A crash course in taxonomy for zoological scientists

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Talk outline

- A crash course in taxonomy including an introduction to 250 years of coral taxonomy including
- Present the Veron (2000) framework and some tests of its validity
- Potential problems working with a flawed taxonomic framework
- The way forward

Species names in zoology

- The International Code of Zoological Nomenclature

https://www.iczn.org/the-code/the-code-online/

- International Commission on Zoological Nomenclature
  - "The ICZN provides and regulates a uniform system of zoological nomenclature ensuring that every animal has a unique and universally accepted scientific name."

How to establish a new nominal species

- Designate a *holotype* - the *single* specimen upon which a new nominal species is based in the original publication
  - provide a formal description with an illustration or photo
  - Publish this description – does not need to be peer reviewed
  - Deposit the specimen in a recognized institution e.g. a museum

Article 25. Formation and treatment of names

Recommendation 25C. Responsibility of authors forming new names. Authors should exercise reasonable care and consideration in forming new names to ensure that they are chosen with their subsequent users in mind and that**, as far as possible, they are appropriate, compact, euphonious, memorable, and do not cause offence**.

- No need for molecular data or any other lines of evidence
- No requirement for peer review

Cyphastrea salae Baird, Hoogenboom & Huang 2017

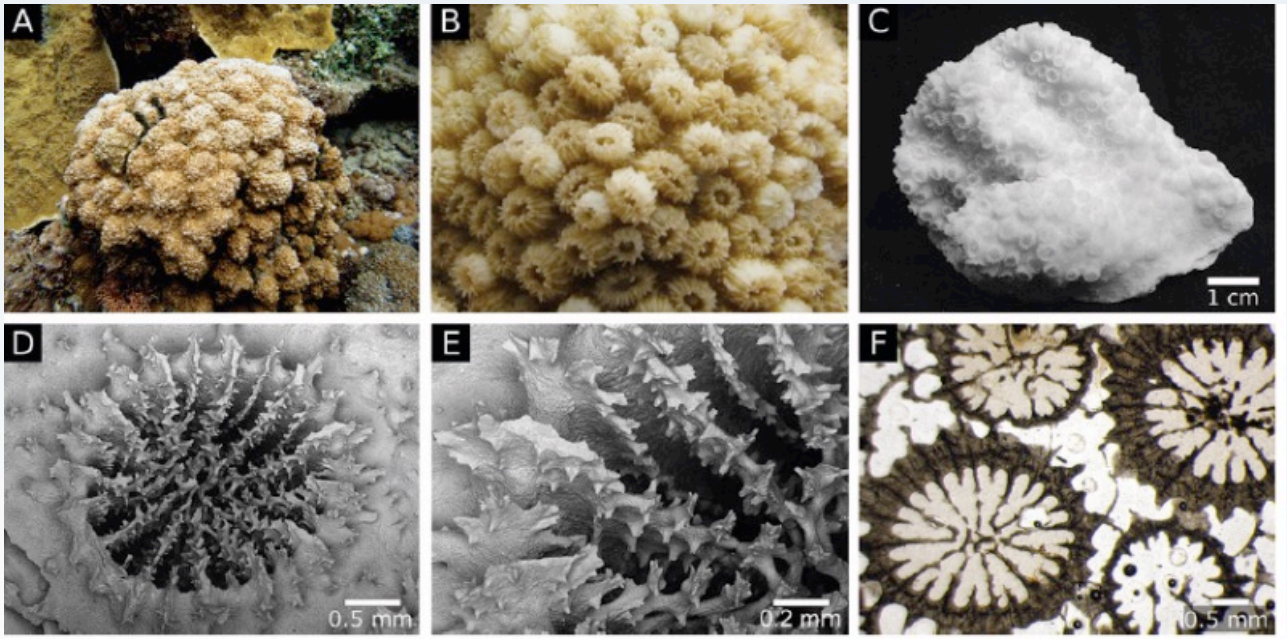


Figure 1. *Cyphastrea salae* sp. n. **A** habit photo of the holotype (G.18222) in situ **B** close up of holotype in situ **C** holotype **D** SEM of corallite **E** SEM of septa **F** transverse thin section.

Cyphastrea salae Baird, Hoogenboom & Huang 2017

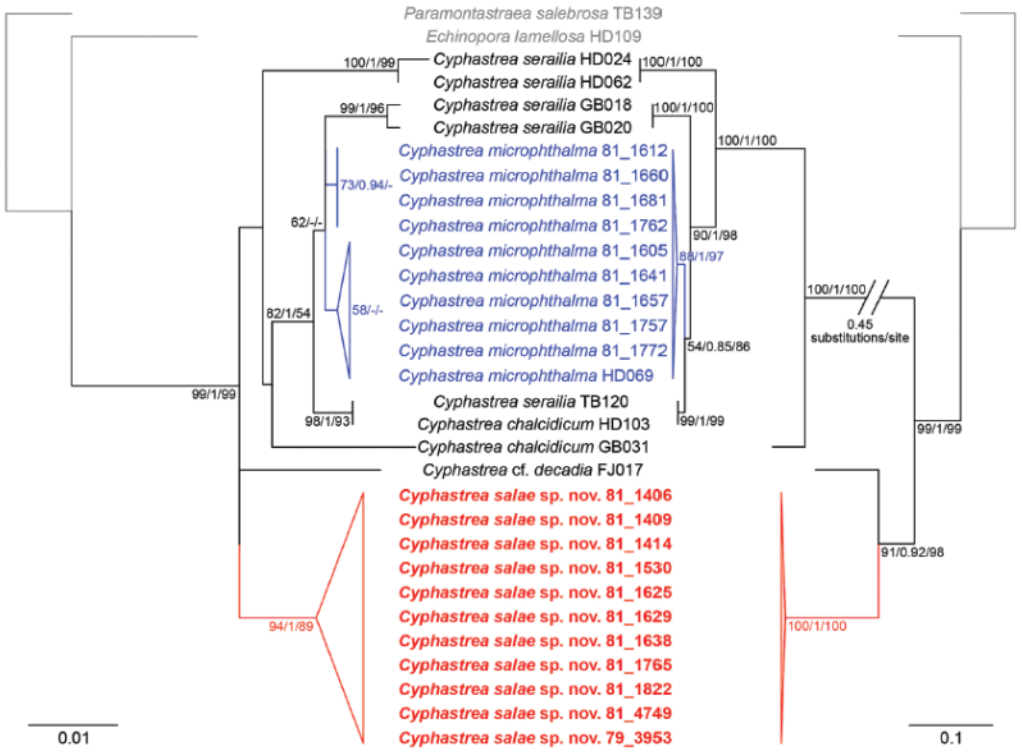


Figure 4. Maximum likelihood phylogenies based on the nuclear 28S rDNA (left) and mitochondrial noncoding intergenic region (right). Taxa in grey are outgroups. *Cyphastrea salae* sp. n. and *C. microphthalma* in red and blue respectively. Numbers adjacent to each branch represent support values (maximum likelihood bootstrap ≥ 50; Bayesian posterior probability ≥ 0.85; maximum parsimony bootstrap ≥ 50).

Millepora muricata Linneaus, 1758

murica-ta. 14. M. ramoſa, poris conſertis ſtellatis prominentibus erecto-truncatis.

Hort. cliff. 481. Millepora ramoſiſſima, punctis ſubtus ſemiovato-prominulis, ramis acutis.

Sloan. jam. 1. *p.* 51. *t.* 18. *f.* 3. Corallium album poroſum maximum muricatum.

Tournef. inſt. 573. Madrepora erectior ramoſa, tuberculis crebris ſurſum ſpectantibus.

Gualt. teſt. t. 81. Madrepora candida digitata, ramis tenuioribus peracutis quaſi dimidiatis & ſurſum ſpectantibus denſiſſime exaſperata.

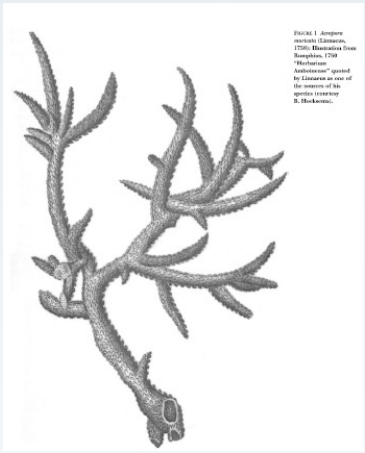
Rumph. amb. 6. *p.* 239. *t.* 86. *f.* 1. Lithodendron calcareum.

Muſ. hoſt. 3. *p.* 566. *ſ.* 15. *t.* 10. *f.* 3. Porus albus erectior ramoſus, tuberculis crebris ſurſum ſpectantibus.

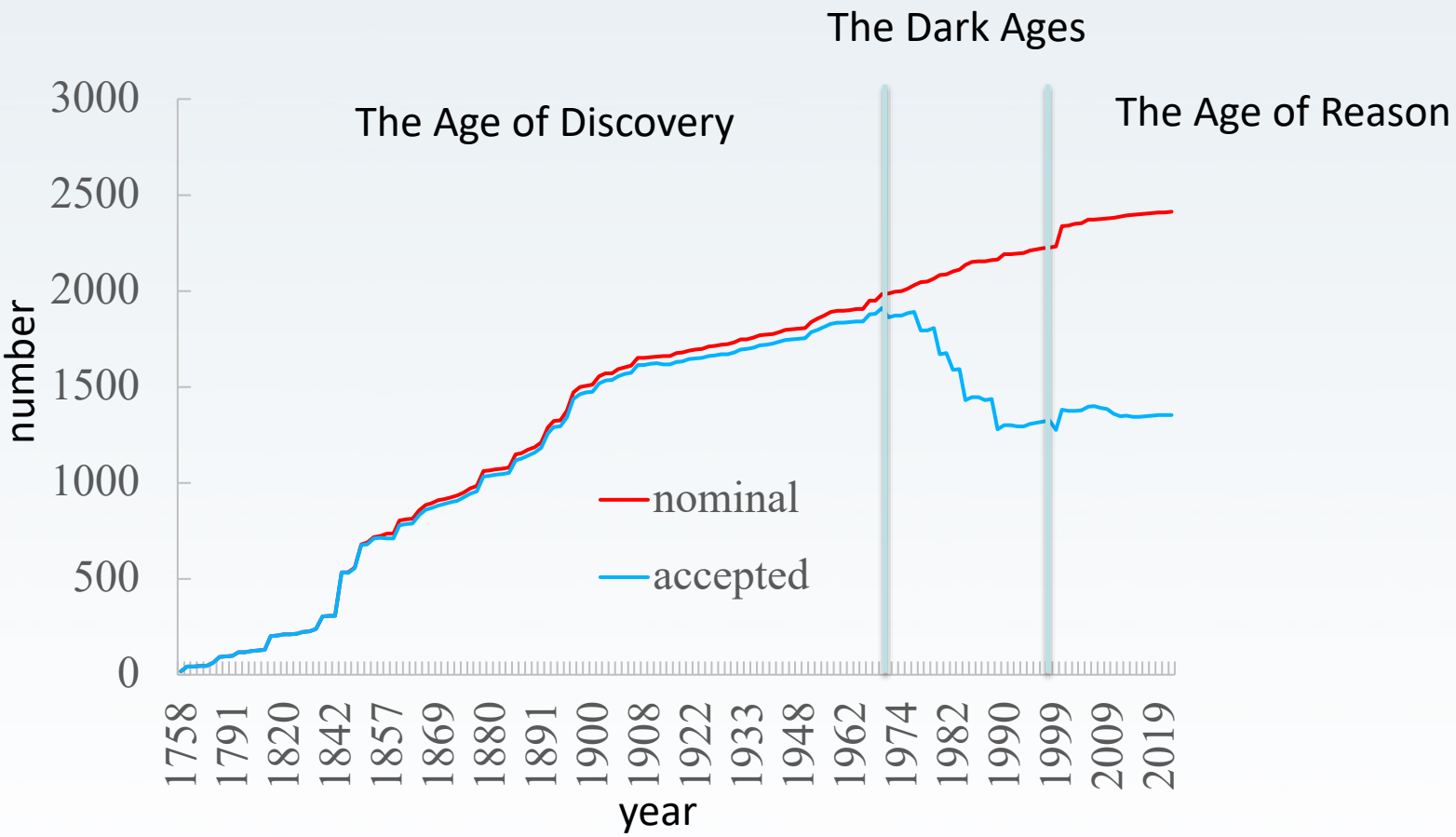
β. *Muſ. Teſſ.* 116. Madrepora ramoſa, ramis adſperſis papillis ſubcylindricis apice introrſum magis hiantibus.

