

1           **An enhanced target-enrichment bait set for Hexacorallia provides phylogenomic**  
2                           **resolution of the staghorn corals (Acroporidae) and close relatives.**

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29           **Keywords:** Scleractinia, targeted enrichment, ultraconserved elements, UCEs, exon,  
30           phylogenetics.

34 **Abstract:** The phylogenetic utility of targeted enrichment methods has been demonstrated in  
35 taxa that often have a history of single gene marker development. These genomic capture  
36 methods are now being applied to resolve evolutionary relationships from deep to shallow  
37 timescales in clades that were previously deficient in molecular marker development and  
38 lacking robust morphological characters that reflect evolutionary relationships. Effectively  
39 capturing 1000s of loci, however, in a diverse group across a broad time scale requires a bait  
40 set that incorporates multiple baits per locus. We redesigned a custom bait set for the  
41 cnidarian class Anthozoa to target 1,436 UCE loci and 1,572 exon regions within the subclass  
42 Hexacorallia. We test this redesigned bait set on 99 specimens of hard corals (Scleractinia)  
43 spanning both the “complex” (Acroporidae, Agariciidae) and “robust” (Fungiidae) clades.  
44 With focused sampling in the staghorn coral genus *Acropora* we explore the ability of capture  
45 data to inform the taxonomy of a clade deficient in molecular resolution. A mean of 1850 ( $\pm$   
46 298) loci were captured per taxon (955 UCEs, 894 exons). A 75% complete concatenated  
47 alignment included 1792 loci (991 UCE, 801 exons) and ~1.87 million base pairs. Parsimony  
48 informative sites varied from 48% for alignments including all three families, to 1.5% among  
49 samples within a single *Acropora* species. Maximum likelihood and Bayesian analyses  
50 recover highly resolved topologies and robust molecular relationships not previously found  
51 with traditional markers within the Acroporidae. Species level relationships within the  
52 *Acropora* genus do not support traditional morphological groups or morphological  
53 phylogenies. Both UCE and exon datasets delineated six well-supported clades within  
54 *Acropora*. The enhanced bait set for Hexacorallia will allow researchers to survey the  
55 evolutionary history of important groups of reef building corals where previous molecular  
56 marker development has been unsuccessful.

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## 59 **1. Introduction**

60 Molecular systematics has progressed at an uneven pace across the tree of life. Several plant  
61 and animal branches on the tree of life have benefited the most from the development of  
62 single gene mitochondrial and nuclear markers resulting in large scale phylogenies (Jetz et  
63 al., 2012; Rabosky et al., 2018; Tonini et al., 2016; Upham et al., 2019) leveraging decades  
64 worth of molecular data from public resources (<https://www.ncbi.nlm.nih.gov/>). These large-  
65 scale phylogenies have provided a deep time perspective, systematic resolution, and often  
66 very complete biodiversity inventories of taxa. While few if any higher-level taxa can be  
67 considered complete from a species level molecular perspective, the enhanced taxonomic  
68 framework provided by these ‘Tree of Life’ projects has allowed researchers to complete  
69 shallow clades with species inventories using taxonomy-based grafting and polytomy  
70 resolution methods (Rabosky et al., 2018; Thomas et al., 2013) to incorporate species not yet  
71 sampled by genetic methods. These new methods have enabled testing of broad evolutionary  
72 and ecological hypotheses across broad taxonomic groups (Jetz et al., 2012; Pyron et al.,  
73 2013; Rabosky et al., 2018). While these approaches come with their own hurdles (Rabosky,  
74 2015), new phylogenomic tools are facilitating a shift from the ‘top-down’ approach of  
75 sampling higher taxonomic ranks to a ‘bottom-up’ approach attempting to sample complete  
76 clades of species and even populations on shallow evolutionary time scales, leveraging high  
77 throughput sequencing technologies (Derkarabetian et al., 2018; Manthey et al., 2016; Smith  
78 et al., 2014).

79 Two popular phylogenomic methodologies are (i) Restriction site-associated DNA  
80 sequencing (e.g. RADseq), and (ii) Targeted sequence capture of conserved loci (Faircloth et  
81 al., 2012; Lemmon et al., 2012). Both methodologies use high-throughput sequencing,  
82 genome reduction and sample multiplexing to generate genomic datasets for hundreds of  
83 samples in substantially less time than traditional Sanger sequencing approaches (Branstetter

84 et al., 2017). While targeted capture and RADseq data produce similar topologies (Collins  
85 and Hrbek, 2018), targeted capture of ultraconserved elements (UCEs) or exons has grown in  
86 popularity due to their comparability across taxa, tolerance of lower quality DNA templates  
87 and ability to resolve relationships at deep and shallow time scales (Faircloth et al., 2012;  
88 Harvey et al., 2016).

89 Targeted capture techniques were recently used for phylogenomic reconstruction  
90 across the anthozoan tree of life (Quattrini et al., 2018), with available anthozoan genomes  
91 and transcriptomes used to design a bait set to capture both UCEs and conserved exons. An  
92 average of  $638 \pm 222$  UCE/exon loci were captured per sample, but capture rates differed  
93 greatly between Hexacorallia and Octocorallia, two major subclasses of Anthozoa, with  
94 higher recovery from the Octocorallia (soft corals, sea fans) compared with the Hexacorallia  
95 (stony corals, black corals, anemones, zoanthids). This difference in target efficiency is likely  
96 the result of the addition of octocoral-specific baits and the removal of paralogous (mostly  
97 hexacoral-specific) baits in the bait design process (Quattrini et al., 2018). In this case,  
98 separate octocoral and hexacoral-specific bait sets will increase capture efficiency and thus  
99 phylogenetic resolution across evolutionary time scales.

100 Within the Hexacorallia, the order Scleractinia (stony corals) has historically received  
101 significant research interest due to their role as the key ecosystem engineers on coral reefs,  
102 which host an estimated 830,000 multicellular species (Fisher et al., 2015). Hermatypic (reef-  
103 building) Scleractinia are generally colonial and represent approximately half of all  
104 scleractinian species. The capacity of stony corals to build reefs is attributed to their  
105 photosymbiotic relationship with dinoflagellates of the family Symbiodiniaceae, which  
106 mainly restricts both hermatypic corals and coral reefs to shallow tropical and sub-tropical  
107 regions (Kleypas et al., 1999). In recent years, molecular phylogenetics has fundamentally  
108 altered our understanding of the systematics and evolution of the Scleractinia, revealing that

109 most morphological characters traditionally used to identify families, genera and species do  
110 not reflect their evolutionary history (Fukami et al., 2008, 2004; Romano and Palumbi, 1996).  
111 This has led to taxonomic revisions of the Scleractinia at every taxonomic level (Kitahara et  
112 al., 2016).

113         Within Scleractinia, the family Acroporidae is the most speciose family, accounting  
114 for approximately one-third of all reef-building coral species (Madin et al., 2016). Despite  
115 their ecological importance and use as a model system to understand coral biology and  
116 symbioses, there is, as yet, no well-resolved species-level molecular phylogeny for the family  
117 Acroporidae. Like plants, corals and other Anthozoans have mitochondrial substitution rates  
118 that are slower than rates of substitution across the nuclear genome (Fukami et al., 2000;  
119 Hellberg, 2006; Shearer et al., 2002; Van Oppen et al., 1999) limiting the utility of  
120 mitochondrial markers in DNA barcoding, phylogeography and shallow species-level  
121 phylogenetics in corals (Chen et al., 2009; Hellberg, 2006; Huang et al., 2008; McFadden et  
122 al., 2011). In particular, the diverse and ecologically dominant genus *Acropora* (staghorn  
123 corals) is notorious for its lack of systematic resolution with traditional mitochondrial and  
124 nuclear marker development (Chen et al., 2009). The relatively recent species level  
125 divergence and population level expansion in *Acropora* (Bellwood et al., 2017; Renema et  
126 al., 2016), means traditional mitochondrial markers offer little information to define species  
127 boundaries and robust systematic relationships. The lack of reliable molecular markers for the  
128 genus also means that the rampant synonymization of nominal species is based entirely on  
129 qualitative morphological characters (Veron and Wallace, 1984; Wallace, 1999; Wallace et  
130 al., 2012), despite their proven unreliability in determining evolutionary relationships across  
131 numerous taxonomic levels. As a result, while the genus *Acropora* contains 413 nominal  
132 species (Hoeksema and Cairns, 2019), the most recent taxonomic revision of the genus, based  
133 on morphology, recognises only 122 species (Wallace et al., 2012). Targeted sequence

134 capture offers a new molecular tool for disentangling the relationships in hexacorals, from  
135 deep relationship among families and genera to shallow level species relationships. The  
136 family Acroporidae offers an extreme test case for the utility of a universal Hexacoral bait set  
137 for targeted sequence capture.

138         The aim of this study is to redesign the previously developed anthozoan UCE/exon  
139 bait set (Quattrini et al., 2018) in order to capture additional loci and enhance the capture  
140 efficiency of loci within the subclass Hexacorallia. We highlight a method for redesigning a  
141 class-level custom bait set to increase the number of captured loci within shallower clades.  
142 We use these methods to provide an enhanced RNA bait set for the anthozoan subclass  
143 Hexacorallia that targets both ultraconserved loci and exonic regions for phylogenomic  
144 reconstruction. To test the efficiency of this bait set we focus on the phylogenetically  
145 unresolved staghorn coral family Acroporidae. We include specimens from several defined  
146 morphological groups (Wallace, 1999) sampled across the Indo-Pacific with taxonomic  
147 identity determined by morphological comparisons with type materials and the original  
148 descriptions of all nominal species. We highlight the utility of targeted capture approaches for  
149 taxa that have not benefited from decades of single gene marker development. Our results  
150 demonstrate the utility of targeted capture approaches in unravelling relationships in what  
151 have been phylogenetically challenging taxa.

152

## 153 **2. Materials and Methods**

### 154 *2.1. Bait Design*

155         We re-designed a bait set, originally aimed for target-capturing UCE and exon loci in  
156 anthozoans (anthozoa-v1, Quattrini et al., 2018), to have higher specificity for and target  
157 additional loci in hexacorals. Results generated from target-capture of UCE and exon loci in  
158 235 anthozoans (Quattrini and McFadden, unpubl. data) with the anthozoa-v1 bait set were

159 screened to remove baits that performed poorly in hexacorals or in anthozoans more  
160 generally. Thus, 5844 baits targeting 1,123 loci (553 UCE and 570 exon loci) were retained  
161 from the anthozoa-v1 bait set. Using the program Phyluce (Faircloth, 2016) and following  
162 methods in Quattrini et al. (2018), we added additional hexacoral-specific baits to 1) improve  
163 target-capture performance of the anthozoa-v1 loci and 2) target additional hexacoral loci not  
164 included in the anthozoa-v1 bait set. Methods are briefly outlined below, however, for more  
165 details see both Quattrini et al. (2018) and the Phyluce documentation  
166 (<https://phyluce.readthedocs.io/en/latest/tutorial-four.html>).

167 To redesign baits targeting UCE loci, we first mapped 100 bp simulated-reads from  
168 the genomes of four exemplar taxa, *Acropora tenuis*, *Montastraea cavernosa*, *Amplexidiscus*  
169 *fenestrafer* and *Discosoma sp.*, to a masked *Nematostella vectensis* (*nemve*) genome (Suppl  
170 Table S1). Reads were mapped, with 0.05 substitution rate, using stampy v. 1 (Lunter and  
171 Goodson, 2011), resulting in 0.8 to 1.0% of reads aligning to the *nemve* genome. Any  
172 alignments that included masked regions (>25%) or ambiguous bases (N or X) or were too  
173 short (<80 bp) were removed using *phyluce\_probe\_strip\_masked\_loci\_from\_set*. An SQLite  
174 table that included regions of conserved sequences shared between *nemve* and each of the  
175 exemplar taxa was created using *phyluce\_probe\_get\_multi\_merge\_table*. This table was  
176 queried using *phyluce\_probe\_query\_multi\_merge\_table* to output a file containing conserved  
177 loci found in *nemve* and all other exemplar taxa.  
178 *Phyluce\_probe\_get\_genome\_sequences\_from\_bed* was used to extract these conserved  
179 regions from the *nemve* genome. Regions were then buffered to 160 bp by including an equal  
180 amount of 5' and 3' flanking sequence from the *nemve* genome. A temporary set of target  
181 capture baits was then designed using *phyluce\_probe\_get\_tiled\_probes*; two 120 bp baits  
182 were tiled over each locus and overlapped in the middle by 40 bp (3X density). This  
183 temporary set of baits was screened to remove baits with >25% masked bases or high (>70%)

184 or low (<30%) GC content. At this stage, we concatenated the temporary baits with the baits  
185 retained from the anthozoa-v1 bait set and then removed any potential duplicates using--  
186 *phyluce\_probe\_easy\_lastz* and  
187 *phyluce\_probe\_remove\_duplicate\_hits\_from\_probes\_using\_lastz*. Bait sequences were  
188 considered duplicates if they were  $\geq 50\%$  identical over  $\geq 50\%$  of their length.

