Crop freezes and land-use change in Florida

Draining the state's southern wetlands may have raised the incidence of harmful frosts.

South Florida experienced a significant change in land usage during the twentieth century, including the conversion of natural wetlands into agricultural land for the cultivation of winter vegetable, sugar cane and citrus crops. This movement of agriculture from more northerly areas was intended partly to escape the risk of damaging winter freezes. Here we present evidence from a case study using a coupled atmosphere and land-surface computer-modelling system that suggests that the draining of wetlands may have inadvertently increased the frequency and severity of agriculturally damaging freezes in the south of Florida.

On 19 January 1997, a rare freeze inflicted severe damage in agricultural areas of south Florida that were once natural wetlands, with below-freezing temperatures extending to the tip of the peninsula. This event, chosen here for our case study, resulted in losses in the fresh-vegetable and sugar-cane sectors that alone exceeded US$300 million[1]. Furthermore, nearly 100,000 migrant farm workers were displaced or unemployed as a result of the freeze[2].

We used the Regional Atmospheric Modeling System (RAMS)[3], a comprehensive meteorological modelling system that includes a sophisticated land-surface scheme to represent the effects of surface properties on atmospheric processes[4], to investigate the impact of anthropogenic changes in land coverage on this freeze. A pair of simulations was undertaken in which the model configuration was identical, except that in one simulation the data represented pre-1900s (almost natural) land cover, whereas in the other they represented 1993 (near-present-day) land usage. These data sets (Fig. 1a, b) reflect the conversion of natural wetlands to agricultural land in the areas of south Florida that were affected by the freeze.

In key agricultural areas that were once natural wetlands, particularly the areas used for high-density cultivation of winter vegetables, sugar cane and citrus fruits to the south and southwest of Lake Okeechobee, the simulation incorporating current land coverage produced minimum temperatures that were generally colder (Fig. 1c) and were below freezing for a longer period (Fig. 1d) than that using natural land coverage. The results reveal that when land-surface properties were specified to represent natural land cover, a persistent heat flux from wetlands was sufficient to hold the simulated temperature above freezing throughout the night in many of these areas (results not shown).

In other agricultural areas of south Florida that were once natural wetlands, such as portions of the Kissimmee Valley (north of Lake Okeechobee), the model simulated a freeze regardless of the specification of land-surface properties. However, even in these areas, minimum temperatures were generally colder and were below 0 °C for a longer period when present-day land use was prescribed (Fig. 1c, d). The duration of exposure to sub-zero temperatures is critical in determining the amount of crop damage that occurs during a freeze[5].

