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The resurgence of the South American locust (*Schistocerca cancellata*)

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The South American locust (*Schistocerca cancellata* Serville, 1838) was the most destructive agricultural pest in late 1800's to early to mid 1900's Argentina. However, since the 1950s its numbers decreased considerably until a notable upsurge in Argentina in 2015. Here, we give historical context for this species, discuss the current upsurge, and outline ongoing and upcoming research and management activities and collaborations.

The South American locust: 1800 to 1960

The South American locust, *S. cancellata*, first appeared as a destructive agricultural pest in 1538, affecting cassava crops in Buenos Aires (Gastón, 1969). While *S. cancellata* has an expanded range during plagues—from southeast Bolivia, Paraguay, south Brazil, Uruguay, Chile, and Argentina as far as the 42°S—the biggest impact and economic losses have been in Argentina (Kölher, 1962; Lieberman, 1972). Indeed, virtually no crop in Argentina has escaped locust swarms (de Wysiecki and Lange, 2005). Similar to how the Rocky Mountain locust (*Melanoplus spretus* Walsh, 1866) shaped pest management in the U.S., the history of pest management in Argentina began with *S. cancellata*. Locust control campaigns in the early 19th century gave birth to the first governmental agency with the mission of controlling pests and regulating national plant health, a task that is now integrated into the duties of the National Plant and Animal Health and Quality Service of Argentina (SENASA). During plague years, locusts would be distributed across half the country (1.4 million km^2) (Gastón, 1969). Stories were passed on at family gatherings of clear skies suddenly darkened by swarms and crops entirely lost to locusts. However, by the 1960s after many years of control campaigns heavily relying on DDT, a preventive strategy was officially established that succeeded in keeping the locust population at bay. The locusts were restricted to a relatively small region in northwest Argentina (Barrera and Turk, 1983; Waloff and Pedgley, 1986; Hunter and Cosenzo, 1990). In Argentina, 1954 was the last year a major plague period was reported (De Wysiecki and Lange, 2005). Monitoring continued in Catamarca and La Rioja provinces where locust populations remained, but was minimal elsewhere because the locust populations had diminished.

2015-2017 upsurge

After six decades of limited *S. cancellata* activity (only three smaller outbreaks in 1961, 1989 and 2010; Barrientos Lozano, 2011), a sequence