189 This new temporary bait set was aligned (with an identity value of 70% and a  
190 minimum coverage of 83%) to the genomes of *A. digitifera*, *Exaiptasia pallida*, *Discosoma*  
191 sp., *M. cavernosa*, and *N. vectensis* (Suppl. Table S1), and UCE loci of *Cerianthus*  
192 *membranaceus*, *Zoanthus* cf. *pulchellus*, and *Myriopathes ulex* (Quattrini et al., 2018) using  
193 *phyluce\_probe\_run\_multiple\_lastzs\_sqlite*. From these alignments, baits that matched  
194 multiple loci were removed. We then extracted 180 bp of the sequences from the alignment  
195 files and input the data into FASTA files using  
196 *phyluce\_probe\_slice\_sequence\_from\_genomes*. A list containing loci found in at least five of  
197 the taxa was created. The anthozoan UCE bait set was re-designed to target these loci using  
198 *phyluce\_probe\_get\_tiled\_probe\_from\_multiple\_inputs*. Using this script, 120-bp baits were  
199 tiled (3X density, middle overlap) and screened for high (>70%) or low (<30%) GC content,  
200 masked bases (>25%), and duplicates as described above. Finally, the baitset was screened  
201 against the *Symbiodinium minutum* (Suppl. Table S1) genome to look for any potential  
202 symbiont loci using the scripts *phyluce\_probe\_run\_multiple\_lastzs\_sqlite* and  
203 *phyluce\_probe\_slice\_sequence\_from\_genomes*, with a minimum coverage of 70% and  
204 minimum identity of 60%. This UCE bait set included a total of 15,226 non-duplicated baits  
205 targeting 1,436 loci.

206 All of the above methods were repeated using transcriptome data to re-design the  
207 baits for target-capture of exons. We mapped 100 bp simulated-reads from the transcriptomes  
208 of three exemplar taxa, *A. digitifera*, Cerianthidae, and *Edwardsiella lineata*, to the *nemve*



209 transcriptome (Suppl. Table S1), resulting in 4.5 to 15.3% of reads for each alignment. From  
210 these alignments, conserved sequences were added to an SQLite database. We queried this  
211 database to select loci found in *nemve* and the three exemplar taxa. Following a screening for  
212 masked regions, high/low GC content, and duplicates, a temporary exon bait set was  
213 designed. At this stage, we concatenated the temporary baits with the baits retained from the  
214 anthozoa-v1 bait set and then removed any potential duplicates using  
215 *phyluce\_probe\_easy\_lastz* and  
216 *phyluce\_probe\_remove\_duplicate\_hits\_from\_probes\_using\_lastz*. Bait sequences were  
217 considered duplicates if they were  $\geq 50\%$  identical over  $\geq 50\%$  of their length.

218         The temporary baits were re-aligned to the transcriptomes of *A. digitifera*,  
219 Cerianthidae, *Protopalythoa variabilis*, *Orbicella faveolata*, *Pocillopora damicornis*, *E.*  
220 *lineata*, *N. vectensis* (Suppl. Table S1), and exon loci of *Lebrunia danae* and *Myriopathes*  
221 *ulex* (Quattrini et al., 2018) to ensure we could capture the loci with this bait set. We then re-  
222 designed the bait set to target these exon loci using  
223 *phyluce\_probe\_get\_tiled\_probe\_from\_multiple\_inputs*. Using this script, 120-bp baits were  
224 tiled (3X density, middle overlap) and screened for high ( $>70\%$ ) or low ( $<30\%$ ) GC content,  
225 masked bases ( $>25\%$ ), and duplicates as described above. Finally, this bait set was also  
226 screened against the *S. minutum* genome to look for any potential symbiont loci using the  
227 scripts *phyluce\_probe\_run\_multiple\_lastzs\_sqlite* and  
228 *phyluce\_probe\_slice\_sequence\_from\_genomes*, with a minimum coverage of 70% and  
229 minimum identity of 60%. This exon bait set included a total of 15,750 non-duplicated baits  
230 targeting 1,572 loci.

231         The exon and UCE bait sets were concatenated and then screened to remove  
232 redundant baits ( $\geq 50\%$  identical over  $>50\%$  of their length), allowing us to create a final non-  
233 duplicated hexacoral-v2 bait set. For this study, we subset this hexacoral bait set to include

234 baits designed against all scleractinians as well as the corallimorpharians, the antipatharian,  
235 and *N. vectensis*. This reduced the cost of the bait synthesis, while still allowing us to target a  
236 maximum number of loci. Baits were synthesized by Arbor BioSciences (Ann Arbor, MI).

237

## 238 2.2. Sample collection and morphology assessment

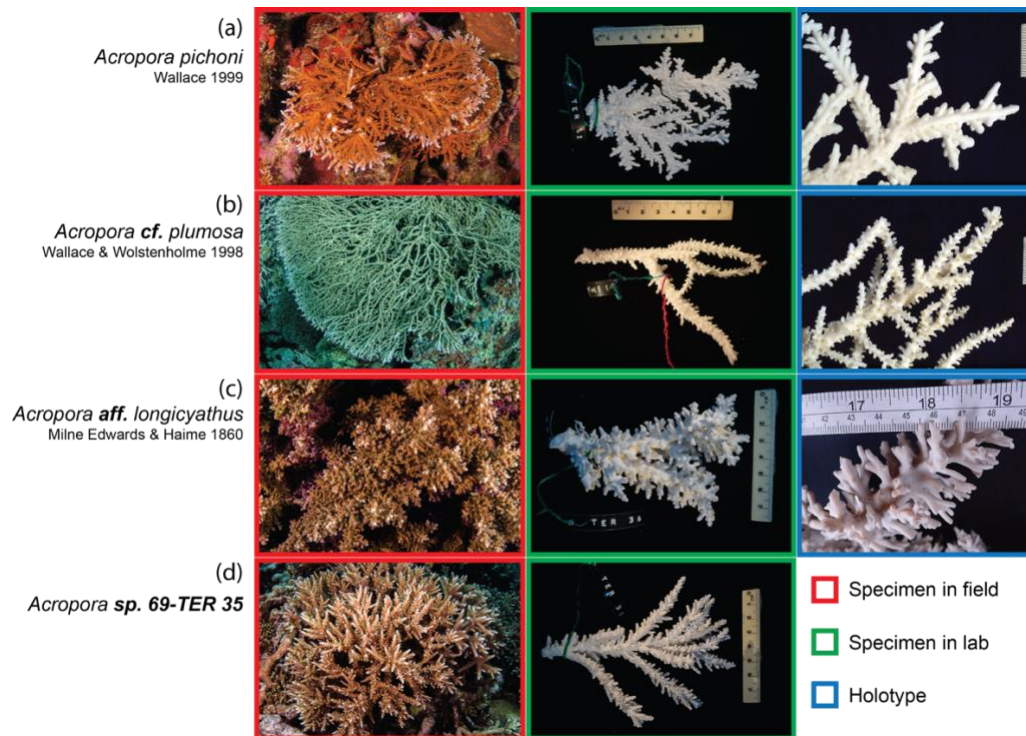
239 We tested the efficiency of this enhanced bait set on capturing loci from 99 specimens from  
240 the families Acroporidae (n=86), Agariciidae (n=5), and Fungiidae (n=9). Specimens were  
241 collected on snorkel and scuba using chisel and hammer from 2015 to 2017. Specimens  
242 spanning five of the six recognised genera of Acroporidae (*Alveopora* is unsampled) were  
243 sampled from locations across the Indo-Pacific (Suppl Table S2). The outgroup species  
244 chosen include specimens from the Agariciidae (*Leptoseris*), a close sister family of  
245 Acroporidae, and species from the more distantly related Fungiidae. Both Acroporidae and  
246 Agariciidae are members of the “complex” clade within Scleractinia, while Fungiidae is from  
247 the “robust” clade (Romano and Palumbi, 1996). This taxon sampling enables testing of the  
248 capture efficiency of the bait set at both deep (among major scleractinian clades and families)  
249 and shallow (among acroporid genera and species) evolutionary time scales.

250 Acroporid specimens were identified by comparing skeletons to the ‘type’ material  
251 and the original descriptions of all nominal species. Uncertainties in the identifications are  
252 indicated by the use of a series of open nomenclature (ON) qualifiers (Bengtson, 1988;  
253 Sigovini et al., 2016) which provides flexibility to assign specimens to nominal species with  
254 varying degrees of certainty. Specimens with skeletons that closely resemble the original type  
255 specimen and were collected from the type location (e.g. *Acropora pichoni*; Fig. 1, Suppl  
256 Table S2) were designated as ‘topotypes’ and are given the nominal species name with no  
257 qualifier. Specimens that closely resemble the type of a nominal species but were not  
258 sampled from the type locality are given the qualifier *cf.* (e.g. *Acropora cf. plumosa*; Fig. 1,

259 Suppl Table S2). Specimens that have morphological affinities to a nominal species are given  
260 the qualifier *aff.* (e.g. *Acropora aff. turaki*; Fig. 1, Suppl Table S2). These specimens may  
261 represent geographical variants of species with high morphological plasticity or undescribed  
262 species. Species that could not be matched with the type material of any nominal species  
263 were labelled as *sp.* in addition to the voucher number in its specific epithet (e.g. *Acropora*  
264 *sp. 69-TER 35*; Fig. 1, Suppl Table S2); these specimens are most probably undescribed  
265 species. In addition to identifying specimens with comparisons to nominal type material, we  
266 also categorized specimens into morphological grouping (“morpho-groups”) delineated by  
267 Wallace (1999) in a cladistic analysis of morphological traits. Wallace (1999) placed species  
268 into morpho-groups base on a phylogeny reconstructed from qualitative trait data. For  
269 example, the species *A. walindii* was placed in the ‘*elegans group*’. By categorizing our  
270 *Acropora* and *Isopora* specimens in this manner we can assess the molecular support for  
271 these morphological groups. Our sampling contains representatives of 16 of the 25 morpho-  
272 groups (including *Isopora*) delineated by Wallace (1999).

273

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276

277 **Figure 1.** Coral specimens were identified by comparison to type material when available (in  
278 situ examination at MTQ; images and original descriptions). Based on these comparisons  
279 specimens were (a) identified to nominal species if they were considered a topotype sample;  
280 (b) assigned the ON qualifier “cf” if they resembled the type material but were not collected  
281 from the type location; (c) assigned the ON qualifier “aff.” if they had morphological  
282 affinities to a nominal species but could not be reliably identified using the information  
283 available; and (d) assigned the ON qualifier “sp.” if they showed little resemblance to any  
284 nominal species type specimen.

285

### 286 2.3. DNA extraction and target enrichment

287 DNA was extracted using a Qiagen DNeasy Blood & Tissue kit or a CTAB extraction  
288 protocol. DNA quality was assessed using a Nanodrop spectrophotometer, with 260/280  
289 ratios ranging from 1.8-2.1 and 260/230 ratios ranging from 1.4-3.2. The initial concentration  
290 of each sample was measured with a Qubit 2.0 fluorometer and sent to Arbor Biosciences  
291 (Ann Arbor, MI) for library preparation.

292 Library preparation was performed by Arbor Biosciences following details in  
293 Quattrini et al., 2018). A total of 600 ng DNA (10 ng per  $\mu\text{L}$ ) was sheared to a target size  
294 range of 400-800 bp using sonication, and the Kapa Hyper Prep (Kapa Biosystems) protocol  
295 was used. Universal Y-yoke oligonucleotide adapters and custom iTru dual-indexed primers  
296 as described by Glenn et al., (2019) were used. For target enrichment, the Arbor Biosciences  
297 MyBaits v. IV protocol was followed. Target enrichment was performed on pools of up to  
298 eight samples. Following target-capture enrichment, target-enriched libraries were sequenced  
299 on one lane of Illumina HiSeq 3000 (150bp PE reads). Library preparation and target  
300 enrichment were conducted by Arbor Biosciences.

301

#### 302 2.4. Post-sequencing analyses

303 De-multiplexed Illumina reads were processed using *Phyluce* (Faircloth, 2016;  
304 <http://phyluce.readthedocs.io/en/latest/tutorial-one.html/>), with a few modifications. Reads  
305 were trimmed using the Illumiprocessor wrapper program (Faircloth et al., 2012) for  
306 *trimmomatic* (Bolger et al., 2014) with default values and then assembled using Spades v.  
307 3.10 (Bankevich et al., 2012; Nurk et al., 2013). UCE and exon bait sequences were then  
308 separately matched to the assembled contigs at 70% identity and 70% coverage using  
309 *phyluce\_assembly\_match\_contigs\_to\_probes*. *Phyluce\_assembly\_get\_match\_counts* and  
310 *phyluce\_assembly\_get\_fastas\_from\_match\_counts* were used to extract loci into FASTA  
311 files. Locus coverage was estimated using *phyluce\_assembly\_get\_trinity\_coverage* and  
312 *phyluce\_assembly\_get\_trinity\_coverage\_for\_uce\_loci*. *Phyluce\_align\_seqcap\_align* was  
313 used to align (with MAFFT; Katoh et al., 2002) and edge trim the loci across individuals,  
314 with default settings. Alignment matrices were created in which each locus was represented  
315 by either 75% or 95% species occupancy. Concatenated locus alignments consisted of exon  
316 loci only, UCE loci only, and all loci. The total number of variable sites, total number of

317 parsimony informative sites, and number of parsimony informative sites per locus were  
318 calculated (using *phyluce\_align\_get\_informative\_sites*) for alignments across the following  
319 taxonomic datasets: all taxa (n=96), Acroporidae (n=83), *Acropora* (n=65), and *Acropora*  
320 *walindii* (n=3).

