NEWS & VIEWS

PLANT ECOLOGY

Resourceful invaders

Tim Seastedt

Plant species that colonize new environments tend to favour habitats with ample water and nutrients. But invasive plants can be more efficient in their use of resources than that observation might imply.

There are few places on Earth that are not susceptible to invasions by plants intentionally or accidentally introduced into areas outside their native ranges. Such species can wreak ecological and economic havoc in their new habitat, hence the continuing search for long-term solutions to control them[1]. With the findings of Funk and Vitousek[2], however, described on page 1079 of this issue, that endeavour has just become more difficult.

Invasive plants must first colonize and then persist in their new environment. A small percentage of these may then become abundant and dominant components of the plant community. For example, an annual grass, cheatgrass (*Bromus tectorum*), was accidentally introduced from Asia into grasslands throughout the world, and now occupies many millions of hectares in the environments into which it was introduced. An ornamental plant called the cartwheel flower (*Heracleum mantegazzianium*) escaped its garden environments; it is now known as 'giant hogweed' and is a serious problem on three continents. The Monterey pine (*Pinus radiata*), originally from a small area in the western United States, was planted for wood production worldwide. This tree is now considered a weed in many regions. These examples illustrate the diversity of growth forms that can characterize plant invaders.

Until now, most invasive species were thought to be largely opportunistic, exploiting changing environmental conditions and human or natural disturbances. A survey of available studies[3] showed that most native species equalled or outperformed invaders for those traits known to be beneficial to the survival and reproduction of the species. That same analysis suggested that low-resource environments are least susceptible to invasions. Low-resource environments are those that provide little in the way of light, water or nutrients such as nitrogen and phosphorus. A limitation in one or more resources has the potential to exclude plant species from occupying such habitats. Although exceptions to invasion of low-resource habitats are known[4], findings from studies on ecosystem restoration indicate that low-resource environments have the lowest abundances of unwanted species[5].

In their paper, however, Funk and Vitousek[2] show that invasive plants also have the ability to compete in low-resource environments. In a study that included a broad spectrum of different forms of plant growth, and different habitats, the authors show that, over short time periods, invasive species tend to be more efficient at capturing energy per unit of leaf mass or per unit of leaf nitrogen. Water-use efficiencies are similar between natives and invaders. Native plants tend to retain their leaves longer than invaders, so after longer time intervals the efficiencies for exploiting light, water and nitrogen, with the exception of one resource in one habitat, are also similar. Nonetheless, the demonstrated efficiencies of the invaders, accompanied by other traits such as slightly higher seed production or reduced mortality compared with the natives, would make these species superior competitors in low-resource environments.

Funk and Vitousek's conclusion that diverse plant groups — grasses, ferns, trees and garden ornamentals (Fig. 1) — demonstrate high resource-use efficiency is strong evidence that invasive plants can indeed fare well under

F. & K. STARR
K. BRIDGES

Figure 1 | Pretty, but not wanted. Hawaii is especially vulnerable to invasive species, which include these two ornamental plants — firethorn (*Pyracantha angustifolia*, left) and montbretia (*Crocosmia pottsii* × *aurea*). These species were included in Funk and Vitousek's study[2] demonstrating that invasive plants are competitive in low-resource environments.

low-resource conditions. The generalization that native species have a 'home field advantage' in such conditions is not valid. Reconciling these results with existing studies is possible, but the outcome broadens our view of what characterizes successful invaders.

First, plant invaders include the usual suspects — weeds capable of exploiting high-resource, disturbed conditions. These appear in gardens, along roadsides and, occasionally, in natural areas. But such species do not usually pose a long-term problem in natural areas because they cannot compete once resources such as soil nutrients become more limiting.

A second group of invaders can be viewed as those species that, in the process of being introduced into new habitats, have escaped enemies and/or formed fortuitous associations with other organisms. These associations include beneficial soil microbes that assist the invader in obtaining resources[6,7]. The loss of enemies and the gain of mutualist organisms can provide invaders with more resources than they would have obtained in their native lands[8]. Some of these plants can out-grow and out-reproduce native species in a wide range of habitats.

Funk and Vitousek[2] now show that there are also many species that are well adapted to low-resource conditions. This group might also benefit from being attacked by fewer pathogens and fewer herbivores, and from more beneficial associations with soil organisms. If this is the case, genetic constraints may — at least in the short term — limit the value of these benefits[9]. But the ability of these species to invade and persist in new, low-resource environments is at least undiminished, and may be enhanced.

