internal report 410

Internal presentation on toxicity of $MgSO_4$ to Magela Creek, NT: laboratory and field results to date

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supervising scientist

Internal presentation on toxicity of $MgSO_4$ to Magela Creek, NT: laboratory and field results to date

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Abstract

Background

Magnesium sulphate ($MgSO_4$) is a common mine contaminant for many mines through increased rates of weathering of waste rock. This is also true for the waste rock of the Ranger Uranium Mine (RUM) where $MgSO_4$ is a major constituent of waste waters. A discharge containing leachate with elevated solutes from this waste rock, flows from Retention Pond One (RP1) of the Mine into the Magela Creek via Coonjimba Billabong during the wet season. However, the salinity arising from this salt has received very little ecotoxicological assessment and results of recent surveys of waterbodies receiving RUM run-off indicated that differences in macroinvertebrate community composition may be correlated with increased salinity arising from $MgSO_4$ (O'Connor et al 1995, O'Connor et al 1996). Therefore, a study has been initiated to examine its effects on the ecology of Magela Creek downstream of RUM through laboratory ecotoxicity tests in natural creek water on specific species, and field mesocosm experiments on macroinvertebrate communities.

Research findings

Single species laboratory ecotoxicological experiments using a range of local endemic species determined that magnesium sulphate is toxic at a Lowest-Observed-Effect-Concentration (LOEC) range of 6.3 mg/L for *Hydra viridissima* through to 302 mg/L for *Chlorella* sp. At this threshold concentration *Hydra* (the most sensitive species) begin to demonstrate a lack of muscular control, reduced feeding and reproduction rates and eventually death. However, it was not clear whether this toxicity was due to the cation (magnesium ion, Mg^{2+}) or the anion (sulphate, $SO4^{2-}$).

In order to determine the contribution of SO_4^{2-} to $MgSO_4$ toxicity, an experiment was conducted where *Hydra* were exposed to Na_2SO_4 over the same range of SO_4^{2} concentrations tested in the $MgSO_4$.experiments. The *Hydra* were far less sensitive to Na_2SO_4 (LOEC 366 mg/L) compared to $MgSO_4$ (21 mg/L) indicating that the toxicity was not due to the anion, sulphate.

To further clarify this, another experiment looked at the toxic effect of the magnesium ion cation (Mg^{2-}) on *Hydra* in the absence of sulphate, using Magnesium chloride ($MgCl_2.6H_2O$). This was found to produce a LOEC of 6.1 mg/L; indicating that the cation Mg^{2+} was responsible for the toxic effect of magnesium sulphate.

The physiological mechanism of this toxicity is thought to be through an inhibition of calcium channels at a cellular level. However, qualitative surveying revealed that *Hydra* still occur in water bodies receiving mine outflow, such as RP1 itself, at levels exceeding this threshold for Mg^{2+} (e.g. 31.6 mg/L at the RP1 spillway and 20.6 mg/L for Coonjimba Billabong in April 2000). This appeared to be through an amelioration by the elevated Ca^{2+} levels in this discharge (4.1 mg/L at this same time and place). However, it could also be argued that this tolerance over predicted RP1 water toxicity could be due to a different variety of Hydra inhabiting these impacted waters.

To test for this, another series of experiments were undertaken. *Hydra* from Coonjimba billabong were tested for their tolerance to elevated Mg^{2+} levels, whilst both Coonjimba Billabong and ***eriss*** stocks of *Hydra* were exposed to a series of dilutions of Coonjimba

water. At the time of collection of Coonjimba Billabong *Hydra*, the billabong Mg^{2+} and Ca^{2+} concentrations were 20.6 and 2.5 mg/L respectively (a Mg:Ca ratio of 8.2:1). Both strains (***eriss*** and Coonjimba Billabong) demonstrated no LOEC for Coonjimba water, yet Coonjimba Billabong *Hydra* displayed a NOEC and LOEC of 5.5 and 16.5 mg/L respectively, indicating very slight, if any, adaptation to elevated Mg^{2+}.

Hydra tests undertaken where Mg^{2+} concentration were maintained at 10 mg/L while Ca^{2+} concentrations were increased with each treatment showed that as long as the Mg:Ca ratio was maintained at 10:1 or below, then Mg^{2+} should not be of significant toxicity. The major mechanism allowing *Hydra* to exist in waters elevated in Mg^{2+} therefore appeared to be through the calcium cations also present in the RP1discharge.

Conclusion

The concentration of Mg^{2+} in the Magela Creek below the discharge is not expected to exceed 10 mg/L at a Mg^{2+}:Ca^{2+} ratio of 3.6:1 (ERA environmental data, sourced from ERA Ranger Mine Environment Department). Therefore, from these preliminary data, this discharge may not be causing a detrimental effect to the Magela Creek. However, this result is tentative and awaits further data collection and analysis including bringing the *Mogurnda* fry bioassay up to Australian and New Zealand Environment and Conservation Council (ANZECC) guidelines requirements (ANZECC & ARMCANZ 2000).

