

Adaptation of the Old World Lupins to Mediterranean Environments: Lessons from Wild and Domesticated Germplasm

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Lupin ecophysiology -rationale & approach

- **Understanding adaptation is important:** lupins (*L. angustifolius* & *L. luteus*) recently domesticated (1920-30s), new to Australia.
- **GxE studies** define important traits in target environments.
- **Screening genetic resources:** evaluating traits in germplasm from diverse habitats provides insight into adaptation & identifies promising material.

Background-the state of play in *L. angustifolius*

(Summary of GxE studies using L Hist trials: 61 site/years of all NLL cultivars since 1967)

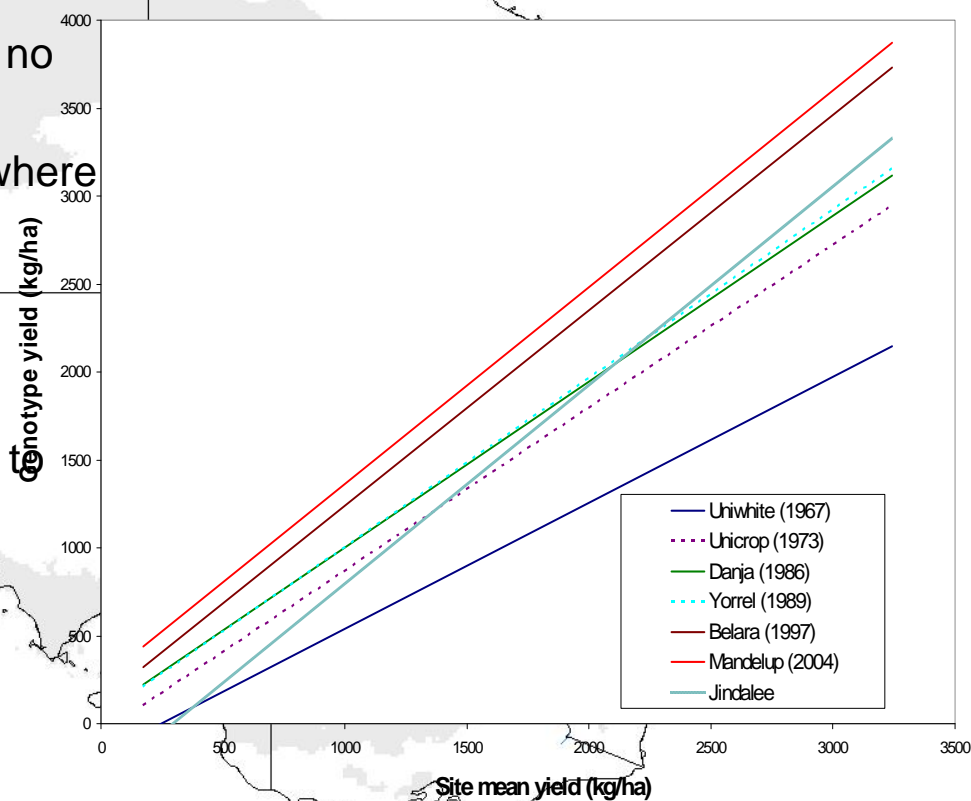
Finlay-Wilkinson analysis shows no specific adaptation = little diversity

Evidence

- Almost no cross-over interaction = no specific adaptation
- The best varieties are good everywhere & vice versa for poor cultivars.
- Have we optimized yield for any environment?
- G x E interaction = increasing responsiveness (regression slope) to good sites

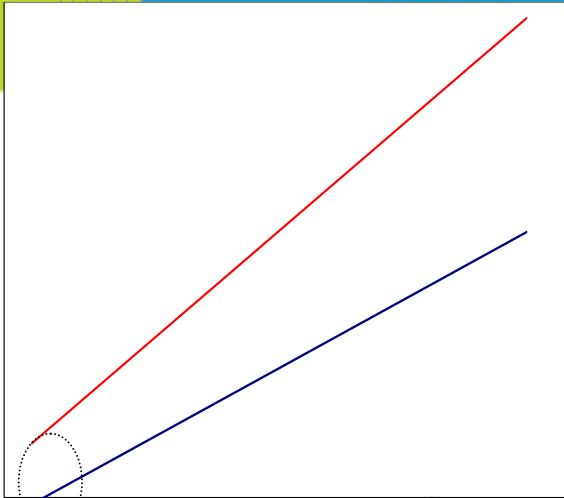
■ 300-600 mm annual rainfall

● Historical variety trial site



FW analysis-putting responsiveness into perspective

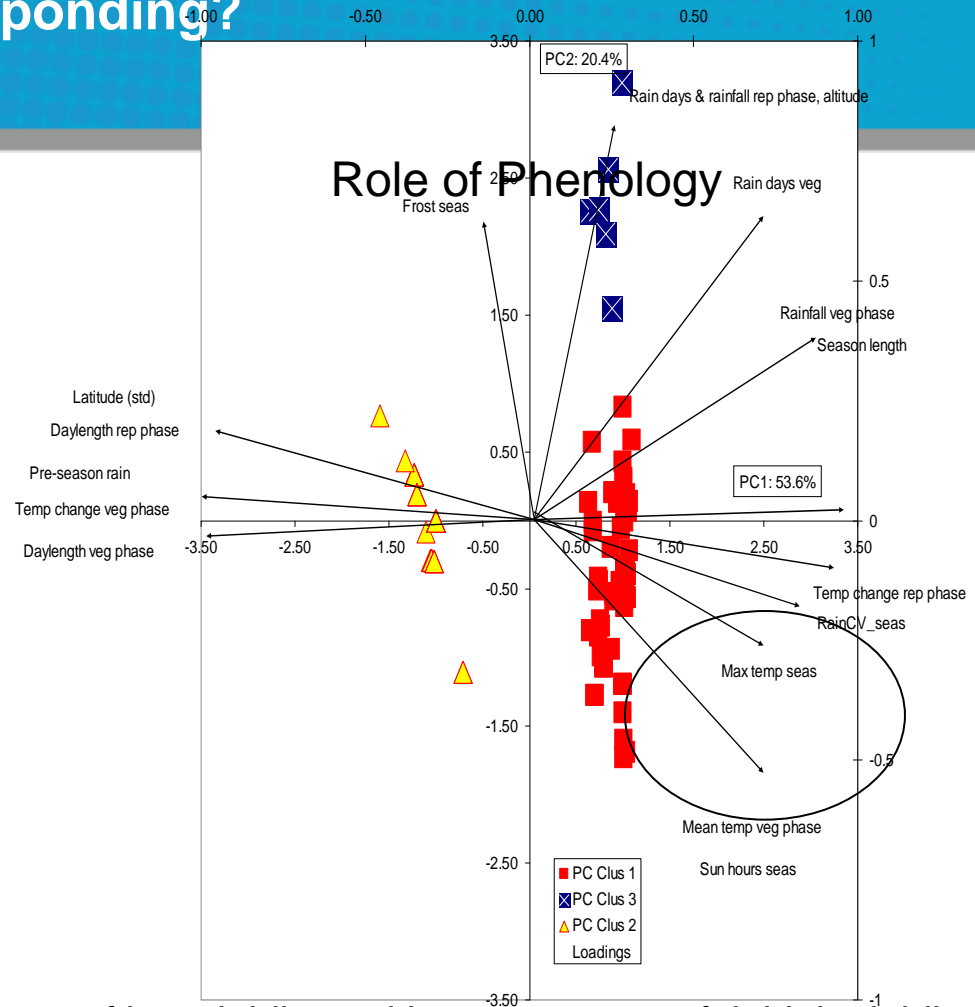
How are cultivars responding?



