Palaeontological evidence shows long-term declines in Red Sea coral colony size

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Abstract

# Keywords

Conservation palaeobiology, ecosystem baselines, coral reef, Last Interglacial, MIS5e, scleractinia

# Introduction

Tropical coral reef ecosystems support the greatest biodiversity of marine organisms on Earth, and are frequently referred to as the rainforests of the sea [REFs]. Reef-building corals are essential for maintaining this biodiversity by contributing to the physical structure and stability of coral reef ecosystems [REFs]. Specifically, the variety of sizes and growth forms (e.g. branching, plating, massive) displayed by reef-building corals promotes the development of complex three-dimensional habitats within the reef that provides shelter [REF], food [REF], and breeding sites [REF] for a diverse array of reef-associated organisms. This structural complexity supports biodiversity by generating a variety of niches for organisms of various sizes, behaviors, and ecological requirements [REF].

Unfortunately, recent work has shown prominent declines in the absolute abundance of large colonies and coral growth rates [REFs], as well as potential evidence of increasing community homogenisation [REFs]. These changes have prominent consequences for the colony size structure of coral populations, with large impacts on the structural complexity of coral reef ecosystems and the vast array of habitats they provide. Current rising sea surface temperatures and associated coral bleaching are expected to further exacerbate these trends, resulting in a near-complete loss of structural complexity on reefs as reef-building coral communities are replaced by algal-dominated communities (Roth et al., 2021). However, ecological studies are generally limited to analyses at the scale of decades, which may not be indicative of the long-term ecological trends [REFs]. Consequently, such studies might not be capturing the full extent of shifts in colony size structure of coral populations. Furthermore, studies based on neontological data do not necessarily provide a fair baseline for coral colony size structure as many anthropogenic impacts have been active since ecological monitoring began. The fossil record provides the only empirical evidence of coral colony size structure prior to the influence of anthropogenic impacts at both local (e.g. pollution, destructive fishing practices) and global scales (e.g. global warming), offering the opportunity to assess baselines of coral colony size structure.

The Red Sea provides a unique natural laboratory to observe long-term changes in coral colony size structure. Extensive Last Interglacial (125,000 years ago) coral terraces are preserved alongside present-day fringing reefs of the Red Sea. These fossil reefs are almost indistinguishable from their modern counterparts in terms of taxonomic composition and their excellent preservation allows the application of methods comparable to ecological surveys (e.g. Line-Intercept Transects) [REFs]. Furthermore, the long-term aridity of the region has fostered the preservation of skeletal features key to taxonomic identification and supports accessibility through low vegetation cover.

Here, we evaluate long-term changes in the colony size structure of coral populations along the Egyptian coastline of the Red Sea. To do so, we make quantitative and statistical comparisons between colony size structure estimates from surveys conducted between XXX–XXX with palaeontological baselines from the Last Interglacial (125,000 years ago). We examine changes in colony size structure between taxa and within two reef zones–the reef edge (0–3 m) and shallow reef slope (3–6 m).

# Materials and methods

## Survey locations and protocol

Modern (survey years: 1988, 1989, 1997) and Last Interglacial (~125,000 years ago) coral communities and their colony size structure were assessed along the Egyptian coastline of the Red Sea between XXX and XXX, with a total of XXX modern and XXX Last Interglacial survey localities [Figure 1](#fig-map). To do so, we carried out XXX m-long line-intercept transects [REFs] with XXX replications in the reef edge (0–3 m) and the shallow reef slope (3–6 m). While we would have preferred to expand the depth of our study, eustatic sea level during the Last Interglacial was less than 10 m above current levels [REFs], resulting in only the shallowest reef zones being preserved and readily accessible for study. The length of the intercept of each physically discrete colony was measured to the nearest cm using the transect tape. Due to the challenging nature of identifying coral colonies to species level based on fossil material, we identified all colonies to genus level and used this taxonomic rank for our subsequent analyses. Therefore, the size distributions presented here represent the size distribution within the genus taxonomic level, but they may not accurately reflect the distributions of individual species within that genus. Nevertheless, our study does not diverge from previous work, including many neontological studies which conduct analyses at the genus taxonomic level [REFs], or even using morpho-functional groups [REFs]. All transects were recorded and evaluated by the same author (AI), eliminating observer-specific identification or measurement variability. A total of XXX intercepts were recorded (XXX modern and XXX Last Interglacial) across all survey locations, with XXX genera identified.