321 Maximum likelihood inference was conducted on each alignment (exon loci only,  
322 UCE loci only, and all loci) for both 75% and 95% data matrices (six alignment sets) using  
323 RAxML v8 (Stamatakis, 2014). This analysis was carried out using rapid bootstrapping,  
324 which allows for a complete analysis (20 ML searches and 200 bootstrap replicates) in one  
325 step. We also conducted a Bayesian analysis (100 million generations, 35% burnin) on both  
326 taxon occupancy matrices, for all loci only, using ExaBayes (Aberer et al., 2014). An  
327 extended majority rule consensus tree was produced. A GTRGAMMA model was used in  
328 both ML and Bayesian analyses.

329

### 330 **3. Results**

#### 331 *3.1. Bait design*

332 The hexa-v2 bait set for all hexacorals included 25,514 baits targeting 2,499 loci (1,132 UCE  
333 and 1,367 exon loci). The bait set subset for scleractinians included 16,263 baits designed to  
334 target a total of 2,497 loci. The UCE specific bait set consisted of 8,880 baits that targeted  
335 1,132 loci. The exon specific bait consisted of 7,383 baits that targeted 1,365 loci. In  
336 screening the combined baits set for potential hits to the *Symbiodinium* genome, 141 loci  
337 were removed. Bait sets are included as supplemental files 1 (hexa-v2) and 2 (hexa-v2-  
338 scleractinia); baits designed against transcriptomes have “design: hexatrans” in the .fasta  
339 headers.

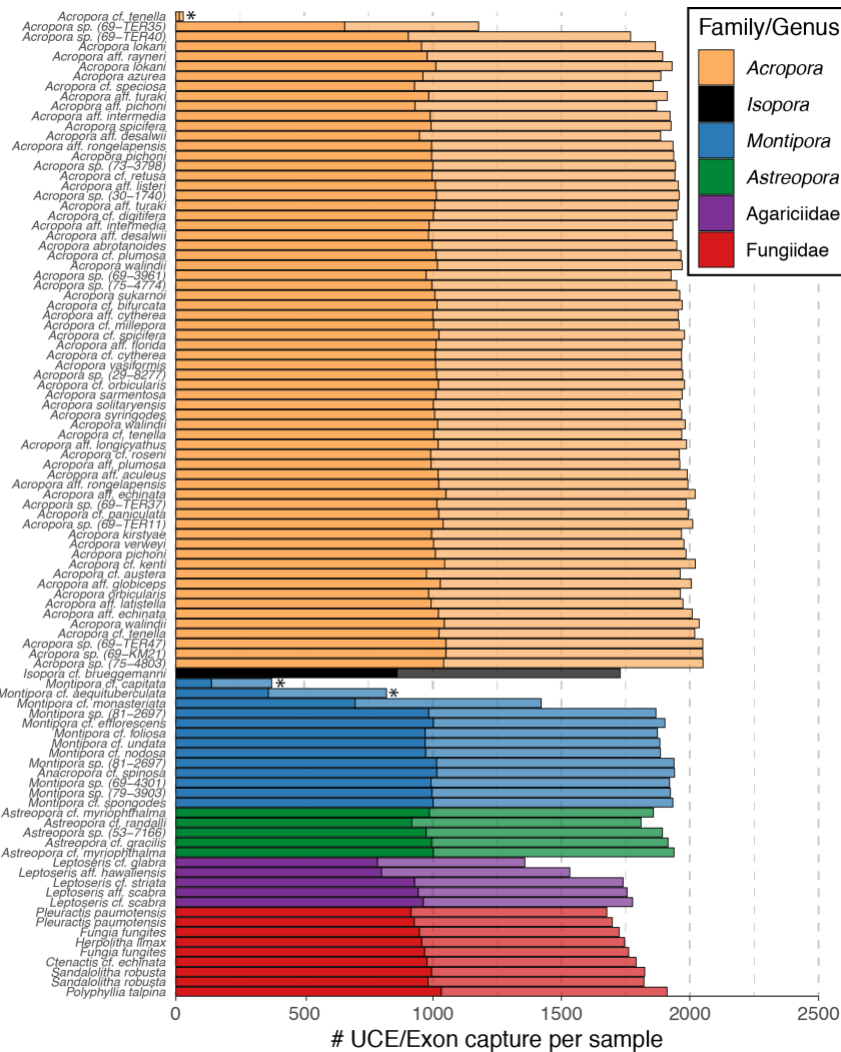
340

#### 341 *3.2. Enrichment statistics and matrix results*

342 The total number of reads obtained from Illumina sequencing ranged from 3,206 to  
343 10,357,494 reads per sample (Suppl Table S3). Following removal of one sample (*Acropora*  
344 *cf. tenella*) that failed sequencing (<4K reads), and quality and adapter trimming, a mean of  
345 3,766,889  $\pm$  1,516,262 SD trimmed reads per sample was retained (Tables 1). Trimmed reads  
346 were assembled into a mean of 11,858  $\pm$  9,682 SD contigs per sample (range: 1,498 to  
347 53,766) with a mean length of 506  $\pm$  75 bp using SPAdes (Tables 1; Table S3). Read  
348 coverage per contig ranged from 0.3 to 75X.

349 A total of 1131 UCE loci and 1332 exon loci (2463 total loci out of 2,497 targeted  
350 loci) were recovered from the assembled contigs (Fig. 2, Table 1). Following the removal of  
351 two samples (*Montipora cf. aequituberculata*, *Montipora cf. capitata*) due to relatively few  
352 loci recovered (Fig. 2, <1000 loci), mean number of loci was 1,900  $\pm$  140 SD per sample  
353 (range: 1,178 to 2,051). We recovered slightly higher numbers of loci from acroporids (1,930  
354  $\pm$  116 SD) than from agariciids (1,632  $\pm$  182) and fungiids (1,773  $\pm$  73 SD). The total  
355 number of UCE loci recovered was 983  $\pm$  63 SD per sample (range: 657 to 1051) with a  
356 mean length of 933  $\pm$  139 bp (range: 297 to 1,099 bp). The total number of exon loci  
357 recovered was 917  $\pm$  82 (range: 521 to 1009) with a mean length of 976  $\pm$  168 bp (range: 287  
358 to 1,192 bp) (Suppl Table S3). Read coverage per locus ranged from 1 to 337X for UCE loci  
359 and 0.5 to 270X for exon loci.

360



361

362 **Figure 2.** Number of UCE (solid) and exon (transparent) loci captured per taxa. Colours  
 363 reflect family/genus membership. \* denotes samples that were subsequently removed due to  
 364 low capture rate.

365

366 Extracted loci were aligned and pruned to form 75% and 95% occupancy matrices for

367 UCEs only and exons only. The final UCE only alignments consisted of 991 and 470 loci

368 (75% and 95% matrices respectively) for 96 samples that passed quality assessment. The

369 final exon only alignments contained 801 and 148 loci (75% and 95% matrices respectively)

370 for the 96 samples. The final combined concatenated alignments contained 1792 UCE/exon

371 loci in the 75% matrix and 618 in the 95% matrix (Table 2). The number of parsimony

372 informative sites varied from 48% in alignments containing all three families (Acroporidae,

373 Agariciidae, Fungiidae), to 1.5% among samples within a single *Acropora* species (*A.*



374 *walindii*). Within the family Acroporidae parsimony informative sites accounted for 38%  
375 among genera, and 18% within the genus *Acropora* (Table 2).

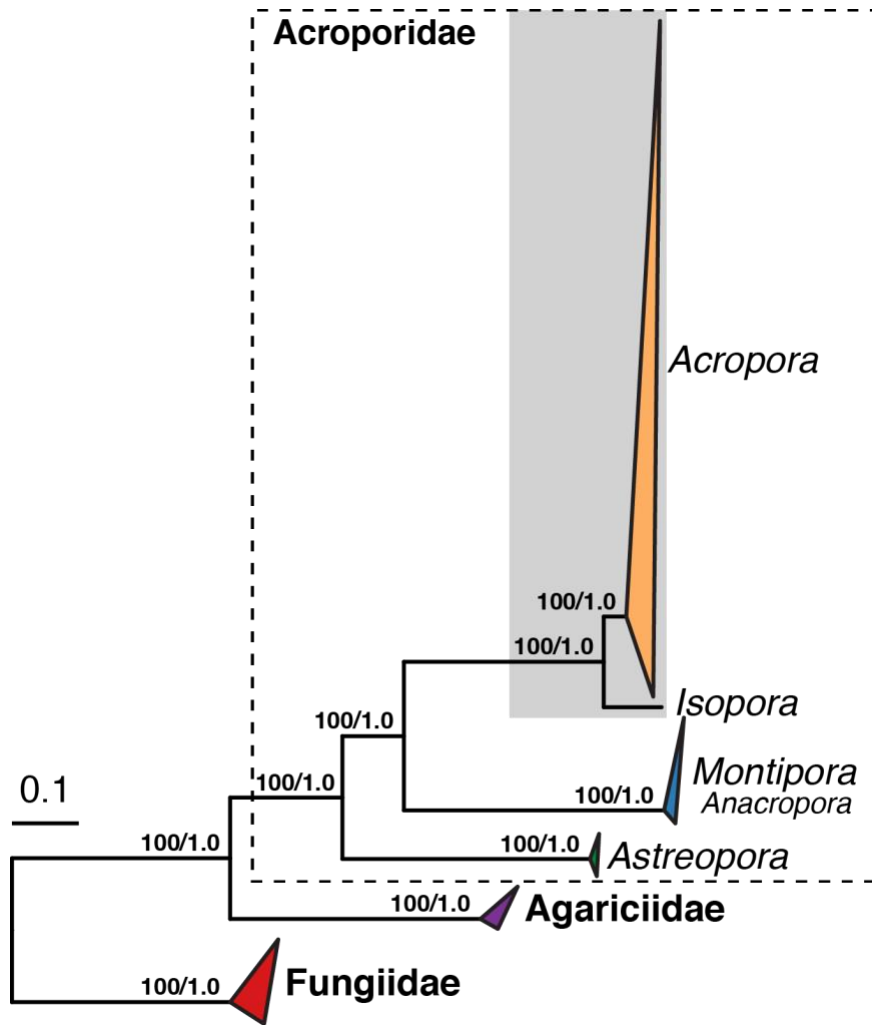
376

### 377 3.4. Coral phylogenomics

378 All six alignment matrices produced robust phylogenies separating the three families and the  
379 deep split between “complex” (Acroporidae + Agariciidae) and “robust” (Fungiidae) clades  
380 within the Scleractinia (Fig. 3; Suppl Figs S1-3). Given the congruent topologies across  
381 alignment sets, we discuss all systematic relationships below referring to the combined  
382 UCE/exon data alignments with 75% completeness (Figs 3-4).

383 Both maximum likelihood (ML) and Bayesian analyses resulted in high support for  
384 nodes in resulting consensus topologies (Fig. 3, Suppl Fig. S4). In the ML tree 83% of  
385 internal nodes are resolved with RAxML bootstrap values of 100 (92%  $\geq$  70), and in the  
386 Bayesian analyses 94% of nodes received posterior probabilities of 1 (96%  $\geq$  0.7; Suppl Fig.  
387 S4). Within the Acroporidae, the genus *Astreopora* is the first lineage to branch off in the  
388 family, followed by *Montipora* which contains *Anacropora* (Fig. 4). *Isopora* and *Acropora*  
389 are recovered as sister clades but independent genera. Within *Acropora*, all phylogenetic  
390 reconstructions highlight six major clades with high resolution (Fig. 4). Our molecular  
391 phylogeny indicates that most of the morphological species groups of Wallace (1999) are  
392 paraphyletic (9 of the 16 groups represented) (Fig. 4 inset). For example, species assigned to  
393 the *robusta* group appear in clades VI, V and III in the phylogeny (Fig. 4). Similarly,  
394 representatives of the *echinata*, *aspera* and *divaricata* groups are found across multiple  
395 clades. Representatives of some morpho-groups (e.g. *elegans* and *hyacinthus* groups) occur in  
396 the same molecular clade, but are paraphyletic at the species level, and do not reflect  
397 morphological relationships among member species (Fig. 4).