Decreasing terminal drought

- Late flowering penalizes low yielding cultivars at stressful sites
- High yielding cultivars escape terminal drought more effectively at low yielding sites by flowering early

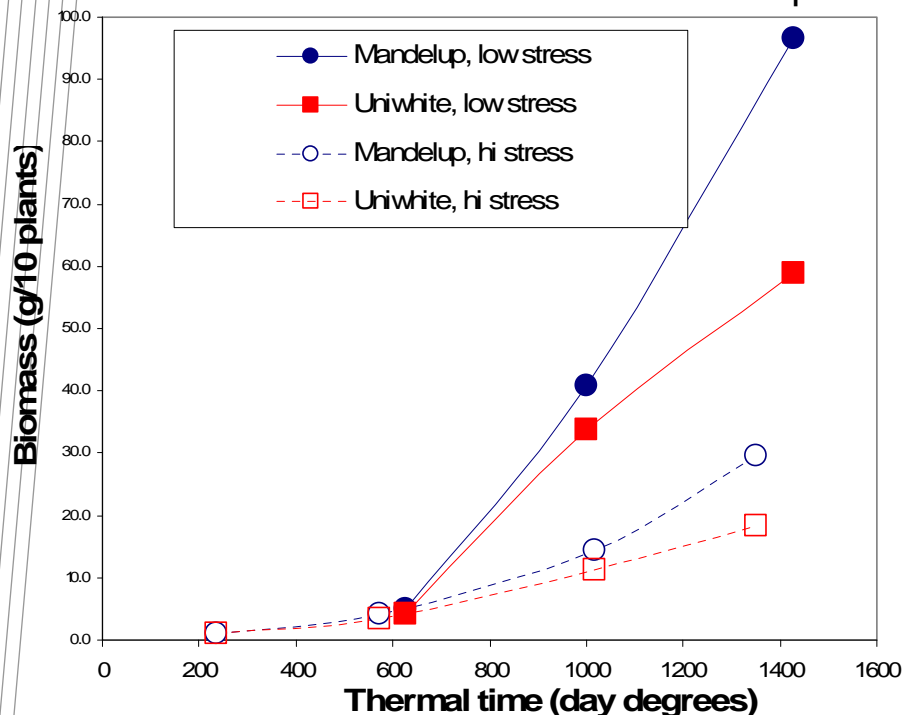
- Late flowering can't explain reduced response of low yielding cultivars to unstressful, high yielding sites
- Late flowering genotypes should perform relatively better at unstressful, high yielding sites than they do under terminal drought
- Why don't they? What else is different?
- Late flowering genotypes are vernalization-responsive, early genotypes are thermoneutral.



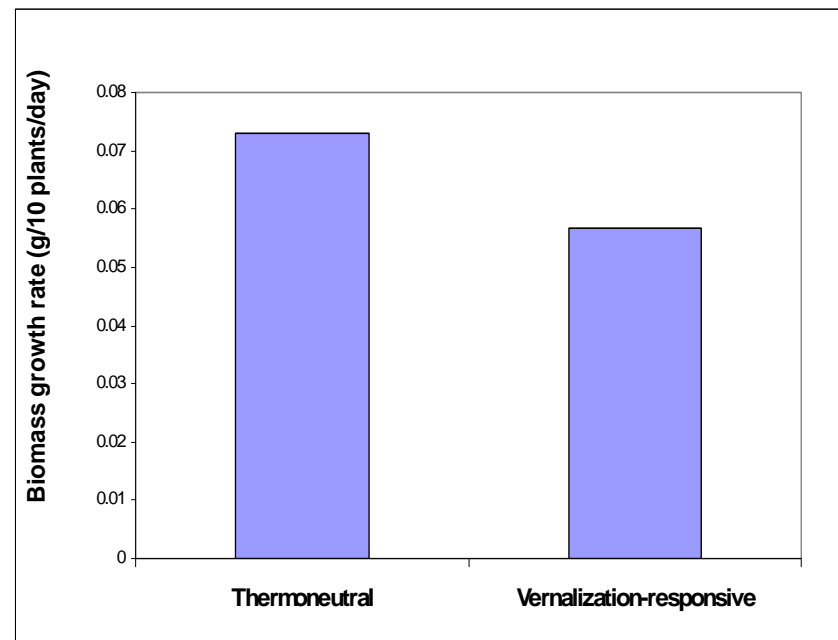
Does the need for vernalization affect lupin growth rates in the field: Biomass growth curves from L Hist

Regression in the linear phase explains 83% of variance, & demonstrates:

- Significant thermal time by site interaction: growth rates vary across sites (ie lower under stress).
- Significant thermal time by genotype interaction: growth rates vary across genotypes.
- **No significant** site by genotype or genotype by thermal time by site interaction: genotypes behave the same way regardless of where they were grown (echoes of yield G x E...)
- Slow growers are slow everywhere and vice versa for fast growing lupins.
- Vernalization responsive genotypes grow more slowly than thermoneutral types.
- Is this because their vernalization requirements are unsatisfied?



12th ILC, Fremantle 2008



L. angustifolius adaptation to Mediterranean environments -working hypothesis

- Current lupin idiootype: responsive, high yielding genotypes flower early & grow quickly, can escape terminal drought & have long seed filling phases...
- ... BUT never grow as long as is possible in favourable environments.
- Phenology & vernalization responsiveness are confounded, therefore the role of phenology in specific adaptation is obscured.
- **Speculation:** to generate specifically adapted material for longer season environments (ie southern WA), later flowering, non-vernalization responsive genotypes are required.

