T. argentinus* is considered the less dangerous of the Argentine *Tityus* species with no records of fatal accidents attributable to it (Salomón 2005; Roodt et al. 2014).

On the other hand, our study highlights that climate change may have a significant effect on the distributional patterns of the other examined species (*T. bahiensis, T. confluens* and *T. trivittatus*) where a clear southward shift of their distributions was predicted (Fig. 1). Currently, *T. bahiensis* is frequently found in Misiones province (Roodt et al. 2014). To this day, no serious cases of envenomation with this species have been reported in Argentina (Roodt et al. 2014). However in Brazil, where this species is widely distributed many severe cases of envenomation are reported (Bucaretchi et al. 2014). A worrisome situation is that this species is frequently found in urban settings causing the highest number of accidents in big metropolises such as São Paulo city (von Eickstedt et al. 1996). The analysis of the possible effects of climate change on the distribution of *T. bahiensis* shows a clear significant southward shift of the area of occupancy in Argentina involving a ca. 37% increase of the potentially favorable area (Table 1). An alarming point is that the future climatically favorable regions for the species overlap large urban centers such as Santa Fe, Resistencia, Santiago del Estero and Tucumán cities (Fig. 1b). This predictions turn *T. bahiensis* into a foreseeable probable for the Argentine public health system.

The two species that are currently of most public health concern in Argentina, namely *T. confluens* and *T. trivittatus* (de Roodt et al. 2009, Álvarez Parma & Palladino 2010) also showed significant shifts of their geographic distribution in the future scenarios (Fig. 1c-d). There is ample evidence that venom of these two species is higly toxic and dangerous for human beings (De Roodt et al. 2003, Saracco et al. 2006, de Roodt et al. 2009, Álvarez Parma & Palladino 2010). *T. confluens* show death reports of people in many provinces of northwestern Argentina such as Jujuy, Catamarca and Tucumán (de Roodt et al. 2014). On the other hand, SDM projections for *T. trivittatus* show that the main increase in geographic distribution is predicted for the potentially favorable areas of Buenos Aires province, he more densely populated district in Argentina (Fig. 1d). Contrary *to T. confluens*, *T. trivittatus* easily adapts to urban environments and is the main cause of deaths by scorpion stings in Argentina (de Roodt et al. 2014; Docampo, 2014). This behavior of *T. trivittatus* highlights a limitation of our study using SDMs because only the external climatic characteristics were considered but *T. trivittatus* adapts easily to urban settings using subterranean galleries, drainpipes, and cavities and crevices of buildings (Ministerio de Salud 2011, de Roodt et al. 2014). These habits allow the species to

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thrive even if the external climatic conditions are not favorable if it founds suitable microclimates within urban structures (de Roodt et al. 2014). This may produce cases of omission that is, locals that are not projected by the SDMs but in which the species can nevertheless occur (Guisan & Zimmermann 2000). Then, our models are conservative because they could underestimate the distribution area of species highly adapted to urban settings. Finally, *T. serrulatus*, considered as the most dangerous scorpion of South America (Bucaretchi et al. 1995) did not show environmental continuity between Brazilian and Argentine populations (Fig. 1S). Camargo & Richiardi (2000) recorded the occurrence of this species in Corrientes province; however our SDM supports the hypothesis that the presence of the species is the result of accidental transport and not a natural range expansion.

From our SDMs we were able to construct an accident risk map with the studied *Tityus* species (Fig. 2). Our risk map for current climatic conditions shows high concordance with published statistics of accidents as reported by the Ministerio de Salud (Ministry of Health) of Argentina (2011). The Argentine provinces of Santa Fe, Córdoba, Corrientes, Chaco, Santiago del Estero, Tucumán and Jujuy are among those with the higher risks of scorpion stings and envenomation (Fig. 2a). The Argentine Ministerio de Salud (2011) also emphasizes the provinces of Catamarca and La Rioja as showing a high number of accidents. Our own risk estimation for both provinces showed an intermediate risk level (Fig. 2a). In our SDMs *T. confluens* showed high suitability in Catamarca and La Rioja (Fig. 1). We must stress that our risk index does not consider the number of accidents but the toxicity of the venoms and the species richness of the locality. Thus, this small discrepancy imay be associated with the species richness estimated by the SDMs for this region. The future potential risk map shows that in the provinces of Entre Ríos and San Luis, the risk of accidents may increase dramatically. Also, the risk maps are generally displaced towards southern Argentina increasing the probability of accidents in central and southern Buenos Aires and La Pampa, while in the provinces of Chaco and Formosa and eastern Salta the probability of accidents will diminish with climate change (Fig. 2b).

CONCLUSIONS

Climate changes have strong consequences for the geographic distribution of species (Vanderwal et al. 2013). For this reason the consideration of the future derivations of global warming is of central importance in the studies of public health problems involving risky animal species (Githeko et al. 2000, McMichael et al. 2003). With this perspective, SDMs have become a fundamental tool for predicting potential impacts of climate change on the distributional patterns of wild species such as vectors of disease and venomous species (e.g. Saupe et al. 2011, Nori et al. 2013, Conley et al. 2014, Yañez-Arenas et al. 2016). Our study using SDMs permitted the identification of areas with climatic conditions favorable for the occurrence of dangerous scorpion species and also allowed the prediction of future potentially risky areas.

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AUTHOR'S CONTRIBUTION

PAM and CJB conducted the study, PAM and MAA participated in data acquisition and models analyses. All the authors contributed to the interpretation of the result, writing of the work and approved the final version of manuscript.