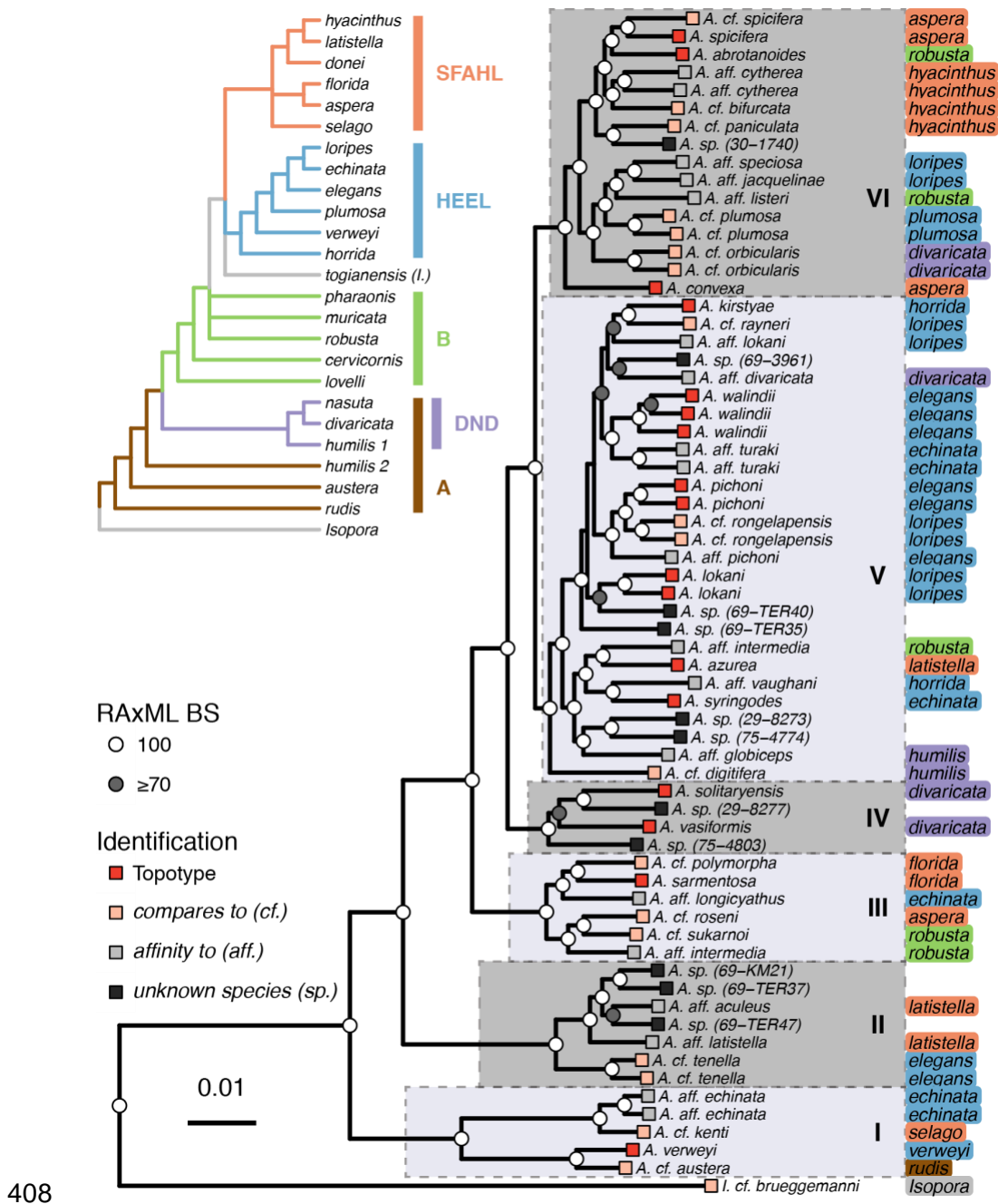
398



399

400 **Figure 3.** RAxML phylogeny based on 75% UCE/exon complete matrix. Phylogenetic  
401 relationship are delineated between Acroporidae genera (dashed outline) and outgroup families  
402 Agariciidae and Fungiidae. Acroporidae and Agariciidae are both from the complex  
403 scleractinian clade, while Fungiidae is from the robust clade (Romano & Palumbi, 1996).  
404 Node values show RAxML bootstrap values and posterior probabilities from ExaBayes  
405 analysis. Species level relationships within the Acropora/Isopora clade (in grey box) are  
406 shown in Figure 4.

407



418 greater than 70% (grey) are indicating on internal nodes. Robust molecular clades are  
419 delineated I-VI.

420

421 Of the 65 *Acropora* specimens, 17 were classified as topotypes and 18 designated as  
422 *cf.* In combination, these 35 specimens represent 26 nominal species of *Acropora*. In  
423 addition, 20 specimens had affinities (*aff.*) to nominal species and 12 samples could not be  
424 matched to any of the 414 nominal species (Suppl Table S1). In general, specimens given the  
425 same open nomenclature clustered together with high bootstrap support (e.g. *A. walindii*, *A.*  
426 *aff cytherea*, *A. cf plumosa*), as did the specimens identified as topotypes and those that  
427 matched the type from another region (e.g. *A. spicifera* and *A. cf spicifera*) (Fig. 4). However,  
428 not surprisingly, specimens with an affinity to a given nominal species often occurred in  
429 different clades (e.g. *A. aff. pichoni*, *A. aff. intermedia*, Fig. 4) suggesting that the  
430 morphological characters on which these affinities were qualitatively assessed (gross  
431 morphology and radial corallite shape) are not phylogenetically informative.

432

#### 433 **4. Discussion**

##### 434 *4.1 An enhanced target-enrichment baits set for Hexacorallia*

435 Here, we provide a pipeline to redesign a class level UCE/exon bait set (Anthozoa; (Quattrini  
436 et al., 2018) to improve the capture efficiency of loci from a variety of taxa within a lower  
437 taxonomic rank (subclass Hexacorallia). Our new bait set, however, also includes a subset of  
438 the originally targeted loci (anthozoa-v1), which will allow for future comparisons and  
439 integration with the original probe set. We tested our enhanced hexacoral UCE/exon probe  
440 design by focusing on a phylogenomic reconstruction of the staghorn corals (Acroporidae),  
441 while also including families from both complex (Agariciidae) and robust (Fungiidae) clades  
442 within the Scleractinia. This new enhanced probe set increases the capture efficiency of  
443 UCE/exons for scleractinians when compared to the class-level design (Quattrini et al., 2018)

444 and results in higher phylogenetic resolution within an important group of reef building  
445 corals.

446 Our new bait design greatly increases the number of UCE and exon loci captured  
447 within the Hexacorallia (Fig. 2; Table 1, 2). Overall, there is an almost four-fold increase in  
448 the number of loci captured with the hexa-v2 bait set when compared to the original antho-v1  
449 bait set. Resulting alignments retain higher numbers of loci for phylogenomic reconstruction  
450 within hexacorals in more complete alignment matrices: 1792 and 618 UCE/exon loci in 75%  
451 and 95% complete matrices respectively, compared to 438 UCE/exon loci in a 50% complete  
452 matrix (Quattrini et al., 2018). In addition, individual locus alignments are longer ( $1042 \pm$   
453  $529$  bp; Table 2) when compared to those captured from the antho-v1 probe design ( $205 \pm 93$   
454 bp; Quattrini et al., 2018), with a greater number of parsimony informative sites (46%; Table  
455 2). Fewer numbers of reads and contigs were recovered in this study compared to Quattrini et  
456 al., (2018) therefore, it is possible that more on-target reads were obtained using this new bait  
457 set and/or the MyBaits v IV protocol, which was not used in Quattrini et al., (2018). In  
458 parallel to our redesign approach of the Anthozoa probe set, Quek et al., (2020) recently  
459 released a transcriptome-based targeted-enrichment bait set focused on Scleractinia targeting  
460 1,139 exon regions. This Scleractinia focused exon bait set appears to have no overlap with  
461 the targeted exons of the Antho-v1 bait design (Quattrini et al., 2018; Quek et al., 2020) and  
462 only overlap in 12 exon loci, at a 50% similarity level, in our enhanced hexa-v2 scleractinia  
463 bait set (AMQ). While the dissimilarity are like due to the different taxonomic focus (Quek et  
464 al., 2020), future combinations of these independent bait designs will improve and expand the  
465 phylogenomic resolution of corals.

466

467 *4.2 Coral systematics and taxonomy*

468           The redesigned bait set provides a high throughput tool for phylogenetic inference in  
469 a systematically challenging group of corals. Initial molecular assessment of numerous  
470 groups within the Scleractinia have highlighted the fact that traditional morphological  
471 taxonomic schemes do not reflect systematic relationships or the evolutionary history  
472 revealed by molecular phylogenetics (Fukami et al., 2004; Huang et al., 2014; Kitahara et al.,  
473 2016; Romano and Palumbi, 1996). Similarly, our targeted capture data identifies many  
474 problems with the current systematics of the Acroporidae (Fig. 4), in particular, the  
475 incongruence between morphological and molecular based phylogenies (see also Richards et  
476 al., 2013). Unlike many other groups that have gained systematic resolution through the  
477 sequencing of single gene mitochondrial and nuclear markers, such markers provided limited  
478 phylogenetic resolution in the Scleractinia, particularly the hyperdiverse Acroporidae.  
479 However, a handful of informative markers have been exploited in an opportunistic way for  
480 phylogenetics in some clades. For example, the mitochondrial spacer region between COI  
481 and 16S rRNA has been used to resolve species boundaries in agariciid genera *Leptoseris* and  
482 *Pavona* from Hawaii (Luck et al., 2013; Pochon et al., 2015; Terraneo et al., 2017). Similarly,  
483 the putative mitochondrial control region and an open reading frame located between the  
484 mitochondrial ATP6 and NAD4 genes have provided resolution among genera in the family  
485 Pocilloporidae (Flot et al., 2011; Pinzón et al., 2013; Schmidt-Roach et al., 2013). However,  
486 the utility of these and other markers are not universal across coral taxa and sampling has not  
487 been uniform across clades or genes.

488           Obtaining informative phylogenetic markers capable of delineating species has been  
489 particularly problematic in the Acroporidae (but see Van Oppen et al., 2000; Márquez, Van  
490 Oppen, Willis, Reyes, & Miller, 2002). A recent phylogenetic reconstruction for the family  
491 Acroporidae (Huang et al., 2018) which mined two decades of molecular data resulted in an  
492 alignment representing a total 119 accepted species across seven mitochondrial markers and

493 two nuclear markers (ITS1 and 2, Pax-C). However, species sampling varied greatly among  
494 gene datasets (n = 17-73 species), resulting in a concatenated matrix that was 35% complete  
495 and where 25% of sampled species were represented by a single gene (Huang et al., 2018).  
496 Our testing of the enhanced bait set resulted in a 75% complete matrix consisting of 1792  
497 UCE/exon loci for specimens linked to 26 nominal and 32 potentially undescribed species,  
498 where the lowest number of loci for a single species in the alignment was 976. Phylogenomic  
499 reconstructions of our UCE/exon dataset agree with other molecular phylogenetic studies of  
500 Scleractinia with a deep split between “complex” and “robust” corals (Romano and Palumbi,  
501 1996; Ying et al., 2018) and the relationships among acroporid genera (Fig. 3; Fukami et al.,  
502 2000). At a shallower scale, this enhanced bait design provided a level of resolution within  
503 the genus *Acropora* that has not been achieved with available single markers or  
504 morphological analysis.

505

#### 506 *4.3. Phylogenomic resolution of staghorn coral*

507 Phylogenomic reconstruction, using both ML and Bayesian methods, consistently  
508 resolved six molecular clades within *Acropora* with high support (bootstrap = 100; posterior  
509 =1), regardless of alignment type (Fig. 4; Suppl Figs S1-S4). While some traditional  
510 morphological characters seem to distinguish nominal species lineages they appear to offer  
511 little congruence with the molecular systematic relationships reconstructed here (Fig. 4) and  
512 in previous single gene reconstructions within *Acropora* (Huang et al., 2018; Richards et al.,  
513 2016, 2013). Richards et al. (2013) found 6-7 clades within *Acropora*, although the  
514 phylogenetic resolution was too low to support relationships among and within the clades.  
515 Despite little overlap in the species sampled, deep splits in the single gene tree of Richards et  
516 al. (2013) show some concordance with the arrangement of Clade I and II in our  
517 reconstruction (Fig. 4.), however, other clades differ considerably. Our sampling only

518 presents a small fraction of the diversity of *Acropora* and so increased sampling effort could  
519 reveal further differentiation within and among the molecular clades highlighted here. Given  
520 our sampling includes a broad range of traditional morpho-groupings (Fig. 4) from across the  
521 Indo-Pacific (Table S2), it is probable that the genus *Acropora* is broadly represented by the  
522 six molecular clades found here.