Key themes

- We've bred predominantly for drought escape, which may be limiting our options.
- Lupin growing areas are now largely northern short season environments.
- Vernalization appears to be wholly negative in our environment
- Can we learn something from the adaptation of wild germplasm to it's native habitat range?

Learning from nature

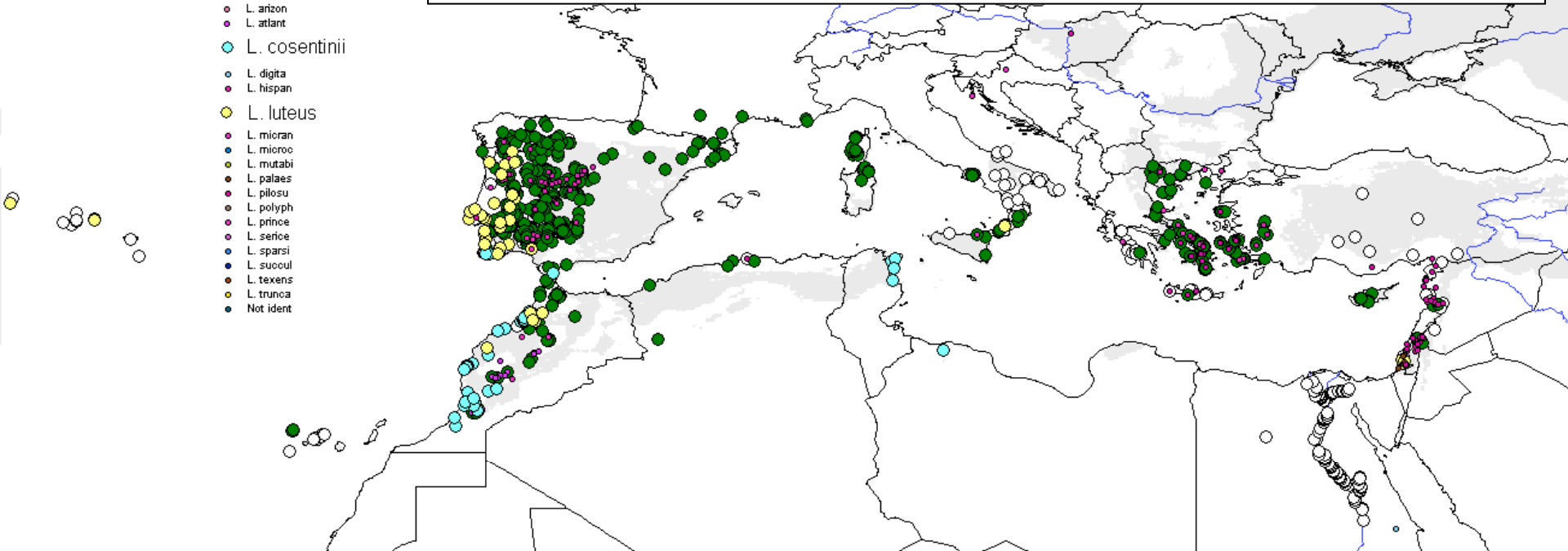
-adaptation of old world lupins to their native habitats

Annual rainfall (mm)

□ 300-600

Species

- *L. albus*
- *L. angustifolius*
- *L. arizon*
- *L. atlant*
- *L. cosentinii*
- *L. digita*
- *L. hispan*
- *L. luteus*
- *L. micran*
- *L. microc*
- *L. mutabi*
- *L. palaes*
- *L. pilosu*
- *L. polyph*
- *L. prince*
- *L. serice*
- *L. sparsi*
- *L. suocul*
- *L. texens*
- *L. trunca*
- Not ident



1. Characterize the habitats

2. Ask the questions:

- How are wild populations specifically adapted to stress gradients?
- What is the role of phenology?

Lupin habitat characterization

-setting up the question

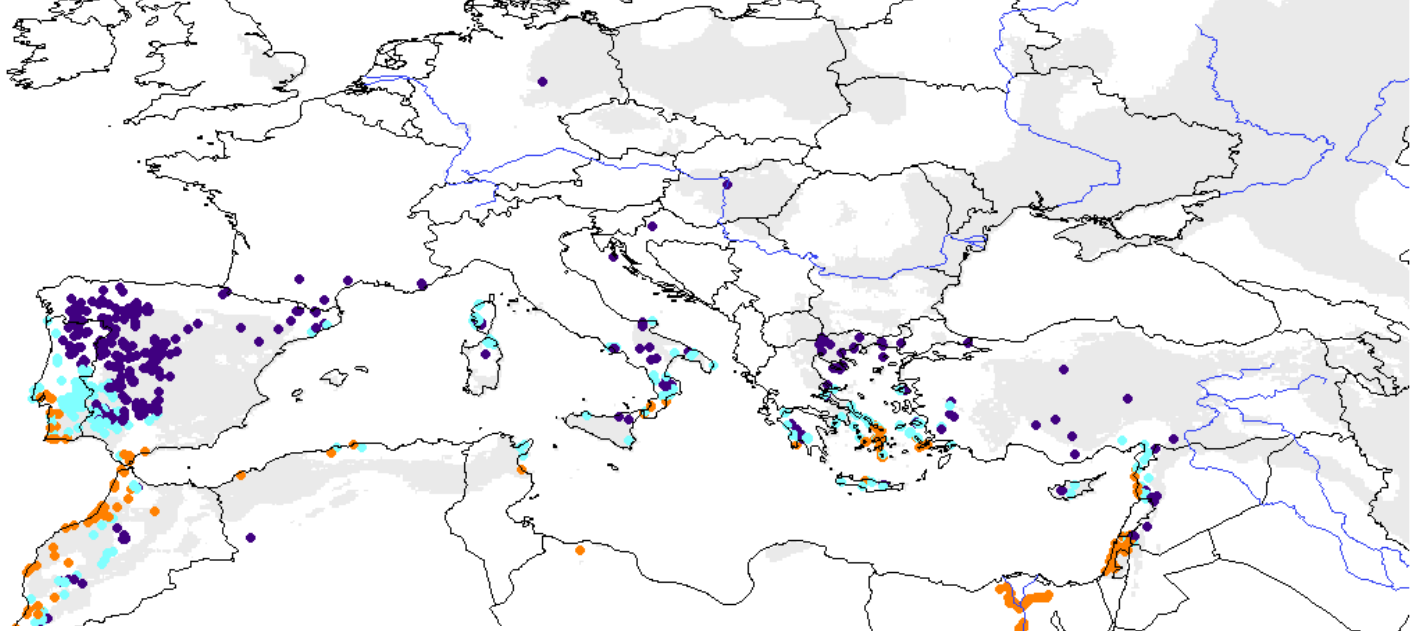
- 1. Map the collection sites.**
- 2. Extract site-specific climate data**
 - 30 second resolution (ca 1 km grid): altitude, monthly min & max temp, precipitation, 19 bio-climatic variables (temp/rainfall CVs, mean temps etc). (WORLDCLIM:<http://www.worldclim.org/>)
 - 10 minute resolution (ca 12 km grid): monthly frost days, rain days, precipitation CVs, relative humidity, sun hours, wind speed. (Ten Minute Climatology: <http://www.cru.uea.ac.uk/cru/data/tmc.htm>)
- 3. When does lupin grow?** Define phenology (germination, flowering, maturity) using temperature and daylength modelling and breeder feedback.
- 4. Calculate lupin-specific bioclimatic variables** using definitions in 3. Where are the terminally drought-stressed areas?
- 5. Characterize habitats** holistically using multivariate techniques visualized graphically and by mapping.
- 6. Choose contrasting habitats** that highlight the stress of interest (ie drought stress gradients) and evaluate germplasm from these areas.

