Four principles for improved statistical ecology

I live and work on the unceded lands of the Bedegal and Gadigal peoples of the Eora Nation.

vISEC 2020 discussion

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In press at MEE.

Motivation

Questionable research practice	Prevalence	Reference	Consequence
Hypothesising after results are known (HARKing)	51% at least once	Fraser et al., 2018	False positives / Type I error
Not reporting non-significant results	64% at least once	Fraser et al., 2018	Bias
Hypothesis testing based on a null hypothesis that is known a priori to be false	95% of *Ecology* articles	D. R. Anderson et al., 2000	Nonsense results
Misinterpreting non-significant results as evidence of “no effect” or “no relationship”	63% of published papers	Fidler et al., 2006	Misleading
Not providing sufficient detail on methods and analysis	73% of published papers	Culina wt. al. 2020	Not reproducible / replicable

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Principles

1. First, define a focused research question, then plan sampling and analysis to answer it.
2. Develop a model that accounts for the distribution and dependence of your data.
3. Emphasise effect sizes to replace statistical significance with ecological relevance.
4. Report your methods and findings in sufficient detail so that your research is valid and reproducible.

Blue tit

bird_example.Rmd
https://github.com/gordy2x/principles

Janas, K., Lutyk, D., Sudyka, J., Dubiec, A., Gustafsson, L., Cichoń, M. and Drobniak, S. (2020), Carotenoid-based coloration correlates with the hatching date of Blue Tit *Cyanistes caeruleus* nestlings. Ibis, 162: 645-654. https://doi.org/10.1111/ibi.12751

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```
Scale for y is already present.
Adding another scale for y, which will replace the existing scale.
```

▾ Code

```
est_plot1 + theme_bw()
```

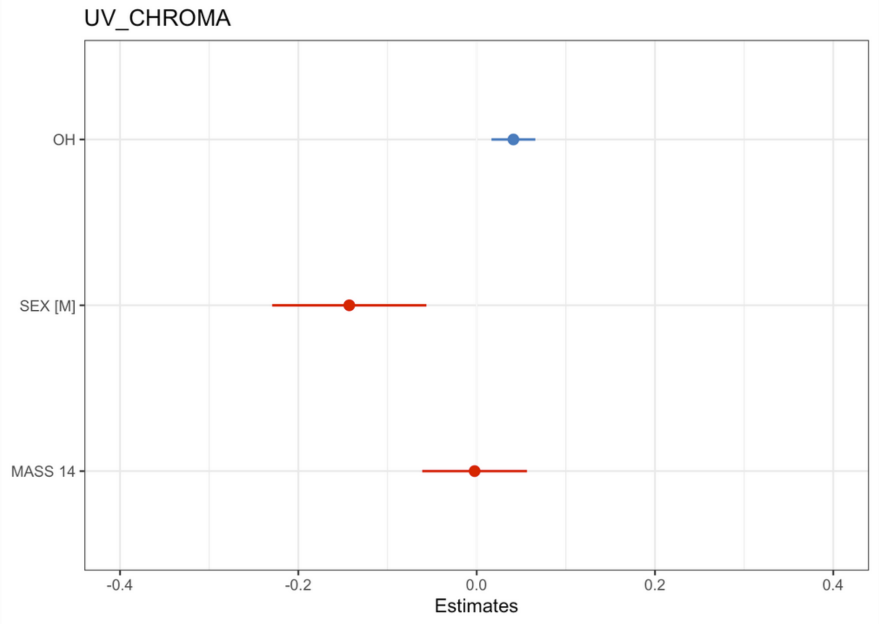

Figure 7— Estimated coefficients of UV chroma vs hatching date, with 95% CIs.

▾ Code

```
pred_plot2 <- plot_model(brightness1,
  type = "pred",
  terms = c("OH", "SEX")
)
# always include confidence intervals
pred_plot2 + theme_bw()
```

Wetland biomass

wetland_example_biomass.Rmd
https://github.com/gordy2x/principle

Mason, T. J., Popovic, G. C., McGillycuddy, M., & Keith, D. A. (2023). Effects of hydrological change in fire-prone wetland vegetation: An empirical simulation. *Journal of Ecology*, 111, 1050–1062. https://doi.org/10.1111/1365-2745.14078

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Read in biomass data

▾ Code