Our results indicate that, even in areas where a freeze would have occurred irrespective of land-surface properties, the agricultural damage may have been worse than it would have been if natural wetlands had still been present in those areas. Results were similar when the same modelling method was applied to other recent agriculturally damaging freezes in south Florida, including the events of 26 December 1983 and 25 December 1989.
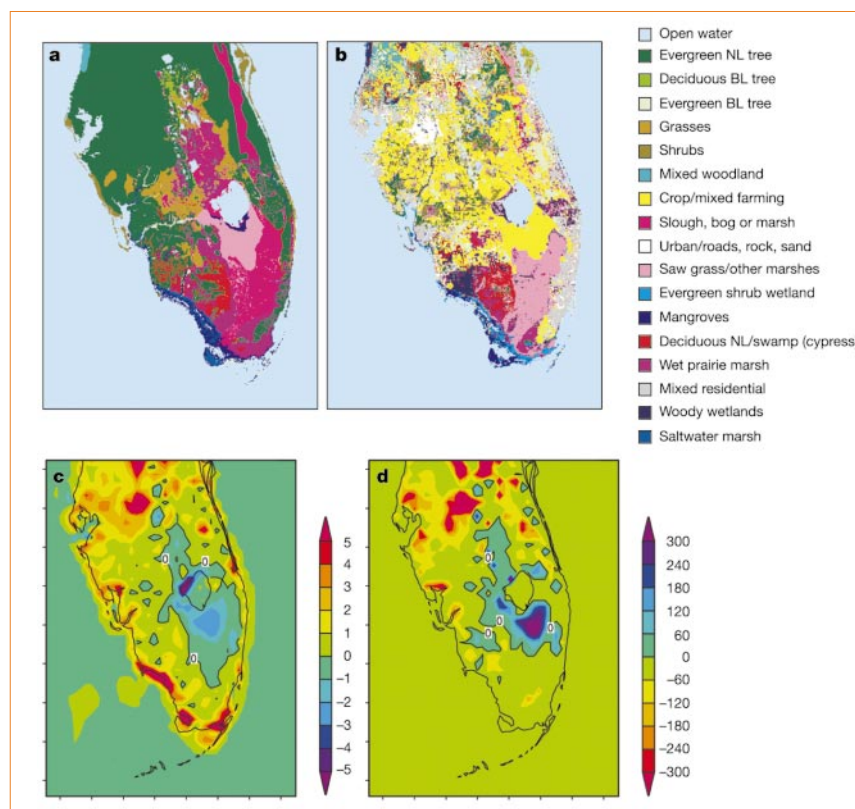
We have shown that the likelihood of agriculturally damaging freezes in south Florida has increased as a result of the conversion of its natural wetlands to agriculture. This is ironic, considering that the move was instigated partly to avoid the freezes that occur further to the north[6–8]. Our results provide another example of the potential for anthropogenic changes in land usage to perturb the climate system[9].

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Figure 1 Minimum temperatures, and the duration of periods of of sub-zero temperatures, in areas cultivated from drained wetlands in south Florida. **a, b,** Classes of land use specifying model properties for simulations incorporating land-surface conditions before the 1900s (**a**) and in 1993 (**b**). NL, needleleaf; BL, broadleaf. **c,** Difference between the model's simulated minimum temperatures (in °C) near ground level on 19 January 1997; differences were determined as the values derived from 1993 usage minus those from pre-1900s usage. Locations inside the zero contour experienced colder minimum temperatures when 1993 land use was used in the model. **d,** Difference in the duration (in min) of subzero-temperature periods for the two different model simulations; differences were determined as in **c**. Areas inside the zero contour experienced freezing temperatures for longer when 1993 land use was used in the model.

brief communications

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Arachnology

Scavenging by brown recluse spiders

The brown recluse spider (*Loxosceles reclusa*) is a threat to humans and establishes huge populations in urban habitats throughout central North America[1,2] — more than 2,000 of these spiders were recorded in a single house in Kansas[3]. What do these spiders eat in order to build and maintain such numbers? Here I combine laboratory prey-choice experiments with observations of the behaviour of *L. reclusa* in houses to show that this spider prefers dead, scavenged prey over live prey. This finding may explain how immense populations of these spiders can flourish even in adverse conditions.

All spiders consume live prey and they have evolved a diverse array of adaptations to enhance its detection and capture. Some spiders also supplement their diets with unusual food sources such as pollen[4], nectar[5] and insect eggs[6]. However, spiders would not be expected to prefer dead prey, given the stimulus of catching live prey that results from their extreme sensitivity to even the slightest movement of their victim.

Bites from brown recluse spiders (Fig. 1) can constitute a medical emergency in humans, inflicting slow-healing necrotic wounds and extensive tissue damage[1,2]. The same powerful paralysing venom that causes these effects in humans also allows the spider to immobilize its prey and avoid being injured itself[7]. Unlike most wandering spiders, which use vision, stealth and strength to capture prey, *L. reclusa* attacks, retreats and then returns to feed at its convenience[7]; it has relatively poor vision[7] and does not readily respond to substrate or airborne vibration.

I investigated the predatory behaviour of *L. reclusa* in 71 homes in Kansas and did not see spiders catching live prey — indeed, the spiders actually fled from potential prey. However, I witnessed the spiders locating and consuming dead prey, without prior attack, in more than 25 houses.