Funk and Vitousek's take-home message is less than encouraging for conservation biologists and restoration ecologists. Attempts to exclude invasive species, by reducing the availability of resources for example, will not protect these habitats from non-native species with the traits shown in this study. Management activities that create or enhance low-resource habitats are unlikely to prove effective barriers to invaders, unless they are accompanied by the planting of large numbers of equally adapted, native species. ■

Tim Seastedt is in the Department of Ecology and Evolutionary Biology, and INSTAAR, University of Colorado, Boulder, Colorado 80309, USA.
e-mail: timothy.seastedt@colorado.edu

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ASTROPHYSICS

The answer is blowing in the wind

Yousaf M. Butt

A source of astoundingly energetic γ-rays associated with a star cluster might provide a clue to a century-old question: where do the cosmic rays that constantly bombard Earth come from?

Massive stars have extreme lifestyles. They are born in clusters of up to several thousand members, blow fierce charged-particle winds during their short lives, and die — more or less together — in powerful supernova explosions. Now comes word from the High Energy Stereoscopic System (HESS) collaboration, to be published in *Astronomy and Astrophysics*[1], that γ-rays of very high energy have been spotted coming from the powerful young stellar association Westerlund 2 located in the southern sky[1] (Fig 1). This emission is of a higher energy than ever seen before from a group of stars, and pushes the limits of our understanding of the processes behind it.

Stars typically emit light around the visible part of the spectrum, where photons have an energy of a few electronvolts (eV). The γ-rays that HESS detected have energies in the range of tera-electronvolts (TeV), or 10^{12} eV. Previously, TeV γ-rays have been seen emanating from only a handful of exotic celestial objects. These include energetic pulsars (rapidly spinning and highly magnetized neutron stars just 30 or so kilometres across); the huge interstellar shock waves associated with the remnants of powerful supernovae; binary systems of a neutron star or a black hole coupled with a regular star; jets from distant 'active galaxies'; and the supermassive black hole thought to lurk at the centre of our Galaxy. So the HESS collaboration's discovery[1], dubbed HESS J1023–575, amounts to finding a completely new species of celestial γ-ray source. In fact, another TeV source discovered recently[2] might also be a member of the same species. Designated TeV J2032+4130, this source is probably related to a subgroup of powerful stars in the Cygnus OB2 stellar association[3], but this identification is not quite as firm as in the case of Westerlund 2.

The most likely model for the origin of these highly energetic γ-rays is that multiple, supersonic winds of charged particles blowing from the dozens of massive stars (for our purposes, stars bigger than 8 solar masses) create violent plasma motions within Westerlund 2. This turbulence can accelerate particles to TeV energies (ref. 4 and references therein), and these particles can then interact with the ambient material and light to produce the detected γ-rays. This type of turbulent particle acceleration process is called the second-order Fermi mechanism, or Fermi-II acceleration for short. First-order Fermi (Fermi-I) acceleration is thought to be at work in the better-formed interstellar shock waves created by isolated supernova explosions.

Could such an isolated supernova remnant be behind the HESS J1023–575 detection? This possibility is rendered unlikely by the presence of a great deal of turbulence caused by the massive stars of the Westerlund 2 association. The evolution of a supernova remnant would be greatly perturbed in such an environment, and it could hardly be considered as 'isolated'.

On the other hand, the possibility that one supernova remnant or more could have added to the turbulence created in Westerlund 2 by the massive stars resident there, and thus provided

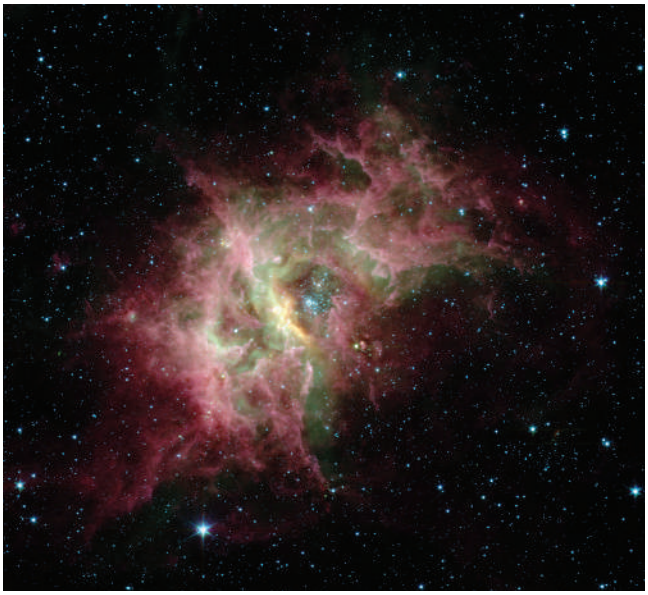

Figure 1 | Turbulent association. A composite infrared image from NASA's orbiting Spitzer observatory shows the Westerlund 2 stellar association. According to observations from the HESS telescope[1], it seems that turbulent processes at work in the fierce winds of the massive stars in Westerlund 2 create γ-ray photons 10^{12} times more energetic than visible light. The same processes might cause the acceleration of the cosmic rays that constantly hit Earth.

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