Habitat in Pelago Aſiatico.

Rami *varii, albi, ſtriis exeſis tecti, adſperſi undique mucronibus cavis latere ſuperiore truncatis ſ. cochlearibus, interne fere ſtellatis.*



The three Ages of coral taxonomy



The Age of Discovery: 2000+ nominal species in 230 years

Linneas 1758
Esper 1789
Ellis & Solander 1786
Lamark 1814
Ehrenberg 1832
Klunzinger 1879
Dana 1846
Milne-Edwards & Haime 1849+
Bernard 1896
Brook 1891
Eguchi et al 1935
Ma 1951

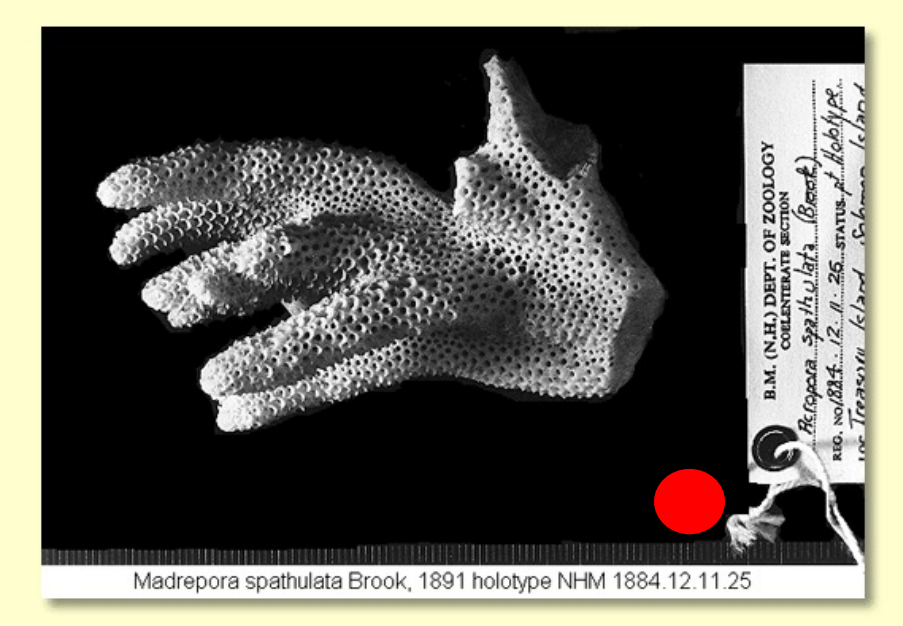
A nominal species is forever

- The name associated with the holotype never changes
- However, if a later author does not accept that it is a valid species i.e. distinct from all other nominal species, they can synonymise the nominal species

Synonymies


Heteropora millepora Ehrenberg, 1834 holotype MNB 854

*Acropora millepora (*Ehrenberg 1834)
Type location: not recorded



Madrepora spathulata Brook, 1891 holotype NHM 1884.12.11.25

Acropora spathulata Brook 1891
Type location: Solomon Islands

Synonymies

- Based on the morphology of the holotypes Veron & Wallace (1984) decided that *Acropora millepora* Ehrenberg 1834 and *A. spathulata* Brook 1891 were the same species
- Therefore, they synonymised the later name on the basis of priority i.e. the earlier name wins

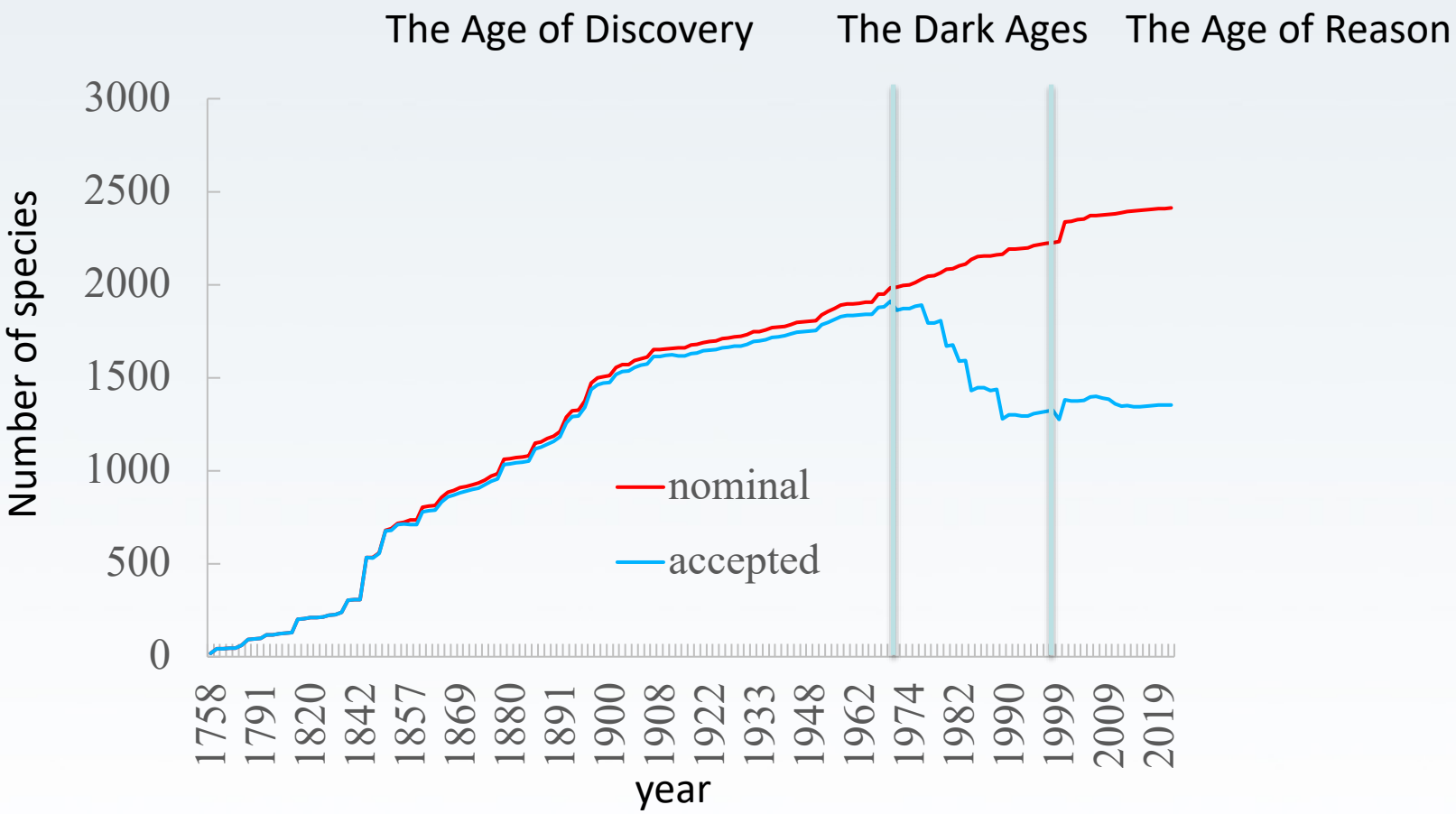
Synonymies

- Based on breeding trials Wallace & Willis (1994) decided that *Acropora millepora* Ehrenberg 1834 and *A. spathulata* Brook 1891 were different species.
- Therefore, they resurrected the name *Acropora spathulata* Brook 1891

Synonymies: names through time

- 1834 - one nominal species
- 1891 - two nominal species
- 1984 - two nominal species: one valid; one synonymised
- 1994 - two nominal species: both valid

The three Ages of coral taxonomy

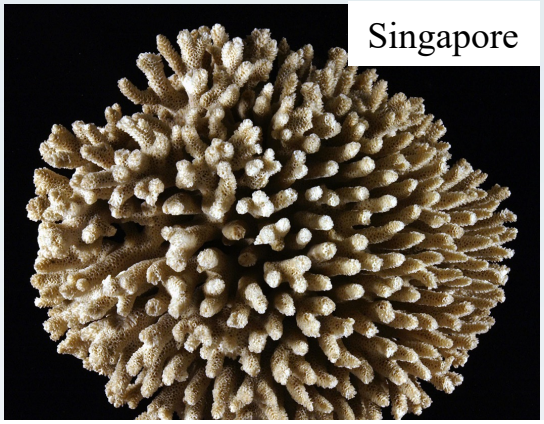


Synonymies for *Acropora millepora*

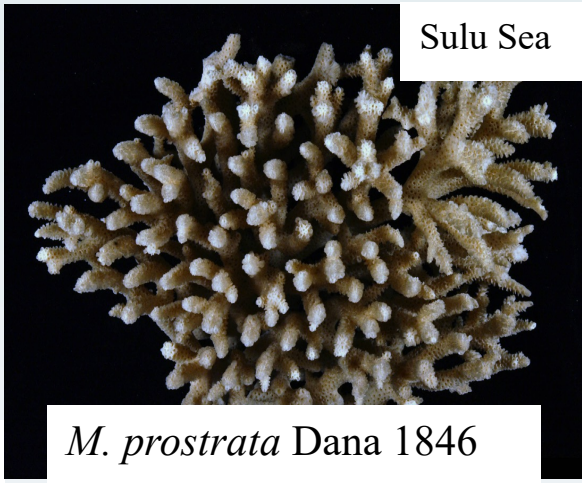
Veron & Wallace 1984 list 7 nominal species

- one valid:
  - *Acropora millepora* (Ehrenberg 1834)
- six synonymised:
  - *Madrepora convexa* Dana 1846
  - *M. prostrata* Dana 1846
  - *M. squamosa* Brook 1892
  - *M. rubra* Studer 1878
  - *Acropora singularis* Nemenzo 1967
  - *Acropora librata* Nemenzo 1967