Mean temperature of coldest quarter (°C)

- <8.4
- >=8.4<11.5
- >=11.5

Annual rainfall (mm)

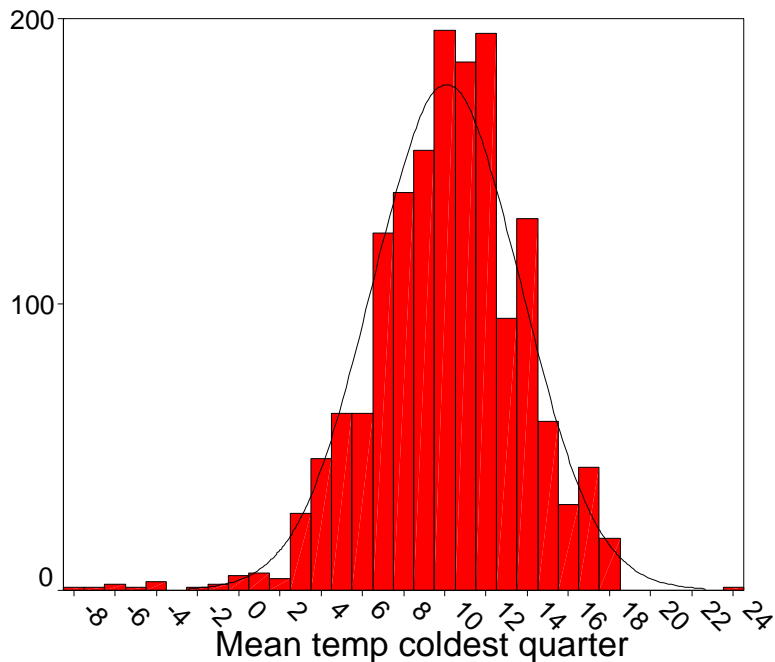
□ 300 - 600



Old world collection site winter temps are mild

Mean=10.2°C

Interesting Questions



Why is vernalization so common in wild germplasm?

How low/long do we need to go to stimulate a vernalization response?

Does the vernalization response in wild germplasm vary with species & environment ?

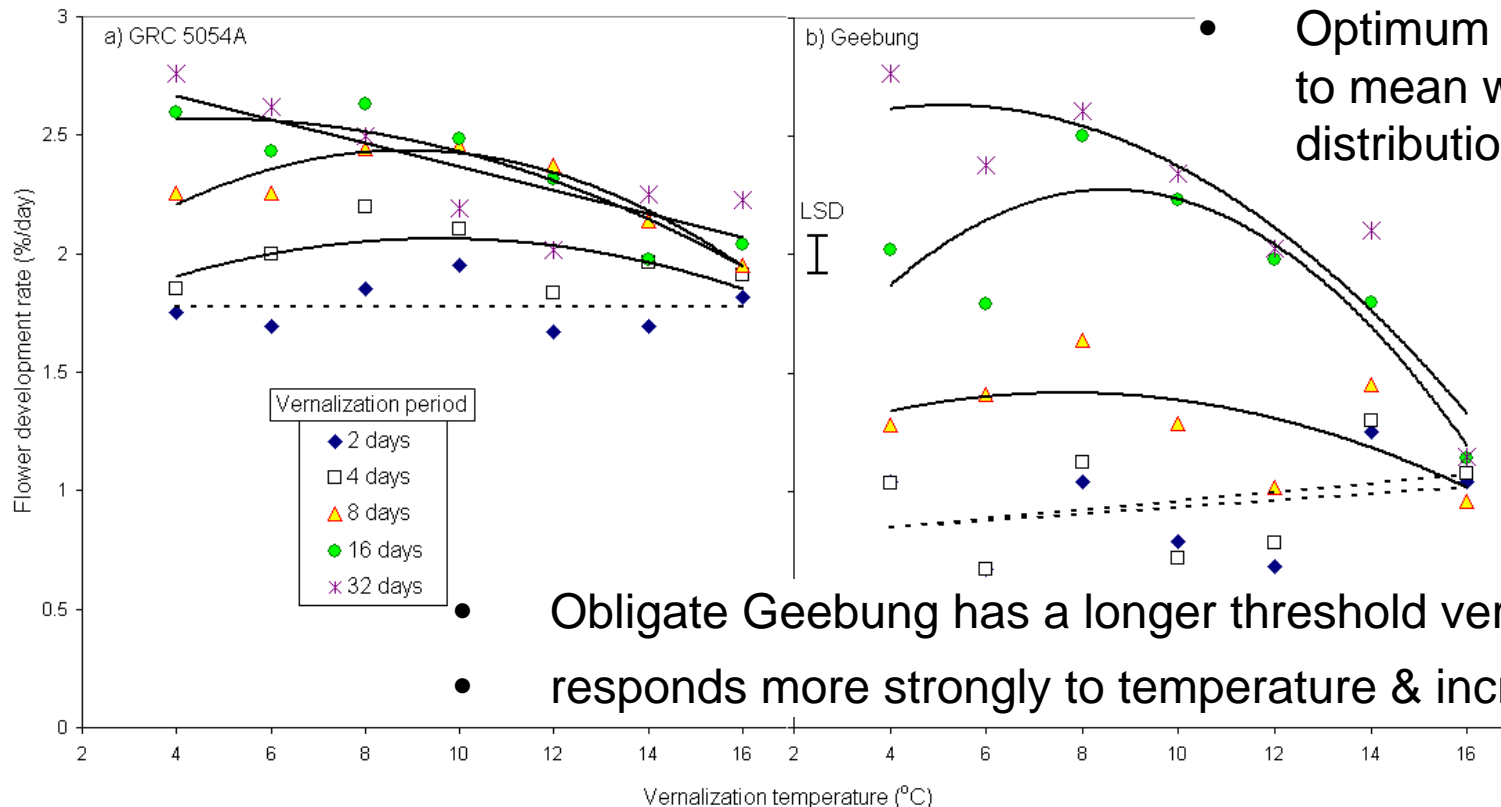
Given that drought escape is the key adaptive mechanism in Australian cultivated lupins, do we find the same patterns in the wild?



