Jaguar: risk of having to move to less suitable areas

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The future of nature and agriculture

Mathematical models help predict the effects of global warming in Brazil

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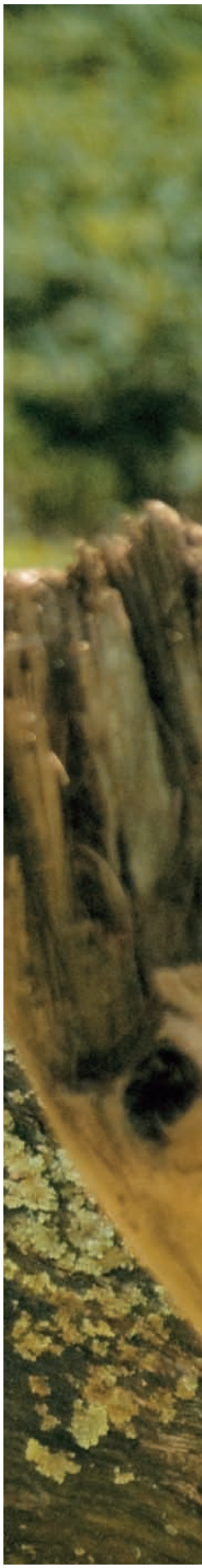
A hundred years from now climate change may cause major alterations in the natural landscape and in Brazilian agriculture. It's possible that the jaguar, the largest feline in the Americas, will find no suitable living areas in the Amazon. In turn, the Cerrado [savannah] may disappear once and for all from the west of the State of São Paulo and losses in the soybean crop in Brazil run the risk of reaching 40%, i.e., an annual loss of R$ 4.3 billion. These are just some of the estimates of researchers who are concerned with climate change, as forecast by the Intergovernmental Panel on Climate Change (IPCC). What is enabling environmentalists and agronomists to take their eyes off the present and look at the future are mathematical models that try to sum up, in a few parameters, the essential environmental conditions for each species and to simulate what might happen to the climate in different scenarios depending on the concentration of gas in the atmosphere.

"Current conservation units may not serve to preserve species," warns Paulo De Marco Júnior, of the Federal University of Goiás (UFG). Along with José Alexandre Diniz-Filho he heads the Laboratory of Theoretical Ecology and Synthesis, one of the main Brazilian research groups using environmental models. For the environmentalist from UFG, it is useless choosing a forest area to be protected if it has little chance of containing the biological diversity that the country wants to maintain in the future. Such is the case with the jaguar (*Panthera onca*), the theme of the PhD of Natália Torres, whose thesis advisor was Diniz-Filho.

From the 1,053 records of jaguars on the database of the Jaguar Institute, based on rainfall and temperature parameters, Nátalia has defined the ideal weather conditions for jaguars. Although they can live in very varied environments – ranging from the thick, damp and dark vegetation in the heart of the Amazon Region to the arid expanses of the Caatinga scrubland and thorn forests – studies involving photographic traps and monitoring these big cats reveal that they prefer more enclosed areas near water, with temperatures between 20 and 25 degrees Celsius (°C) and rainfall most of the year. The model, which was produced based on the current distribution of jaguars and then applied to weather conditions from the past, passed its first test. The distribution found in this assessment of a past forecast coincides with the historical data – from when panthers covered almost all of Brazil, an



It is useless to protect an area of forest if it has few chances in the future of harboring the biological diversity that we would like to keep

area twice as large as today, and looming large in popular imagination.

Natalia's data were published in late 2008 in *Cat News* and predict that during the course of the next 100 years there will be a large reduction of areas suitable for jaguars. In the Amazon Region, for example, these ideal zones may be restricted to the so-called arc of deforestation, which includes the north of the State of Mato Grosso and the south of the State of Pará, where there is greater pressure for planting soybeans and sugar cane. The challenge now is to find areas that can be preserved and that are capable of sustaining populations of these large predators.

