depolarization and calcium-ion influx that is necessary for cellular differentiation, proliferation and survival. In cancer cells, these same processes instead support the proliferation of the tumour and contribute to cancer's eventual lethality. These intriguing findings raise the possibility that approaches targeting specific types of glutamate receptor, postsynaptic signalling processes or the mechanisms needed for synapse formation might provide therapeutic targets for slowing tumour proliferation. ■

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This article was published online on 18 September 2019.

ECOLOGY

Captivity concerns for monarch butterflies

Monarch butterflies' ability to migrate over long distances is impressive. Evidence that some monarchs reared in captivity have impaired migratory skills compared with wild monarchs has conservation implications.

KAREN S. OBERHAUSER

The eastern population of North American monarch butterflies (*Danaus plexippus*) migrates annually in early autumn to a mountainous region in central Mexico. The incredibly long distances covered during these journeys, and the striking sight of these butterfly populations on the move have captivated people's imaginations. Writing in the *Proceedings of the National Academy of Sciences*, Tenger-Trolander *et al.*[1] document the loss of migratory behaviour in monarchs that had been bred in captivity over multiple generations.

Tenger-Trolander and colleagues' research has captured the attention of a broad community of individuals, including scientists, conservationists, people who breed butterflies for commercial purposes, the media and monarch-butterfly aficionados. Commercial breeders of monarch butterflies produce large numbers of butterflies that are sold for educational purposes or for mass-release events at special occasions such as weddings, for example. 'Citizen scientists' and educators often raise, in comparatively small numbers, monarchs that they have collected from the wild as eggs or larvae, and which they release when the adult butterflies emerge from the pupae.

Monarch numbers have declined in recent decades[2,3], leading to a petition for them to be listed as threatened species under the Endangered Species Act in the United States (see go.nature.com/2ipcsc2). The solutions needed to tackle this decline are not straightforward. Many researchers and conservation groups have expressed worries about efforts focused on the release of captively reared monarchs, citing concerns that such releases might have negative consequences for the genetic diversity of butterfly populations and might introduce disease (see go.nature.com/2iw8rhk).

The first key conclusion of Tenger-Trolander and colleagues' work is that commercially bred monarchs can be highly different genetically from individuals from wild populations, and that these differences can result in the loss of the butterflies' propensity to migrate. The authors studied migratory behaviour using a flight simulator (Fig. 1a) that allowed them to compare the flight paths of wild North American monarchs to those of the offspring of commercially bred individuals.

When both the wild and commercially obtained groups were reared outside and emerged in mid-August, they did not exhibit strong directional flight, and the females produced eggs. This is to be expected; in the summer, monarchs focus on finding mates, nectar-bearing plants and their milkweed host plants for egg-laying, rather than migrating. However, in the autumn, eastern North American monarchs migrate south, and are in reproductive diapause, a hormonally driven condition that is characterized by the lack of maturation of reproductive organs[4], and which is triggered by changes in day length and temperature conditions experienced during development[5]. When Tenger-Trolander and colleagues reared monarchs outside during the time that wild migratory monarchs would

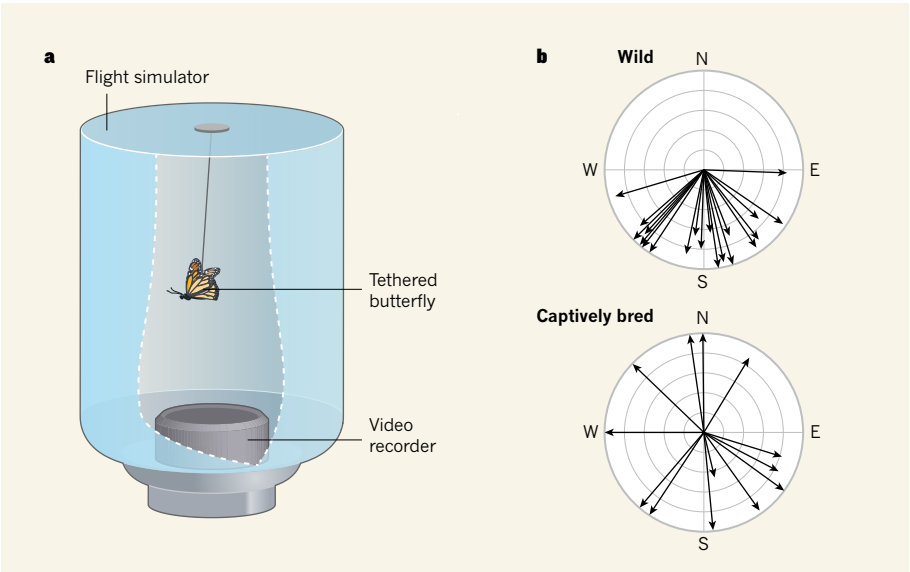

Figure 1 | The flight path of monarch butterflies. **a**, Tenger-Trolander *et al.*[1] studied monarchs (*Danaus plexippus*) using a flight simulator. In this apparatus, the direction of flight of tethered butterflies is tracked using a video recording device at the base of the simulator. **b**, When the authors studied wild monarchs reared outside that emerged in the autumn, at a time when wild monarchs normally migrate south, these butterflies flew in a southerly direction, as expected. In the flight-simulator data shown, each line represents the mean flight direction for each butterfly, and longer lines represent a stronger preference. Captively bred monarchs that were reared outside and that emerged in the autumn did not show any specific directional preference in their flight path.

usually be developing, emerging in October, the wild individuals oriented their flight paths to the south, and most were in reproductive diapause. But the commercially bred monarchs reared under exactly the same conditions did not exhibit directional flight (Fig. 1b) and produced as many eggs as the summer butterflies.