Vernalization -how much, how long?

-controlled temp cabinets, 3-way factorial design:

- 2 genotypes: GRC 5054A, facultative; Geebung, obligate response
- 7 temperatures in 2°C increments: 4-16°C (reflects natural range).
- 5 periods: 2, 4, 8, 16 and 32 days.
- Response to temperature is strongly quadratic, with optima largely 8-10°C.



• Optimum range corresponds to mean winter temperature distribution in wild germplasm

• Obligate Geebung has a longer threshold vern period

• responds more strongly to temperature & increasing vern period

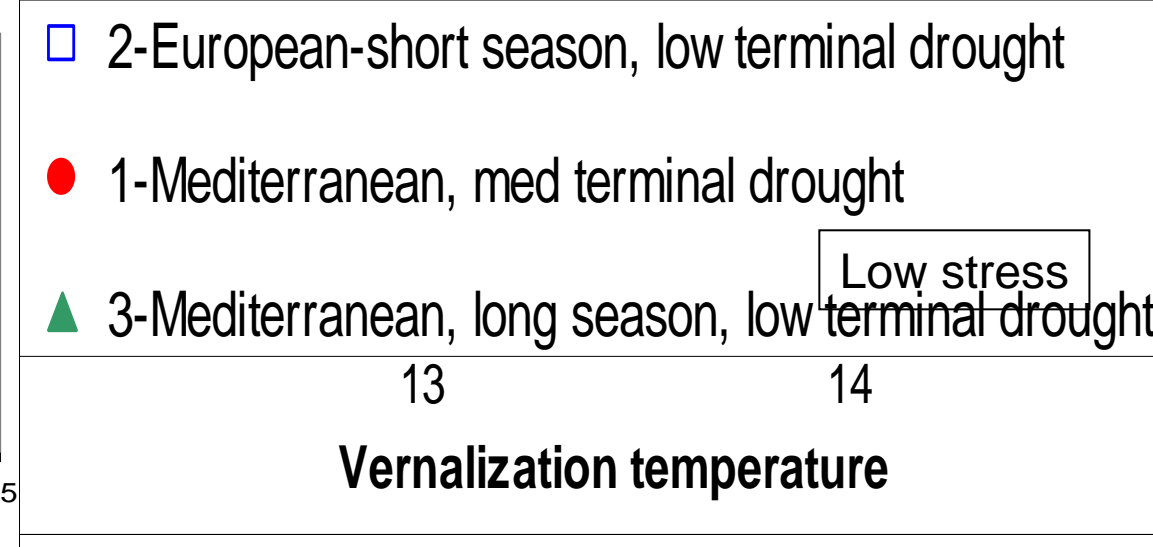
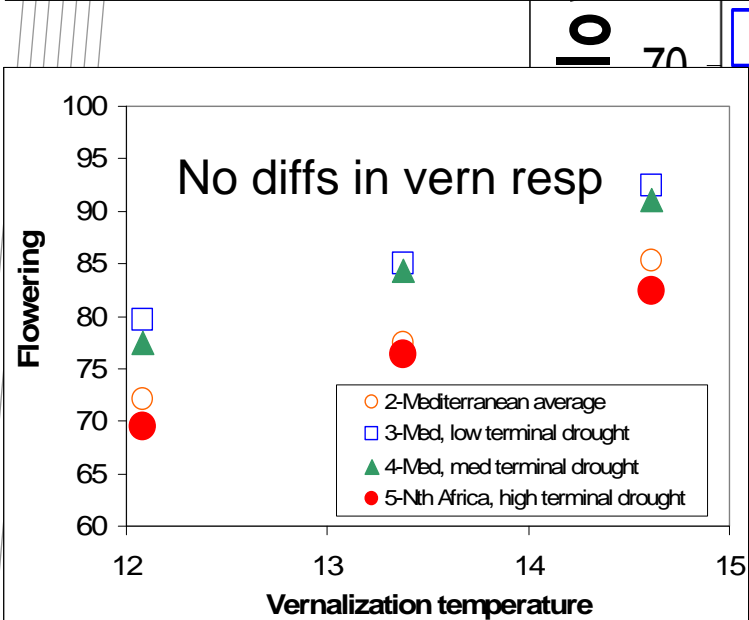
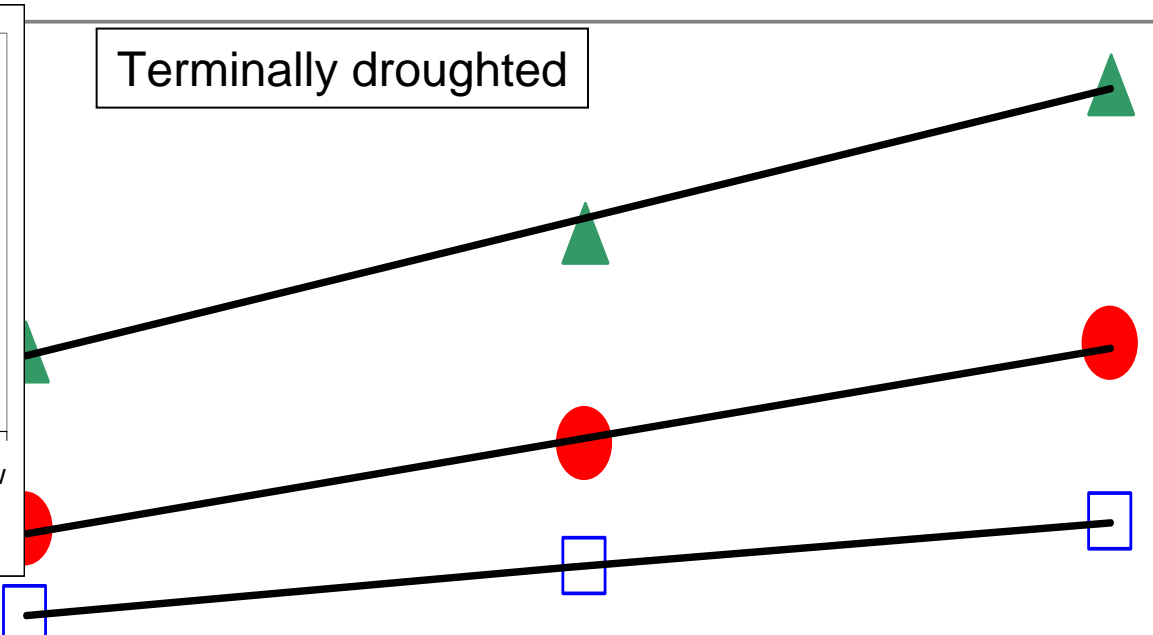
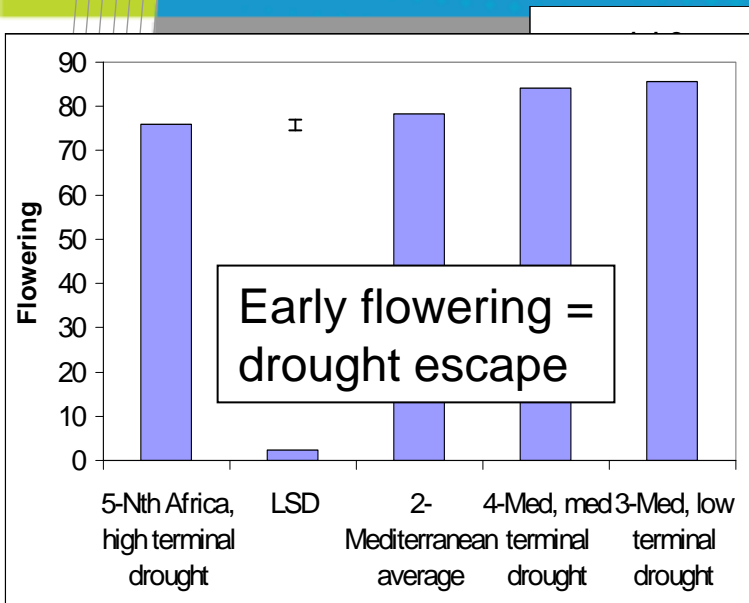
Phenology across species & habitats