"It's important to point out that the model indicates the occurrence potential of this species, not necessarily where it will be found," Natália reminds us. She is going to add more detailed information to the climate model, such as the size of the patches of vegetation. With this she intends to indicate priority areas for preserving the jaguar. In the south of the Amazon, one promising area is along the Araguaia River, the source of which lies on the border between Mato Grosso and Goiás and which flows north into the Tocantins River, where the States of Maranhão, Pará and Tocantins meet. "There are still very well preserved areas there," says Natália, "and it's an important corridor for the jaguar because it connects the Amazon Region and the Cerrado." It also coincides with part of the area that is expected to continue being ideal for it in the future, a forecast that may improve with more detailed analyses. Climatologist Carlos Nobre, from the National Space Research Institute (Inpe), is surprised that the model does not highlight the permanence of jaguars in the west of the Amazon. "All the models forecast that there will be dense and humid forests there," he says.

The researcher is not overlooking the fact that jaguars can live in very different environments and that, therefore, a reduction in ideal areas does not necessarily mean the end of these big cats. "Climate change is unlikely to affect the general distribution," she reflects, "but, if the quality of the environment has an effect on the abundance of the animals, it may be worrying for the long-term persistence of populations." She is now trying to gather information to suggest areas for preservation, which must take into account the size of remaining areas – large predators need a lot of space to get sufficient resources.

Amphibians, which are more sensitive to environmental conditions and less mobile, are good indicators of what happens with forests. "They depend on the temperature and humidity of their surroundings and that's why they are restricted to their particular environment," says João Giovanelli, from Paulista State University (Unesp) in Rio Claro, who used environmental models to investigate future distributions of amphibians from the Atlantic Rainforest – toads restricted to the tops of mountains and a frog with more flexible preferences.

Considering a scenario for 2100 with double the amount of carbon dioxide (CO_2) than there was in the pre-industrial period (one of the possibilities forecast by other researchers), some species of small toads of the genus *Brachycephalus*, which are the size of a person's thumbnail, may disappear. They only live in the humid areas of the Mata Atlantica rain forest at a high altitude, where the rise in temperature may alter the cloud system and eliminate a large part of the forests, which would start growing dozens or hundreds of meters higher up the mountains – provided they find suitable conditions. Even if this happens, this migration process of the forest will take a long time and the minute toads, which look like drops of gold on the leaves that form a carpet on the forest floor, may have nowhere to wait. So, *Brachycephalus* may lose more than half its distribution and various species may become extinct, according to a chapter written by the Unesp group, which includes zoologist Célio Haddad, for the book *A biologia e as mudanças climáticas no Brasil* [Biology and climate change in Brazil], edited by Marcos Buckeridge, of the University of São Paulo, and published last year by the RiMa publishing house.

Giovanelli also shows that not all species will come out of this as losers. The tree frog, *Hypsiboas bischoffi*, for example, may benefit from fewer cold spells in some areas of Rio Grande do Sul, leading to a growth of 57% in its distribution.

Mobile environments – Environmental modeling may help forecast the destiny of entire ecosystems. That is what Carlos Nobre's group is doing. "We define the biome by a set of climate parameters, which include soil humidity, temperatures, the evapotranspiration of plants and resistance to fire, among other things," explains the climatologist. The group estimates, for example, that at the end of this century Uruguay, which today is very cold, will be able to support Atlantic rainforests. The results, published in 2007 in *Geophysical Research Letters*, also indicate that in certain regions of the Amazon Region only plants adapted to savannah conditions will survive. "But the model does not allow us to talk about biome migration, which is a very complex and slow process," he advises.