```
bio_data <- read.csv(here("data","wetland_biomass.csv")) %>%
  mutate(water = factor(water, levels = c("H","M","L")))
```

Mixed model

▾ Code

```
bio_live <- lmer(log(biomass + 1) ~ swamp + veg + factor(days) * water + factor
                      water*fire  +
                      (1 | Mesocosm),
                    data = bio_data)
```

The warning about rank deficiency means is expected. It is because we don't have measurements of burnt swamps prior to the burning treatment at 2 years.

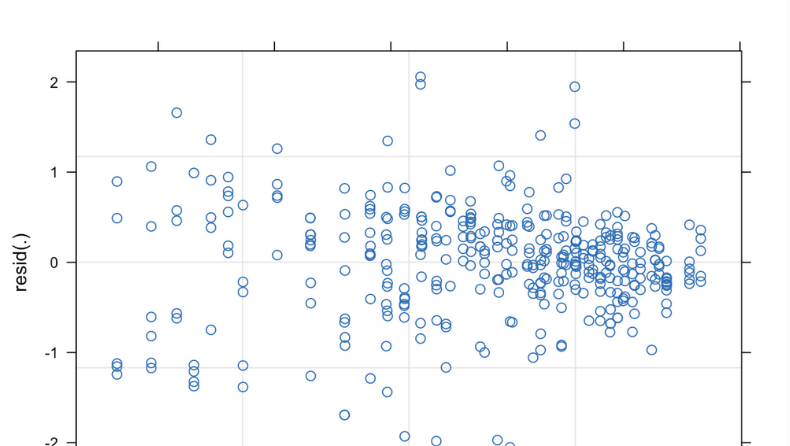
2B – Check assumptions

Residual v.s. fitted plot (marginal)

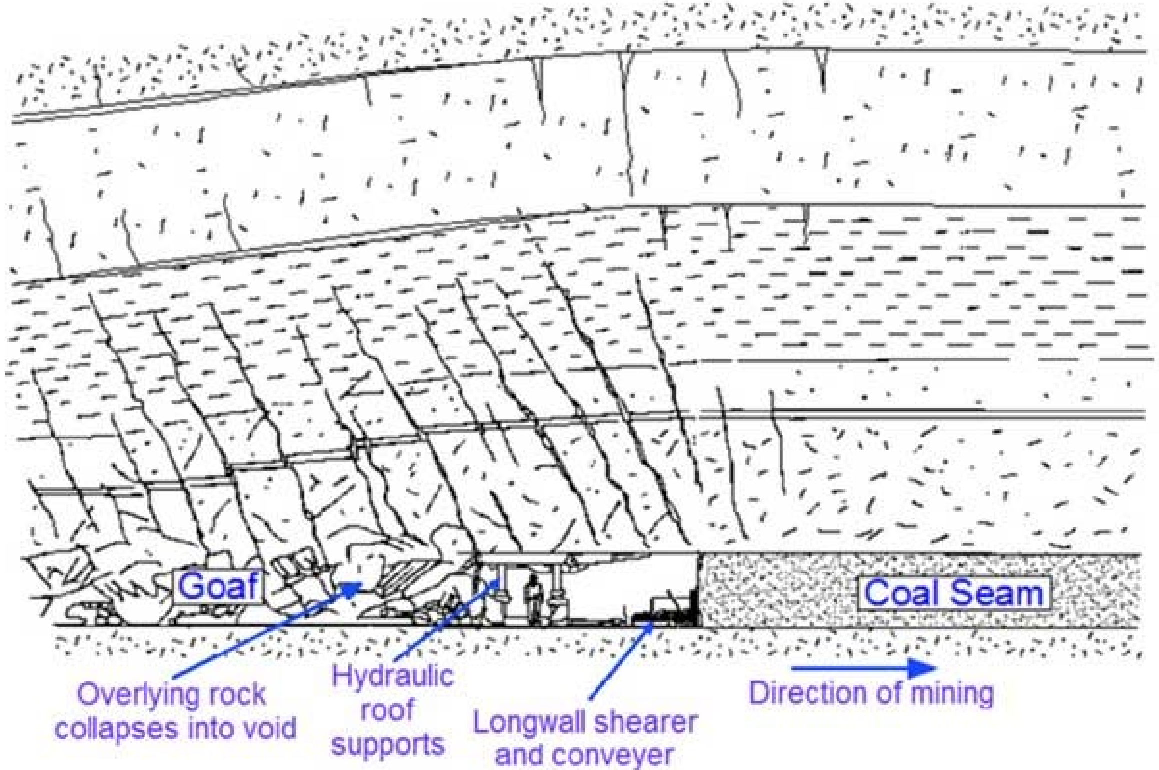
Note - `re.form = NA` gives marginal residuals.

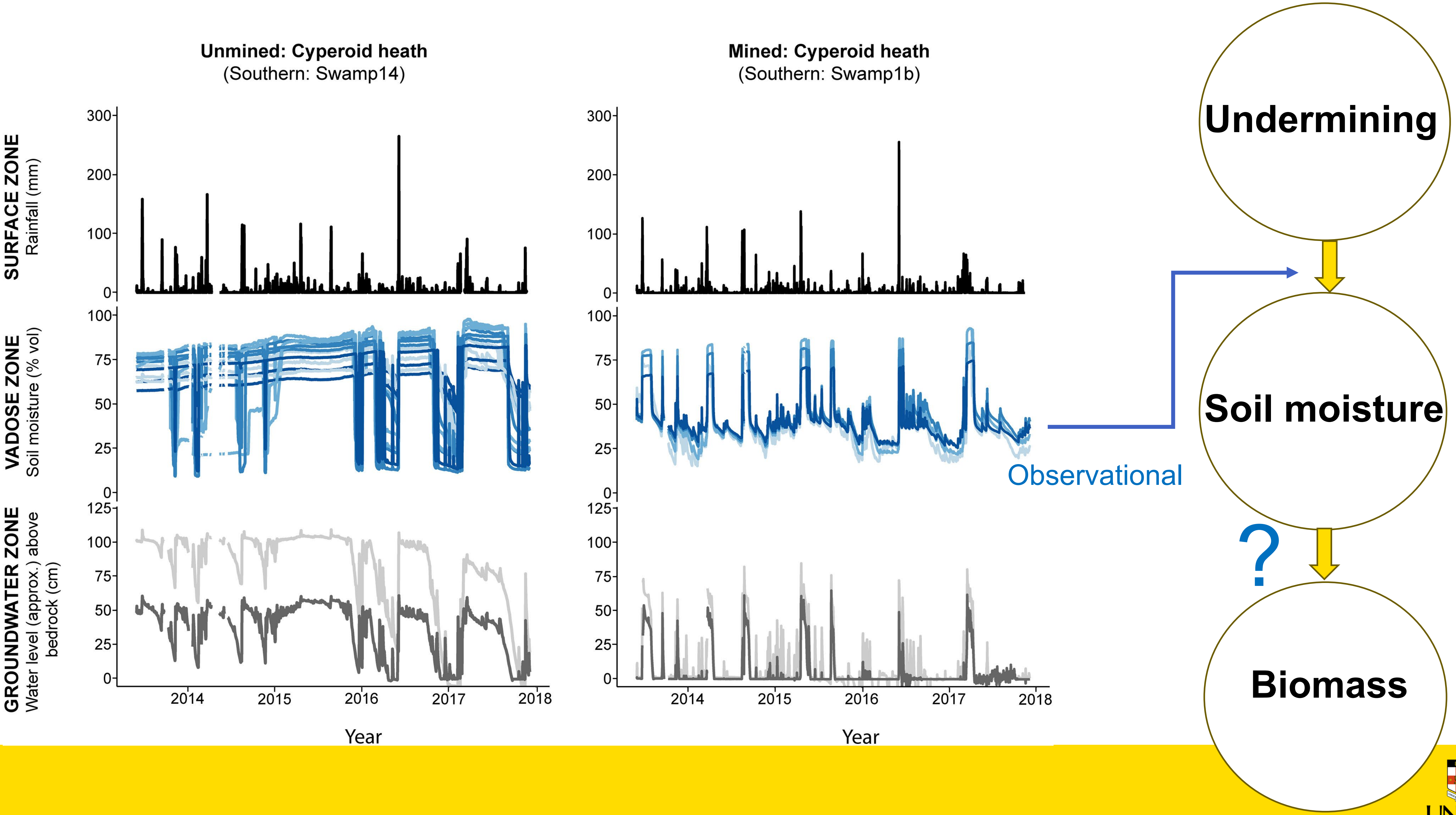
▾ Code