- **CSIRO field 2007, 2-way factorial design (RCBD, n=3):**

- 4 species: *L. albus* (n=88), *L. angustifolius* (n=133), *L. luteus* (n=73), *L. mutabilis* (n=19).
 - Seasonal climate of collection sites characterized & processed via Maximin clustering to generate maximally diverse habitat subsets.
 - 3 vernalization treatments: low (ambient air = 14.6°C mean over 1st 30 days), med (8 days@10°C; 13.4°C mean), & high (16 days@8°C; 12.1°C mean).
- Data: flowering, podding, flower end, maturity, early vigour, growth rate, seed & biological yield, mainstem/lateral proportion...

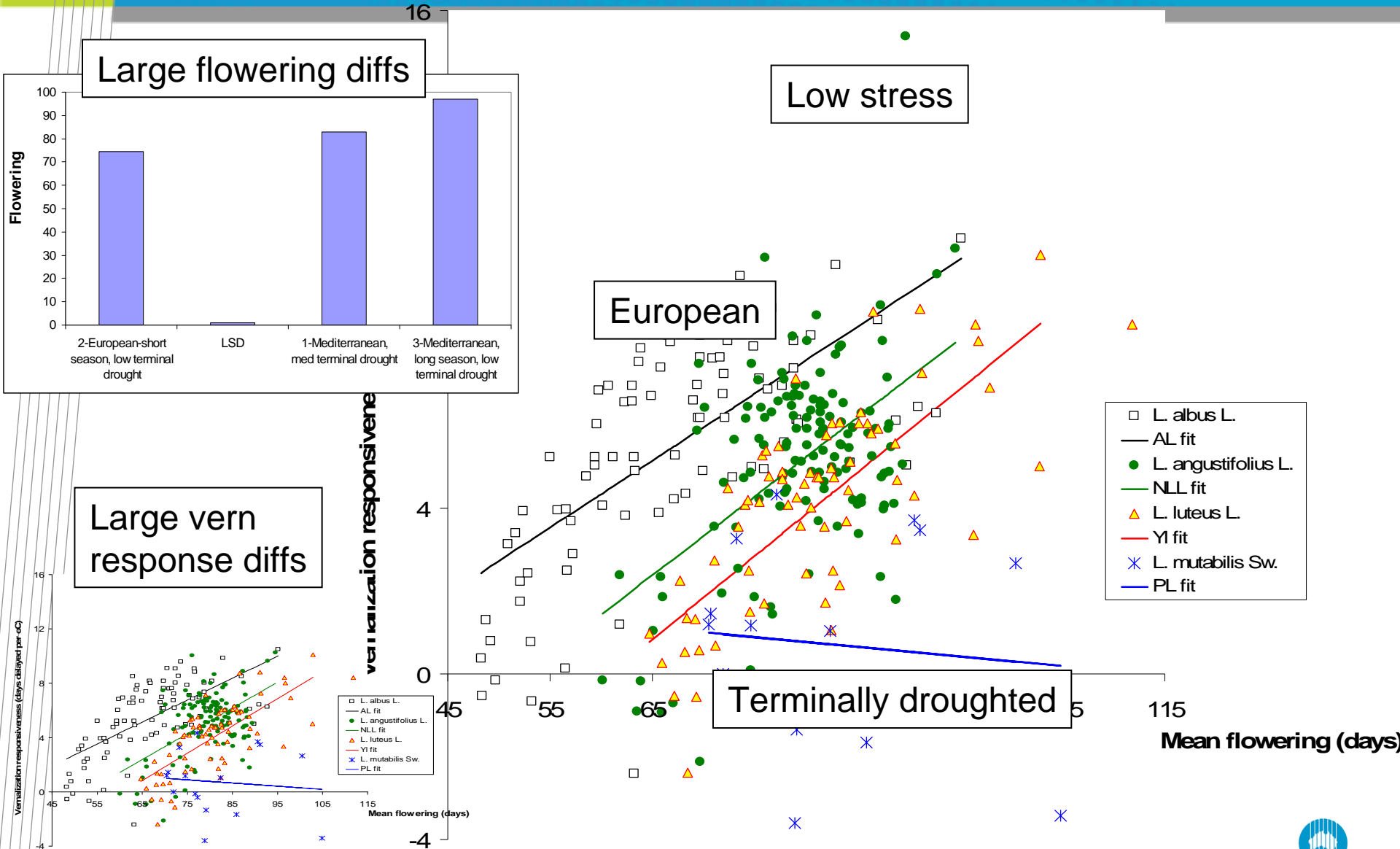
Phenology across habitats within *L. angustifolius*