In her PhD, tutored by Giselda Durigan, from the State of São Paulo Forest Institute, botanist Marinez Siqueira, from the Rio de Janeiro Botanical Garden, concentrated on the effect of climate change on trees from the Cerrado, which is the typical vegetation of Central Brazil. One outcome of this work was the article published in 2003 in *Biota Neotropica*, in which Marinez modeled the distribution of 162 species of trees and forecast that in 50 years time there will be a drastic reduction in the area occupied by most of them. The best conditions for the Cerrado are

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Cerrado savanna: increasingly less suitable climate in the central region

likely to be displaced to the south of the region currently occupied by this ecosystem, coming close to the border between the states of São Paulo and Mato Grosso do Sul.

Marinez is now detailing what is likely to happen in São Paulo, a panel presentation she gave at the International Conference on Biodiversity IT, held in London this year. In projections for 2020 and 2080, she shows that the ideal climate conditions for the Cerrado are likely to move to the east of the state, close to the coastal range of hills – today the domain of the Mata Atlântica rainforest. "But this does not mean that the Cerrado is going to invade Mata Atlântica areas."

The fact is that, at the regional and local level, the distribution of species is not only defined by the climate. "Temperature and rainfall alone do not determine the occurrence of Cerrado species," says the researcher from the Rio de Janeiro Botanical Garden. The species that manage to survive in a certain region are partly determined by the soil's capacity to retain water – a category of data not taken into account in the models she used. Changing this will be the next step.

More complete models will help imagine the destiny of birds from the Cerrado. Environmentalist Miguel Ângelo Marini, from the University of Brasília (UnB), led a study that estimated where the 26 species will be in 2030, 2065 and 2099. According to the results, published in June on the *Conservation Biology* website, most of these birds are likely to move to the southeast by an average of 200 km – precisely the country's most urban region. In the State of São Paulo, for example, it is estimated that less than 1% of the original Cerrado remains. "It's no use if the climate is good for birds if the Cerrado vegetation takes a long time to arrive," says Marini, who estimates a reduction in areas occupied by all the species he studied, which may make the birds whose distribution is already restricted even rarer. By analyzing the conserved areas, in an article accepted by *Biological Conservation*, he showed that birds from the Cerrado are already poorly protected today – and in the future they will be even less protected. "We're identifying possible locations for new conservation units in regions of Minas Gerais where there is an overlap between today's climate and the climate 50 years ahead."

Planning preservation with an eye to the future seems essential – perhaps the areas defined as priority in the State of São Paulo, during a workshop of specialists in 2007, may not have the climate necessary for accommodating the Cerrado in 2080, according to Marinez's projections. "The Cerrado areas that already existed in the east of the state are beginning to take on a greater importance," she says. Such is the case of the Cerrado enclaves in the Paraíba Valley in the northern part of the State of São Paulo, between the Mar and Mantiqueira ranges of hills, a region that has already been heavily altered by human activity and where few fragments of natural vegetation remain. Even so, Marinez believes that it is worth establishing areas of preservation there.

Calculated risk – The same principles may help plan the planting of the main Brazilian crops. This is just what Embrapa, the Brazilian Company of Agricultural and Livestock Farming Research, has done in a partnership with the State University of Campinas (Unicamp) and Inpe, with support from the British Embassy. According to a publication released last year and coordinated by agronomist Hilton Silveira Pinto, from Unicamp, and by agricultural engineer Eduardo Assad, from Embrapa, if nothing is done global warming may be responsible by 2020 for losses of R$ 7.4 billion a year in grain harvests. By 2070, this figure could reach R$ 14 billion a year. The report analyzed where the ideal conditions for Brazil's nine most important crops will be located. These crops – cotton, rice, coffee, sugar cane, beans, sunflowers, cassava, corn and soybeans – account for 86% of the country's planted area.