Slides

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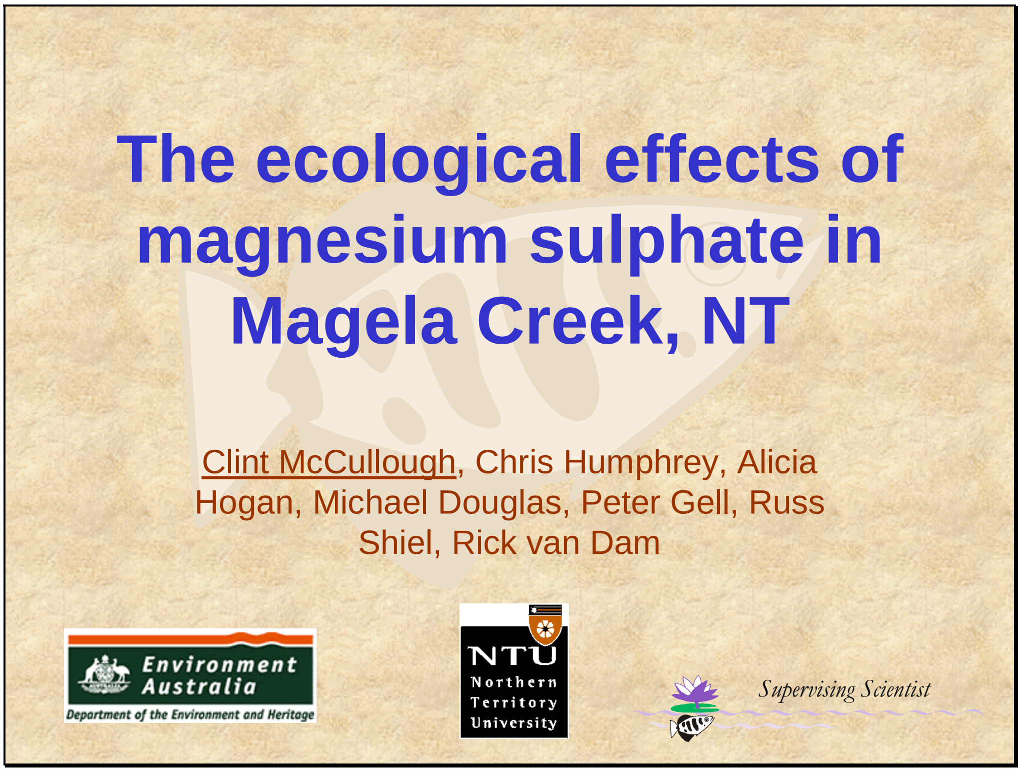

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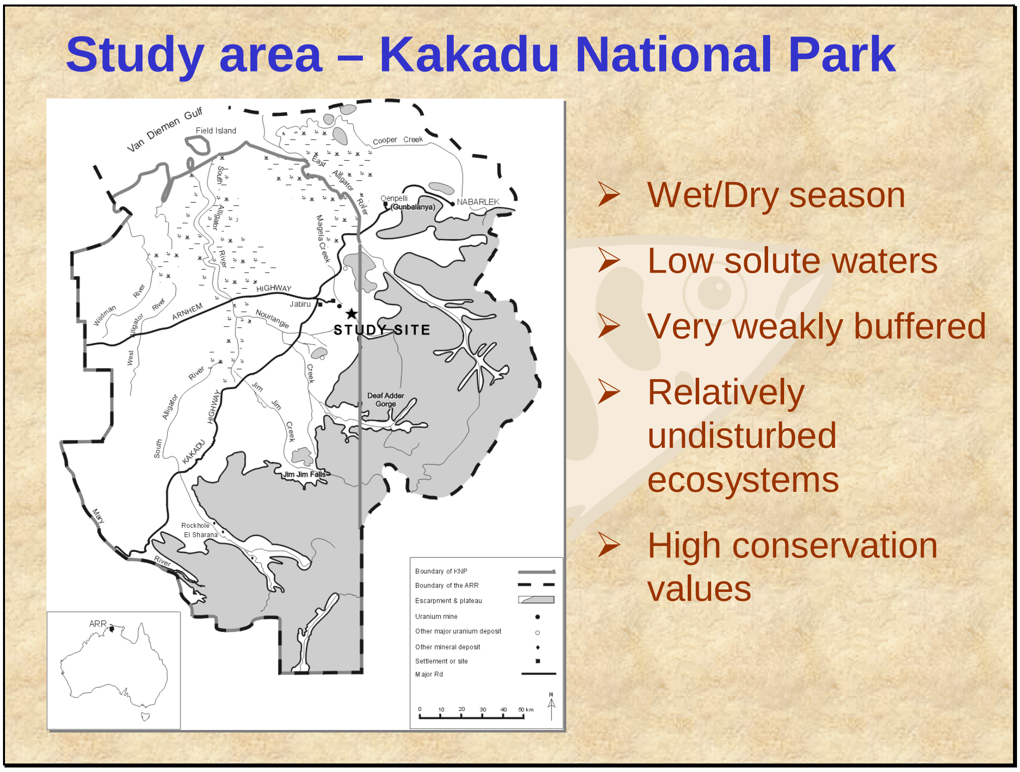

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Study area – Magela Creek

- Seasonally flowing tributary of the East Alligator River
- Flows into the world Heritage listed Magela Wetlands
- Extremely soft, poorly buffered waters of low conductivity and pH.