523

## 524 **5. Conclusions**

525 Our enhanced hexacoral bait set has the ability to generate new phylogenomic datasets to  
526 resolve deep to shallow-level evolutionary relationships among reef building corals and their  
527 relatives. This new bait set improved on the capture efficiency of the previous anthozoan bait  
528 design resulting in higher numbers of UCE and exons in more complete and longer  
529 alignments. Our subsequent phylogenomic analyses demonstrated that the  
530 macromorphological characters traditionally used for taxonomic identification in corals do  
531 not reflect evolutionary relationships. As climate change impacts coral reefs around the  
532 world, conservation efforts rely on a robust taxonomy (Thomson et al., 2018) and a  
533 phylogenetic framework in which to assess extinction risk (Huang, 2012). Importantly, over  
534 50 % of our specimens cannot readily be assigned to any of the 414 nominal species of  
535 *Acropora*, suggesting the true diversity of this genus has been seriously underestimated in  
536 recent revisions (Wallace et al., 2012). Our new bait set, in conjunction with wider  
537 geographic sampling of species and a close examination of the type material, will provide a  
538 renewed taxonomic focus for reef building corals.

539

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553

#### 554 **Author Contributions**

555 PFC designed the project with help from AMQ and CSM. Sample collection was conducted  
556 by AB, TB, TER and MG. Morphological assessment of acroporids was conducted by TB  
557 and AB. The hexa-2 bait set was designed by AMQ. AMQ assembled contigs and performed  
558 phylogenomic analyses. Initial draft of paper was written by PFC and AMQ with input from  
559 TB. All authors contributed to subsequent drafts.

560

#### 561 **Data Accessibility**

562 Tree and alignment files: Data Dryad Entry <https://doi.org/10.5061/dryad.9p8cz8wc8>;  
563 Raw Data: SRA GenBank SUB6852542, BioSample #SAMN13871686-1781;  
564 Hexacoral bait set: Supplemental Files 2 and 3, Data Dryad Entry  
565 <https://doi.org/10.5061/dryad.9p8cz8wc8>

566

#### 567 **References**

- 568 Aberer, A.J., Kobert, K., Stamatakis, A., 2014. Exabayes: Massively parallel bayesian tree  
569 inference for the whole-genome era. *Mol. Biol. Evol.* 31, 2553–2556.  
570 <https://doi.org/10.1093/molbev/msu236>
- 571 Bankevich, A., Nurk, S., Antipov, D., Gurevich, A.A., Dvorkin, M., Kulikov, A.S., Lesin,  
572 V.M., Nikolenko, S.I., Pham, S., Prjibelski, A.D., Pyshkin, A. V., Sirotkin, A. V.,  
573 Vyahhi, N., Tesler, G., Alekseyev, M.A., Pevzner, P.A., 2012. SPAdes: A new genome  
574 assembly algorithm and its applications to single-cell sequencing. *J. Comput. Biol.* 19,  
575 455–477. <https://doi.org/10.1089/cmb.2012.0021>
- 576 Bellwood, D.R., Goatley, C.H.R., Bellwood, O., 2017. The evolution of fishes and corals on  
577 reefs: form, function and interdependence. *Biol. Rev.* 92, 878–901.  
578 <https://doi.org/10.1111/brv.12259>
- 579 Bengtson, P., 1988. Open Nomenclature. *Palaeontology* 31, 223–227.
- 580 Bolger, A.M., Lohse, M., Usadel, B., 2014. Trimmomatic: A flexible trimmer for Illumina  
581 sequence data. *Bioinformatics* 30, 2114–2120.  
582 <https://doi.org/10.1093/bioinformatics/btu170>
- 583 Branstetter, M.G., Longino, J.T., Ward, P.S., Faircloth, B.C., 2017. Enriching the ant tree of  
584 life: enhanced UCE bait set for genome-scale phylogenetics of ants and other  
585 Hymenoptera. *Methods Ecol. Evol.* 8, 768–776. [https://doi.org/10.1111/2041-](https://doi.org/10.1111/2041-210X.12742)  
586 [210X.12742](https://doi.org/10.1111/2041-210X.12742)
- 587 Chen, I.P., Tang, C.Y., Chiou, C.Y., Hsu, J.H., Wei, N.V., Wallace, C.C., Muir, P., Wu, H.,  
588 Chen, C.A., 2009. Comparative analyses of coding and noncoding DNA regions indicate  
589 that *Acropora* (Anthozoa: Scleractina) possesses a similar evolutionary tempo of nuclear  
590 vs. mitochondrial genomes as in plants. *Mar. Biotechnol.* 11, 141–152.  
591 <https://doi.org/10.1007/s10126-008-9129-2>
- 592 Collins, R.A., Hrbek, T., 2018. An in silico comparison of protocols for dated

- 593 phylogenomics. *Syst. Biol.* 67, 633–650. <https://doi.org/10.1093/sysbio/syx089>
- 594 Derkarabetian, S., Starrett, J., Tsurusaki, N., Ubick, D., Castillo, S., Hedin, M., 2018. A  
595 stable phylogenomic classification of Travunioidea (Arachnida, Opiliones, Laniatores)  
596 based on sequence capture of ultraconserved elements. *Zookeys* 760, 1–36.  
597 <https://doi.org/10.3897/zookeys.760.24937>
- 598 Faircloth, B.C., 2016. PHYLUCE is a software package for the analysis of conserved  
599 genomic loci. *Bioinformatics* 32, 786–788.  
600 <https://doi.org/10.1093/bioinformatics/btv646>
- 601 Faircloth, B.C., McCormack, J.E., Crawford, N.G., Harvey, M.G., Brumfield, R.T., Glenn,  
602 T.C., 2012. Ultraconserved elements anchor thousands of genetic markers spanning  
603 multiple evolutionary timescales. *Syst. Biol.* 61, 717–726.  
604 <https://doi.org/10.1093/sysbio/sys004>
- 605 Fisher, R., O’Leary, R.A., Low-Choy, S., Mengersen, K., Knowlton, N., Brainard, R.E.,  
606 Caley, M.J., O’Leary, R.A., Low-Choy, S., Mengersen, K., Knowlton, N., Brainard,  
607 R.E., Caley, M.J., O’Leary, R.A., Low-Choy, S., Mengersen, K., Knowlton, N.,  
608 Brainard, R.E., Caley, M.J., O’Leary, R.A., Low-Choy, S., Mengersen, K., Knowlton,  
609 N., Brainard, R.E., Caley, M.J., 2015. Species Richness on Coral Reefs and the Pursuit  
610 of Convergent Global Estimates. *Curr. Biol.* 25, 500–505.  
611 <https://doi.org/10.1016/j.cub.2014.12.022>
- 612 Flot, J.F., Blanchot, J., Charpy, L., Cruaud, C., Licuanan, W.Y., Nakano, Y., Payri, C.,  
613 Tillier, S., 2011. Incongruence between morphotypes and genetically delimited species  
614 in the coral genus *Stylophora*: Phenotypic plasticity, morphological convergence,  
615 morphological stasis or interspecific hybridization? *BMC Ecol.* 11, 1–14.  
616 <https://doi.org/10.1186/1472-6785-11-22>
- 617 Fukami, H., Budd, A.F., Paulay, G., Solé-Cava, A., Chen, C.A., Iwao, K., Knowlton, N.,

- 618 2004. Conventional taxonomy obscures deep divergence between Pacific and Atlantic  
619 corals. *Nature* 427, 832–835. <https://doi.org/10.1038/nature02339>
- 620 Fukami, H., Chen, C.A., Budd, A.F., Collins, A., Wallace, C.C., Chuang, Y.-Y., Chen, C.,  
621 Dai, C.-F., Iwao, K., Sheppard, C., Knowlton, N., 2008. Mitochondrial and Nuclear  
622 Genes Suggest that Stony Corals Are Monophyletic but Most Families of Stony Corals  
623 Are Not (Order Scleractinia, Class Anthozoa, Phylum Cnidaria). *PLoS One* 3, e3222.  
624 <https://doi.org/10.1371/journal.pone.0003222>
- 625 Fukami, H., Omori, M., Hatta, M., 2000. Phylogenetic Relationships in the Coral Family  
626 Acroporidae, Reassessed by Inference from Mitochondrial Genes. *Zoolog. Sci.* 17, 689–  
627 696. <https://doi.org/10.2108/zsj.17.689>
- 628 Glenn, T.C., Nilsen, R.A., Kieran, T.J., Sanders, J.G., Bayona-Vásquez, N.J., Finger, J.W.,  
629 Pierson, T.W., Bentley, K.E., Hoffberg, S.L., Louha, S., Garcia-De Leon, F.J., Del Rio  
630 Portilla, M.A., Reed, K.D., Anderson, J.L., Meece, J.K., Aggrey, S.E., Rekaya, R.,  
631 Alabady, M., Belanger, M., Winker, K., Faircloth, B.C., 2019. Adapterama I: Universal  
632 stubs and primers for 384 unique dual-indexed or 147,456 combinatorially-indexed  
633 Illumina libraries (iTru & iNext). *PeerJ* 2019, 1–31. <https://doi.org/10.7717/peerj.7755>
- 634 Harvey, M.G., Smith, B.T., Glenn, T.C., Faircloth, B.C., Brumfield, R.T., 2016. Sequence  
635 Capture versus Restriction Site Associated DNA Sequencing for Shallow Systematics.  
636 *Syst. Biol.* 65, 910–924. <https://doi.org/10.1093/sysbio/syw036>
- 637 Hellberg, M.E., 2006. No variation and low synonymous substitution rates in coral mtDNA  
638 despite high nuclear variation. *BMC Evol. Biol.* 6, 1–8. [https://doi.org/10.1186/1471-](https://doi.org/10.1186/1471-2148-6-24)  
639 [2148-6-24](https://doi.org/10.1186/1471-2148-6-24)
- 640 Hoeksema, B.W., Cairns, S.D., 2019. World List of Scleractinia [WWW Document]. URL  
641 <http://www.marinespecies.org/scleractinia> (accessed 12.20.19).
- 642 Huang, D., 2012. Threatened Reef Corals of the World. *PLoS One* 7, e34459.

- 643 <https://doi.org/10.1371/journal.pone.0034459>
- 644 Huang, D., Benzoni, F., Fukami, H., Knowlton, N., Smith, N.D., Budd, A.F., 2014.
- 645 Taxonomic classification of the reef coral families Merulinidae, Montastraeidae, and
- 646 Diploastraeidae (Cnidaria: Anthozoa: Scleractinia). *Zool. J. Linn. Soc.* 171, 277–355.
- 647 <https://doi.org/10.1111/zoj.12140>
- 648 Huang, D., Goldberg, E.E., Chou, L.M., Roy, K., 2018. The origin and evolution of coral
- 649 species richness in a marine biodiversity hotspot\*. *Evolution (N. Y.)*. 72, 288–302.
- 650 <https://doi.org/10.1111/evo.13402>
- 651 Huang, D., Meier, R., Todd, P.A., Chou, L.M., 2008. Slow mitochondrial COI sequence
- 652 evolution at the base of the metazoan tree and its implications for DNA barcoding. *J.*
- 653 *Mol. Evol.* 66, 167–174. <https://doi.org/10.1007/s00239-008-9069-5>
- 654 Jetz, W., Thomas, G.H., Joy, J.B., Hartmann, K., Mooers, a O., 2012. The global diversity of
- 655 birds in space and time. *Nature* 491, 444–448. <https://doi.org/10.1038/nature11631>
- 656 Katoh, K., Misawa, K., Kuma, K., Miyata, T., 2002. MAFFT: a novel method for rapid
- 657 multiple sequence alignment based on fast Fourier transform. *Nucleic Acids Res.* 30,
- 658 3059–66.
- 659 Kitahara, M. V, Fukami, H., Benzoni, F., Huang, D., 2016. The New Systematics of
- 660 Scleractinia: Integrating Molecular and Morphological Evidence, in: Goffredo, S.,
- 661 Dubinsky, Z. (Eds.), *The Cnidaria, Past, Present and Future: The World of Medusa and*
- 662 *Her Sisters*. Springer International Publishing, Cham, pp. 41–59.
- 663 [https://doi.org/10.1007/978-3-319-31305-4\\_4](https://doi.org/10.1007/978-3-319-31305-4_4)
- 664 Kleypas, J.A., McManu, J.W., Mene, L.A.B., 1999. Environmental limits to coral reef
- 665 development: Where do we draw the line? *Am. Zool.* 39, 146–159.
- 666 <https://doi.org/10.1093/icb/39.1.146>
- 667 Lemmon, A.R., Emme, S. a, Lemmon, E.M., 2012. Anchored hybrid enrichment for