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| Figure 1: Map of survey locations in the Red Sea. The map shows the locations of the studied modern (XXX circles) and Last Interglacial (XXX circles) coral reefs along the Egyptian Red Sea coastline. |

## Statistical analyses

To assess shifts in colony size structure, we followed previous studies and used colony intercept lengths as a proxy for colony size [REFs]. We examined changes in colony size between the Last Interglacial and the Modern within individual taxa (i.e. pooled between all sites and reef zones), and between the reef edge and shallow reef slope (i.e. pooled between sites, but not reef zones). For our analyses, we focused on the most common taxa present during the Last Interglacial and in the Modern, and retained all taxa with more than 20 intercepts in each dataset. Subsequently, we filtered both datasets to include only taxa present in both intervals. This ensured that a reasonable estimate of colony size distributions could be generated for statistical comparisons. Previous work has demonstrated that frequency distributions of colony sizes typically follow a log-normal distribution [REFs]. We ran Shapiro–Wilk tests on log-transformed intercept lengths to test for log-normality in our data. To summarise shifts in coral colony size-frequency distributions for each taxa we used the first four moments of distributions: central tendency (i.e. the mean, ), dispersion (i.e. the variance, 2), skewness (i.e. the asymmetry, ), and kurtosis (i.e. the tailedness, ). To formally test whether Last Interglacial and Modern coral colony size-frequency distributions differ, we used non-parametric two-sample Kolmogorov-Smirnov tests to compare the cumulative distribution functions (CDFs) of the Last Interglacial and Modern coral colony sizes. In addition, using non-parametric one-sided Mann-Whitney *U* tests, we evaluate whether Modern coral colony sizes for each taxa are significantly smaller than those of the Last Interglacial. Finally, using non-parametric one-sided Mann-Whitney *U* tests, we test whether pooled coral colony sizes within reef zones (i.e. reef edge and shallow reef slope) are significantly smaller in the Modern than they were in the Last Interglacial. A significance level of = 0.05 was used for all hypothesis tests in this study.

# Results

## Shifts in taxonomic size-frequency distributions

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| Figure 2: Shifts in colony size structure of common coral taxa along the Egyptian coastline of the Red Sea. XXX density curves depict the coral size structure of common coral taxa during the Last Interglacial (125,000 years ago). XXX density curves depict the coral size structure of common coral taxa during the Present (survey years: 1988, 1989, 1997). The XXX point and segment line depict the mean colony size for each taxa during the Last Interglacial, while the XXX point and segment line depict the mean colony size for each taxa during the Present. |

## Shifts in reef zone size-frequency distributions

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| Figure 3: Shifts in colony size structure within the reef edge and reef slope of common coral taxa along the Egyptian coastline of the Red Sea. The first column depicts data from the reef edge (0–3 m), and the second the shallow reef slope (3–6 m). XXX density curves depict the coral size structure of common coral taxa during the Last Interglacial (125,000 years ago). XXX density curves depict the coral size structure of common coral taxa during the Present (survey years: 1988, 1989, 1997). The XXX point and segment line depict the mean colony size for each taxa during the Last Interglacial, while the XXX point and segment line depict the mean colony size for each taxa during the Present. |

# Discussion

* Summary of results
* Support for other studies
* Baselines
* Caveats
  + Proxy for colony size
  + taphonomy/fossil bias

# Conclusion

# Acknowledgements

# Conflict of Interest

We declare we have no conflict of interest.

# Authors’ contributions

# Data accessibility

# Code accessibility

# References

Roth, F. et al., 2021, High summer temperatures amplify functional differences between coral- and algae-dominated reef communities: Ecology, v. 102, p. e03226, doi:<https://doi.org/10.1002/ecy.3226>.