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Changing flows through seasons

Wet

Early-Dry

Mid-Dry

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Chemical characteristics of waterbodies, May 1995

Waterbodies not receiving mine waters	**Conductivity** (µScm-1)	**[Mg]** (mg/L)	**[SO4]** (mg/L)
Buba	41	1.4	0.22
Sandy	28	0.38	0.59
Georgetown	33	1.6	1.6
Town Lake	45	—	—
Waterbodies receiving mine waters			
Coonjimba	120	7.5	25
Retention Pond 1	190	18	56
Djalkmara	830	110	320

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Some invertebrate responses in billabongs (May 1995)

Waterbodies receiving mine waste waters:

- **Greater numbers of aerial breathing invertebrates:**
  - surface-dwelling hemipterans (bugs)
  - dytiscid beetles
- **Greater numbers of *Tanytarsus* chironomids**
- **Similar responses in Rockhole Mine Creek** (acid-mine drainage)

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Disturbance gradient from multivariate macroinvertebrate data (1995 & 1996)

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Epsom salts; Magnesium sulphate / $MgSO_4.7H_2O$

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Source of $MgSO_4$ at RUM

- Primarily due to weathering of the waste rock pile (expected to peak in 2010)

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Retention Pond 1: Wet Season release

- High salinity (>300 μScm^{-1})
- Primarily due to Mg^{2+} and SO_4^{2-}
- Overflows approximately 4 months of the year (January - April)

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From RUM to Magela Creek

- Solutes from Waste Rock Pile flow into RP1
- RP1 overflows into Coonjimba Billabong
- Coonjimba Billabong flows to Magela Creek

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Main source of $MgSO_4$ from RUM

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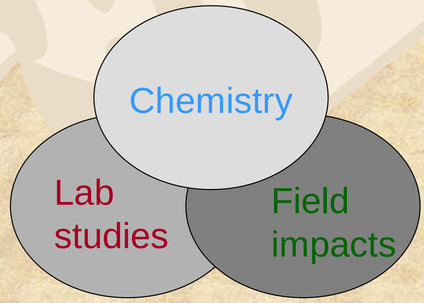
Ecotoxicology – the “Triad approach”

1. Laboratory ecotoxicological assessment
   - single species bioassays
2. Field
   - community-level studies (observational & experimental)
3. Chemistry
   - knowledge of environmental chemical interactions



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Approaches to determining ecological effects of $MgSO_4$ in Magela Creek

1. Laboratory ecotoxicological assessment
2. Field (mesocosm) assessment

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LABORATORY ECOTOXICOLOGICAL APPROACH

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Single-species toxicity tests - background

- Pre-release toxicity tests used historically at Ranger as component of regulatory requirements
- Four species routinely used at ***eriss***
- Species selected for: life cycle, ecologically relevant endpoints, ability to be cultured under lab conditions, wide range of taxa and trophic levels
- Standard conditions: 12:12 h light:dark, 27±1°C, standard test volumes, etc.

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Single-species toxicity tests

Species: purple spotted gudgeon, *Mogurnda mogurnda*

Test duration: 96 h

Endpoint: sac fry survival

Exposure: acute

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Single-species toxicity tests

Species: water flea, *Moinodaphnia macleayi*

Test duration: 5-6 d (production of 3 broods)

Endpoint: reproduction

Exposure: chronic

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Single-species toxicity tests

Species: green hydra, *Hydra viridissima*

Test duration: 96 h

Endpoint: population growth

Exposure: chronic

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Single-species toxicity tests

Species: single-celled green alga, *Chlorella* sp.

Test duration: 72 h

Endpoint: cell division

Exposure: chronic

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Single-species toxicity tests

Species: Freshwater snail, *Amerianna cumingi*

Test duration: 8 days

Endpoint: fecundity (embryos)

Exposure: Chronic

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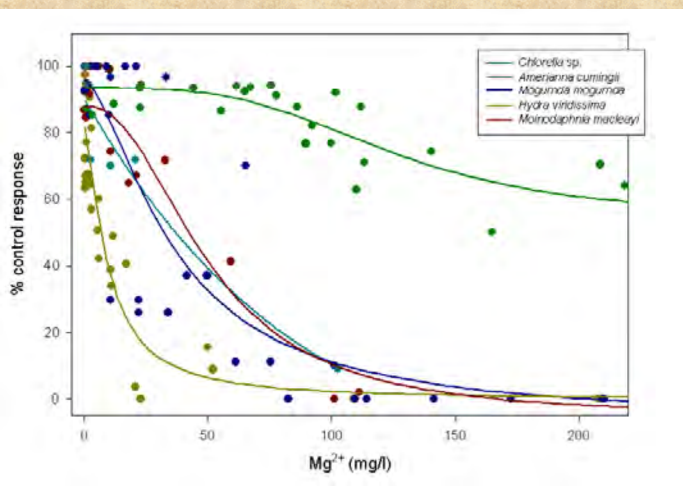
Summary of ecotoxicity results to date



- *Hydra* highly sensitive - an outlier?
- Initial steep response for *Amerianna*
- *Chlorella* very robust

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Single-species NOECs and LOECs

(geometric means of Mg^{2+})

Species tested	NOEC * (mg/L)	LOEC * (mg/L)	No. of tests
Hydra	2.2	4.6	3
Moinodaphnia	10.2	18.0	2
Mogurnda fry	25.2	45.1	4
Chlorella	83.6	143.2	4
Amerianna **	2.0	2.3	1

* Mg^{2+} concentration

** IC10 & IC20 results

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Deriving toxicant guidelines (single-species toxicity tests)

- ***Previously***: assessment factor applied to lowest ecotoxicity value (lowest NOEC)
- ***Now***: Statistical distribution method (ANZECC/ARMCANZ guidelines) - **"BurrliOZ"**
  - Fits ecotoxicity data to the Burr III distribution of curves to protect chosen *x*% of species (e.g. high conservation value sites 99%)
  - Minimum data requirements e.g. ≥ 5 species from ≥ 4 different taxonomic groups