- 668           massively high-throughput phylogenomics. *Syst. Biol.* 61, 727–744.
- 669           <https://doi.org/10.1093/sysbio/sys049>
- 670 Luck, D.G., Forsman, Z.H., Toonen, R.J., Leicht, S.J., Kahng, S.E., 2013. Polyphyly and  
671           hidden species among Hawai'i's dominant mesophotic coral genera, *Leptoseris* and  
672           *pavona* (Scleractinia: Agariciidae). *PeerJ* 2013, 1–20. <https://doi.org/10.7717/peerj.132>
- 673 Lunter, G., Goodson, M., 2011. Stampy: A statistical algorithm for sensitive and fast  
674           mapping of Illumina sequence reads. *Genome Res.* 21, 936–939.
- 675           <https://doi.org/10.1101/gr.111120.110>
- 676 Madin, J.S., Hoogenboom, M.O., Connolly, S.R., Darling, E.S., Falster, D.S., Huang, D.,  
677           Keith, S.A., Mizerek, T., Pandolfi, J.M., Putnam, H.M., Baird, A.H., 2016. A Trait-  
678           Based Approach to Advance Coral Reef Science. *Trends Ecol. Evol.* 31, 419–428.
- 679           <https://doi.org/10.1016/j.tree.2016.02.012>
- 680 Manthey, J.D., Campillo, L.C., Burns, K.J., Moyle, R.G., 2016. Comparison of target-capture  
681           and restriction-site associated DNA sequencing for phylogenomics: A test in cardinalid  
682           tanagers (Aves, Genus: *Piranga*). *Syst. Biol.* 65, 640–650.
- 683           <https://doi.org/10.1093/sysbio/syw005>
- 684 Márquez, L.M., Van Oppen, M.J.H., Willis, B.L., Reyes, A., Miller, D.J., 2002. The highly  
685           cross-fertile coral species, *Acropora hyacinthus* and *Acropora cytherea*, constitute  
686           statistically distinguishable lineages. *Mol. Ecol.* 11, 1339–1349.
- 687           <https://doi.org/10.1046/j.1365-294X.2002.01526.x>
- 688 McFadden, C.S., Benayahu, Y., Pante, E., Thoma, J.N., Nevarez, P.A., France, S.C., 2011.  
689           Limitations of mitochondrial gene barcoding in Octocorallia. *Mol. Ecol. Resour.* 11, 19–  
690           31. <https://doi.org/10.1111/j.1755-0998.2010.02875.x>
- 691 Nurk, S., Bankevich, A., Antipov, D., Gurevich, A.A., Korobeynikov, A., Lapidus, A.,  
692           Prjibelski, A.D., Pyshkin, A., Sirotkin, A., Sirotkin, Y., Stepanauskas, R., Clingenpeel,

- 693 S.R., Woyke, T., McLean, J.S., Lasken, R., Tesler, G., Alekseyev, M.A., Pevzner, P.A.,  
694 2013. Assembling single-cell genomes and mini-metagenomes from chimeric MDA  
695 products. *J. Comput. Biol.* 20, 714–737. <https://doi.org/10.1089/cmb.2013.0084>
- 696 Pinzón, J.H., Sampayo, E., Cox, E., Chauka, L.J., Chen, C.A., Voolstra, C.R., Lajeunesse,  
697 T.C., 2013. Blind to morphology: Genetics identifies several widespread ecologically  
698 common species and few endemics among Indo-Pacific cauliflower corals (*Pocillopora*,  
699 *Scleractinia*). *J. Biogeogr.* 40, 1595–1608. <https://doi.org/10.1111/jbi.12110>
- 700 Pochon, X., Forsman, Z.H., Spalding, H.L., Padilla-Gamiño, J.L., Smith, C.M., Gates, R.D.,  
701 2015. Depth specialization in mesophotic corals (*Leptoseris* spp.) and associated algal  
702 symbionts in Hawai‘i. *R. Soc. Open Sci.* 2. <https://doi.org/10.1098/rsos.140351>
- 703 Pyron, R.A., Burbrink, F.T., Wiens, J.J., 2013. A phylogeny and revised classification of  
704 Squamata, including 4161 species of lizards and snakes. *BMC Evol. Biol.* 13, 93.  
705 <https://doi.org/10.1186/1471-2148-13-93>
- 706 Quattrini, A.M., Faircloth, B.C., Dueñas, L.F., Bridge, T.C.L., Brugler, M.R., Calixto-Botía,  
707 I.F., DeLeo, D.M., Forêt, S., Herrera, S., Lee, S.M.Y., Miller, D.J., Prada, C., Rádis-  
708 Baptista, G., Ramírez-Portilla, C., Sánchez, J.A., Rodríguez, E., McFadden, C.S., 2018.  
709 Universal target-enrichment baits for anthozoan (Cnidaria) phylogenomics: New  
710 approaches to long-standing problems. *Mol. Ecol. Resour.* 18, 281–295.  
711 <https://doi.org/10.1111/1755-0998.12736>
- 712 Quek, R.Z.B., Jain, S.S., Neo, M.L., Rouse, G.W., Huang, D., 2020. Transcriptome-based  
713 target-enrichment baits for stony corals (Cnidaria: Anthozoa: Scleractinia). *Mol. Ecol.*  
714 *Resour.* 1755–0998.13150. <https://doi.org/10.1111/1755-0998.13150>
- 715 Rabosky, D.L., 2015. No substitute for real data: A cautionary note on the use of phylogenies  
716 from birth-death polytomy resolvers for downstream comparative analyses. *Evolution*  
717 (N. Y). 3207–3216. <https://doi.org/10.1111/evo.12817>

- 718 Rabosky, D.L., Chang, J., Title, P.O., Cowman, P.F., Sallan, L., Friedman, M., Kaschner, K.,  
719 Garilao, C., Near, T.J., Coll, M., Alfaro, M.E., 2018. An inverse latitudinal gradient in  
720 speciation rate for marine fishes. *Nature* 559, 392–395. [https://doi.org/10.1038/s41586-](https://doi.org/10.1038/s41586-018-0273-1)  
721 [018-0273-1](https://doi.org/10.1038/s41586-018-0273-1)
- 722 Renema, W., Pandolfi, J.M., Kiessling, W., Bosellini, F.R., Klaus, J.S., Korpanty, C., Rosen,  
723 B.R., Santodomingo, N., Wallace, C.C., Webster, J.M., Johnson, K.G., 2016. Are coral  
724 reefs victims of their own past success ? 1–7.
- 725 Richards, Z.T., Berry, O., van Oppen, M.J.H., 2016. Cryptic genetic divergence within  
726 threatened species of *Acropora* coral from the Indian and Pacific Oceans. *Conserv.*  
727 *Genet.* 17, 577–591. <https://doi.org/10.1007/s10592-015-0807-0>
- 728 Richards, Z.T., Miller, D.J., Wallace, C.C., 2013. Molecular phylogenetics of geographically  
729 restricted *Acropora* species: Implications for threatened species conservation. *Mol.*  
730 *Phylogenet. Evol.* 69, 837–851. <https://doi.org/10.1016/j.ympev.2013.06.020>
- 731 Romano, S.L., Palumbi, S.R., 1996. Evolution of Scleractinian Corals Inferred from  
732 Molecular Systematics. *Science* (80-. ). 271, 640–642.  
733 <https://doi.org/10.1126/science.271.5249.640>
- 734 Schmidt-Roach, S., Miller, K.J., Andreakis, N., 2013. *Pocillopora aliciae*: A new species of  
735 scleractinian coral (Scleractinia, Pocilloporidae) from subtropical Eastern Australia.  
736 *Zootaxa*. <https://doi.org/10.11646/zootaxa.3626.4.11>
- 737 Shearer, T.L., Van Oppen, M.J.H., Romano, S.L., Wörheide, G., 2002. Slow mitochondrial  
738 DNA sequence evolution in the Anthozoa (Cnidaria). *Mol. Ecol.* 11, 2475–2487.  
739 <https://doi.org/10.1046/j.1365-294X.2002.01652.x>
- 740 Sigovini, M., Keppel, E., Tagliapietra, D., 2016. Open Nomenclature in the biodiversity era.  
741 *Methods Ecol. Evol.* 7, 1217–1225. <https://doi.org/10.1111/2041-210X.12594>
- 742 Smith, B.T., Harvey, M.G., Faircloth, B.C., Glenn, T.C., Brumfield, R.T., 2014. Target



- 743 capture and massively parallel sequencing of ultraconserved elements for comparative  
744 studies at shallow evolutionary time scales. *Syst. Biol.* 63, 83–95.  
745 <https://doi.org/10.1093/sysbio/syt061>
- 746 Stamatakis, A., 2014. RAxML version 8: A tool for phylogenetic analysis and post-analysis  
747 of large phylogenies. *Bioinformatics* 30, 1312–1313.  
748 <https://doi.org/10.1093/bioinformatics/btu033>
- 749 Terraneo, T.I., Arrigoni, R., Benzoni, F., Tietbohl, M.D., Berumen, M.L., 2017. Exploring  
750 the genetic diversity of shallow-water Agariciidae (Cnidaria: Anthozoa) from the Saudi  
751 Arabian Red Sea. *Mar. Biodivers.* 47, 1065–1078. [https://doi.org/10.1007/s12526-017-](https://doi.org/10.1007/s12526-017-0722-3)  
752 [0722-3](https://doi.org/10.1007/s12526-017-0722-3)
- 753 Thomas, G.H., Hartmann, K., Jetz, W., Joy, J.B., Mimoto, A., Mooers, A.O., 2013. PASTIS:  
754 an R package to facilitate phylogenetic assembly with soft taxonomic inferences.  
755 *Methods Ecol. Evol.* 4, 1011–1017. <https://doi.org/10.1111/2041-210X.12117>
- 756 Thomson, S.A., Pyle, R.L., Ahyong, S.T., Alonso-Zarazaga, M., Ammirati, J., Araya, J.F.,  
757 Ascher, J.S., Audisio, T.L., Azevedo-Santos, V.M., Bailly, N., Baker, W.J., Balke, M.,  
758 Barclay, M.V.L., Barrett, R.L., Benine, R.C., Bickerstaff, J.R.M., Bouchard, P., Bour,  
759 R., Bourgoin, T., Boyko, C.B., Breure, A.S.H., Brothers, D.J., Byng, J.W., Campbell,  
760 D., Ceriáco, L.M.P., Cernák, I., Cerretti, P., Chang, C.-H., Cho, S., Copus, J.M.,  
761 Costello, M.J., Cseh, A., Csuzdi, C., Culham, A., D'Elía, G., d'Udekem d'Acoz, C.,  
762 Daneliya, M.E., Dekker, R., Dickinson, E.C., Dickinson, T.A., van Dijk, P.P., Dijkstra,  
763 K.-D.B., Dima, B., Dmitriev, D.A., Duistermaat, L., Dumbacher, J.P., Eiserhardt, W.L.,  
764 Ekrem, T., Evenhuis, N.L., Faille, A., Fernández-Triana, J.L., Fiesler, E., Fishbein, M.,  
765 Fordham, B.G., Freitas, A.V.L., Friol, N.R., Fritz, U., Frøslev, T., Funk, V.A., Gaimari,  
766 S.D., Garbino, G.S.T., Garraffoni, A.R.S., Geml, J., Gill, A.C., Gray, A., Grazziotin,  
767 F.G., Greenslade, P., Gutiérrez, E.E., Harvey, M.S., Hazevoet, C.J., He, K., He, X.,

768 Helfer, S., Helgen, K.M., van Heteren, A.H., Hita Garcia, F., Holstein, N., Horváth,  
769 M.K., Hovenkamp, P.H., Hwang, W.S., Hyvönen, J., Islam, M.B., Iverson, J.B., Ivie,  
770 M.A., Jaafar, Z., Jackson, M.D., Jayat, J.P., Johnson, N.F., Kaiser, H., Klitgård, B.B.,  
771 Knapp, D.G., Kojima, J., Kõljalg, U., Kontschán, J., Krell, F.-T., Krisai-Greilhuber, I.,  
772 Kullander, S., Latella, L., Latke, J.E., Lencioni, V., Lewis, G.P., Lhano, M.G., Lujan,  
773 N.K., Luksenburg, J.A., Mariaux, J., Marinho-Filho, J., Marshall, C.J., Mate, J.F.,  
774 McDonough, M.M., Michel, E., Miranda, V.F.O., Mitroiu, M.-D., Molinari, J., Monks,  
775 S., Moore, A.J., Moratelli, R., Murányi, D., Nakano, T., Nikolaeva, S., Noyes, J., Ohl,  
776 M., Oleas, N.H., Orrell, T., Páll-Gergely, B., Pape, T., Papp, V., Parenti, L.R., Patterson,  
777 D., Pavlinov, I.Y., Pine, R.H., Poczai, P., Prado, J., Prathapan, D., Rabeler, R.K.,  
778 Randall, J.E., Rheindt, F.E., Rhodin, A.G.J., Rodríguez, S.M., Rogers, D.C., Roque, F.  
779 de O., Rowe, K.C., Ruedas, L.A., Salazar-Bravo, J., Salvador, R.B., Sangster, G.,  
780 Sarmiento, C.E., Schigel, D.S., Schmidt, S., Schueler, F.W., Segers, H., Snow, N.,  
781 Souza-Dias, P.G.B., Stals, R., Stenroos, S., Stone, R.D., Sturm, C.F., Štys, P., Teta, P.,  
782 Thomas, D.C., Timm, R.M., Tindall, B.J., Todd, J.A., Triebel, D., Valdecasas, A.G.,  
783 Vizzini, A., Vorontsova, M.S., de Vos, J.M., Wagner, P., Watling, L., Weakley, A.,  
784 Welter-Schultes, F., Whitmore, D., Wilding, N., Will, K., Williams, J., Wilson, K.,  
785 Winston, J.E., Wüster, W., Yanega, D., Yeates, D.K., Zaher, H., Zhang, G., Zhang, Z.-  
786 Q., Zhou, H.-Z., 2018. Taxonomy based on science is necessary for global conservation.  
787 PLOS Biol. 16, e2005075. <https://doi.org/10.1371/journal.pbio.2005075>  
788 Tonini, J.F.R., Beard, K.H., Ferreira, R.B., Jetz, W., Pyron, R.A., 2016. Fully-sampled  
789 phylogenies of squamates reveal evolutionary patterns in threat status. Biol. Conserv.  
790 <https://doi.org/10.1016/j.biocon.2016.03.039>  
791 Upham, N., Esselstyn, J., Jetz, W., 2019. Inferring the mammal tree: species-level sets of  
792 phylogenies for questions in ecology, evolution, and conservation. PLoS Biol. 1–44.