For the prey-choice experiments, I placed adult male and female *L. reclusa* ($n = 147$) into individual plastic boxes ($12 \times 17 \times 6$ cm) and fed them a variety of prey, both dead and alive, once a week, and then starved them for two weeks. The spiders were subsequently presented with equally sized live and dead prey (dead prey was killed by freezing at $-80\,^{\circ}\text{C}$). Spiders were kept in the dark and observed under low light every hour for evidence of prey choice, which was verified by fang penetration and feeding for 5 min or longer.

In these experiments, 81.4% of *L. reclusa* chose dead over live waxmoth larvae (*Achroia grisella*; $n = 59$), 75.6% chose dead over live domestic crickets (*Acheta domestica*; $n = 41$) and 97.6% chose dead over live yellow mealworm larvae (*Tenebrio molitor*; $n = 41$). Overall, spiders chose dead prey in 84.4% of trials ($\chi^2 = 72$, $P \ll 0.001$), indicating a clear preference for scavenging dead prey.

To test the effects on the spiders of eating dead rather than live prey, I used three groups of ten spiders that had been respectively given: old dead crickets that had been envenomated and partially digested by other *L. reclusa* two weeks previously; German cockroaches (*Blattella germanica*) that had been dead for at least a month; and *B. germanica* that had been killed 24 h earlier with Cessco-5E insecticide (0.5% pyrethrin). All spiders consumed the prey within 24 h of its being introduced, and showed their resilience in that no obvious negative effect was manifest over the ensuing 10 months, during which a regular feeding regime was followed.

The feeding preferences that I observed in urban habitats are consistent with my findings with captive spiders, indicating that *L. reclusa* actively searches for dead prey and ignores live prey. Spiders will even remain motionless and allow their prey to walk over them without attacking it, such is the extent to which they prefer dead prey. In five *T. molitor* trials, spiders attacked and killed live prey but did not eat it, yet consumed prey killed by freezing. Capture of live prey (15.6%) was often the result of prey walking into spiders rather than of active hunting.

The sequence of predatory behaviour shown by *L. reclusa* (attack, retreat and feed later) means that prey may escape before it is relocated. Spiders sometimes leave partially eaten carcasses that other spiders subsequently find and consume. It is likely that dead prey provides an easily accessible source of nutrition without incurring the additional costs or risks associated with attacking and manipulating live prey.

L. reclusa is an opportunistic feeder rather than an obligate predator or obligate scavenger, but it prefers dead over live prey. In an environment such as a house, opportunists and scavengers have an advantage over more selective predators because their feeding requirements are more easily met[8]. Insects are attracted to houses by light, food and shelter, as well as for other unknown reasons, but they can easily die there from starvation, desiccation, overexertion, pesticide

Figure 1 Still watches: the brown recluse spider *Loxosceles reclusa* prefers prey that is motionless or already dead, feigning indifference itself to avoid a struggle with living prey.

exposure or other causes. I conclude that scavenging contributes significantly to the diet of *L. reclusa* and may be important for the survival of this species in natural habitats, as well as being beneficial to them when they are in close proximity to humans.

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COMMUNICATIONS ARISING

Biophysics

Is rhodopsin dimeric in native retinal rods?

The model of vertebrate rhodopsin that has emerged from a combination of traditional biophysical techniques[1–6] defines it as an archetypal monomeric receptor protein that is randomly dispersed and freely diffusing in a fluid lipid matrix in the rod-disc membrane. A quite different arrangement has been demonstrated by Fotiadis *et al.*[7], however, who use atomic force microscopy (AFM) to reveal rows of rhodopsin molecules packed as dimers in isolated murine disc membranes at twice the surface density estimated from previous *in situ* measurements[3,4,6]; lipids are probably excluded from these rhodopsin packs[8]. We contend that these 'dimers' are in fact long double rows of equally spaced proteins, packed in partially ordered microcrystalline arrays, and suggest that the arrangement of irregular packs of protein and patches of pure lipid with a free-floating border may be an artefact resulting