**DISCUSSION**

Our research demonstrates 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. Consistent with earlier studies ([Negri and Heyward 2001](#_ENREF_43)), the heavy metal copper had significant negative impacts on fertilisation and larval survivorship. Copper, which significantly affects both life history stages, occurs naturally at low levels within the marine environment. However, the levels at which copper significantly impacts coral development are not widespread, but are instead limited to localised pollution caused by anti-fouling agents on vessels ([Reichelt-Brushett and Harrison 2004](#_ENREF_51); [Negri and Heyward 2001](#_ENREF_43)). Lead, which was also found to significantly reduce larval survivorship, can be found at high levels more broadly in nearshore reef environments, as a result of industrial activities ([Li et al. 2001](#_ENREF_40); [Polkowska et al. 2001](#_ENREF_47)). The introduction of nutrients into marine environments, including phosphate and ammonium, severely diminishes water quality, which we show, will lead to a reduction in 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)). 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)). While suspended sediment significantly reduces fertilisation success in corals, it did not appear to have a major influence on larval survivorship (Figure 1). Anthropogenic impacts, including those linked to climate change, greatly affect the marine environment and often lead to changes in ocean temperatures, pH and salinity. Water temperature and salinity both affected coral early life history 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). While both temperature and salinity reduced coral larval success, changes in seawater pH had little influence on either fertilisation or survivorship (Chua et al. 2013).

To be successful, an individual must survive both developmental stages (fertilisation and larval survivorship). As an illustration, we collected water samples from three locations that were expected to differ dramatically in water properties. As expected the properties from the Lizard Island water sample, resulted in the greatest estimated success for both fertilisation success and larval survivorship, with 70% and 60% success, respectively. The beach water sample from Sydney (Mona Vale) as had a high level of success especially when compared to the Sydney Harbour sample (Chowder Bay), where water was expected to be most polluted and indeed it was, with the lowest estimated level of success for both early life stages. The joint probability of succeeding through both stages showed the same pattern (Figure 5). These probabilities are reflective of a single egg at any location surviving through fertilisation and up to 14 days within the plankton as a larvae. While larvae can survive for longer than this within the surface waters, this model was parameterised with larvae survivorship observations within their peak competency period ([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 one-off water samples), it demonstrates how to integrate multiple water quality factors for early life history stages, and then combining success at each stage to give an overall estimate of developmental success. In doing so, the modelling framework can make predictions of success based on actual water quality data from different locations, 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 for understanding and predicting success in different environments. The ability to predict success, and particularly in the early life history stages of sensitive, sessile adult species, is imperative for understanding the effect of environmental change on species distributions. 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.