- 793 Van Oppen, M.J.H., Willis, B.L., Miller, D.J., 1999. Atypically low rate of cytochrome b  
794 evolution in the scleractinian coral genus *Acropora*. Proc. R. Soc. B Biol. Sci. 266, 179–  
795 183. <https://doi.org/10.1098/rspb.1999.0619>
- 796 Veron, J.E.N., Wallace, C.C., 1984. Scleractinia of Eastern Australia, Part 5: Acroporidae.  
797 Aust Inst Mar Sci Monogr Ser 6, 485.
- 798 Wallace, C.C., 1999. Staghorn Corals of the World, Staghorn Corals of the World. CSIRO  
799 Publishing. <https://doi.org/10.1071/9780643101388>
- 800 Wallace, C.C., Done, B.J., Muir, P.R., 2012. Revision and catalogue of worldwide staghorn  
801 corals *Acropora* and *Isopora* (Scleractinia: Acroporidae) in the Museum of Tropical  
802 Queensland. Australia: Memoirs of the Queensland Museum.
- 803 Ying, H., Cooke, I., Sprungala, S., Wang, W., Hayward, D.C., Tang, Y., Huttley, G., Ball,  
804 E.E., Forêt, S., Miller, D.J., 2018. Comparative genomics reveals the distinct  
805 evolutionary trajectories of the robust and complex coral lineages. Genome Biol. 19,  
806 175. <https://doi.org/10.1186/s13059-018-1552-8>

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## 808 **Figure Captions**

809 **Figure 1.** Coral specimens were identified by comparison to type material when available (*in*  
810 *situ* examination at MTQ; images and original descriptions). Based on these comparisons  
811 specimens were (a) identified to nominal species if they were considered a topotype sample;  
812 (b) assigned the ON qualifier “*cf*” if they resembled the type material but were not collected  
813 from the type location; (c) assigned the ON qualifier “*aff.*” if they had morphological  
814 affinities to a nominal species but could not be reliably identified using the information  
815 available; and (d) assigned the ON qualifier “*sp.*” if they showed little resemblance to any  
816 nominal species type specimen.

817 **Figure 2.** Number of UCE (solid) and exon (transparent) loci captured per taxa. Colours  
818 reflect family/genus membership. \* denotes samples that were subsequently removed due to  
819 low capture rate.

820 **Figure 3.** RAxML phylogeny based on 75% UCE/exon complete matrix. Phylogenetic  
821 relationships are delineated between Acroporidae genera (dashed outline) and outgroup families  
822 Agariciidae and Fungiidae. Acroporidae and Agariciidae are both from the complex  
823 scleractinian clade, while Fungiidae is from the robust clade (Romano & Palumbi, 1996).  
824 Node values show RAxML bootstrap values and posterior probabilities from ExaBayes  
825 analysis. Species level relationships within the Acropora/Isopora clade (in grey box) are  
826 shown in Figure 4.

827 **Figure 4.** Phylogeny of *Acropora* and *Isopora* extracted from the ML analysis of the  
828 combined UCE/exon 75% complete matrix. Inset cladogram depicts the systematic  
829 relationships of morpho-groups from Wallace (1999) with branch colours highlighting the  
830 major named morphological clades: Clade A (*rudis*, *austera* and *humilis* 2 groups) which  
831 contains the DND clade (*digitifera-nasuta-divaricata* and *humilis* group 1); clade B (*loveli*,  
832 *cervicornis*, *robusta*, *muricata*, *pharonis*); the HEEL clade (*horrida-elegans-echinata-*  
833 *loripes*); the SFAHL clade (*selago-florida-aspera-hyacinthus-latistella*). Specimen are labels  
834 indicate morpho-group designation coloured by morphological clade (inset). Squares at tips  
835 reflect the ON identification for each specimen (see legend). Bootstrap values of either 100%  
836 (white) or greater than 70% (grey) are indicating on internal nodes. Robust molecular clades  
837 are delineated I-VI.

838 **Table 1.** List of specimens used in the in vitro test of enhanced Hexacoral bait set with assembly summary statistics. Greyed out samples were  
839 removed from further analyses due to low contig number and/or matches to loci. Open nomenclature qualifiers (*cf.*, *aff.*, *sp.*) are used in species  
840 names to denote confidence in specimen identification to nominal species.

Family	Species	Specimen No.	# Contigs	# UCE	UCE Mean Length (bp)	# Exon	Exon Mean Length (bp)	Total # Loci
Acroporidae	<i>Acropora abrotanoides</i>	16-5870	10335	998	980	951	1075	1949
Acroporidae	<i>Acropora aff. aculeus</i>	PN47	7971	1021	988	969	1069	1990
Acroporidae	<i>Acropora aff. cytherea</i>	74-4537	7393	1010	1001	957	1098	1967
Acroporidae	<i>Acropora aff. cytherea</i>	30-5227	11194	1000	1002	955	1095	1955
Acroporidae	<i>Acropora aff. divaricata</i>	73-3798	7680	1000	1041	944	1136	1944
Acroporidae	<i>Acropora aff. echinata</i>	KM27	8079	1051	844	969	893	2020
Acroporidae	<i>Acropora aff. echinata</i>	KM32	7965	1022	949	987	1022	2009
Acroporidae	<i>Acropora aff. globiceps</i>	17-6445	5767	1029	997	977	1082	2006
Acroporidae	<i>Acropora aff. intermedia</i>	30-5271	7164	986	1083	948	1167	1934
Acroporidae	<i>Acropora aff. intermedia</i>	B6	7762	990	1003	933	1104	1923
Acroporidae	<i>Acropora aff. jacquelinae</i>	PN54	6531	983	1056	951	1143	1934
Acroporidae	<i>Acropora aff. latistella</i>	75-4779	9676	993	1035	980	1112	1973
Acroporidae	<i>Acropora aff. listeri</i>	75-4879	10598	1010	819	945	866	1955
Acroporidae	<i>Acropora aff. lokani</i>	PN51	10063	978	1025	916	1105	1894
Acroporidae	<i>Acropora aff. longicyathus</i>	TER_36	9322	1021	782	966	830	1987
Acroporidae	<i>Acropora aff. pichoni</i>	TER_20	9475	931	981	940	1095	1871
Acroporidae	<i>Acropora aff. speciosa</i>	PN62	8978	948	1065	938	1153	1886
Acroporidae	<i>Acropora aff. turaki</i>	KM35	8492	984	1099	928	1170	1912
Acroporidae	<i>Acropora aff. turaki</i>	KM50	8194	1008	933	946	1013	1954
Acroporidae	<i>Acropora azurea</i>	75-4857	8498	962	1055	925	1154	1887
Acroporidae	<i>Acropora cf. austera</i>	75-4732	8289	975	1090	987	1183	1962

Acroporidae	<i>Acropora cf. bifurcata</i>	29-8193	9438	1017	967	953	1053	1970
Acroporidae	<i>Acropora cf. digitifera</i>	81-2705	6123	1002	940	947	1014	1949
Acroporidae	<i>Acropora cf. kenti</i>	75-4865	5133	1046	722	975	747	2021
Acroporidae	<i>Acropora cf. orbicularis</i>	16-5974	13383	1022	885	957	965	1979
Acroporidae	<i>Acropora cf. orbicularis</i>	29-8212	14180	984	1043	979	1102	1963
Acroporidae	<i>Acropora cf. paniculata</i>	75-4686	5743	1023	920	970	1005	1993
Acroporidae	<i>Acropora cf. plumosa</i>	KM51	12294	1013	974	952	1067	1965
Acroporidae	<i>Acropora cf. plumosa</i>	69-4038	6009	993	997	968	1091	1961
Acroporidae	<i>Acropora cf. polymorpha</i>	B4	6351	1013	953	956	1042	1969
Acroporidae	<i>Acropora cf. rayneri</i>	TER_44	10527	929	957	928	1046	1857
Acroporidae	<i>Acropora cf. rongelapensis</i>	PN44	7277	995	1059	939	1181	1934
Acroporidae	<i>Acropora cf. rongelapensis</i>	PN45	8232	1023	968	969	1050	1992
Acroporidae	<i>Acropora cf. roseni</i>	29-8208	10316	992	1078	967	1192	1959
Acroporidae	<i>Acropora cf. spicifera</i>	29-8257	13415	1024	943	955	1042	1979
Acroporidae	<i>Acropora cf. sukarnoi</i>	29-8294	6943	1008	984	953	1079	1961
Acroporidae	<i>Acropora cf. tenella</i>	69-3957	6206	1004	1060	964	1168	1968
Acroporidae	<i>Acropora cf. tenella</i>	PN43	6889	1024	923	995	1008	2019
Acroporidae	<i>Acropora cf. tenella</i>	PN52	47	14	247	15	257	29
Acroporidae	<i>Acropora convexa</i>	30-5251	7817	1003	993	955	1081	1958
Acroporidae	<i>Acropora kirstyae</i>	74-4386	6885	995	1059	972	1159	1967
Acroporidae	<i>Acropora lokani</i>	TER_8	12433	956	1036	910	1120	1866
Acroporidae	<i>Acropora lokani</i>	69-4073	14983	1012	948	919	1007	1931
Acroporidae	<i>Acropora pichoni</i>	69-3948	7471	1010	977	975	1063	1985
Acroporidae	<i>Acropora pichoni</i>	TER_42	13089	995	981	942	1055	1937
Acroporidae	<i>Acropora sarmentosa</i>	74-4500	6377	1012	974	958	1041	1970
Acroporidae	<i>Acropora solitaryensis</i>	79-3886	10498	1002	920	960	1009	1962
Acroporidae	<i>Acropora sp. (29-8273)</i>	29-8273	7395	997	930	945	1024	1942
Acroporidae	<i>Acropora sp. (29-8277)</i>	29-8277	16145	1015	966	957	1052	1972

Acroporidae	<i>Acropora sp. (30-1740)</i>	30-1740	10037	1014	903	945	965	1959
Acroporidae	<i>Acropora sp. (69-3961)</i>	69-3961	7763	974	1034	953	1144	1927
Acroporidae	<i>Acropora sp. (69-KM21)</i>	KM21	3193	1051	541	999	528	2050
Acroporidae	<i>Acropora sp. (69-TER11)</i>	TER_11	14622	1040	698	971	733	2011
Acroporidae	<i>Acropora sp. (69-TER35)</i>	TER_35	1498	657	297	521	287	1178
Acroporidae	<i>Acropora sp. (69-TER37)</i>	TER_37	3041	1016	533	970	518	1986
Acroporidae	<i>Acropora sp. (69-TER40)</i>	TER_40	11472	905	832	864	893	1769
Acroporidae	<i>Acropora sp. (69-TER47)</i>	TER_47	4805	1051	833	999	887	2050
Acroporidae	<i>Acropora sp. (75-4774)</i>	75-4774	9197	996	980	953	1080	1949
Acroporidae	<i>Acropora sp. (75-4803)</i>	75-4803	3251	1042	614	1009	612	2051
Acroporidae	<i>Acropora spicifera</i>	30-5267	10635	993	1047	934	1155	1927
Acroporidae	<i>Acropora syringodes</i>	74-4532	11115	1007	1019	961	1107	1968
Acroporidae	<i>Acropora vasiformis</i>	16-5867	7941	1011	923	957	1021	1968
Acroporidae	<i>Acropora verweyi</i>	75-4990	9515	1003	1032	974	1114	1977
Acroporidae	<i>Acropora walindii</i>	KM30	8091	1019	989	963	1080	1982
Acroporidae	<i>Acropora walindii</i>	69-4031	8058	1018	985	952	1077	1970
Acroporidae	<i>Acropora walindii</i>	TER_13	3883	1045	817	991	880	2036
Acroporidae	<i>Anacropora cf. spinosa</i>	53-7072	43708	1016	955	924	903	1940
Acroporidae	<i>Astreopora cf. gracilis</i>	53-6964	48967	995	1011	920	984	1915
Acroporidae	<i>Astreopora cf. myriophthalma</i>	53-6863	20538	987	931	871	907	1858
Acroporidae	<i>Astreopora cf. myriophthalma</i>	53-7112	53608	1002	1034	936	1003	1938
Acroporidae	<i>Astreopora cf. randalli</i>	53-7115	49989	918	1017	892	1021	1810
Acroporidae	<i>Astreopora sp. (53-7166)</i>	53-7166	53766	974	1022	919	1027	1893
Acroporidae	<i>Isopora cf. brueggemanni</i>	53-7063	9041	861	987	868	1050	1729
Acroporidae	<i>Montipora cf. aequituberculata</i>	81-2751	11092	360	739	460	637	820
Acroporidae	<i>Montipora cf. capitata</i>	TER_9	18227	139	805	234	722	373
Acroporidae	<i>Montipora cf. efflorescens</i>	81-2884	9249	1002	762	901	749	1903
Acroporidae	<i>Montipora cf. foliosa</i>	74-4576	13959	970	864	904	816	1874