```
plot(bio_live, resid(. ) ~ predict(., re.form = NA))
```



Longwall mining





Unmined: Cyperoid heath
(Southern: Swamp14)
Mined: Cyperoid heath
(Southern: Swamp1b)
SURFACE ZONE
Rainfall (mm)
VADOSE ZONE
Soil moisture (% vol)
GROUNDWATER ZONE
Water level (approx.) above bedrock (cm)
Year
Observational
Undermining
Soil moisture
?
Biomass

1. First, define a focused research question…

- Must define research question **before** analysing (or plotting, summarising etc.)
- Use PICO (Population, Intervention, Comparison, Outcome) and FINER (Feasible, Interesting, Novel, Ethical, and Relevant) to help define question precisely
- Try to predict what will happen, including direction and magnitude of effect
- Can do post hoc / exploratory analysis but it must be reported as such

…then plan sampling and analysis to answer it

- Plan analyses **before** collecting or exploring data
- Consider registering analysis plan, it’s easy (e.g Open Science Framework)
- If using ‘casual’ language (‘increase’, ‘decrease’, ‘improve’, ‘influence’, ‘affect’…), need to use causal methods.
  - Experiments (with controls / replication / randomisation) can show causation with minimal assumptions.
  - Casual analysis of observations data is hard
    - Draw a directed acyclic graph (DAG), this encodes your assumptions
    - Report all assumptions, check those you can, discuss those you can’t

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First, define a focused research question…

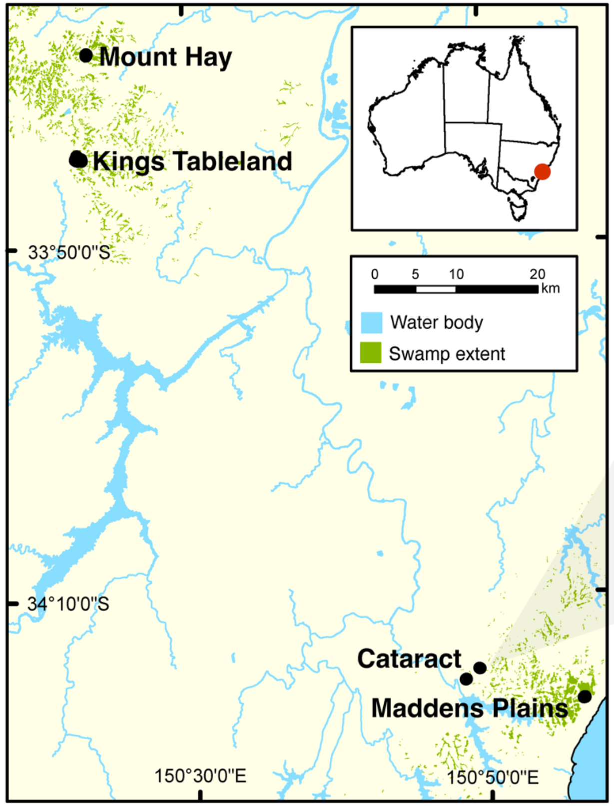
Prediction

- Biomass of wetland plants in low soil moisture conditions declines over time compared with those in high soil moisture conditions. We expect a relative reduction of 20% or more over two years.
- *Low water resource availability will compound fire effects (interaction).*

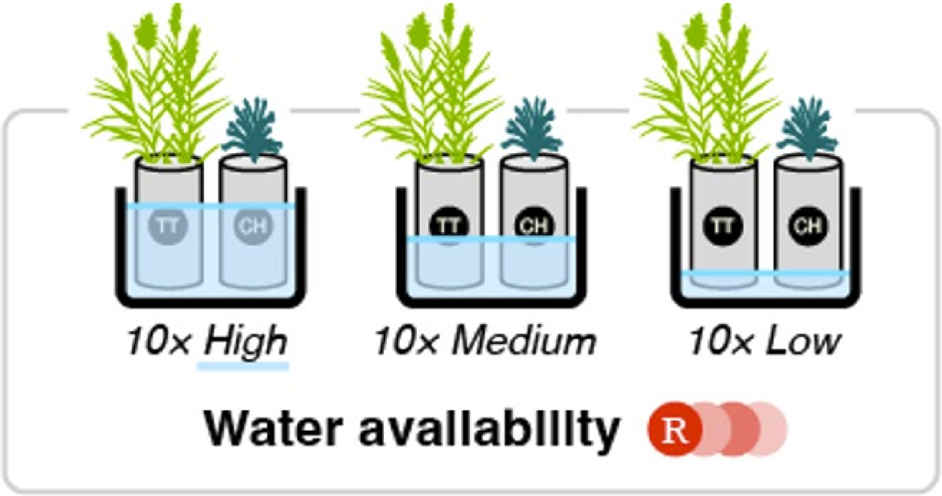
PICO/FINER in markdown.

… then plan sampling, …

… (manipulation) …



Swamp	*Cyperoid heath* CH	*Ti-tree thicket* TT
	Number of replicates	
Mount Hay	30	30
Kings Tableland	30	30
Cataract	30	30
Maddens Plains	30	30



- Cut vegetation (to minimise transplant shock)
- Put in glasshouse for 4 years
- Measure biomass of half in each treatment at 2 years and the other half at 4 years

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2. Develop a model that accounts for the distribution and dependence of your data

- Rather than fitting data to a model, aim to develop a model that accounts for the characteristics of data
- Simple dependence (nested designs, spatial / temporal correlation, multiple taxa) - standard packages (e.g. `lme4`)
- Checking assumptions is often straightforward (`statsmod` and `DHARMa` packages)
- Complex dependence
  - special purpose software (see for example the Analysis of Ecological and Environmental Data CRAN Task View; Simpson, 2023)
  - adapt flexible software to your problem (e.g. RStan: Stan Development Team, 2023; INLA: Rue et al., 2009; NIMBLE: De Valpine et al., 2017; greta: Golding, 2019).

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2. Develop a model that accounts for the distribution and dependence of your data