Narrow leaf lupin habitats cluster reasonably well along a terminal drought stress gradient



Phenology across habitats within *L. luteus*

Yellow lupin habitats cluster tightly between Europe & Mediterranean partly based on differential terminal drought stress

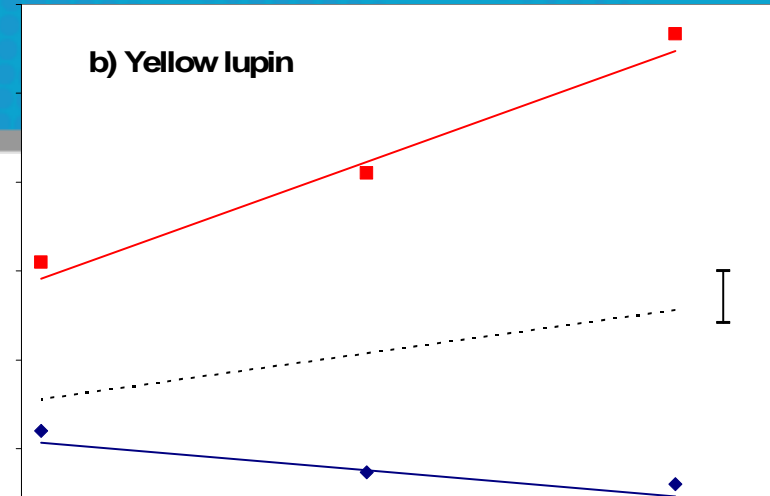
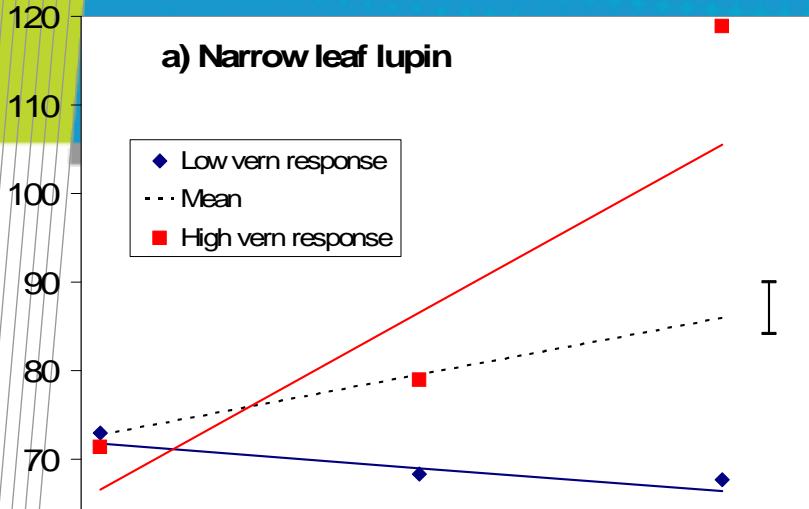


Phenology is a key element of specific adaptation in wild *Lupinus* spp.

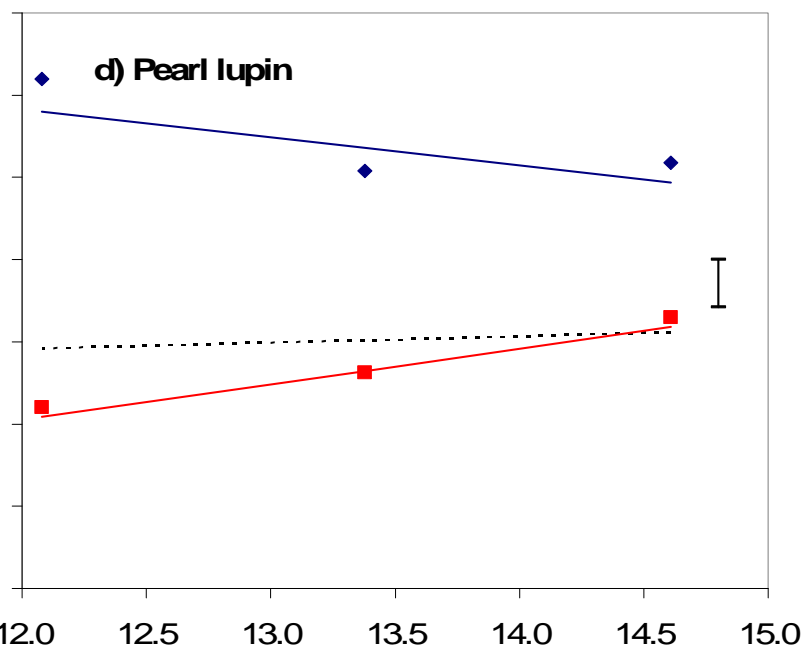
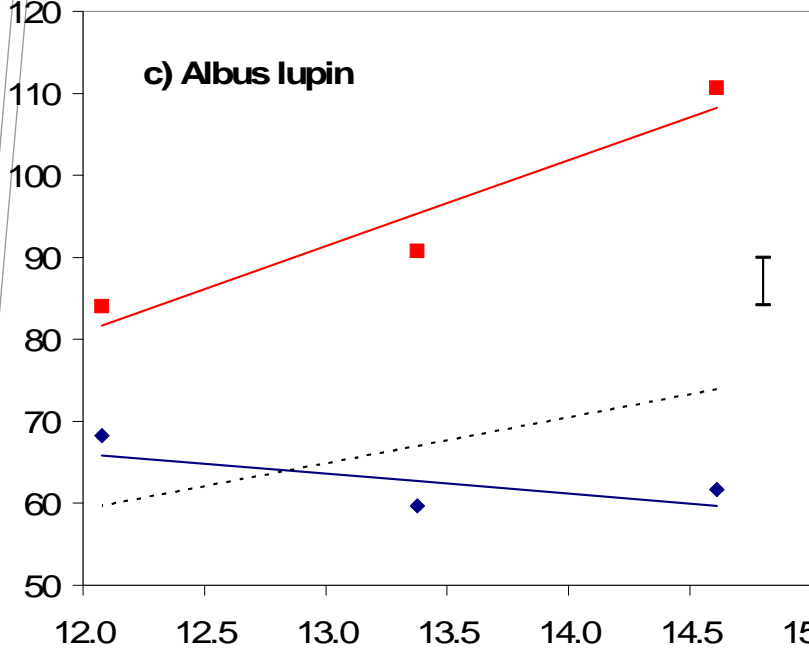
- *L. albus*, *L. angustifolius* & *L. luteus* become earlier as habitats become more stressful (higher temperatures, lower rainfall) and uncertain (higher rainfall coefficient of variance).
- Vernalization response varies between ecotypes in *L. luteus*. Highest response from cool, rainy, long season, higher elevation sites.
- Nevertheless there is a range of vernalization responses in all species.