Acroporidae	<i>Montipora cf. monasteriata</i>	TER_46	15035	698	949	724	917	1422
Acroporidae	<i>Montipora cf. nodosa</i>	75-5006	14672	972	1001	913	963	1885
Acroporidae	<i>Montipora cf. spongodes</i>	81-2847	5295	1001	646	933	633	1934
Acroporidae	<i>Montipora cf. undata</i>	79-3890	11248	970	888	913	871	1883
Acroporidae	<i>Montipora sp. (69-4301)</i>	69-4301	15035	993	874	928	866	1921
Acroporidae	<i>Montipora sp. (79-3903)</i>	79-3903	6283	996	722	928	700	1924
Acroporidae	<i>Montipora sp. (81-2697)</i>	81-2791	7488	1015	741	923	723	1938
Acroporidae	<i>Montipora sp. (81-2697)</i>	81-2697	14906	984	846	884	837	1868
Agariciidae	<i>Leptoseris aff. hawaiiensis</i>	PN36	13524	800	907	733	867	1533
Agariciidae	<i>Leptoseris aff. incrustans</i>	PN25	14186	943	981	813	949	1756
Agariciidae	<i>Leptoseris cf. fragilis</i>	PN12	15120	929	1038	811	983	1740
Agariciidae	<i>Leptoseris cf. glabra</i>	PN09	2159	785	515	573	470	1358
Agariciidae	<i>Leptoseris cf. scabra</i>	PN26	9257	963	994	814	967	1777
Fungiidae	<i>Ctenactis cf. echinata</i>	Cf	12759	977	987	814	926	1791
Fungiidae	<i>Fungia fungites</i>	60f	15389	948	1019	777	950	1725
Fungiidae	<i>Fungia fungites</i>	903f	12924	968	969	794	925	1762
Fungiidae	<i>Herpolitha limax</i>	4f	15865	957	1056	789	994	1746
Fungiidae	<i>Pleuraetis paumotensis</i>	3f	18010	915	1038	762	975	1677
Fungiidae	<i>Pleuraetis paumotensis</i>	11f	14016	928	997	770	945	1698
Fungiidae	<i>Polyphyllia talpina</i>	7f	15708	1033	960	878	921	1911
Fungiidae	<i>Sandalolitha robusta</i>	10f	8447	995	892	829	833	1824
Fungiidae	<i>Sandalolitha robusta</i>	6f	13475	981	963	840	906	1821

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845 **Table 2.** Alignment matrix statistics for different taxonomic datasets. Matrix percentage equals the percent occupancy of species per locus. PI =  
 846 parsimony informative sites as calculated in Phyluce.

<b>Dataset</b>	<b># Taxa</b>	<b>% Matrix</b>	<b>Total # Loci</b>	<b># UCE/exon Loci</b>	<b>Alignment Length</b>	<b>Mean Aligned Locus Length (<math>\pm</math> SD bp)</b>	<b>Aligned Locus Length Range (bp)</b>	<b># PI Sites</b>	<b>% PI Sites<sup>a</sup></b>
All Taxa	96	75	1792	991/801	1,868,953	1042 $\pm$ 529	106-4220	697,843	46
	96	95	618	470/148	611,631	989 $\pm$ 413	222-3653	238,569	45
Acroporidae	83	75	1852	992/860	2,236,868	1208 $\pm$ 532	267-4316	671,600	38
	83	95	899	596/303	1,055,570	1174 $\pm$ 484	423-4213	325,959	38
<i>Acropora</i>	64	75	1916	993/923	2,280,802	1190 $\pm$ 456	342-3837	327,541	18
	64	95	1227	739/488	1,410,701	1157 $\pm$ 402	494-3365	189,608	16
<i>A. walindii</i>	3	100	1781	949/832	1,746,225	980 $\pm$ 256	338-3238	27,248 <sup>b</sup>	1.5

847 <sup>a</sup> calculated by dividing # PI sites by # sites checked for differences

848 <sup>b</sup> calculated as number of variable sites present in all loci

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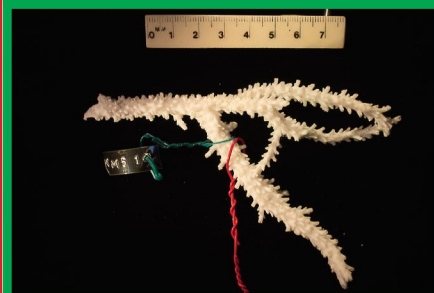
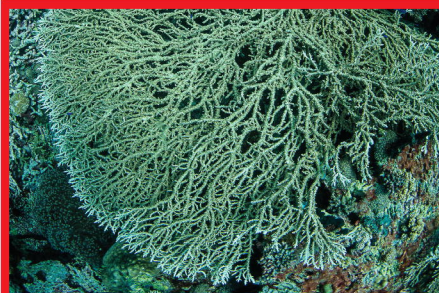
(a)

*Acropora pichoni*  
Wallace 1999



(b)

*Acropora cf. plumosa*  
Wallace & Wolstenholme 1998



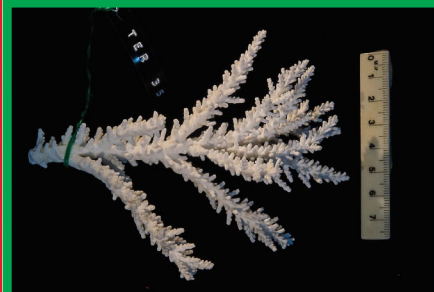
(c)




*Acropora aff. longicyathus*  
Milne Edwards & Haime 1860

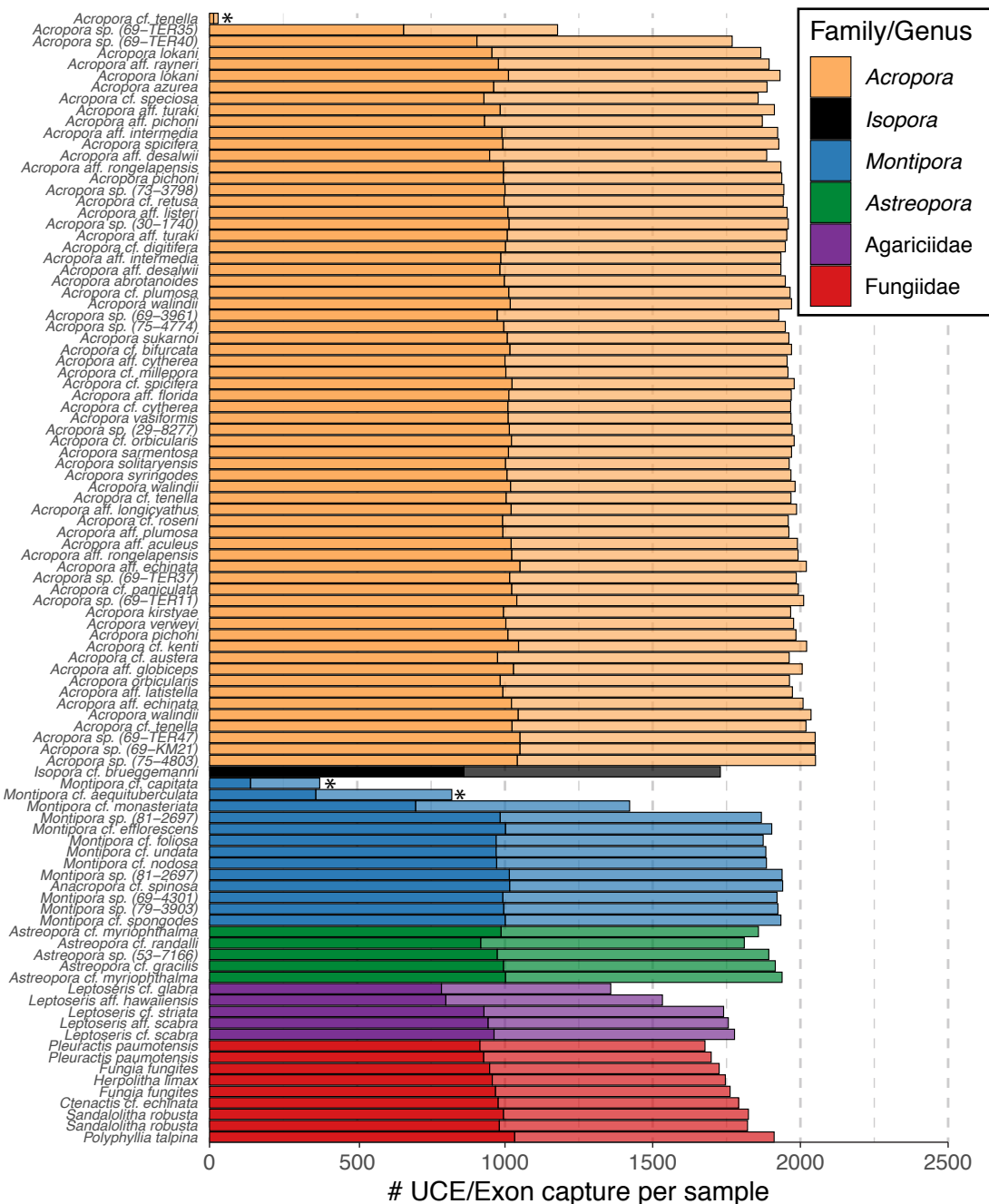


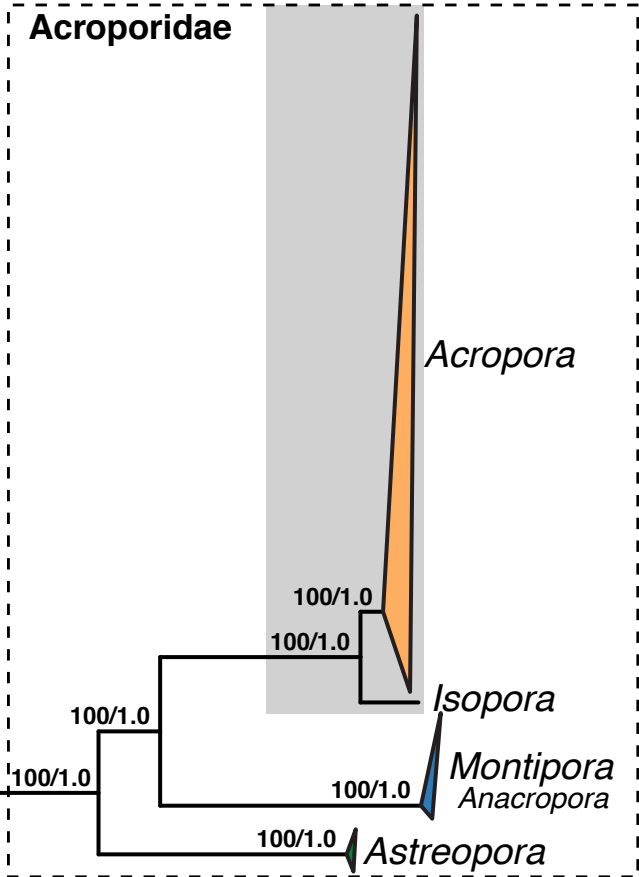
(d)

*Acropora sp. 69-TER 35*



-  Specimen in field
-  Specimen in lab
-  Holotype





**Acroporidae**

*Acropora*

*Isopora*

*Montipora*  
*Anacropora*

*Astreopora*

**Agariciidae**

**Fungiidae**

0.1

100/1.0

100/1.0

100/1.0

100/1.0

100/1.0

100/1.0

100/1.0