Figure 1. *S. cancellata* swarms in Chaco province July 2017

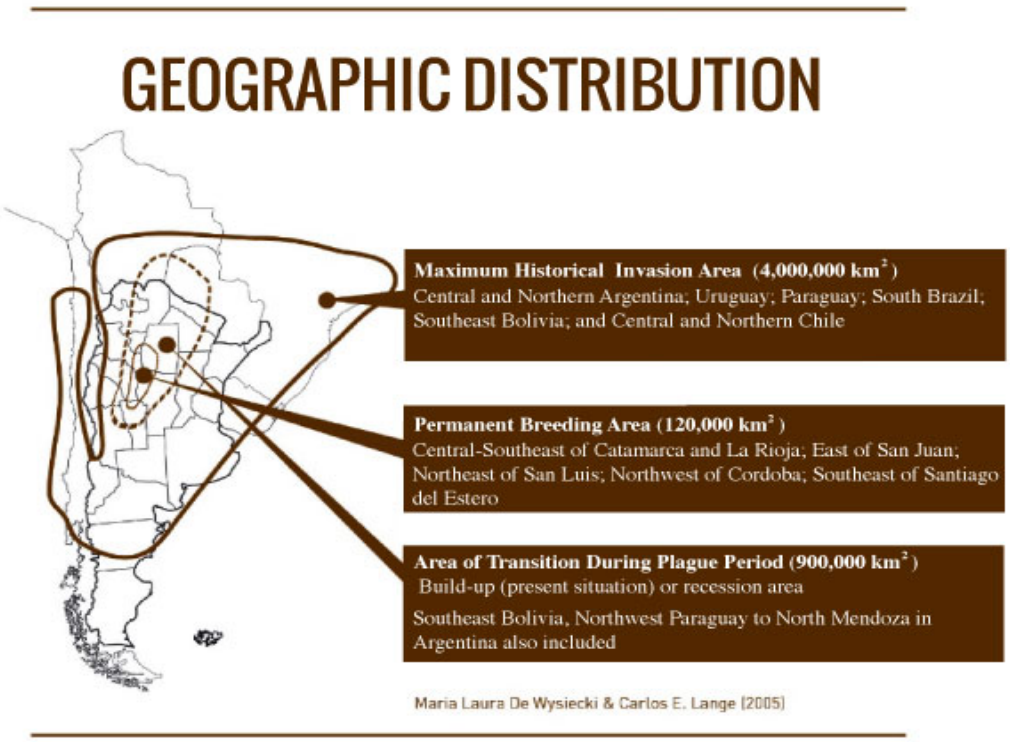

Figure 2. Geographic distribution of *S. cancellata.*

of three ever-increasing upsurges started in 2015. The first was in Argentina. In July 2015, locust swarms up to 25 km^2 were identified in Santiago del Estero province. A rapid response of SENASA working with provincial public institutions and private stakeholders helped to keep the upsurge under control. Damages were reported mainly in dry woodlands and natural pastures, with only minor impact on crops.

The upsurge in Argentina was followed by outbreaks of nymphal bands and adult swarms in southeast Bolivia that threatened 10,000+ ha of crops. The first swarms were detected in January 2016 in Santa Cruz de la Sierra, Cabezas county. By February, swarms were reported in several locations, including as far south as Boyuibe, a town near the border of Argentina. Locusts damaged a number of crops including soybeans, maize, sorghum, peanut and citrus trees. President Evo Morales declared a state of plant health emergency in February. The Bolivian government responded rapidly by requesting visits by experts from Argentina and the FAO UN, and, within three months of the first recorded swarm, had launched a national locust program. The Bolivian locust program was based on the SENASA National Locust Program, which was created in the early 1900s. This collaboration was supported in part by the Argentine Fund for South-South and Triangular Cooperation (FOAR).

A few weeks after the locust swarms were first reported in Bolivia, similar reports appeared in Paraguay. This was likely the first outbreak in Paraguay for more than half a century, so there was limited local knowledge and no locust management in place. The swarms were concentrated in the Alto Paraguay Region in the north and particularly next to the Brazilian border in Toro Pampa and Fuerte Olimpo. Nymphs and adults were found on natural pastures and shrublands. At the request of the Paraguayan government, SENASA Argentina assisted with field evaluations and provided training and general recommendations. By the end of February National Plant and Seed Health and Quality Service of Paraguay (SENAVE), announced the implementation of control actions. Locusts were detected as late as May in Boquerón and Hayes, near the bor-

