

Supplementary Material for Allometric growth in reef-building corals

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Robustness of results to uncertainty in morphotype classification

There is a degree of subjectivity in the classification of species into morphological groups. Within our study species in particular, *Acropora intermedia* and *A. robusta* are general referred to as arborescent, but their morphology is distinct because *A. robusta* often has an encrusting base that we refer to as encrusting arborescent. Additionally, the morphology of colonies of *A. spathulata* is often intermediate between corymbose and digitate. To ensure this uncertainty did not affect our ability to predict change in size as a function of morphological group, we constructed alternative classifications reflecting these potential assignments (Table S1). We used model selection to choose the classification that best explains change in planar area, and ensured all subsequent results are robust to this issue by repeating the analysis with all alternative classifications.

Table S1 - Alternative morphological group classifications. AC corresponds to *Acropora cytherea*, AD to *A. cf digitifera*, AH to *A. hyacinthus*, AI to *A. intermedia*, AL to *A. spathulata*, AM to *A. millepora*, AN to *A. nasuta*, AR *A. robusta*, AS to *A. humilis*, GP to *Goniastrea pectinata* and GR to *G. retiformis*. TAB corresponds to the tabular morphological group, DIG to digitate, ARB to branching, COR to corymbose, encARB to encrusting arborescent and MAS to massive.

	AC	AD	AH	AI	AL	AM	AN	AR	AS	GP	GR
group1	TAB	DIG	TAB	ARB	DIG	COR	COR	encARC	DIG	MAS	MAS
group2	TAB	DIG	TAB	ARB	COR	COR	COR	encARB	DIG	MAS	MAS
group3	TAB	DIG	TAB	ARB	DIG	COR	COR	ARB	DIG	MAS	MAS
group4	TAB	DIG	TAB	ARB	COR	COR	COR	ARB	DIG	MAS	MAS

Model selection indicates that the best morphological classification includes

A. spathulata as digitate, and separates *A. robusta* from *A. intermedia* (Table

S2). This morphological group classification is used in all subsequent analysis presented, but we verified that the best model was consistently the same for the different morphological group classifications.

Table S2 - Model selection of OLS models with alternative morphological group classifications

model	df	AICc	adjusted R ²
$\log(\text{area}_{t+1}) \sim \log(\text{area}_t) + \text{group1}$	7	1948.623	0.7828
$\log(\text{area}_{t+1}) \sim \log(\text{area}_t) + \text{group2}$	7	1951.512	0.7824
$\log(\text{area}_{t+1}) \sim \log(\text{area}_t) + \text{group3}$	8	1946.720	0.7835
$\log(\text{area}_{t+1}) \sim \log(\text{area}_t) + \text{group4}$	8	1949.676	0.7831
$\log(\text{area}_{t+1}) \sim \log(\text{area}_t) * \text{group1}$	11	1955.206	0.7828
$\log(\text{area}_{t+1}) \sim \log(\text{area}_t) * \text{group2}$	11	1957.812	0.7824
$\log(\text{area}_{t+1}) \sim \log(\text{area}_t) * \text{group3}$	13	1955.384	0.7832
$\log(\text{area}_{t+1}) \sim \log(\text{area}_t) * \text{group4}$	13	1958.000	0.7828

The ability to predict growth rates from morphological groups is highly encouraging for the possibility of building trait-based demographic models for corals. Yet, inferring growth rates from morphology requires robust morphological group classifications. Our morphological group analysis illustrates that there are currently uncertainties in the classification of coral species. There are substantial discrepancies in morphological group classifications. For example, [1] uses very different morphological groups to classify the *Acropora* than does [2], and two of our 11 species could be classified in more than one morphological group. Additionally, corals are known to have substantial phenotypic plasticity, with colonies taking on different morphologies in response to different environmental conditions [3, 4]. Moreover, substantial variation in growth rate can also be observed within some morphological groups [5], whereas some morphological groups do not appear to differ in their growth rates. For example, digitate and massive colonies had very similar growth rates, as did corymbose and arborescent colonies (Fig. 2 in the main

text). Clearly there is scope for refining our empirical understanding of drivers of growth in corals in order to build a general mechanistic understanding of this important process.