➢ More work needed on more taxa

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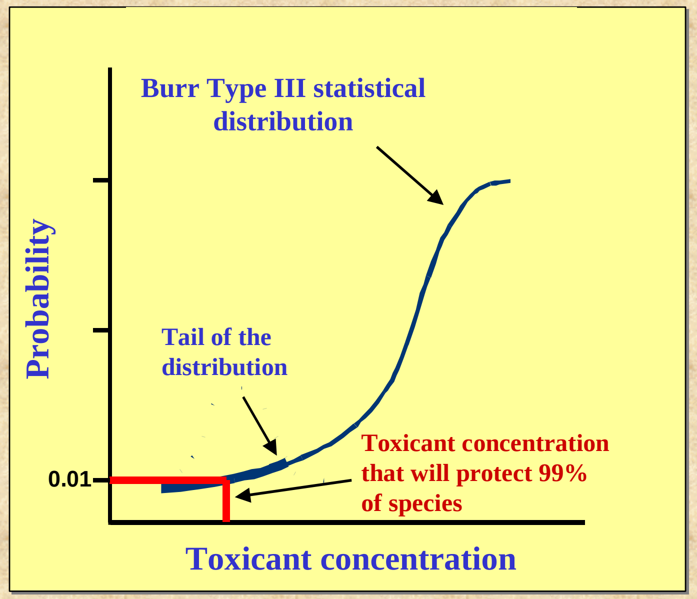
Derivation of toxicant guideline values



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Magnesium concentrations at or near biological effects

Billabong studies (May 1995)

- Waterbodies receiving mine waste waters ~ **7.5 - 110** mg/L

Ecotoxicological studies (2001)

- NOECs: **2.0*, 2.2, 10.2, 25.2, 83.6** mg/L
- LOECs: **2.3*, 4.6, 18.0, 45.1, 143.2** mg/L
- BurrliOZ 99%: **0.8** mg/L

Concentrations in field (e.g. GS0009, 2000-01)

- Max: ~ **4 - 11**; frequency exceeded @ GT009 = *c*.50 **%**

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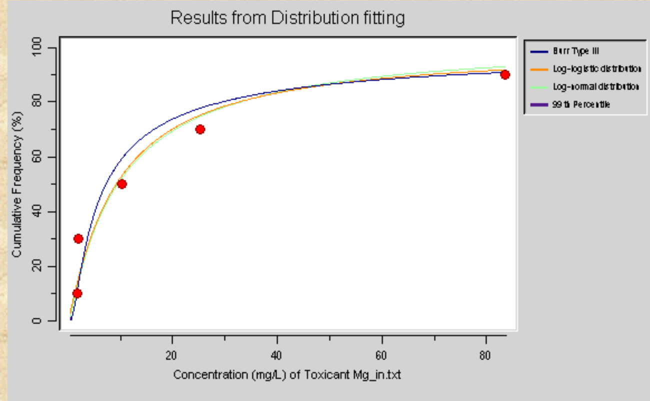
BurrliOz modelling of ecotoxicity results



- 99% ecosystem protection:

  Preliminary estimate

  = 0.8 mg/L Mg^{2+}

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Field validation of lab tests

Anbangbang Billabong: Mg^{2+} ~ 1.2 mg/L

Coonjimba Billabong: Mg^{2+} ~ 20 mg/L

Retention Pond 1: Mg^{2+} ~ 30 mg/L

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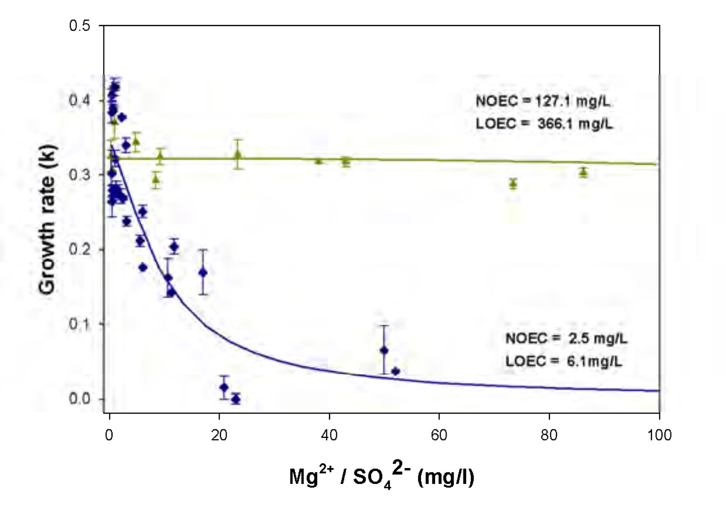
Cation/anion relative toxicity to Hydra



- Toxicity attributed to Mg^{2+}
- SO_4^{2-} ion already noted in water quality guidelines
- Only high SO_4^{2-} values toxic

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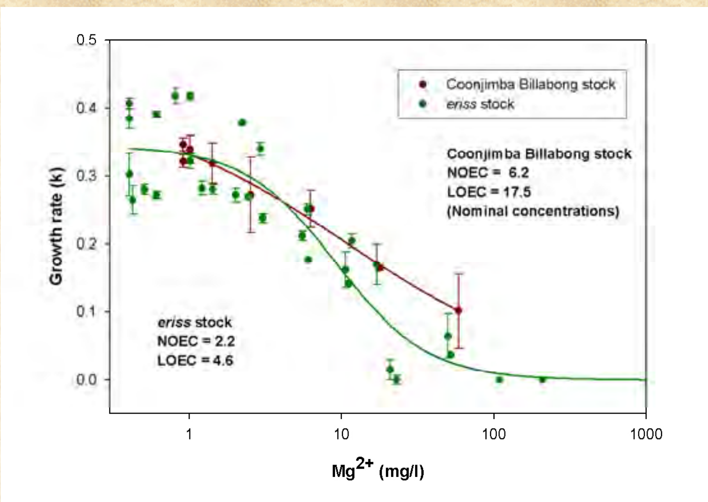
Population tolerance differences?