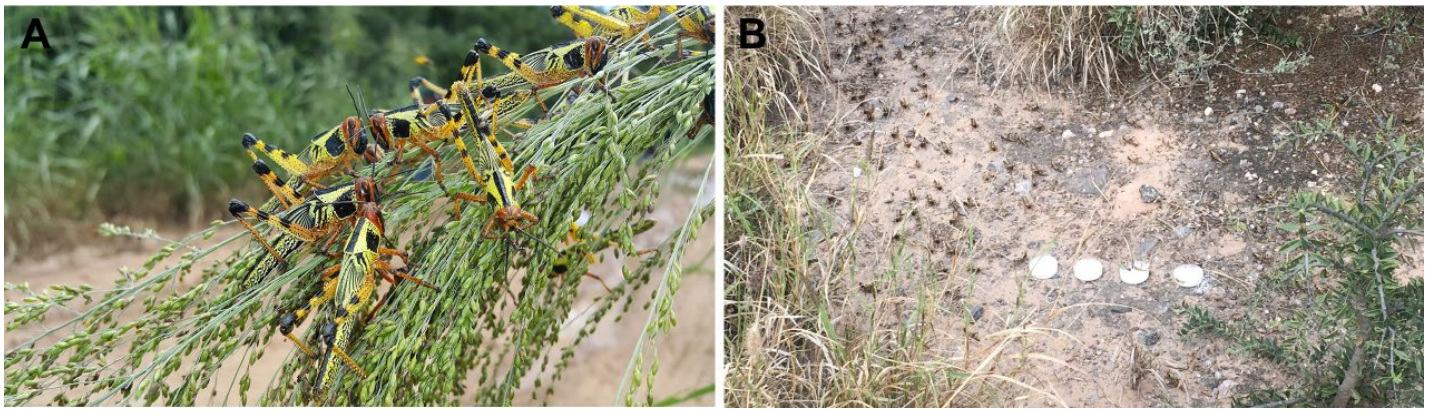

Figure 3. A. *S. cancellata* nymphs eating *Panicum maximum* near Boyuibe, Bolivia; B. Diet study on marching nymphs in Catamarca, Argentina

Figure 4. A-B. Argentina May 2016: Representatives from SENASA, INTA, and ASU in Catamarca (A) and La Rioja (B) provinces; C. Buenos Aires workshop; D. Arianne Cease (ASU), Eduardo Trumper (INTA), and Mónica Roca (SENASA) collecting locusts

der to Argentina.

After a period of relative calm across early winter, on June 24, 2017 large swarms were reported moving southward in the northeast Argentinian province Formosa, likely entering from Paraguay. Several swarms were observed travelling in the same direction (south) through provinces to the south and southwest of Formosa: Chaco, Santiago del Estero, and north Santa Fe provinces. To the east of this region, locusts were reported mating and laying eggs. During mid-August, at least two swarms were reported in Cordoba province dispersing southward as fast as 150 km per day apparently facilitated by high-speed north winds. One of these swarms reached the 32nd parallel south near Monte Ralo in Cordoba Province, which is to the east of the permanent breeding region. SENASA is implementing an intensive monitoring plan and conducting chemical control through aerial sprays when swarms settle in areas not populated by people. As yet in 2017, only minor damages have been observed in scattered crops in northern Argentina.

Why this large-scale upsurge after decades of successful control?

The most plausible hypothesis to explain the recent upsurge and geographic expansion of S. cancellata is that a combination of two major factors converged in the permanent breeding region simultaneously. First, La Rioja, Catamarca, and Santiago del Estero provinces had both a mild winter and frequent rains of 25+ mm from late winter to spring. In addition to increasing locust growth rate, this weather likely induced breaking of the winter adult reproductive diapause earlier than usual (Hunter & Cosenzo, 1990), which paved the way for a third generation. *S. cancellata* typically has two generations per year; three generations per year can lead to exponential population growth. Second, the climatic favorability allowed for expansion of suitable breeding and egg laying sites, making the area too large to be covered by the available scouting personnel. Once locusts passed the density threshold to become gregarious and adults began to migrate, monitoring became increasingly difficult because locusts expanded to regions with no trained personnel available. As a result, several swarms may have migrated northward unchecked. Future studies are needed to determine the migratory pathways, but based on preliminary data we hypothesize a process of geographic expansion with at least one reproduction period in Bolivia and Paraguay. This process plausibly gave rise to the new adult generation that entered Argentina during July 2017.

Ongoing research and management activities and future strategies

Locusts are a continental-level challenge that requires coordinated responses across boundaries by individuals and governments. While upsurges and plagues can have devastating impacts on food security, such large-scale events happen erratically. This 'moving target' is one of the difficulties for sustainable locust management (Lockwood et al., 2001). In the early stages of the current locust upsurge, SENASA responded quickly by intensifying monitoring and control in Argentina. However, for decades the preventative strategy—and training—had been focused on targeting nymphal bands in Catamarca and La Rioja. Quick treatment of nymphal bands meant that adult swarms were rare. Consequently, when the first swarm was found in July 2015, Argentina relied on a handful of the most experienced field officers from Catamarca and La Rioja provinces

to train newer colleagues. As such, in Argentina the response was limited in its efficacy because of the time necessary to train individuals and the reactive nature of the response.