Robustness of results to using colony as a random effect

We tested the robustness of our results to the use of morphological group as a random effect (vs. a fixed effect, as in our main analysis), and we also tested the robustness of our results to the use of colony ID as a random effect. For the first analysis, we fit a series of models using morphological group, species, and colony ID as potential (nested) random effects, Zuur et al. [6]. The best random effects structure includes only morphological group.

We also repeated the model selection procedure using the same fixed effects structures as in the main text, but with colony ID as a random effect. Our sampling design intended for both species and morphological groups to be fixed effects, because we are also interested in the interaction between temporal variation and these two variables, hence we include morphological group as a fixed effect in the main analysis. Repeating model selection with a series of models that include colony as a random effect selects the same model: common slope and intercept determined by the functional group and year interaction (Supplementary Table 3). Finally, comparing AICc of the best model with (1806.638) and without (1804.523) colony as a random factor reveals the latter is a better model.

Table S3 – Model selection for the effect of time, species and morphological group including colony as a random effect.

Model	AICc
$\log(\text{area}_{t+1}) \sim \text{offset}(\log(\text{area}_t))$	1880.676
$\log(\text{area}_{t+1}) \sim \text{offset}(\log(\text{area}_t)) + \text{group}$	1875.332
$\log(\text{area}_{t+1}) \sim \text{offset}(\log(\text{area}_t)) + \text{year}$	1843.946
$\log(\text{area}_{t+1}) \sim \text{offset}(\log(\text{area}_t)) + \text{species}$	1882.050
$\log(\text{area}_{t+1}) \sim \log(\text{area}_t)$	1865.673
$\log(\text{area}_{t+1}) \sim \log(\text{area}_t) + \text{group}$	1857.289
$\log(\text{area}_{t+1}) \sim \log(\text{area}_t) + \log(\text{area}_t):\text{group}$	1859.106
$\log(\text{area}_{t+1}) \sim \log(\text{area}_t) * \text{group}$	1864.352
$\log(\text{area}_{t+1}) \sim \log(\text{area}_t) + \text{species}$	1863.412
$\log(\text{area}_{t+1}) \sim \log(\text{area}_t) + \log(\text{area}_t):\text{species}$	1864.404
$\log(\text{area}_{t+1}) \sim \log(\text{area}_t)*\text{species}$	1868.801
$\log(\text{area}_{t+1}) \sim \log(\text{area}_t) + \text{year}$	1828.718
$\log(\text{area}_{t+1}) \sim \log(\text{area}_t) + \log(\text{area}_t):\text{year}$	1821.073
$\log(\text{area}_{t+1}) \sim \log(\text{area}_t)*\text{year}$	1822.299
$\log(\text{area}_{t+1}) \sim \log(\text{area}_t) + \text{year} + \text{group}$	1818.548
$\log(\text{area}_{t+1}) \sim \log(\text{area}_t) + \text{year} * \text{group}$	1806.638
$\log(\text{area}_{t+1}) \sim \log(\text{area}_t) * \text{group} * \text{year}$	1813.397
$\log(\text{area}_{t+1}) \sim \log(\text{area}_t) + \text{year} + \text{species}$	1824.325
$\log(\text{area}_{t+1}) \sim \log(\text{area}_t) + \text{year} * \text{species}$	1823.664
$\log(\text{area}_{t+1}) \sim \log(\text{area}_t) * \text{species} * \text{year}$	1838.829

References

- [1] Wallace, C.C. 1999 *Staghorn corals of the world*. Collingswood, CSIRO.
- [2] Veron, J.E.N. 2000 *Corals of the World*. Townsville, Australian Institute of Marine Science; 1382 p.
- [3] Bruno, J.F. & Edmunds, P.J. 1997 Clonal variation for phenotypic plasticity in the coral *Madracis mirabilis*. *Ecology* **78**, 2177-2190.
- [4] Willis, B. 1985 Phenotypic plasticity versus phenotypic stability in the reef corals *Turbinaria mesenterina* and *Pavona cactus*. In *Proc 5th int coral Reef Symp* (pp. 107-112).
- [5] Hughes, T.P. & Jackson, J.B.C. 1985 Population Dynamics and Life Histories of Foliaceous Corals. *Ecological Monographs* **55**, 142-166. (doi:10.2307/1942555).
- [6] Zuur, A., Ieno, E., Walker, N., Saveliev, A.A. & Smith, G.M. 2009 *Mixed effects models and extensions in ecology with R*, Springer Verlag; 574 p.