Genetic analyses of the commercially bred monarchs showed that they were distinct from any other wild population tested. This finding provides a crucial lesson about the fragility of the behavioural and morphological characteristics that lead monarchs that emerge in late summer or autumn to put off reproduction for many months and migrate, and monarchs that emerge earlier to reproduce just days after emerging as adults without exhibiting directional flight. How many generations of captive breeding led to the changes that resulted in the loss of migratory abilities is unknown. Regardless of the uncertainty about this, Tenger-Trolander and colleagues' study is a necessary reminder that such changes can happen.

The second conclusion of Tenger-Trolander and colleagues' study is that even wild monarchs reared in captive conditions can lose their propensity to migrate. In a separate experiment, wild North American monarchs were reared outdoors or indoors. Indoor-bred monarchs were kept in incubators in which they experienced either 25 °C and a 16-hour day, or 18 °C with a 14-hour day — temperatures and day lengths that Tenger-Trolander and colleagues described as representing summer- or autumn-like conditions, respectively. The butterflies reared outside during the summer showed no directional flight, whereas those reared outside in the autumn did, as expected. But none of the butterflies reared inside in either of the incubators showed directional flight. This was even true when the monarchs were inside only for their final three days of development.

This is a sobering finding about the importance of the conditions that monarchs experience during captive rearing. However, it is not surprising that the conditions under which these monarchs were reared did not lead to migratory behaviour or diapause. The monarchs were not exposed to natural autumnal light or temperature fluctuations; instead, they experienced 14 hours of light followed by 10 hours of dark throughout the experiment, and the temperature was kept constant. These are not conditions that truly mimic autumn, when day length is changing rapidly and there are usually substantial differences between day- and night-time temperatures. Shortening days and day–night temperature fluctuations are both drivers of diapause induction[5]. In most small-scale inside-rearing conditions, such as in people's houses and classrooms, windows and daily temperature fluctuations are likely to provide sufficient exposure to such natural environmental cues.

Some people release monarchs that they have either purchased from commercial breeders or reared from eggs or larvae collected from the wild, with the aim of giving this butterfly population a boost. However, given the magnitude of the number of extra monarch butterflies that would be needed for these butterfly populations to reach sustainable levels[2,6], there is widespread agreement that the best way to boost monarch-butterfly conservation is to protect and create the habitats that they need[6]. Focusing on habitat has the added benefit of also helping many other plant and animal species.

Tenger-Trolander and colleagues provide evidence that mass rearing monarchs over many generations might not only have few positive benefits, especially if the released butterflies do not migrate, but could also have negative consequences if such butterflies spread versions of genes that could thwart migration processes if introduced into wild populations. The authors used monarch butterflies from one commercial source. Many commercial breeders of monarch butterflies claim to regularly interbreed their stock with wild butterflies, which might alleviate such problems, but this industry is mainly unregulated. The results reported by Tenger-Trolander *et al.* confirm concerns, voiced previously by many scientists, about the consequences of the captive mass rearing of monarch butterflies.

As Tenger-Trolander and colleagues mention, rearing monarchs under suitable conditions has educational, inspirational and scientific benefits[7,8]. However, their recommendation that these butterflies should be reared outdoors is often not practical. The lack of exposure to decreases in day length and to fluctuating temperatures in the authors' experiments precludes drawing the conclusion that monarchs collected from the wild and reared on kitchen tables or in classrooms will not migrate. ■

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This article was published online on 9 September 2019.

IMMUNOLOGY

The structure of a T-cell mechanosensor

T-cell receptors orchestrate immune-system responses against infection and cancer. A structure of an entire T-cell receptor complex clarifies its assembly and signalling, and sheds light on its dynamic ligand recognition. SEE ARTICLE P.546

ELLIS L. REINHERZ

Immune cells called T cells have T-cell receptors (TCRs) on their cell membrane that recognize dysfunctional cells expressing abnormal protein fragments. Such abnormalities can arise in cells if, for example, cancer develops or infection occurs. When TCRs recognize these unusual peptides, the receptors become activated and stimulate T cells to destroy or inhibit the abnormal cells. Such T-cell responses are being harnessed for anti-cancer clinical therapies. TCRs are also of interest because their dysfunction can lead to autoimmunity or immunodeficiency diseases.

On page 546, Dong *et al.*[1] present the structure of a human TCR, at a resolution of 3.7 ångströms, obtained using an imaging technique called single-particle cryogenic electron microscopy (cryoEM). Such a high-resolution structure of the entire TCR was previously lacking, and it provides a wealth of detail about this receptor.

For more than 35 years[2], it has been known that each TCR of the type called an αβTCR is a protein complex. Eight proteins form the TCR: six of these are collectively known as CD3, which acts in a signalling capacity when a TCR is activated. CD3 comprises a heterodimer of CD3ε and CD3δ (CD3εδ), a heterodimer of CD3ε and CD3γ (CD3εγ) and a homodimer of CD3ζ (CD3ζζ). The other two proteins that form the TCR are TCRα and TCRβ. They create the ligand-binding heterodimer (TCRαβ) that recognizes a peptide bound to a major histocompatibility complex