**DISCUSSION OUTLINE**

Our research demonstrates the use of a single model to combine and estimate the relative importance of a range of environmental factors in estimating the success of early life history stages in corals. Coral fertilisation success and larval survivorship were affected by multiple water quality factors. Suspended sediment, phosphate, ammonium, copper and salinity significantly reduced fertilisation success. Larval survivorship was most affected by the presence of the heavy metals copper and lead, as well as temperature.

Coral early life history stages are vulnerable to changes in heavy metal toxicity, nutrient concentrations and ocean chemistry which can affect development and success.

* Heavy metals including copper and lead are known to have widespread negative impacts on marine invertebrates ([Reichelt-Brushett and Harrison 2004](#_ENREF_51); [Rivera-Duarte et al. 2005](#_ENREF_55); [Wang et al. 2009](#_ENREF_66); [Fitzpatrick et al. 2008](#_ENREF_22); [Caldwell et al. 2011](#_ENREF_12)).
  + Copper, which significantly affects both life history stages occurs naturally within the marine environment however, is in excess due to its use in anti-fouling agents on vessels ([Reichelt-Brushett and Harrison 2004](#_ENREF_51); [Negri and Heyward 2001](#_ENREF_43)).
  + Lead was also found to significantly reduce larval survivorship and is of concern as it can be found in high levels in nearshore reef environments as a result of industrial activities.
* The introduction of nutrients to marine environments, including phosphate and ammonium, severely diminishes water quality, leading to a reduction in the fertisliation success of corals.
  + These nutrients are common in run-off from agricultural land uses including the use of fertilisers ([Correll 1998](#_ENREF_15); [Harrison and Ward 2001](#_ENREF_31)).
* Anthropogenic impacts including those linked to climate change greatly affect the marine environment and often lead to increased suspended sediment as well as changes to ocean temperatures and salinity.
  + Suspended sediment was shown to significantly reduce fertilisation success in corals. Natural and anthropogenic disturbances ranging from storms to seafloor dredging increase the amount of suspended sediment within marine environments, especially in shallower or nearshore habitats ([Humphrey et al. 2008](#_ENREF_35); [Erftemeijer et al. 2012](#_ENREF_19); [Styan and Rosser 2012](#_ENREF_62)).
  + Water temperature and salinity both affected coral early life stages with temperature changes decreasing fertilisation and changes in salinity decreasing larval survivorship.
    - Increased water temperatures as a result of climate change threaten marine environments and therefore coral reefs ([Solomon et al. 2007](#_ENREF_60)).
    - Episodic increases in freshwater influxes, decreasing salinity as a result of increase storms and runoff from urban areas is also a significant threat to coral larval survival (Knutson et al. 2010; Scott et al., 2013).

To demonstrate our models use in a real-world scenario, we incorporated water chemistry data collected from three locations.

* These locations differed in both their climate (tropical or temperate) as well as in their proximity to urbanised areas.
* Mona Vale in Sydney resulted in the greatest success for both life stages, fertilisation and larval survivorship with ?% and ?% success respectably. Samples taken from Lizard Island were close behind in their success with Chowder Bay in Sydney the most polluted water sample having the lowest level of success for both life stages.
* While these results were not as expected and most likely the result of differing salinity levels at each location, with low levels having greater success in the case of the Mona Vale and Lizard Island examples.
* This analysis was based on a single water sample, whose goal was to be used as an example of the model created not to comment on water chemistry in any given location.
* This example does however highlight the use of the model to determine the likelihood of success using water chemistry data and how slight changes in factors and how factors work synergistically can lead to a greater or reduced success for each life stage.

To be successful, an individual needs to survive both stages of development (fertilisation and larval survivorship).

* As an example we conducted a joint probability analysis for each of the three locations Chowder Bay and Mona Vale in Sydney as well as Lizard Island, to determine the likelihood of a single egg at any location surviving through fertilisation, as well as up to 14 days within the plankton.
* While larvae can survive for longer than this within the surface waters, this model was created to include larvae within their peak competency period who are most likely to settle within their natal reef ([Richmond 1997](#_ENREF_54); [Connolly and Baird 2010](#_ENREF_13)).
* This model shows that at each location the probability of a single egg surviving through both stages of development was lower, compared to the probability of each life stage individually.
* While this analysis is just an example (based on a single sample) it shows the importance of the model created, as it can incorporate more than a single factor and can be based on actual water quality data at different sites, to determine the effect of environmental changes on larval development.

Our study is significant because it estimates the relative importance of various environmental factors on the early life history stages of corals. However, there were several issues that might have influenced the predictive capacity of the models.

* While the models likely isolated the important environmental factors reducing fertilisation and larvae success, they were based on only 20 experimental studies.
* The low number of studies forced us to group data for all species. Because studies mainly focused on one species at a time, we accounted for variation among species by including study as a random factor. However, species would be expected to respond differently to one another under more rigorous experimentation.
* We were unable to check for interactions among factors, because studies tended to focus on one variable at a time.
* This limitation also forced us to select background levels of non-focal variables, which could be particularly problematic for factors with non-zero quadratic response curves.
* Finally, in order to demonstrate the applications of our models we utilised water chemistry data collected from a single sample at each location, which does not reflect the daily fluctuations of some variables including salinity.
* Despite these limitations, we believe our analysis to be a good first step for improving our understanding of early life history responses to environmental variables. The study highlights the importance of specific factors that reduce the success of coral development. While a number of previous studies have identified factors none have been able to determine which of these factors would be most effective for mitigating negative effects on corals as well as allow real-world data to be analysed for success.

While this analysis is small in scale it does highlight the practical applications of generalised linear models. Within the changing global environment the ability to predict success and particularly in the early life history stages of sensitive, sessile adult species, is imperative for their survival and proliferation in novel environments.

* Future studies should focus on later life history stages (e.g., settlement and metamorphosis).
* Once this is done, our approach can be used to identify bottlenecks to population persistent and also to develop guidelines for threshold levels of pollution in coral reef environments.
* Such models can also be used to determine dispersal and recruitment success under given water quality data scenarios and identify sensitive locations for protection.
* Finally, with use of the combined model developed within this analysis, we can better understand and predict the success of coral species in novel environments, such as might occur following observations and predictions of poleward range shifts associated with increasing sea surface temperatures ([Yamano et al. 2011](#_ENREF_68)).
* The application of this research to identify more optimal and novel environmental locations for the survival of corals, will enable the persistence of these very important organisms into the future, along with coral reef ecosystems and the high diversity of organisms that inhabit them.