```
bio_live <- lmer(log(biomass + 1) ~ swamp + veg +
                   days * water + days * fire +
                   water * fire  + (1 | Mesocosm),
                 data = bio_data)

plot(bio_live, resid(. ) ~ predict(., re.form = NA))
```

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3. Emphasize effect sizes to replace statistical significance with ecological relevance.

- A focus on p-values can emphasises results which are significant (e.g. $p<0.05$), but may not be ecologically meaningful (e.g. a tiny increase in abundance)
- Focusing on effect sizes (and confidence intervals) helps to emphasise ecologically relevant results.
- Effect sizes and confidence intervals from models can be visualised (e.g `emmeans` and `sjPlot` packages)

Emphasize effect sizes …

- Effect of *water* availability on change in biomass on unburnt mesocosms, controlling for swamp and vegetation type.
- Planned contrasts of change between water availability levels at 2 years and 4 years.
- Effect of *burning* on difference in biomass among water availability levels, controlling for swamp, vegetation type and water availability treatment. Planned contrast between burnt and unburnt at 4 years (conclusion of experiment).

Emphasize effect sizes …

```
library(emmeans)
em_water <- emmeans(bio_live,  ~ water + days , type = "response",
                    at = list(days = c(1270, 592), fire = "ub"))
water_changes <- contrast(em_water, interaction = "pairwise",