A systems approach may help address this continental-level challenge over the long-term, reducing the need for reactionary responses. Locusts are part of complex coupled human and natural systems, or CHANS (Cease et al., 2015). CHANS are systems of feedback linking people and ecosystems that connect people across time and space. For example, land use and/or locust management practices in one region can affect the likelihood of another region being the recipient of locust swarms. Policy and markets also link outbreak regions through space and time and can affect the probability of swarms, as well as how swarms and locust control impact people and the environment. To develop sustainable locust management approaches that consider multiple outcomes in this complex CHANS system, many disciplines and sectors are needed. To that aim, in May 2016, SENASA, INTA (the National Institute for Agricultural Technology), and the National Ministry of AgroIndustry organized the "Workshop on bio-ecology, impact and management of locusts and grasshoppers" (http://www.senasa.gov.ar/senasa-comunica/noticias/taller-sobre-bioecologia-impacto-y-manejo-de-langostas-y-tucuras). This workshop included topics from acridid management, forecasting, taxonomy, and ecophysiology, to community well-being and environmental safety. Representatives from many organizations attended, including the Center for Parasitologi-

Figure 5. A. Bolivia April 2017: Bolivia workshop; B. Hector Medina giving a seminar at the workshop; C. Hector Medina providing advice to a group of farmers, SENASAG colleagues, private consultants and NAPO representatives; D. The April 2017 field team including representatives from SENASAG, INIAF, SENASA, INTA, CIAT, Institute of Agricultural Research "El Vallecito", and ASU; E-F. Field work near Boyuibe collecting samples of locusts and vegetation: in intact forest (E), and along the road (F).

cal and Vector Studies (CEPAVE), the National University of La Plata (UNLP), and Arizona State University (ASU). CEPAVE, UNLP, and Texas A & M University (TAMU) researchers are currently collaborating to study phase change in *S. cancellata*. This study complements ongoing research at TAMU comparing phase change in *Schistocerca* species, as well as ongoing research at CEPAVE and UNLP studying the phylogeography and ecophysiology of acridids more broadly. Following the May 2016 workshop, Arizona State University (ASU) researchers worked with INTA and SENASA to collect data from multiple populations to determine their nutrient and host plant preference. Such data will improve our understanding of bottom-up control of locust populations and what triggers migration. These studies complement ongoing CHANS research by ASU and collaborators looking at the connections among soil nitrogen, locust outbreaks, livelihoods, and livestock markets.

Following the appearance of swarms in Bolivia, SENASAG hosted three official missions between February and April to integrate knowledge and actions of the international community, particularly from Argentina. The first two missions focused on how to achieve effective networking between public and private sectors to improve efficiency for field operations. The goal of the third mission was to formalize institutional cooperation among organizations in Bolivia and Argentina and to promote the development of a long-term and integrated research and management strategy. To achieve these goals, representatives participated from INIAF (Institute of National Agricultural and Forestry Innovation), the Gabriel René Moreno University, the Center for Tropical Agriculture Research (CIAT), the Institute of Agricultural Research "El Vallecito", Arizona State University, SENASA, and INTA. The Entomological Society of Bolivia developed a report to assist with identifying *S. cancellata* and to advocate for the use of pesticide alternatives to avoid non-target effects on other organisms such as bees (http://cebem.org/wp-content/uploads/2017/02/SBE-14-de-febrero-general.pdf). Following the workshop, ASU collaborated with SENASAG, INIAF, SENASA, INTA, and CIAT to collect nutritional data on outbreaks and determine vegetation preferred and avoided. Additionally, ASU collected live *S. cancellata* to supplement established lab colonies from Argentina and to continue ecophysiological research. ASU invites other institutions to use these colonies for research if interest exists.

Many stakeholders in agriculture and the general public are deeply concerned about the resurgence of large swarms of *S. cancellata* (reaching up to 25 km^2 in size) across Argentina, Bolivia, and Paraguay. The governments of these three countries share these concerns and have agreed that integrated approaches and joint actions to manage *S. cancellata* are necessary. The first steps have been taken by the Argentine Ministry of Foreign Affairs to develop a Regional Program of Management of the South American locust through the Argentine Fund for South-South and Triangular Cooperation (FOAR). The convergence of institutions and stakeholders has led to a focus beyond tackling the immediate problem. These cross-sectoral collaborations are emphasizing longer time frames, learning from mistakes, and gaining a deeper knowledge of the mechanisms driving locust population dynamics and migration to support sustainable locust management.

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