Acropora millepora and synonymies

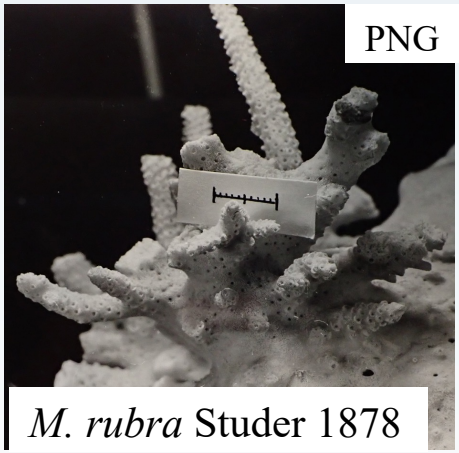


Madrepora convexa Dana 1846



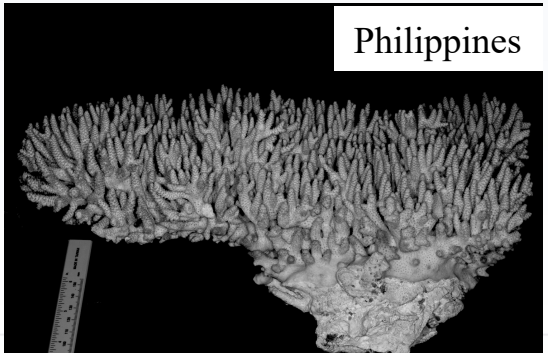
M. prostrata Dana 1846

Heteropora millepora Ehrenberg 1834



M. rubra Studer 1878

M. squamosa Brook 1892

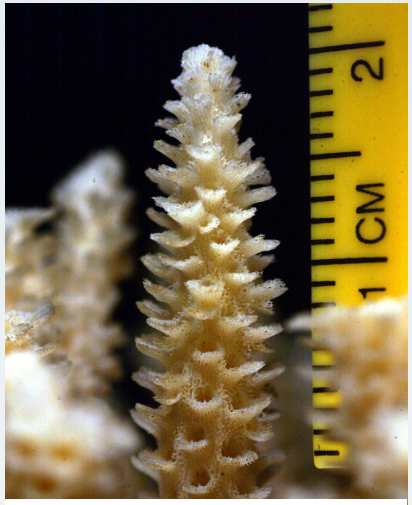


Acropora librata Nemenzo 1967

A. singularis Nemenzo 1967

Heteropora millepora
Ehrenberg 1834

Madrepora convexa
Dana 1846

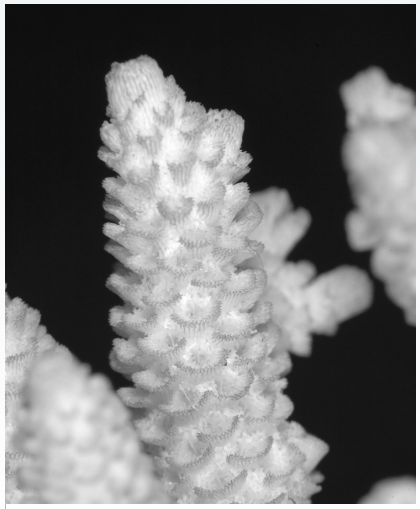


M. prostrata
Dana 1846

M. rubra
Studer 1878

M. squamosa
Brook 1892

Acropora librata
Nemenzo 1967

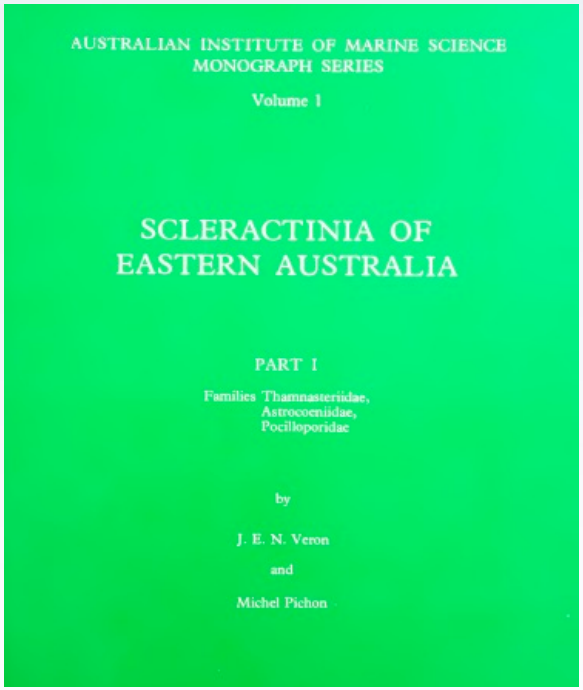


Acropora singularis
Nemenzo 1967

Common Great Barrier Reef species and synonyms (Veron & Wallace 1984)

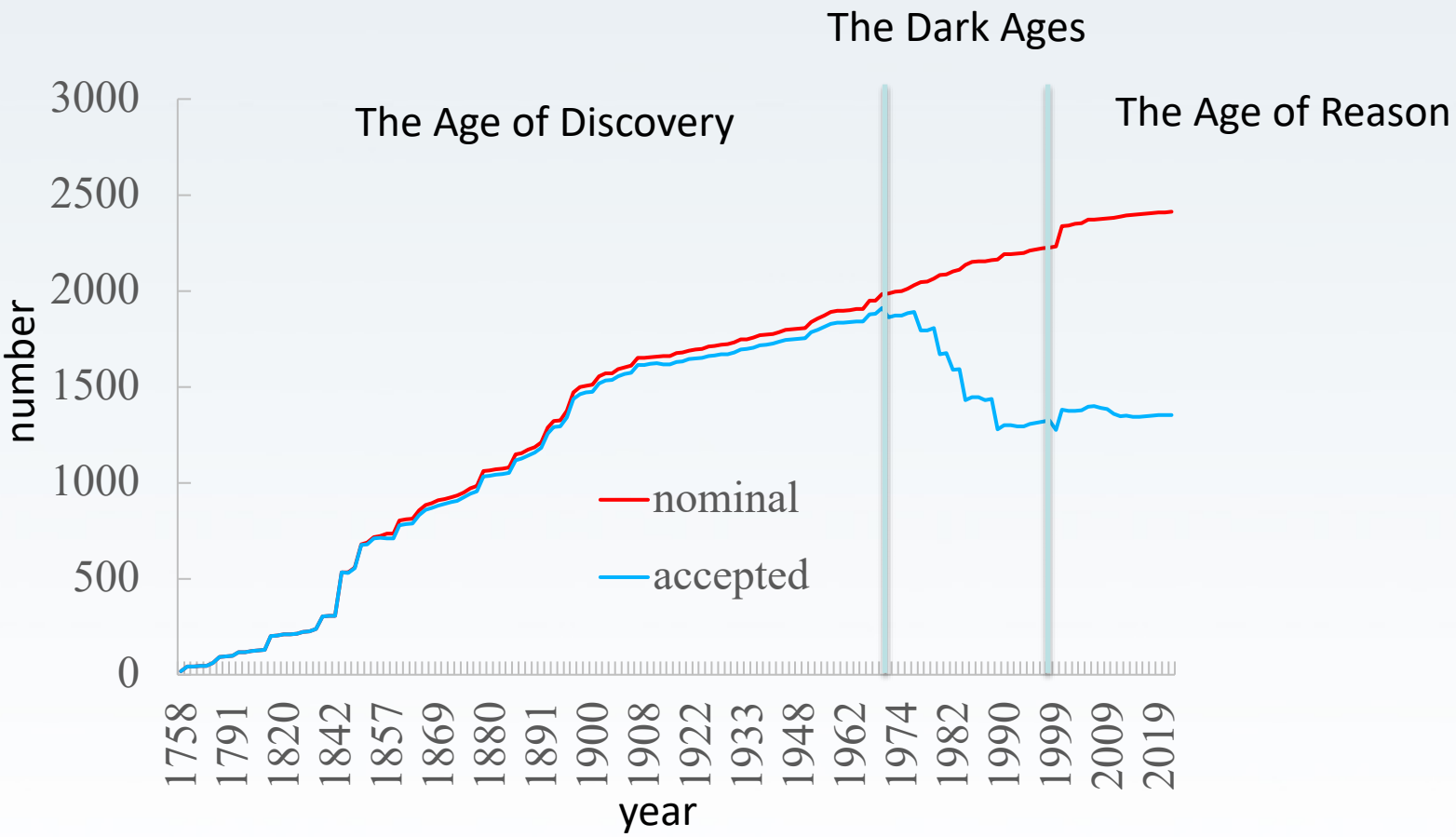
- *Acropora hyacinthus* - 8 synonyms
- *Acropora millepora* - 7 synonyms
- *Acropora nasuta* - 3 synonyms
- *Acropora tenuis* - 5 synonyms
- *Acropora valida* - 5 synonyms

Scleractinia of Eastern Australia



- Five volumes over 8 years

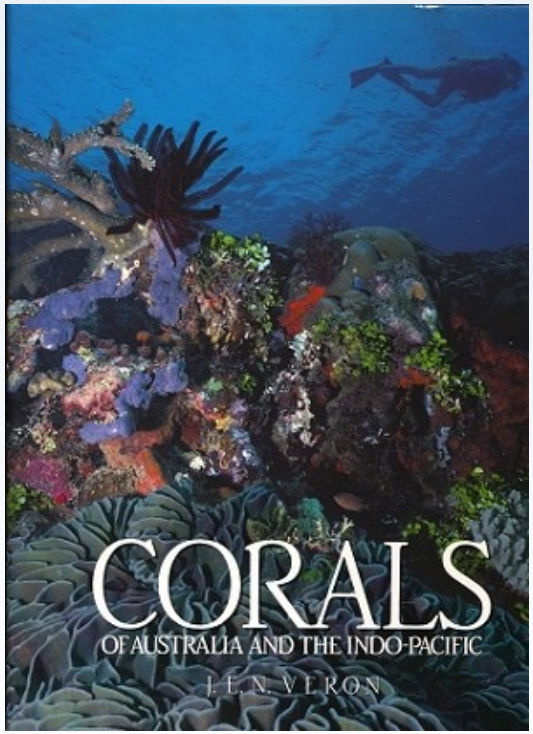
The three Ages of coral taxonomy



The Dark ages or “The Great Lumping”

- Prior to 1970s only 85 nominal species had been synonymised in over 200 years
- Wijsman-Best 1972 synonymies 50 nominal species in her revision of the Family Faviidae.
- Veron et al 1976-84 synonymise 454 species, 20% of the nominal species at the time
- Veron et al 1976-84 ignore another 350+ species