Sunflower: sufficient area to escape from an inhospitable climate and from pests

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The group considered two scenarios. The pessimistic one estimates a temperature rise of 2°C to 5.4°C by 2100, which is plausible if nothing is done to reduce emissions. The more optimistic scenario foresees a temperature rise of 1.4°C to 3.8°C by 2100, if human population growth stabilizes, natural resources are preserved and greenhouse gas emission are reduced. "If Brazil's inaction remains the same," Hilton Pinto states provocatively, "this is what the losses will be." Losses in soybean production, the crop that is likely to suffer the most, may exceed R$ 7 billion a year by 2070, with the loss of areas that can be cultivated, mainly in the south and in the northeastern Cerrado region. At less than 10°C, plants hardly grow at all and from 40°C they do not flower normally and tend to lose their beans. Furthermore, during germination and the period between flowering and grain production, soybeans need a lot of water.

Changes are already happening. "Coffee in the west of São Paulo has moved to the northeast of the state, to the region of Mogi," says Hilton Pinto. In conversations with coffee growers he discovered that from 1995 until today flowering has been more and more compromised by heat waves in normally not very hot months, like September. This causes the flowers to abort. But the damage is not generalized. "Sugar cane likes high temperatures and higher levels of CO_2," he recalls. According to his calculations, even if nothing is done to adapt this crop to the new conditions, the area suitable for its production may increase by about 150% as early as 2020.

The group is now estimating how much Brazil will need to invest in the production of plants adaptable to the new conditions. According to the engineer from Unicamp, each new cultivar costs R$ 1 million a year. The data are in a new publication, to be launched this month, that focuses on mitigation and adaptation. As it takes at least ten years to develop a new variety, the cost will rise to R$ 10 million for each of them.

The projections may have a direct application in practice through Climate Risk Zoning, which estimates the risk of planting each crop for each municipality in the country – a success probability of at least 80% qualifies the farmer for financing. It is a system that is worth R$ 19 billion in financing for family farming," comments the researcher.

Though the production of sunflowers in Brazil is small, they are among the plants with the greatest planting potential, almost 4.4 million square kilometers – an area that is likely to shrink by up to 18% by 2070, mainly in the northeastern Agreste area of dry, stony soil and Cerrado regions. Over and above climate change, another threat to this crop is the caterpillar of the *Chlosyne lacinia* butterfly that eats the leaves and reduces productivity by as much as 80%. This insect, known in Brazil as the sunflower pest, was the theme of work by biologist Juliana Fortes, from the Federal University of Viçosa, in a partnership with De Marco. In the work, a Master's Degree dissertation, under the guidance of Evaldo Vilela, the researcher adopted a scenario that forecasts a temperature rise of 2.6°C over the next 100 years. Juliana realized that producing a model taking into account the species as a whole might lead to errors in the forecast distribution, because in the case of these butterflies each subspecies has different environmental needs – and only *C. lacinia saundersii*, the commonest in Brazil, is known as the sunflower pest.

If climate change comes true, it might be good news for the sunflower: the overlap between the caterpillar and

areas suitable for planting the yellow flowers that are rich in oil is likely to shrink. But the dissertation, which was accepted this year, also warns: if the *C. lacinia lacinia* subspecies, which is typical of Central America, were to be introduced into Brazil, it could take advantage of the climate change and adapt to a large part of the center and northeast of the country. "If this were to happen, instead of a future area reduction, the possible hybridization of the *lacinia* subspecies with might mean an increase in the species' area in Brazil," imagines Juliana, fearing greater damage for the sunflower.

Future under construction – The use of models is becoming increasingly disseminated and may be an essential tool for facing up to climate change, but as knowledge grows they are still being improved. There are dozens of different models and each one attributes a different weight to the various climate variables. What many researchers do is apply several of these models and use their points in common to produce future distribution maps. "Our work is to supply projections of the future climate," says climatologist José Antonio Marengo, coordinator of the climate change group at the Terrestrial System Science Center at Inpe. There, an interdisciplinary team is constantly improving the models, inserting more data and improving the mathematical representation of the complex processes that happen in nature. "The models are mathematical tools and all models have their uncertainties." For Marengo, one must take this uncertainty into account in order to find out where the safest projections lie – including looking for ways to improve the model where it does not function. His team uses data and information – both Brazilian and international – to develop regional models that supply more details about the climate of Brazil and South America. However, it has not been possible, to date, to reach the desired level of detail for the country as a whole. "The reliability of the projections tends to be relatively smaller in the Midwest and Southeast, because some continental zone processes have not been properly represented in the models yet," he says. "And the Pantanal poses even greater difficulties, because the models do not handle emissions and the hydrological representation of a swamp that size very well."