Vernalization responses across species

Mainstem flowering (DAS)



- Regression analysis: Flow 1, Vern temps*genotype explains 90.8% var. Slope is a measure of vernalization response.

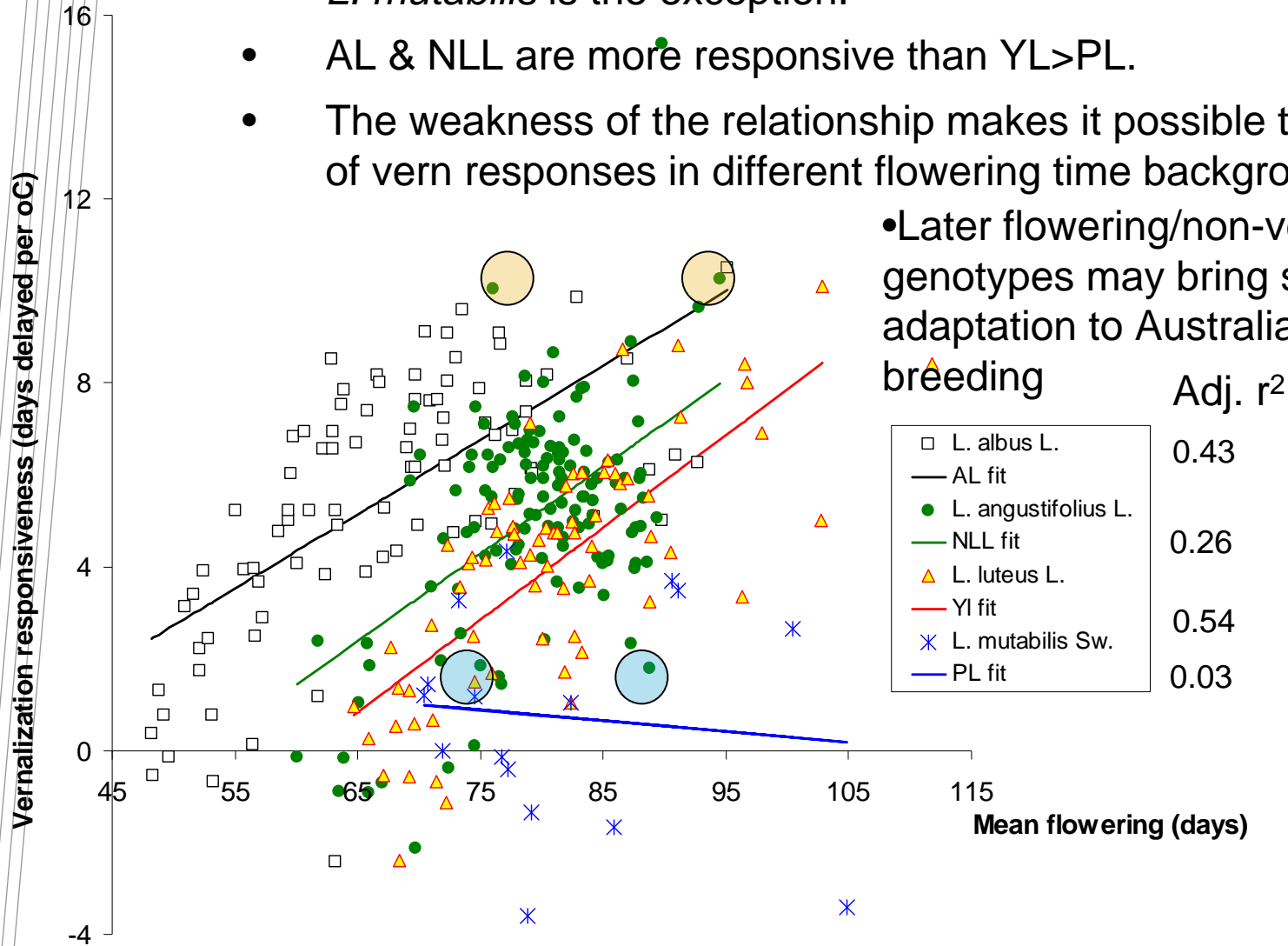


Vernalization responses across species

Vern response is +ve correlated to flowering time (reg model explains 46.1% var).

- *L. mutabilis* is the exception.
- AL & NLL are more responsive than YL>PL.
- The weakness of the relationship makes it possible to select a range of vern responses in different flowering time backgrounds

• Later flowering/non-vern responsive genotypes may bring specific adaptation to Australian lupin breeding



Conclusions

- Lupins are typical Mediterranean winter annuals: reproductive strategies become more conservative (earlier) as habitats become more stressful or variable.
- Breeders are correct in selecting for early phenology for our short season northern environments, but haven't been able to capitalize in potentially more productive, longer season environments.
- Later flowering thermoneutral germplasm should help introduce specific adaptation.
- Vernalization is so common in wild germplasm because the optimum temperatures are relatively high (8-10°C) and threshold periods short (>4 days).
- Vernalization responses can be explained by habitat types in yellow lupin: a strong response allows high elevation *L. luteus* to avoid cold stress during the reproductive phase.
- In most lupin species the vernalization response does not vary significantly between habitat types. The combination of hard seededness and vernalization response to mild temperatures may be a risk-free strategy of exploiting early autumn rains to maximize biomass accumulation in the short Mediterranean season.

Future Directions

- Confirm thermo-neutrality of promising later flowering germplasm.
- Assess relative influence of vernalization and photoperiod on phenology and plant growth (biomass accumulation, seed yield...).
- Promising material enters breeding program, and is evaluated in different environments.
- Ecophysiology of terminal drought tolerance in *L. angustifolius* & *L. luteus*. What traits have been selected for along stress gradients in both wild and domesticated populations?