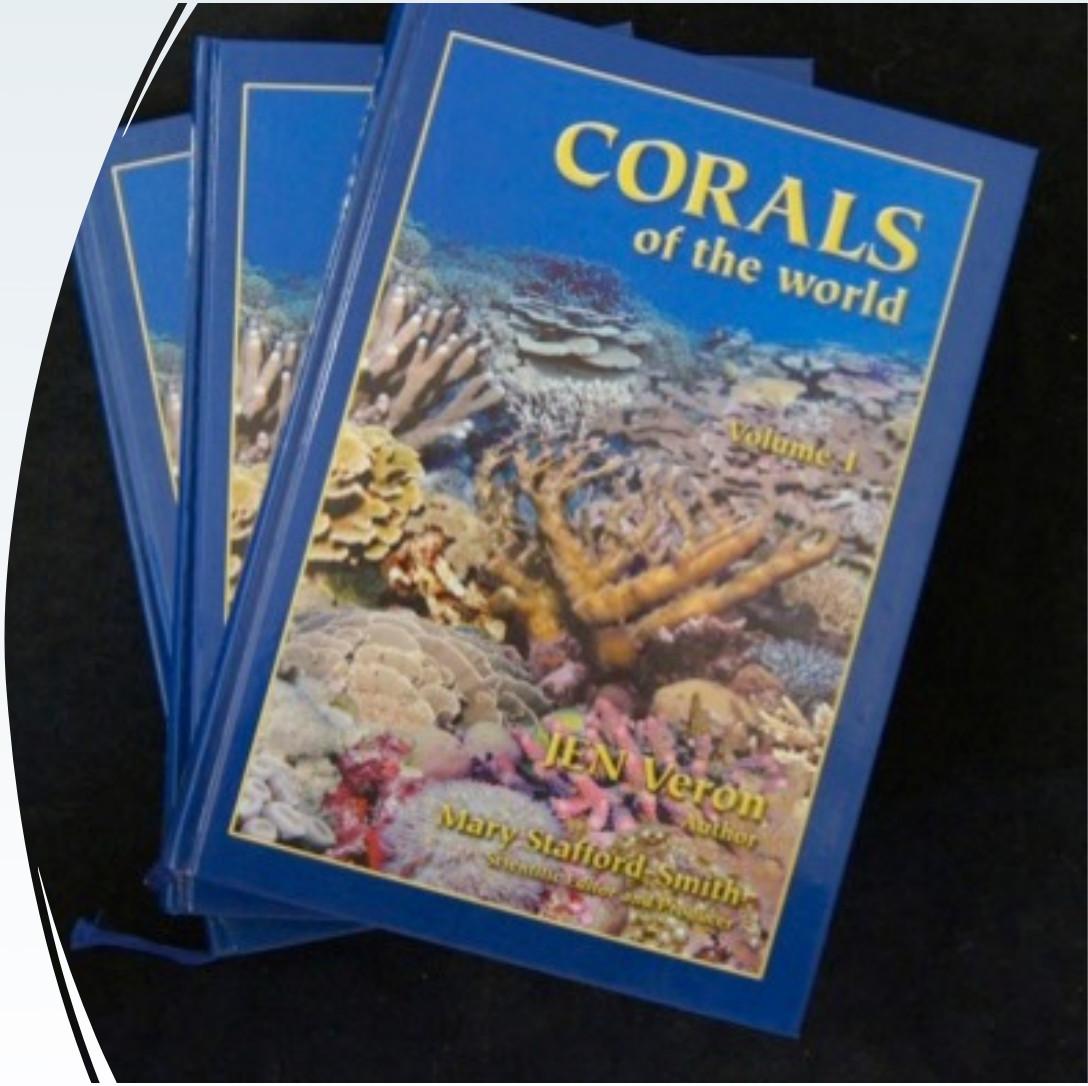
Veron 1986 Corals of Australia and the Indo-Pacific



The hubris begins- coral identification not taxonomy

Veron (2000)

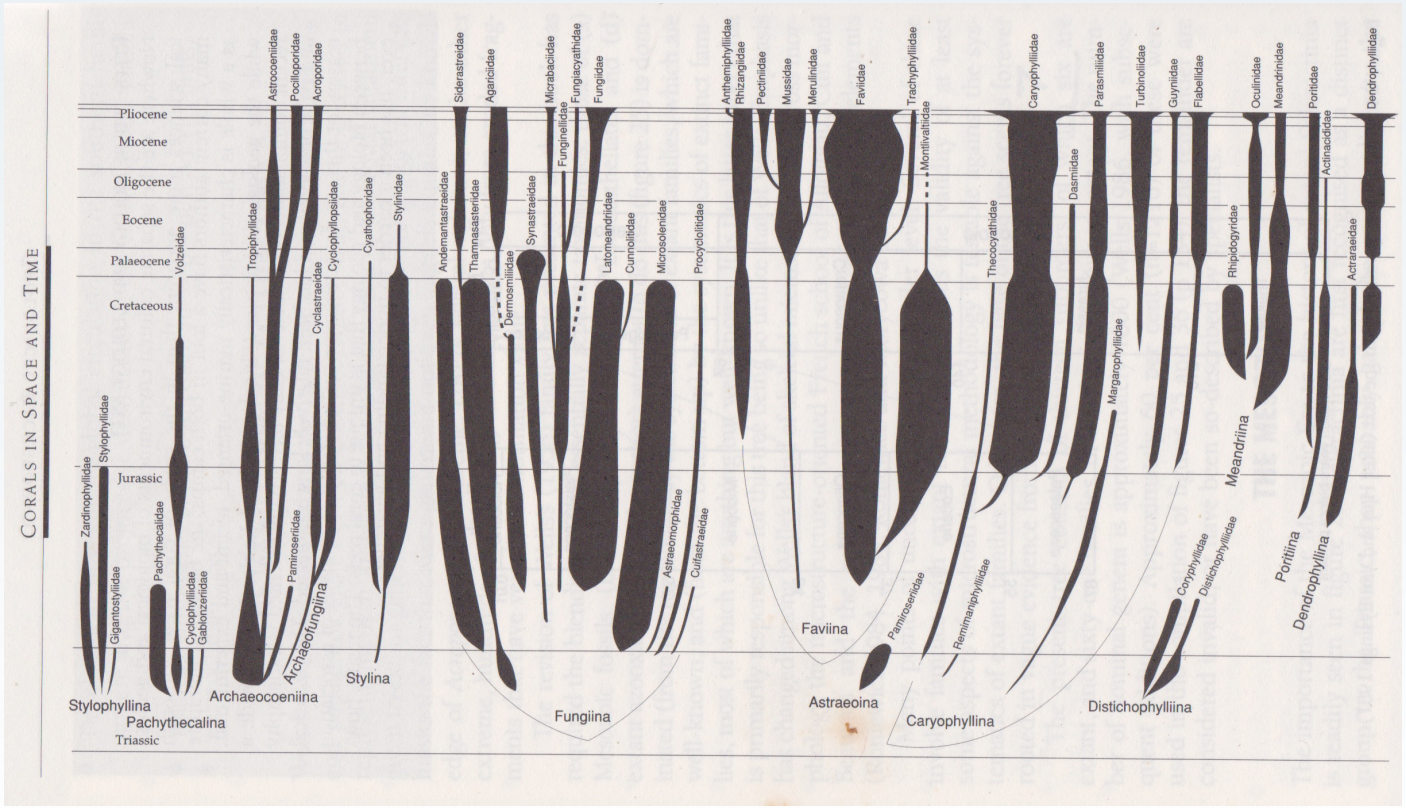
- 18 families
- 112 genera
- 799 species



Corals of the World: species distribution

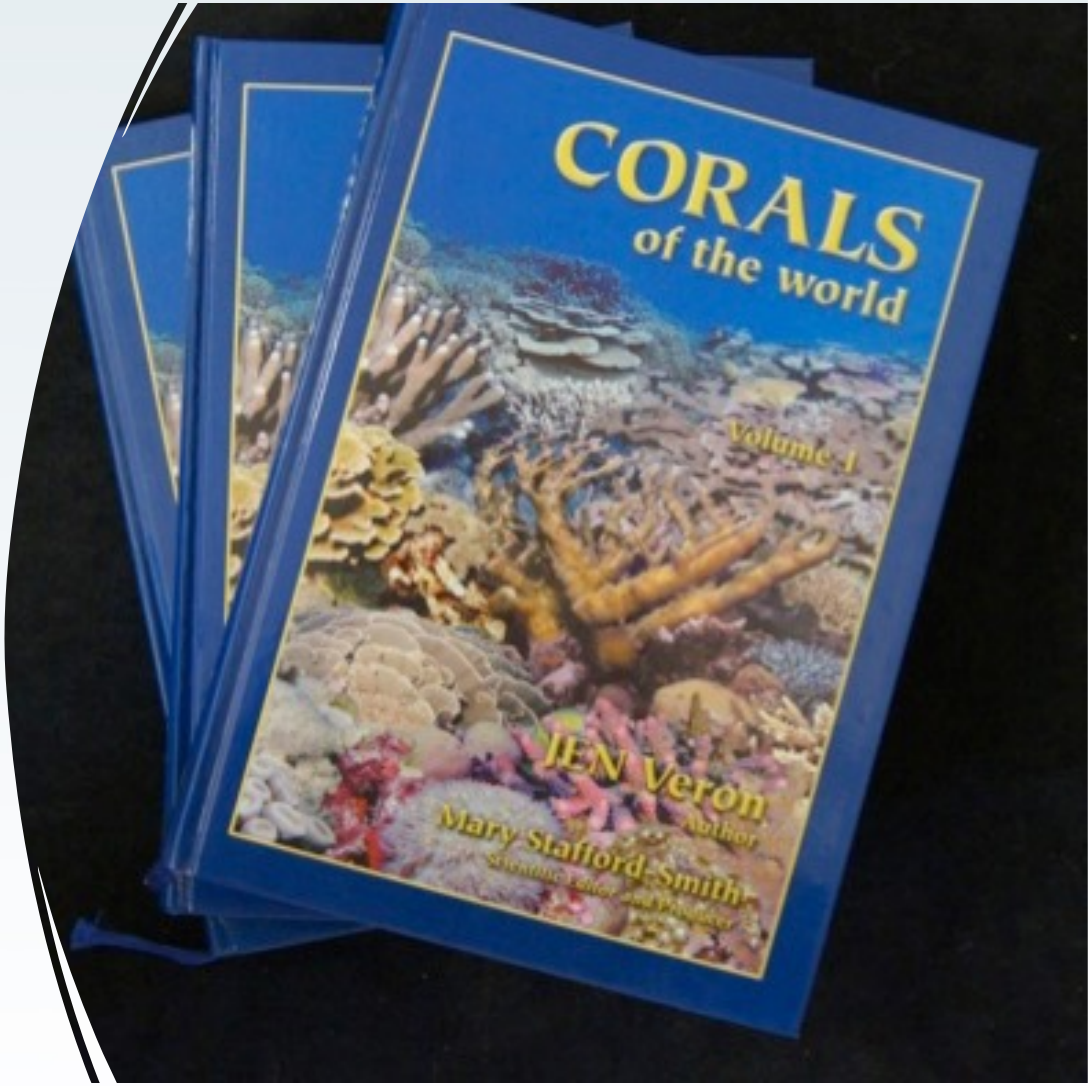
Acanthastrea bowerbanki Milne-Edwards and Haime, 1851

Corals of the World: family tree



Veron (2000)