                          adjust = "tukey")
confint(water_changes)
```

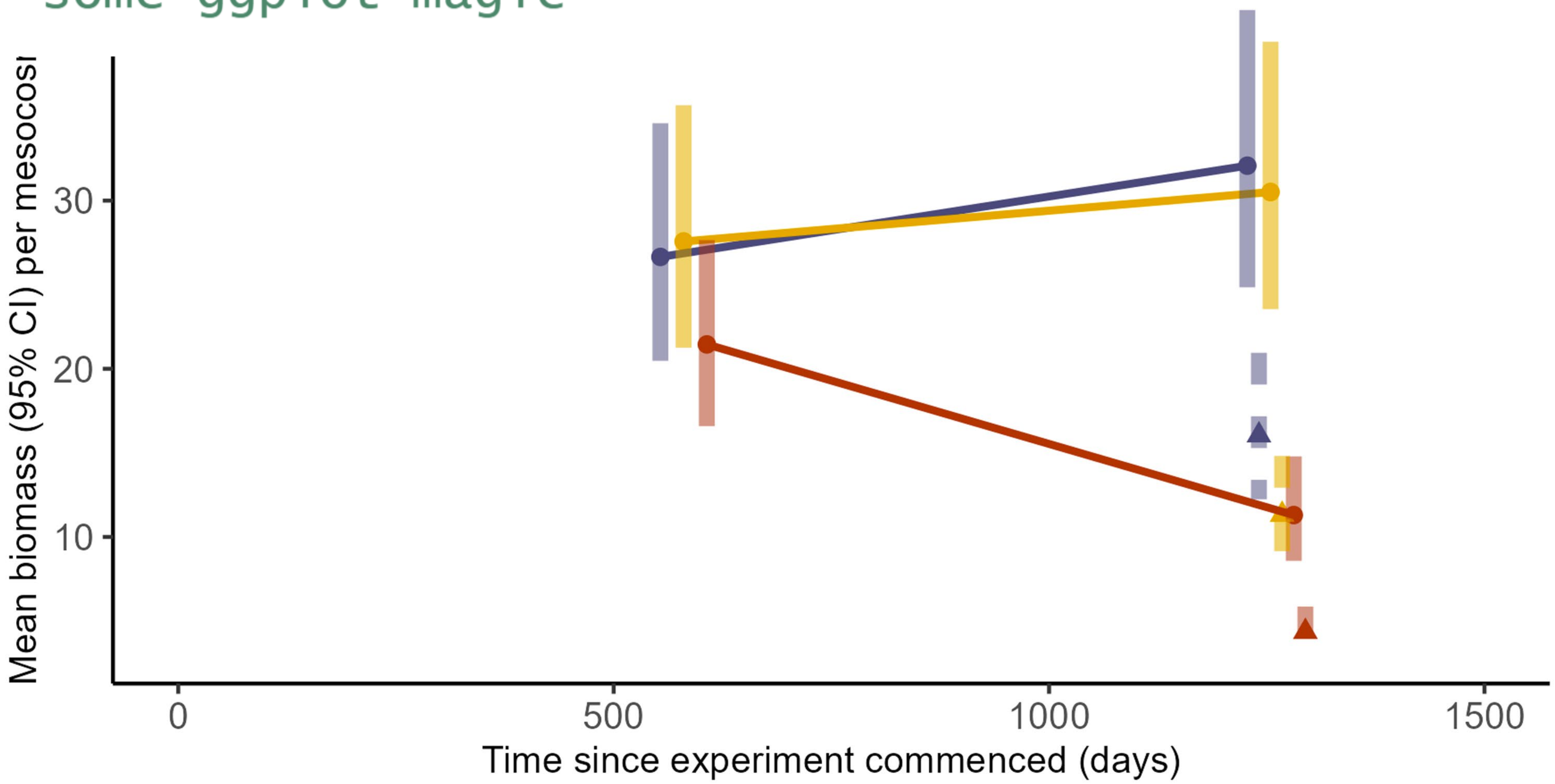
```
 water_pairwise days_pairwise ratio    SE  df lower.CL upper.CL
 H / M          1270 / 592     1.08 0.275 341    0.597     1.97
 H / L          1270 / 592     2.18 0.551 341    1.205     3.96
 M / L          1270 / 592     2.01 0.508 341    1.111     3.65
```

Results

Differences in biomass between high and low water unburnt mesocosms more than doubled (relative change = 2.2 (95% CI: 1.2 – 4.0)) between two and four years.

Emphasize effect sizes …

```
emmip(bio_live,  ~ water ~ days | fire ,
       CIs = TRUE, type = "response")
### + some ggplot magic
```



4. Report your methods and findings in detail so that your research is valid and reproducible.

- Your goal should be to have your study replicated, it increases your research impact
- Start small with your next paper, build up over time
- Keep a research journal, use it to write detailed methods
- Publish your code, even if it’s not very good, just make sure it runs
- Publish your data
- Lots of tools are available to help with this (Markdown, Git, Zenodo etc.)

DATA AVAILABILITY STATEMENT

Data and R code used in the study are available at: https://github.com/mmcgillycuddy/wetland_paper and archived using Zenodo: https://doi.org/10.5281/zenodo.7559493 (McGillycuddy, 2023).

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