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FIGURE CAPTION

Figure 1. Changes in suitable climatic areas between present and future condition (2070: RCP 6.0 scenario) for five species of genus *Tityus* of Argentina: a) *T. argentinus*; b) *T. bahiensis*; c) *T. confluens*; d) *T. trivittatus* and e) *T. serrulatus.*

Figure 2. Accident risk map for present and future (2070; RCP 6.0 scenario) climatic condition for *Tityus* species in Argentina.

Table 1 (on next page)

Table 1

Climatically suitable areas (km^2) in the present and future (2070: RCP 6.0 scenario) for *Tityus* species in Argentina

Table 1. Climatically suitable areas (km^2) in the present and future (2070: RCP 6.0 scenario) for *Tityus* species in Argentina

Species	Current Area	Future Area	Gain or Loss
T. argentinus	190350	179050	-11300
T. bahiensis	462575	635475	172900
T. cunflens	1072675	1210700	138025
T. trivittatus	934675	1024750	90075

Figure 1

Figure 1

Changes in suitable climatic areas between present and future condition (2070: RCP 6.0 scenario) for five species of genus *Tityus* of Argentina: a) *T. argentinus*; b) *T. bahiensis*; c) *T. confluens*; d) *T. trivittatus* and e) *T. serrulatus.*

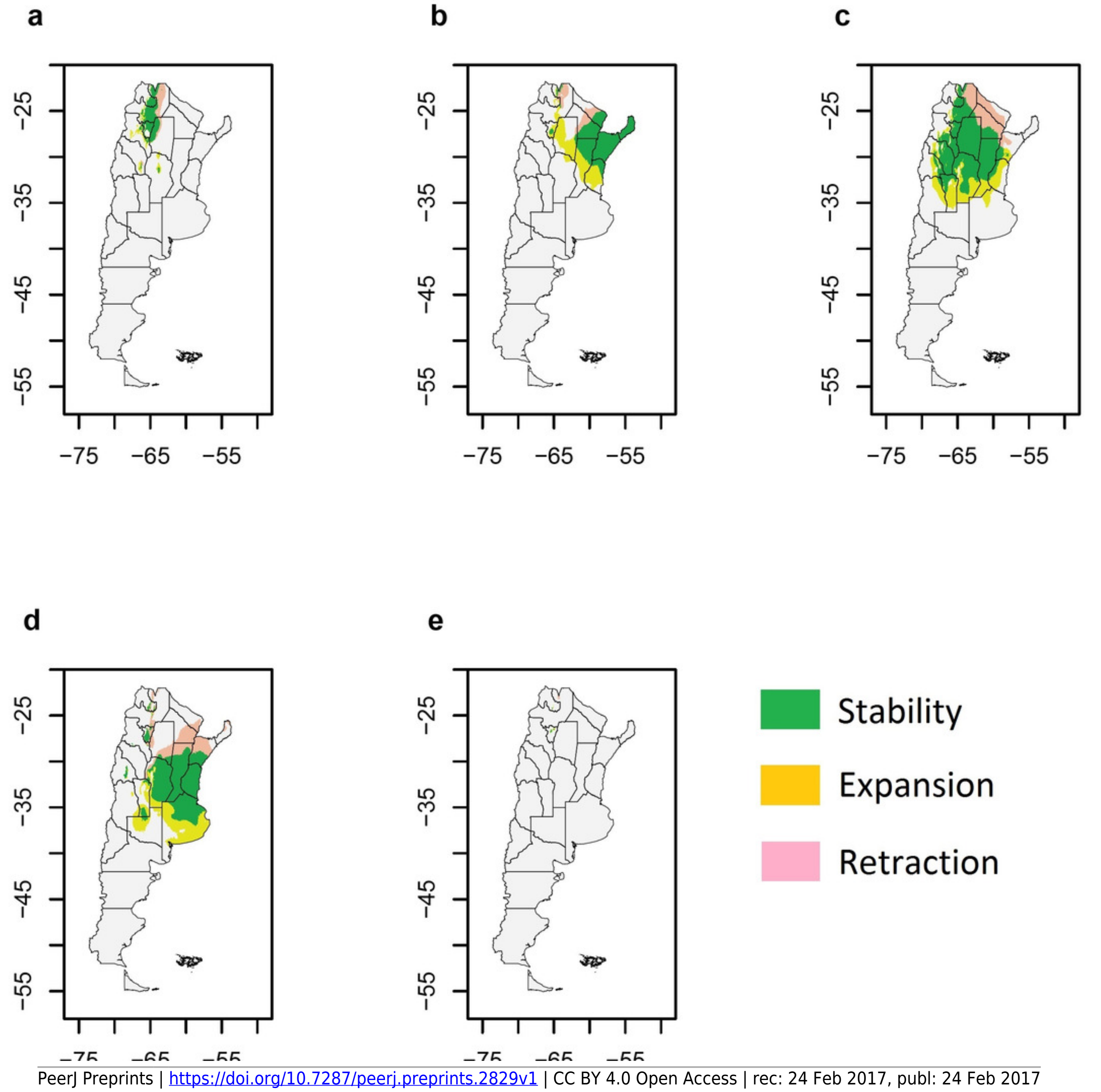

Figure 2

Figure 2

Accident risk map for present and future (2070; RCP 6.0 scenario) climatic condition for *Tityus* species in Argentina.