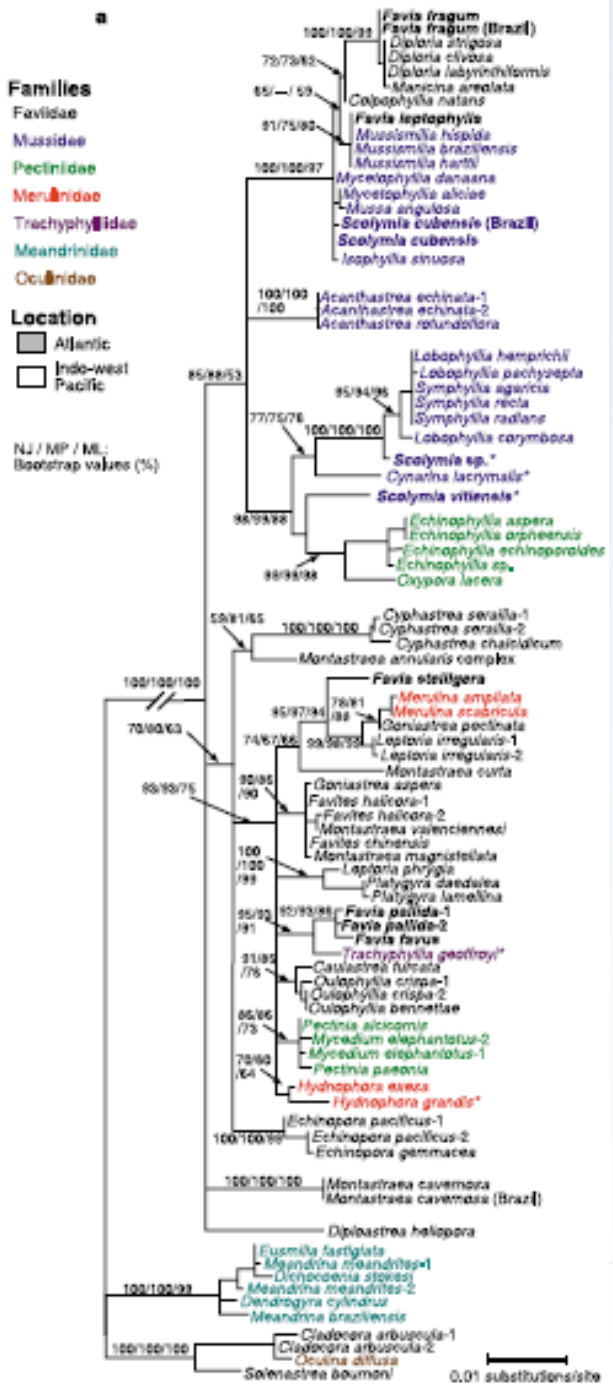
- No molecular data
- No quantitative morphology
- No reproductive biology
- No experimental tests of key concepts, such as morphological plasticity
- Surprising indifference to much of the type material



Testing Veron's hypothesis: the family tree

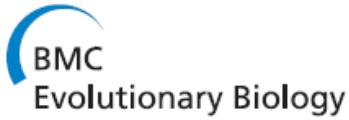
Few if any families monophyletic

Fukami et al 2004



The Bigmessidae

Huang *et al. BMC Evolutionary Biology* 2011, **11**:37
http://www.biomedcentral.com/1471-2148/11/37



RESEARCH ARTICLE Open Access

Cleaning up the 'Bigmessidae': Molecular phylogeny of scleractinian corals from Faviidae, Merulinidae, Pectiniidae and Trachyphylliidae

Danwei Huang[1,2*], Wilfredo Y Licuanan[3], Andrew H Baird[4], Hironobu Fukami[5]

Genus Veron 2000	Genus molecular	Family molecular
Australogyra	Australogyra	Merulinidae
Barabattoai	Dipsastrea	Merulinidae
Caulastrea	Caulastrea	Merulinidae
Cladocora	Cladocora	Oculinidae
Colpophyllia	Colpophyllia	Mussidae
Cyphastrea	Cyphastrea	Merulinidae
Diploastrea	Diploastrea	Diploastridae
Diploria	Diploria	Mussidae
	Psuedodiploria	Mussidae
Echinopora	Echinopora	Merulinidae
Erythrastrea	Erythrastrea	Merulinidae
Favia	Favia	Merulinidae
	Dipsastrea	Merulinidae
	Goniastrea	Merulinidae
Favites	Favites	Merulinidae
	Paragoniastrea	Merulinidae
	Paramontastrea	Merulinidae
Goniastrea	Goniastrea	Merulinidae
	Paragoniastrea	Merulinidae
	Coelastrea	Merulinidae
Leptastrea	Leptastrea	Fungiidae
Leptoria	Leptoria	Merulinidae
Manicina	Manicina	Mussidae
Montastrea	Montastraea	Montastreidae
	Astraea	Merulinidae
	Paramontastraea	Merulinidae
	Orbicella	Merulinidae
	Micromussa	Lobophyllidae
	Favites	Merulinidae
Moseleya	Moseleya	Lobophyllidae
Oulastrea	Oulastrea	Outlastreidae
Oulophyllia	Oulophyllia	Merulinidae
Parasimplastrea	Blastomussa	Plesiastreidae
Platygyra	Platygyra	Merulinidae
Plesiastrea	Plesiastrea	Plesiastreidae
	Dipsastrea	Merulinidae
Solenastrea	Solenastrea	Oculinidae

The former Family Faviidae

- Most genera either synonymised e.g. *Barabattoia* or split, e.g. species of *Favia* in 3 genera
- Veron's 24 genera now distributed among at least 35 genera in 9 different families

Testing the family tree: the genus *Montastrea*

Veron species	Molecular species	Molecular family
Montastrea annuligera	Astrea annuligera	Merulinidae
Montastrea curta	Astrea curta	Merulinidae
Montastrea colemani	Favites colemani	Merulinidae
Montastrea magnistellata	Favites magnistellata	Merulinidae
Montastrea valenciennesi	Favites valenciennesi	Merulinidae
Montastrea multipunctata	Micromussa multipunctata	Lobophyllidae
Montastrea cavernosa	Montastraea cavernosa	Montastreidae
Montastrea annularis	Orbicella annularis	Merulinidae
Montastrea faveolata	Orbicella faveolata	Merulinidae
Montastrea franksi	Orbicella franksi	Merulinidae
Montastrea salebrosa	Paramontastraea salebrosa	Merulinidae
Montastrea serageldini	Paramontastraea serageldini	Merulinidae

The 12 species accepted by Veron 2000 are now in 6 genera in 3 Families

The Genus *Acropora*

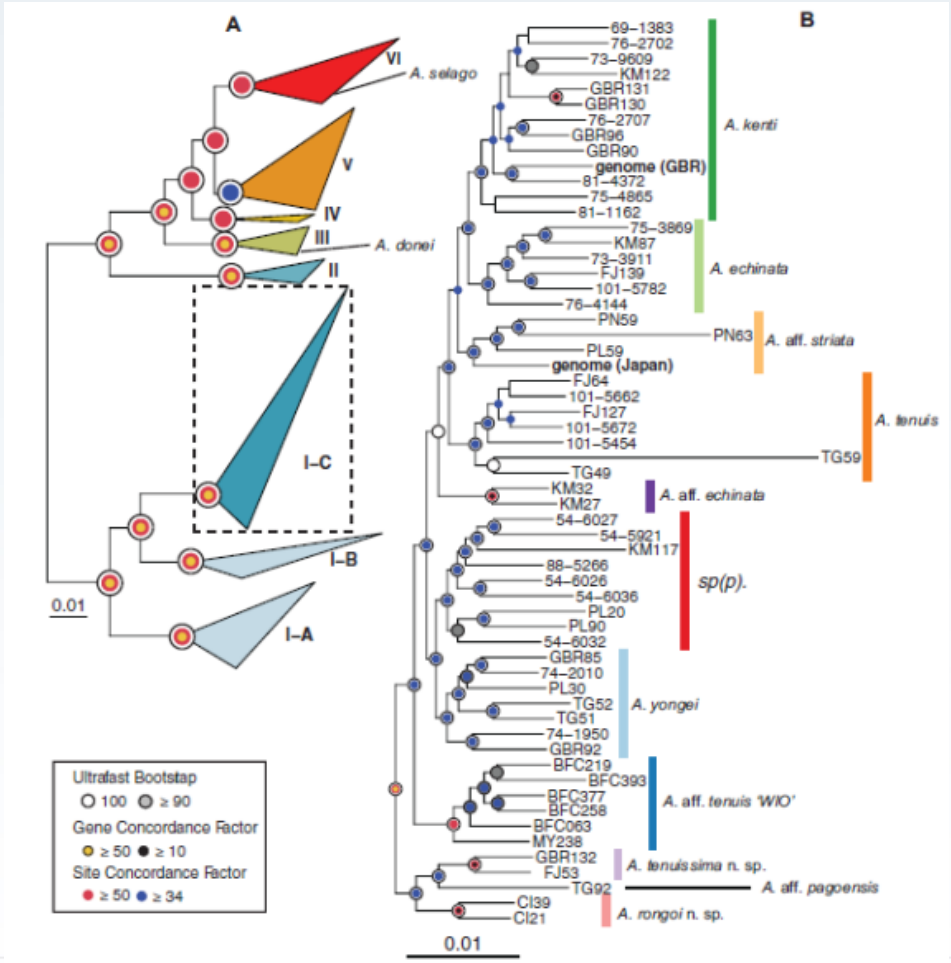
Cowman et al in review

890 specimens, 272 Primary Species hypotheses (PSH)

- 50 PSH - accepted species
- 28 PSH – previously synonymised
- 122 PSH – unresolved, many likely to be new
- 72 PSH – undescribed

- Only 50 of 272 species are in the identification guides

Bridge et al 2024 – tenuis complex

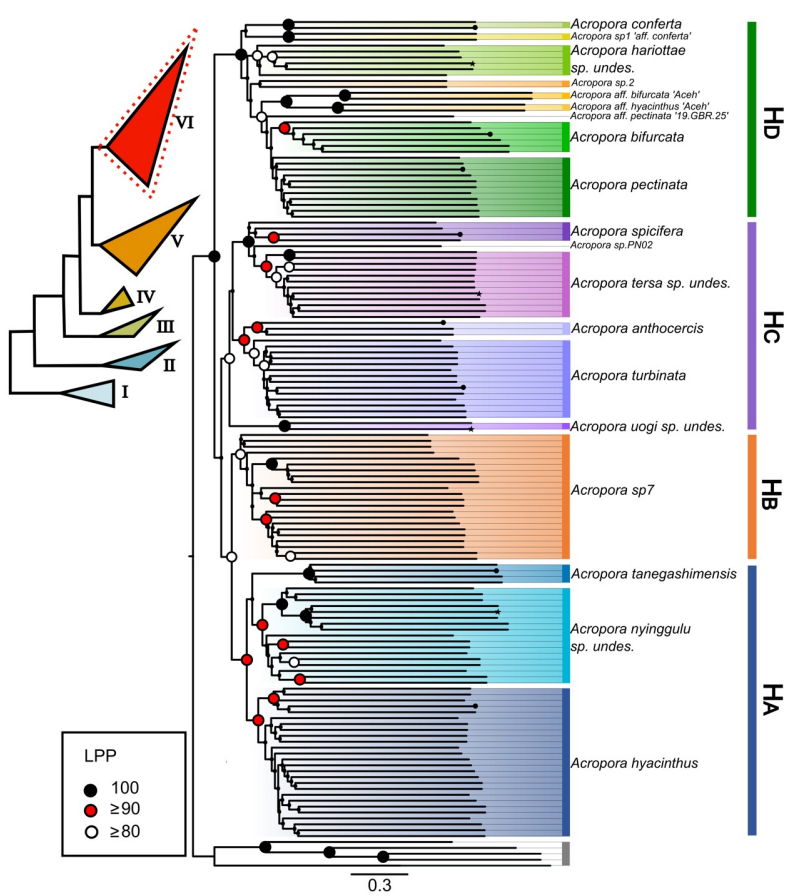


The resurrection of five junior synonyms
Acropora macrostoma (Brook, 1891)
Acropora kenti (Brook, 1892)
Acropora bifaria (Brook, 1892)
Acropora africana (Brook, 1893)
Acropora akajimensis Veron, 1990