- Coonjimba NOEC/LOEC range within approx. 2 – 3 x ***eriss*** stock
- Possibly "noise" between tests
- Tests on "control" and RP1 stock to follow

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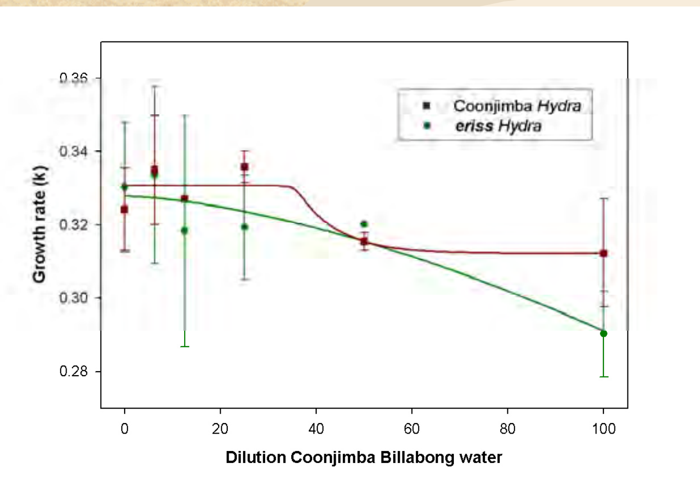
Physiological tolerance or chemical amelioration?



- Both strains exposed to Coonjimba water
- Similar response of strains
- Mg^{2+} *c.* 20 mg/L, Ca^{2+} *c.* 2.5 mg/L
- Mg:Ca water ratio = 8

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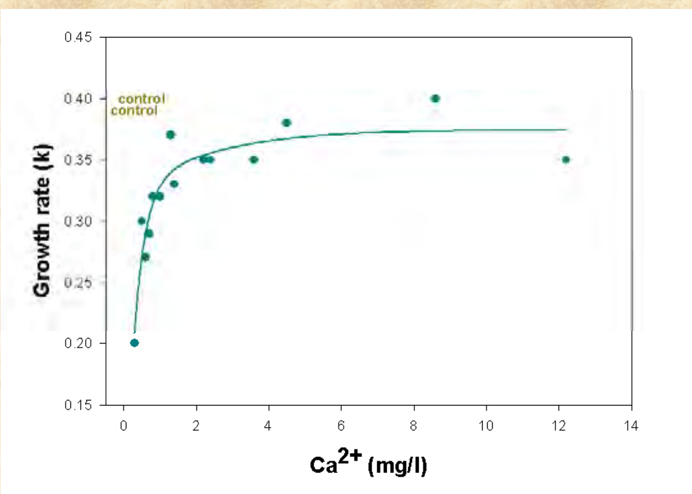
Calcium amelioration



- Complete recovery @ *c.* 10 mg/l and greater concentrations of Ca^{2+}
- NOEC geometric mean of 1.2 mg/L
- Mg:Ca ratios of 12:1

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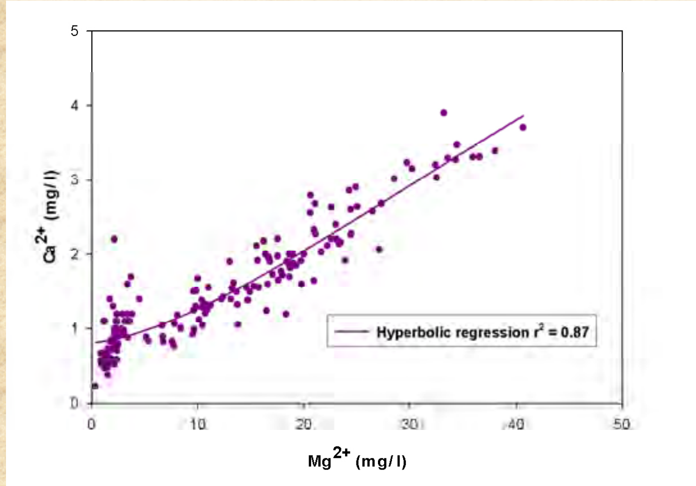
Mg^{2+}/Ca^{2+} relationship in RUM discharge



- Arithmetic average $Mg^{2+}:Ca^{2+}$ = 6.76 (< 10 mg/L range)
- Ratio higher at higher Mg^{2+} concentrations

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FIELD EXPERIMENTAL APPROACH

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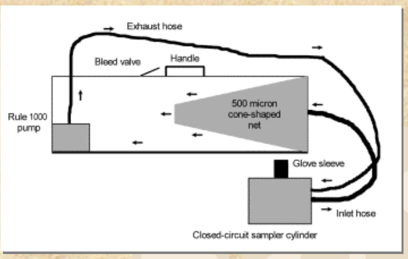
The benthic sampler