Marengo say that Inpe works with models that he knows in detail, but it is difficult to obtain top quality climate data for certain regions covering a long time span, as required for studying climate extremes. "If we had finer databases, we could carry out more detailed analyses – on the scale of a basin in the State of São Paulo, for example," says De Marco. Furthermore, one must be conversant with the various models in depth. "It's no good just pressing the button and looking at the output," says Giovanelli. "One must understand how the model functions and the database available on the species to know if they're going to be compatible with the question we asked."

Another difficulty that the models face is environmental: the places where a species exists are not necessarily the only ones where they could exist. Just as Marinez Siqueira cannot be sure that the Cerrado will invade the areas of Atlantic rainforest, so the jaguars may manage to live well in less favorable areas and the mountain toads will perhaps not suffer from climate change as much as expected – according to Haddad, there are already records of amphibians typical of the Cerrado being found in the Atlantic rainforest. For Paulo De Marco, this is not a problem as such. "We make projections for the future using species for which we have sufficient data to allow us to represent their distribution and their ecology," he states. "Furthermore, the current work shows that the current environmental niche of a species offers a good estimate of its future niche," under normal circumstances. The environmentalist from Goiás explains that these invading species, which suddenly change habitat, quickly adapt to their new conditions.

The knowledge derived from these projections makes the tools more reliable to deal with the environmental changes caused by man, which also include the heightened effects of deforestation, as the article that follows will show. ■

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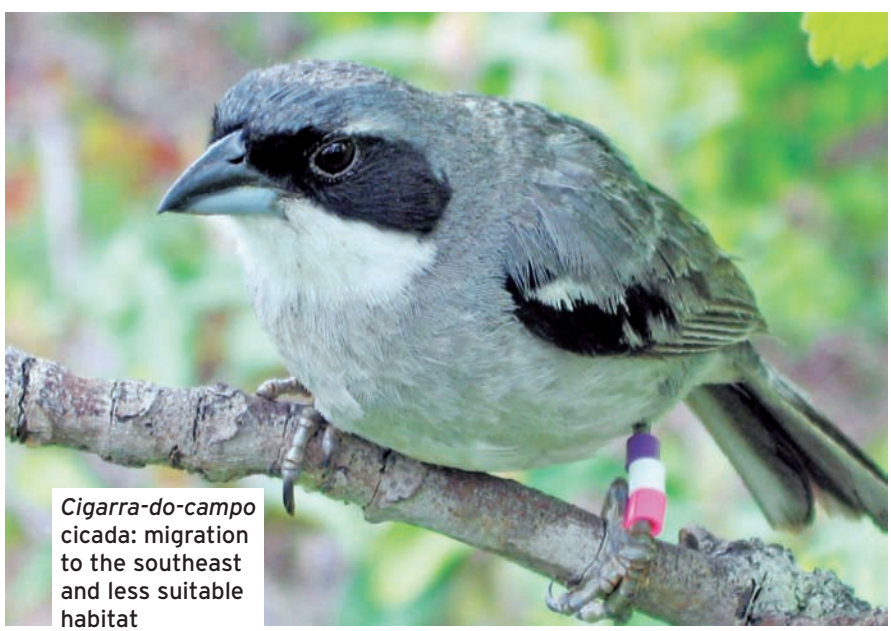

Cigarra-do-campo cicada: migration to the southeast and less suitable habitat

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