The paper also describes two new species:

- *Acropora tenuissima* Bonito, Bridge, Fenner & Baird, 2023
- *Acropora rongoi* Bridge & Cowman, 2023

Rasumussen et al 2025: *hyacinthus* complex



At least 11 undescribed species, four named

Acropora tersa

Acropora harriottae

Acropora uogi

Acropora nyingaloo

Resurrect 5 species in synonymy

Acropora pectinata (Brook 1893);

A. conferta (Dana 1846);

A. turbinata

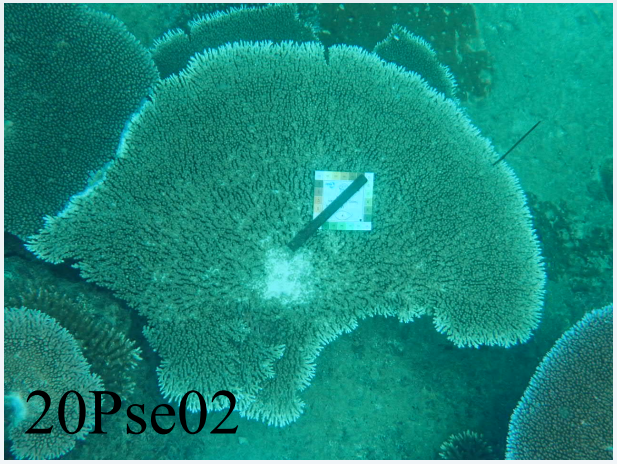
A. tanegashimanensis Veron 2000

A. sinensis (Brook 1891)

Testing Veron's hypotheses: range size of *Acropora hyacinthus* (Dana 1846)

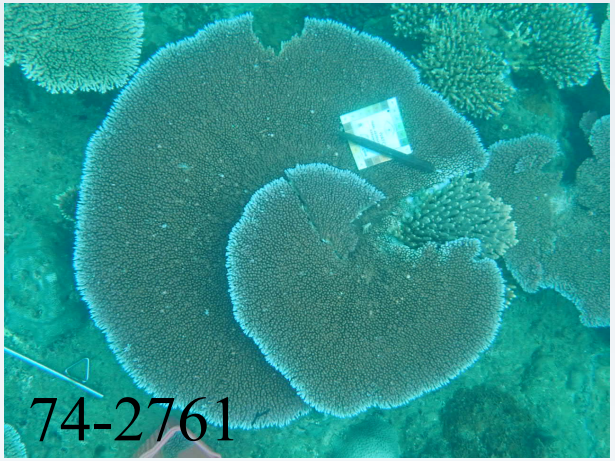
The *Acropora hyacinthus* species complex is composed of at least 20 different species all with restricted geographical distributions

Acropora hyacinthus sensu Veron & Wallace 1984 at south-east Pelorus on the Great Barrier Reef



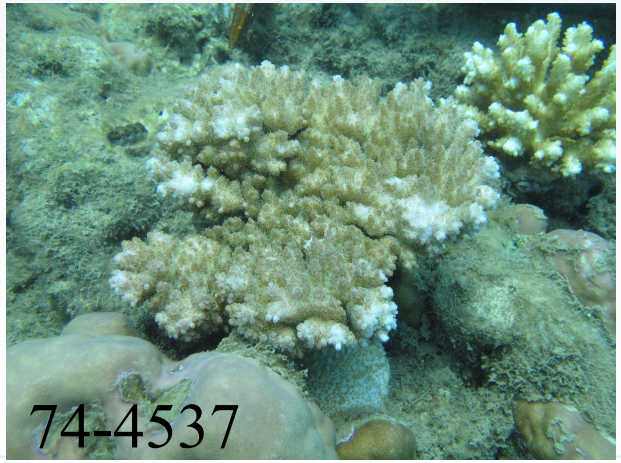
A. aff pectinata

A. pectinata



A. hyacinthus

A. tersa



A. hya-bifurcata

Species richness of the *Acropora*

- We estimate that the number of *Acropora* species is between 400-500 rather than the 166 recognized by Veron (2000)
- Almost all the synonymies we have tested are incorrect
- dozens of undescribed species

Southern Kenya – *Acropora*

Species-WoRMS	authority	type location	comment
abrotanoides	(Larmarck)	Indian Ocean	maybe
aculeus	(Dana, 1846)	Fiji	no
appressa	(Ehrenbeg 1834)	unknown	maybe
arabensis	Hodgson & Carpenter, 1995	Kuwait	maybe
austera	(Dana, 1846)	unknown	maybe
branchi	Riegl (1995)	South Africa	maybe
cerealis	(Dana, 1846)	Sulu Sea, Philippines	no
clathrata	(Brook 1891)	Mauritius	maybe
copiosa	Nemenzo (1967)	Philippines	no
cytherea	(Dana, 1846)	Tahiti	no
digitifera	(Dana, 1846)	Fiji	no
divaricata	(Dana, 1846)	Fiji	no
donei	Veron & Wallace, 1984	Great Barrier Reef, Australia	no
florida	(Dana, 1846)	Fiji	no
gemmifera	(Brook, 1892)	Great Barrier Reef, Australia	no
grandis	(Brook, 1892)	Great Barrier Reef, Australia	no
granulosa	Milne-Edwards, 1860	Reunion	maybe
hemprichi	(Ehrenbeg 1834)	Red Sea	maybe
hyacinthus	(Dana, 1846)	Fiji	no
inermis	(Brook, 1891)	Fiji	no
intermedia	(Brook, 1891)	Maldives	maybe
latistella	(Brook, 1892)	Great Barrier Reef, Australia	no
listeri	(Brook, 1893)	Tonga	no
lutkeni	Crossland, 1952	Great Barrier Reef, Australia	no
microclados	(Ehrenbeg 1834)	nomen dubium	no
microphthalma	Verrill, 1869	Japan	maybe
millepora	(Ehrenbeg 1834)	unknown	maybe
muricata	(Linneaus 1878)	Banda Island, Indonesia	maybe
nana	(Dana, 1846)	Fiji	no
nasuta	(Dana, 1846)	Tahiti	no
pharaonis	(Milne-Edwards, 1860)	Red Sea	no
retusa	(Verrill, 1864)	Singapore	no
robusta	(Dana, 1846)	Fiji	no
nobilis	(Dana, 1846)	Singapore	maybe
rosaria	(Dana, 1846)	Fiji	no
samoensis	(Brook, 1891)	Samoa	no
secale	(Studer, 1878)	Singapore	maybe
selago	(Studer, 1878)	Papua New Guinea	no
squarrosa	(Ehrenbeg 1834)	Red Sea	no
subulata	(Dana, 1846)	Fiji	no
tenuis	(Dana, 1846)	Fiji	no
valida	(Dana, 1846)	Fiji	no

- 42 *Acropora* species
- 25 of these are from the Pacific and definitely are not in Kenya
- 2 are from the Red Sea and almost certainly don't occur in Kenya

Obura 2012

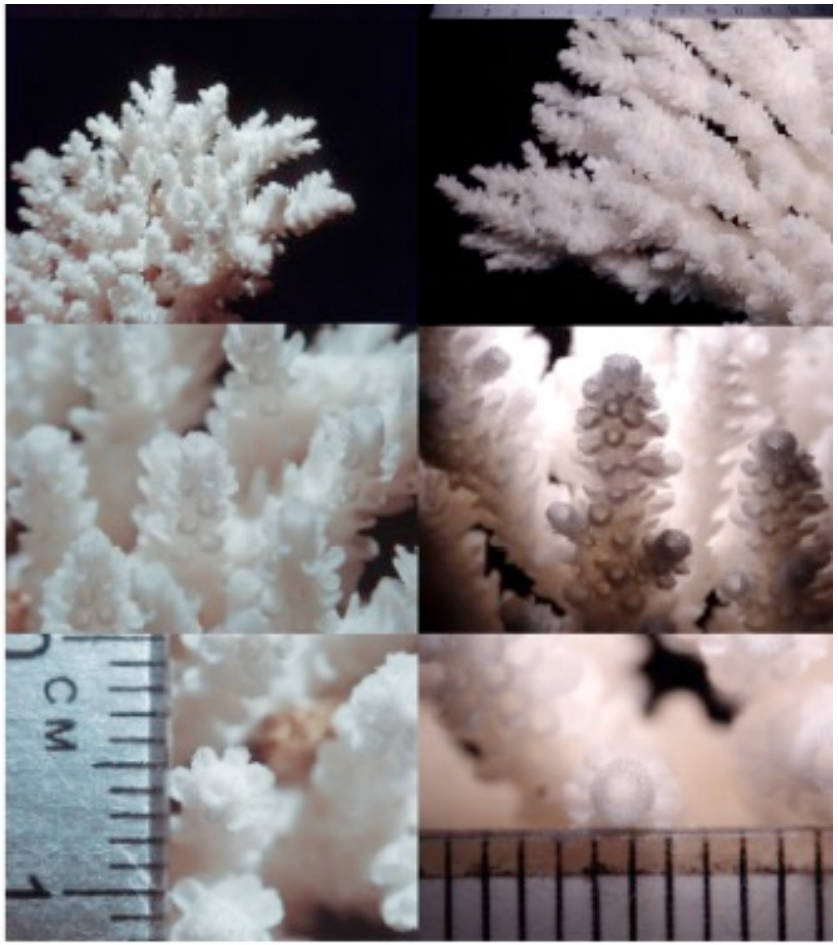
African-east coast nominal species

original_species	Authority_originalspecies	Type_Location_Current
Acorpora horizontalis	(Ortmann, 1892)	Tanzania, Dar es Salaam
Acropora africana	(Brook, 1893)	South Africa
Acropora branchi	Riegl, 1995	South Africa, Dolphin Coast, Shaka's Rock
Acropora lamarcki	Veron, 2000	Tanzania, Zanzibar
Acropora mossambica	Riegl, 1995	Mozambique, Xai Xai
Acropora natalensis	Riegl, 1995	South Africa, Sodwana Bay
Acropora sordiensis	Riegl, 1995	South Africa, Sodwana Bay
Acropora stellulata	Verrill, 1902	Tanzania, Zanzibar
Anomastraea irregularis	von Marenzeller, 1901	Tanzania, Zanzibar
Astraeosmilia connata	Ortmann, 1892	Tanzania, Dar es Salaam
Fungia concinna	Verrill, 1864	Tanzania, Zanzibar
Fungia haimei	Verrill, 1864	Tanzania, Zanzibar
Fungia valida	Verrill, 1864	Tanzania, Zanzibar
Goniastrea columella	Crossland, 1948	South Africa, Bhangazi Lake
Goniopora crassa	Crossland, 1948	South Africa, Bhangazi Lake
Goniopora paliformis	(Veron, 2000)	Tanzania, Zanzibar
Herpetolitha ampla	Verrill, 1864	Tanzania, Zanzibar
Isopora cylindrus	(Ortmann, 1892)	Tanzania, Dar es Salaam
Lobophyllia simplex	(Crossland, 1948)	South Africa, Umhlali
Lobophyllia studeri	(von Marenzeller, 1901)	Tanzania, Zanzibar
Montipora paupera	von Marenzeller, 1901	Tanzania, Zanzibar
Oulophyllia stuhlmanni	(Rehberg, 1892)	Tanzania, Zanzibar
Pectinia africana	Veron, 2000	Tanzania, Zanzibar, Changu Island
Pocillopora stellata	Verrill, 1864	Tanzania, Zanzibar
Porites reticulum	Ortmann, 1892	Tanzania, Dar es Salaam
Seriatopora stricta	Brüggemann, 1877b	South Africa, Cape of Good Hope