- Specifically samples benthic communities
- Functions like a ‘vacuum cleaner’
- Quantitative measurements made (0.09 m^2)

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Pool mesocosm experiments

- Quantitative ‘vacuuming’ of pool benthic macroinvertebrate communities in creek bed pools

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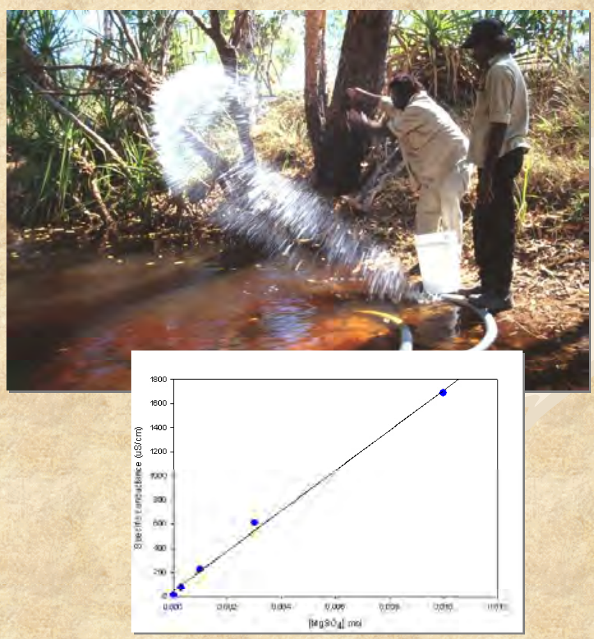
Spiking pools with epsomite



- Pools spiked with BP grade $MgSO_4.7H_2O$
- Pools (including control) well mixed
- Concentrations checked with simple conductivity / concentration regression

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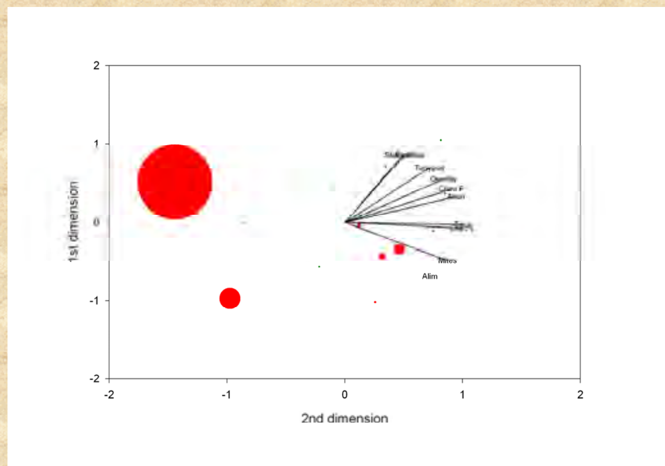
2001 pool spiking data



- Acute impact
- Only 2 pools remaining of 'notable' $MgSO_4$ concentration
- All significant taxa correlates *away* from strongly $MgSO_4$ spiked pools

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Current mesocosm experiments

- ➢ 3,000 L tubs in drying creek channel in recessional flow ‘seeded’ with wet creek sediments and waters from the Creek

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Current mesocosm experiments

Colonisation…

- ➢ Aerial dispersal
- ➢ Wetted sand
- ➢ Leaf litter
- ➢ Creek water

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"BACI" experimental design

➢ "Before/After, Control/Impact"

- Sample all tubs before — ❖ Week 0
- Spike tubs to varying extents (leave control)

- Sample second time — ❖ Week 4

- Repeat post-impact sample — ❖ Week 7

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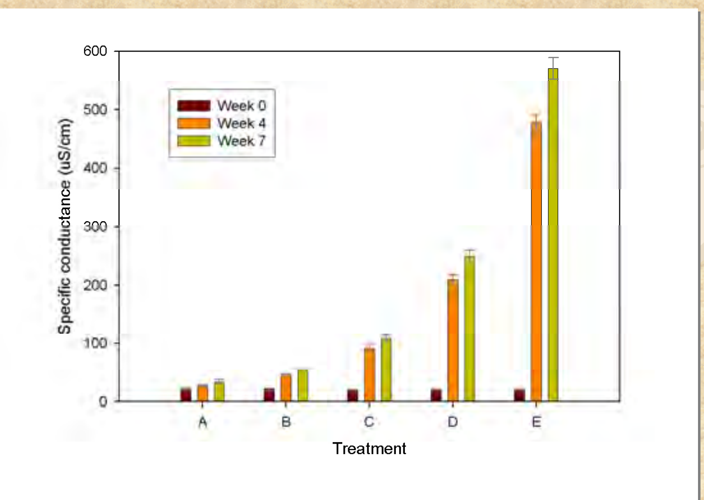
$MgSO_4$ concentrations



- Conductance increases over time due to evaporation
- Accuracy of spiking good (within *c.* 10? nominals)

