How disturbance affects the establishment of new polyploid plant species

Polyploidisation is thought to be fundamental in the diversification of plant species. Both mutation and hybridisation that leads to additional sets of chromosomes (polyploidy) are commonplace in plant taxa, having occurred in almost all lineages. While polyploids have been studied for over a century, the factors that drive the success of their establishment in the face of reproductive disadvantages and high extinction rates are still unclear. Polyploids are often recorded in recently disturbed locations, but exactly how disturbance may affect the establishment of polyploids has not been clearly addressed. This research will contribute to answering a classic problem of plant biology using a modelling technique that has not yet been applied to the problem.

1 Background

According to Ramsey and Ramsey (2014), polyploidisation is thought to be fundamental in the diversification of plant species due to polyploidy being a ubiquitous feature in the lineages of most plant taxa. Furthermore, polyploids repeatedly account for around 25% of plants in frequency surveys (Barker et al. 2016) and polyploidisation (a saltational event) has been found to coincide with a similar proportion of speciation events (Wood et al. 2009). However, a study by Arrigo and Barker (2012) on the extinction rates of polyploids has suggested that many of these new lines are evolutionary dead ends. They conclude that polyploids tend to become extinct at the establishment phase due to reproductive disadvantages such as lack of mates, diploid pollen swamping, and triploid sterility. Therefore, understanding demographics at the establishment phase is critical to predicting polyploidisation of plant species. Benefits associated with polyploidy may offset these costs to explain their frequency within natural populations. Polyploids are frequently linked with distinct traits such as "gigas effects", which include increases in plant organs, reversal of selfing inhibition, enhanced capabilities for buffering of deleterious mutation (due to increased heterozygosity), and hybrid vigour (heterosis) (Woodhouse et al. 2009; Ramsey and Ramsey 2014). These traits are thought to overcome the reproductive disadvantages of polyploidy and instead make this mutation key to the invasive and adaptive potential of plants, ultimately shaping broader patterns of plant diversification.

Polyploids can be organised into two broad groups: autopolyploids which arise via genome duplication events, and allopolyploids which arise via hybridization. In natural populations, both types of polyploid maintain distinct spatial distributions relative to progenitors and other diploids, suggesting the importance of polyploidy as a mechanism of ecological divergence (Ramsey and Ramsey 2014). Recent niche modelling, however, has not supported this theory and proposes that glacial retreat and environmental disturbance (conditions which correlate with increased polyploid frequency) may be more influential (Godsoe et al. 2013).

2 The Issue

Despite the long-term study of polyploidy in plant taxa, fundamental questions regarding demographic establishment and mediation of adaptation to new environments are yet to be understood. While polyploids have been studied for over a century, the factors that drive the success of their establishment in the face of reproductive disadvantages and high extinction rates are still unclear. Polyploids are often recorded in recently disturbed locations, but exactly how disturbance may affect the establishment of polyploids has not been clearly addressed (Ramsey and Ramsey 2014). Due – in part – to lack of predictive power with regard to demographics of polyploids, population assignment of these taxa is especially difficult. Elucidating the effect of disturbance on the distribution of polyploids could, therefore, have great importance to those in both forensics and conservation (Field et al. 2017). This relationship could be understood by creating a simplified model system to clearly link establishment patterns to specific processes of polyploidisation.

3 Methodology

Q: How does disturbance on a landscape affect the establishment of new polyploid plant species?

This study aims to determine how environmental disturbance affects polyploid distribution by means of an individual based model (IBM), a method which has not yet been applied to this classic problem of plant biology. By simplifying a complex biological system into a model one, then manipulating its variables (ie: disturbance) and underlying biological processes (ie: polyploidisation), biological patterns (such as species distribution) can be revealed. Analysis of these patterns can make sense of relationships which are hard to pinpoint in natural environments. IBMs in particular model discrete individuals so that fewer assumptions need to be made when dealing with data at the individual level (such as whether genomes are polyploid), and so are particularly suited to this task.

Simulated plants will be initialised on a spatially explicit landscape. Their genomes will be modelled so that, over generations, both auto and allopolyploidy can occur mechanistically – in line with some appropriate probability. Fitness costs (reproductive disadvantages) and benefits (increased stature and deleterious mutation buffering etc) of polyploidy will be parameterised to ensure a competitive element to the simulation. Plant diversification and polyploid distribution will be quantified through repeated simulations of the model across varying levels of disturbance (where the highest level causes complete mass plant death in a given area). This will test how important disturbance really is for predicting successful polyploid establishment and distribution.

4 Results

Results from the model will be analysed and written up as a report with a poster session and talk to highlight our findings. The model itself will be published as an R package and submitted to CRAN. The package will provide functions which users can utilise to manipulate and run their own simulations.

References

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