Testing the genomes: methods

1. Harvest our UCE markers from the 23 published *Acropora* genomes
2. Include these sequences in our *Acropora* phylogeny
3. Our phylogeny is informed by **topotypes** – a specimen collected from the same location as the holotype that is morphological similar to the holotype. A molecular archetype against which to test species identities

Acropora hyacinthus (Dana 1846) - topotype

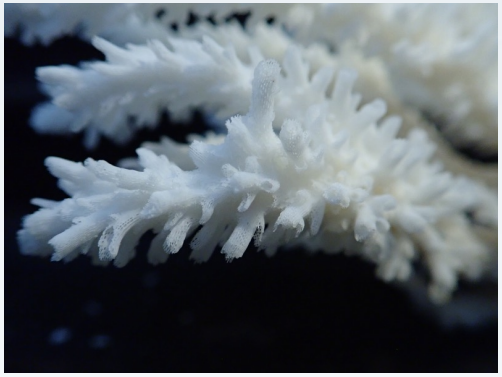


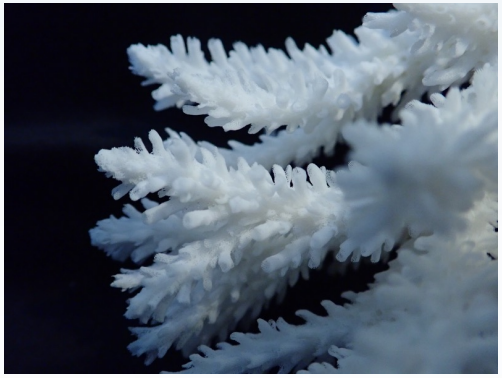
Madrepora hyacinthus Dana 1846
Lectotype USNM_246

101-5718

101-5718

Acropora cytherea (Dana 1846) - topotype

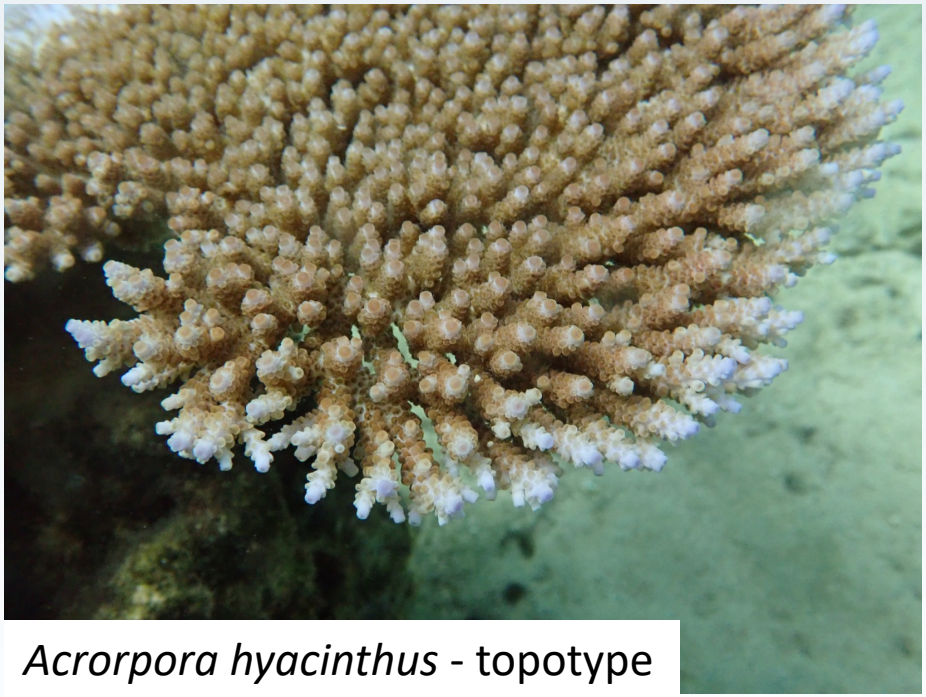



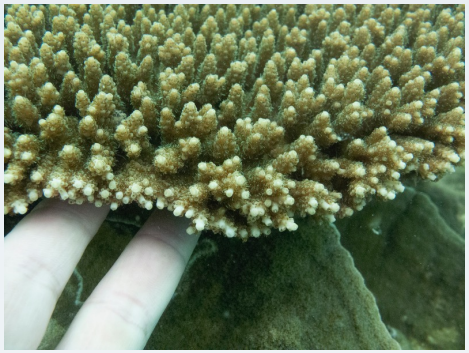

Acropora cytherea (Dana 1846) Lectotype USNM_423

Topotype 105-9492

Acropora hyacinthus genomes

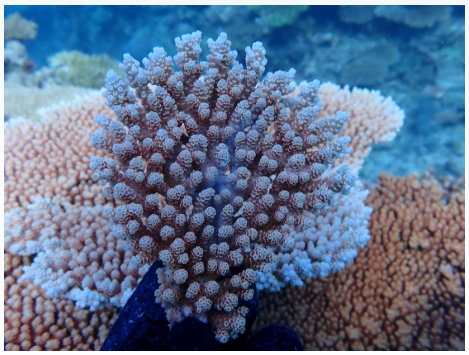


Acrorpora hyacinthus - topotype



hyacinthus - GBR

hyacinthus - Japan



hyacinthus - Palau

Taxonomic identities of the 23 genomes: summary

- 3 are almost certainly correct
- 1 is very possibly correct
- 19 are almost certainly incorrect

Taxonomic status of the 23 genomes: summary

- 9 are undescribed
- 8 junior synonyms
- 6 accepted

Philippines *Acropora*

- 119 specimens; 43 primary species hypotheses; 7 currently accepted; 19 junior synonyms; 17 undescribed; between 2-5 likely to be endemic
- 5-9 of these PSH also occur on the Great Barrier Reef ie between 10-20% overlap vs 50-60% overlap between the Philippines and Western Australia
- Of the 11 junior synonyms among the Philippines nominal species that we tested, most are likely to be good species.

Conclusions

- These examples highlight the fact that the current taxonomic framework is deeply flawed.
  - Most of the synonymies prior to the use of molecular data were incorrect
  - Fails to capture the true species richness i.e. there are lots of undescribed species
  - The result is that almost every image in Veron 2000 is incorrect

How did it all go so wrong?

- Too much respect for a limited number of authorities

Planck's principle

"*Science progresses one funeral at a time*"

How did it all go so wrong?

- Too much respect for a limited number of authorities
- Qualitative approach

How did it all go so wrong?

- Too much respect for a limited number of authorities
- Qualitative approach
- Morphological characters were not phylogenetically informative

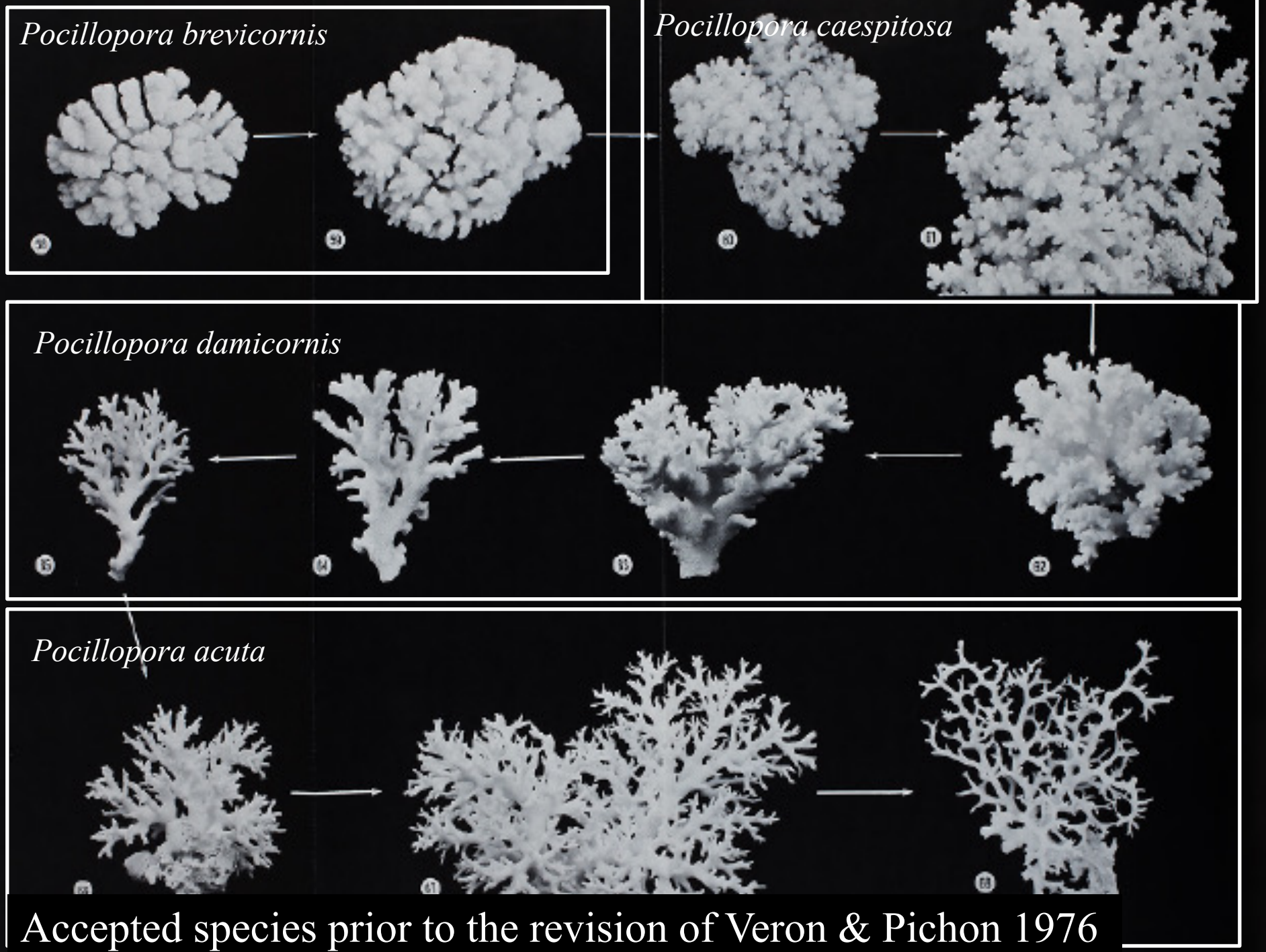
Traditional morphological characters uninformative