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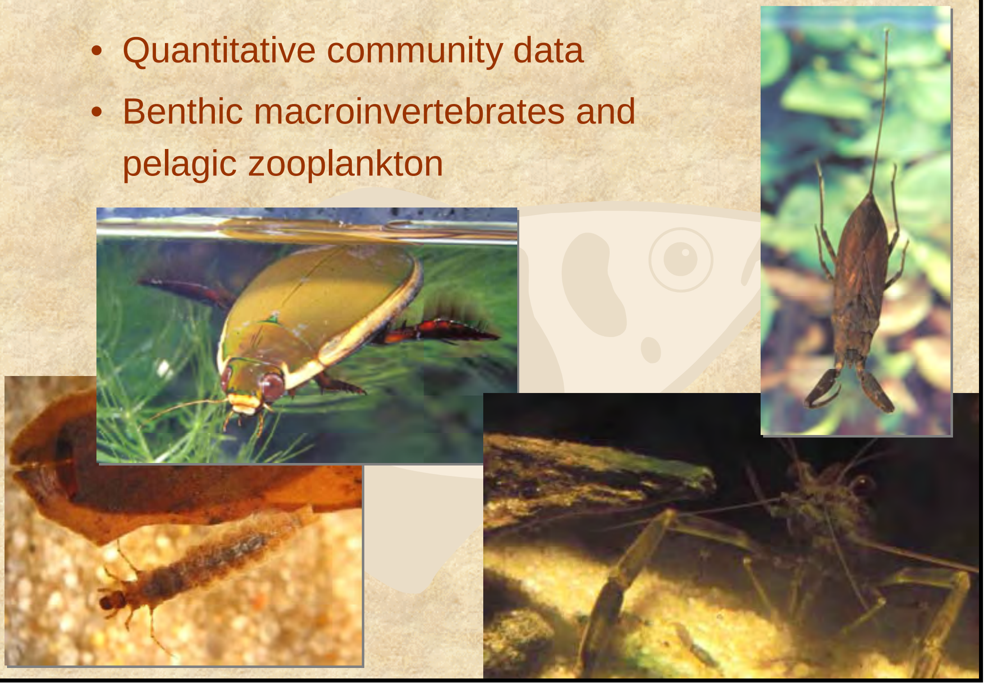
Mesocosms – (macroinvertebrates)

- Quantitative community data
- Benthic macroinvertebrates and pelagic zooplankton



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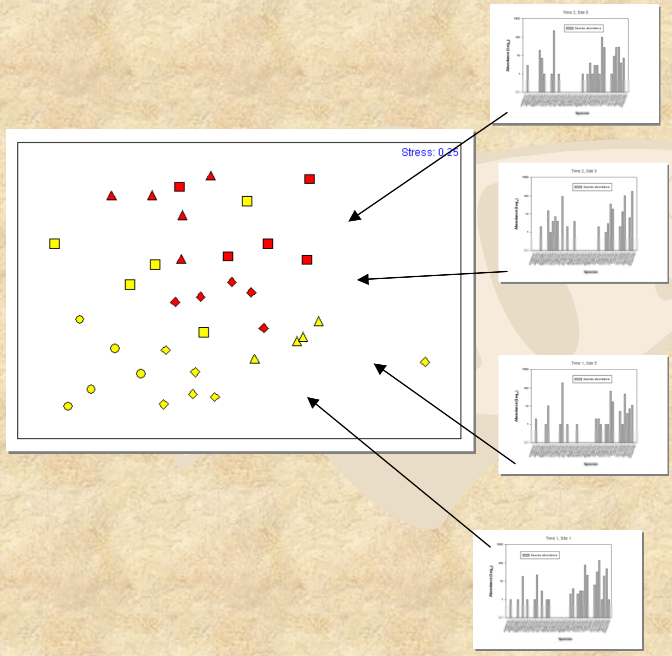
MDS – Multi-Dimensional Scaling



- Reduces extensive community data down to a single scatter plot
- Statistically testable differences

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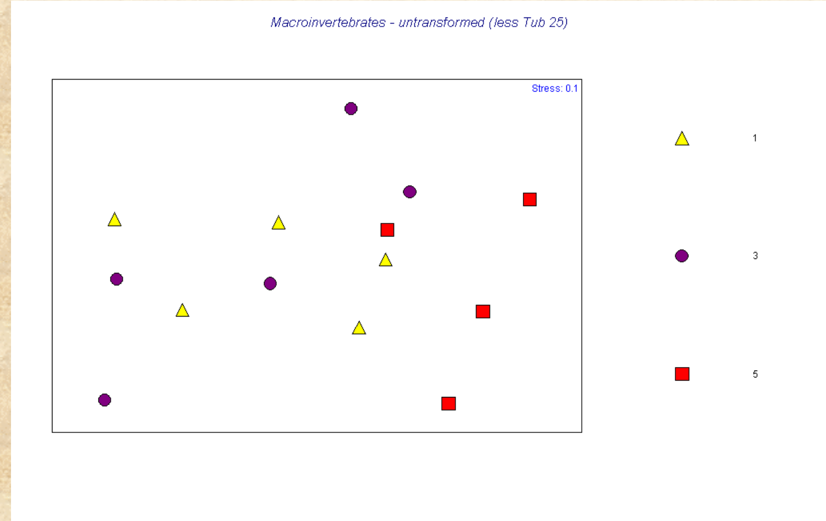
Mesocosms – (macroinvertebrates)



- Quantitative community data
- Benthic macroinvertebrates and pelagic zooplankton

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Mesocosms – (diatoms)

- Very sensitive to water quality changes
- Artificial substrates used for diatom algae
- Quantitatively and qualitatively measured (JJ periphytometers)

