Clinal variation in life-history traits of the invasive plant species *Echium plantagineum* L.

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Certificate of Authorship/Originality

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Abstract

Range expansion during the invasion of a novel environment requires that invading species adapt to geographical variation in climate and maintain positive population growth in the face of environmental heterogeneity. Thus, invasive species are expected to undergo adaptive evolutionary changes as they encounter novel selection pressures. The aim of this thesis was to identify adaptive changes in plant growth and reproductive traits throughout the lifecycle of a model invasive species to determine which traits are vital to the success of invasive species encountering novel environments.

The model species used in this study was the widespread European invader, *Echium plantagineum,* which has invaded over 33 million ha across Australia, causing ~$30 million (AUD) damage per annum. I investigated geographic variation in life-history traits of 34 populations of *E. plantagineum* across a 1,000 km arid-mesic gradient throughout south-eastern NSW, Australia. Seeds were collected for each population along the arid-mesic gradient, germinated in the laboratory and grown in the glasshouse in a common environment.

I found that *E. plantagineum* has rapidly adapted to environmental selection pressures throughout its range, resulting in two major clines linked to plant flowering time and seed size of progeny. Compared with populations from mesic habitats along the arid-mesic gradient, plant populations from arid environments had significantly higher relative growth rate and leaf production which was associated with much earlier flowering time and reduced time between stem production and flower production. Plants from arid regions also produced significantly larger seeds compared with plants from mesic habitats. Interestingly, seeds from all *E.*

plantagineum populations along the arid-mesic gradient germinated rapidly (within 48 hours of water exposure) allowing them to quickly and opportunistically take advantage of available resources. Considered together, these adaptations allow *E. plantagineum* to grow rapidly, reproduce and produce progeny before conditions become unsuitable.

The findings in this thesis provide compelling evidence for the rapid development, within 150 years, of clines in reproductive strategies linked to flowering and seed size evolution. My results support the notion that the successful invasive spread of species can be increased through genetic divergence of populations along arid-mesic climatic gradients. The climate of south-eastern Australia is predicted to change to become hotter and drier inducing many species to adapt or perish. The range and distribution of *E. plantagineum* is unlikely to be altered by these climatic changes as pre-adapted genotypes currently exist in the range margins and have persisted in arid regions for over 100 years. Consequently, further work is required to investigate the evolutionary capacity of other native and invasive species to determine how ecosystem dynamics and composition may change in the future.

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Acronyms

Δ	Carbon isotope discrimination
AAGB	Average above ground biomass
ACT	Australian Capital Territory
AGB	Above ground biomass
AI	Aridity index (AI = P/PET)
ANCA	Automated Nitrogen Carbon Analysis
AVH	Australian Virtual Herbarium
AWB	Atmospheric water balance (AWB = P - PET)
B	Unstandardised regression coefficient
B_{leaf}	Leaf biomass
BHC	Broken Hill Complex bioregion
BGB	Below ground biomass
C	Carbon
COAST	Coastal bioregion including south-east corner and Sydney basin bioregions
EICA	Evolution of increased competitive ability
FI_{time}	Time to first flower in days
FIV	Flower initiation variance
IBRA	Interim Biogeographic Regionalisation for Australia – a frame work for the grouping of regions by vegetation, climate and soil characteristics
L	Largest leaf length
LAR	Leaf area ratio
LMA	Leaf mass area
LMM	Linear mixed model

MDD	Murray Darling depression bioregion
N	Nitrogen
NPK	Nitrogen, phosphorous and potassium
NSW	New South Wales
P	Precipitation
P_{area}	Photosynthetic area
PC1	Principal component one representative of climate
PC2	Principal component two representative of edaphic factors
PET	Potential evapotranspiration
RGR	Relative growth rate
RIV	Riverina bioregion
RSR	Root:shoot ratio
SE	Standard error
SEH	South-eastern highlands bioregion
SF_{time}	Time between stem initiation and flower initiation
SILO	Climate database that contains Australian climate data from 1889 to current, hosted by the the State of Queensland Department of Environment and Resource Management 2012.
SI_{time}	Time to first stem in days
SIV	Stem initiation variance
SLA	Specific leaf area
SWS	NSW south-west slopes bioregion
t	Time in days
WUE	Water use efficiency
W	Total water use