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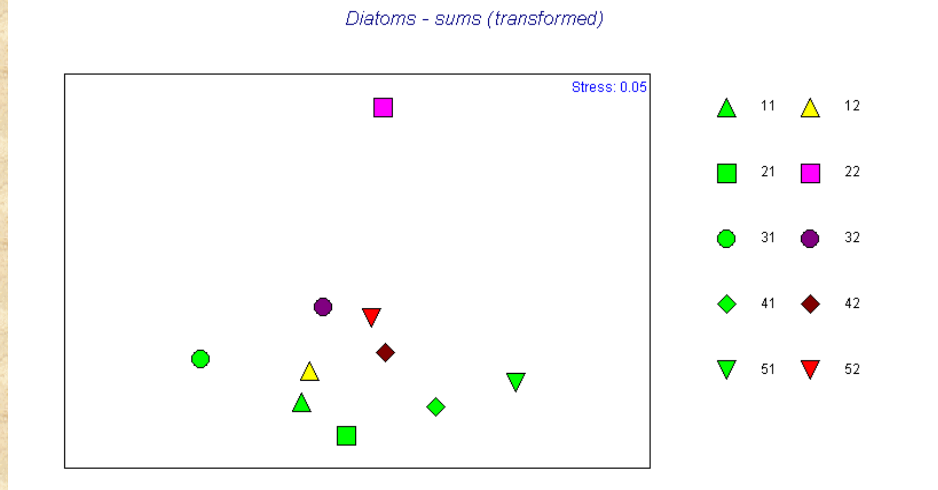
Mesocosms – (diatoms)



- Community changes over time (α = 0.3%)
- No significant difference between treatments

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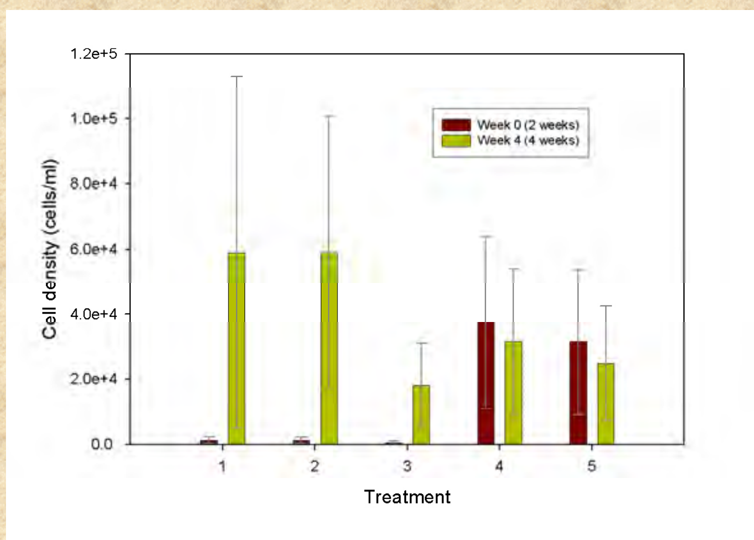
Mesocosms – (diatoms)



- Low conc's / high conc's behave differently
- Very noisy

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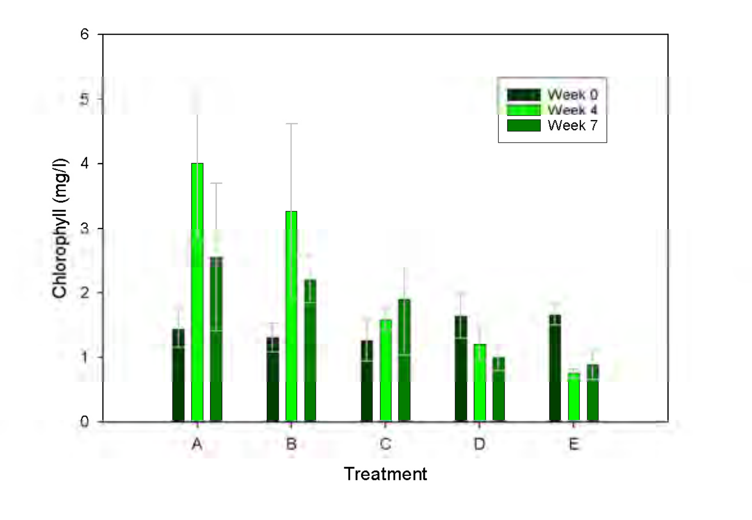
Mesocosms – (phytoplankton)



- Chlorophyll was significantly higher in the control ($p = 0.014$)
- Similar response for other pigments (C*b* & Cc)
- High intra-treatment variability

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Mesocosms – microinvertebrates

- Quantitative community data
- Pelagic zooplankton
- Large pelagic phytoplankton

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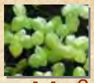
Future work…

- Inclusion of other species for lab ecotoxicity tests (*Lemna* and black-striped rainbowfish) and repeat some tests (= robust assessment and modelling).



- Learn more about the influence of Ca^{2+} on Mg^{2+} toxicity on other species.
- Compare laboratory and field results to derive a suitable Mg^{2+} standard for Magela Creek.
  - *At low concentrations, in low solute waters, $MgSO_4$ may be a stimulant e.g. freshwater snails*
  - *'High-sensitivity' of* Hydra *and* Amerianna
  - *New Guidelines place greater emphasis on multi-species test results - field NOECs and LC50s?*

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Thanks to…

- Co-authors / collaborators
- The Traditional Owners of the Ranger Mineral Lease, Gundjehmi Aboriginal Association, for permitting the field experiments
- The numerous workers and volunteers that have assisted in the project

References

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