Goniastrea retiformis

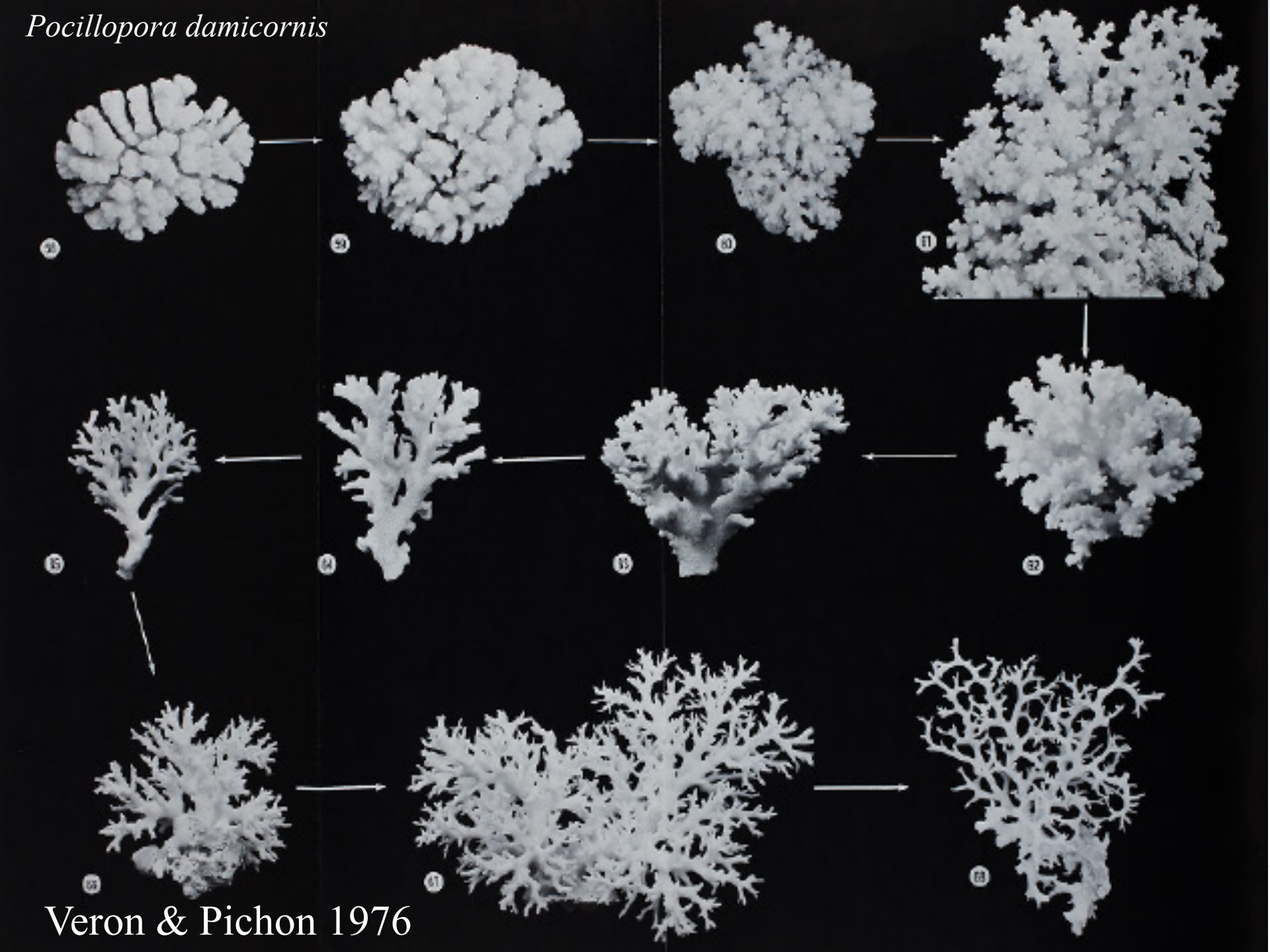
~~Favia~~ Goniastrea stelligera

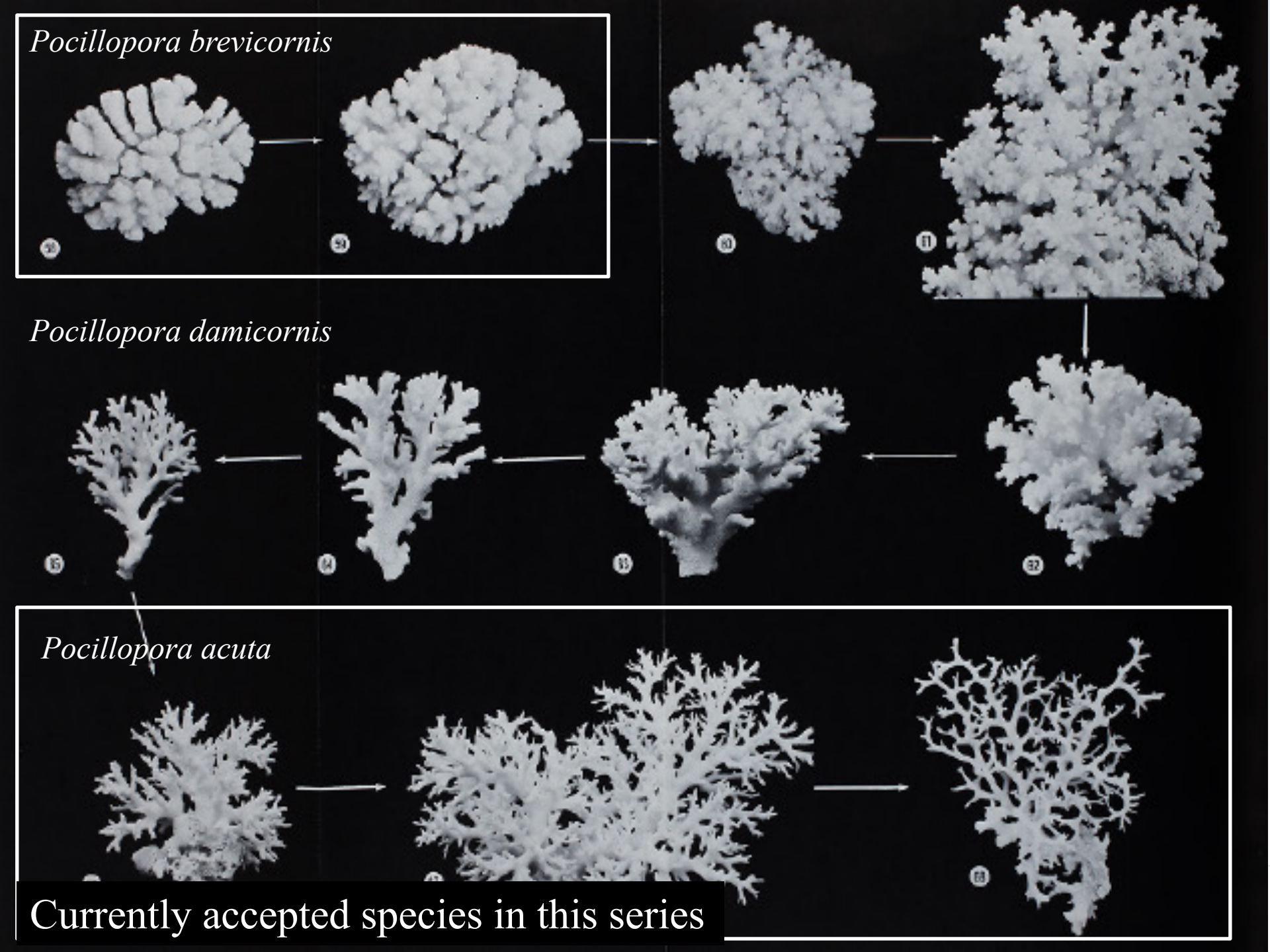
How did it all go so wrong?

- Too much respect for a limited number of authorities
- Qualitative approach
- Morphological characters were not phylogenetically informative
- Phenotypic plasticity over-emphasised

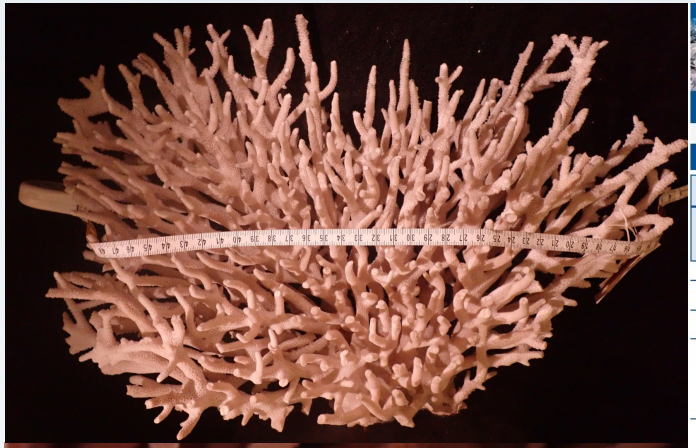


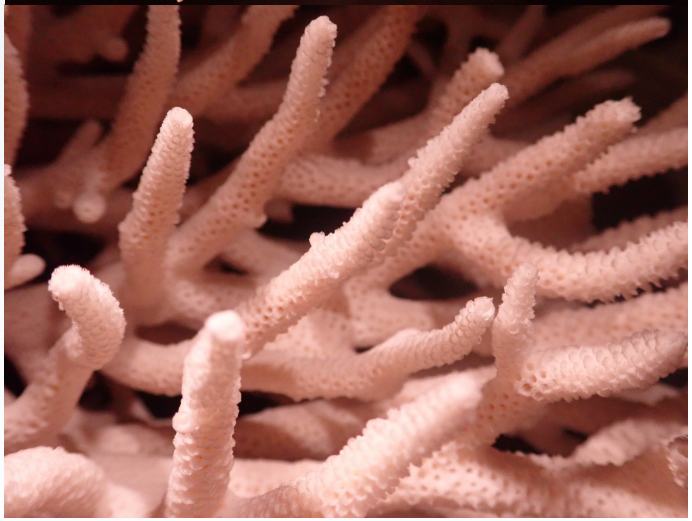
Accepted species prior to the revision of Veron & Pichon 1976


Pocillopora damicornis
Veron & Pichon 1976


Pocillopora brevicornis
Pocillopora damicornis
Pocillopora acuta
Currently accepted species in this series

A surprising indifference to the type material

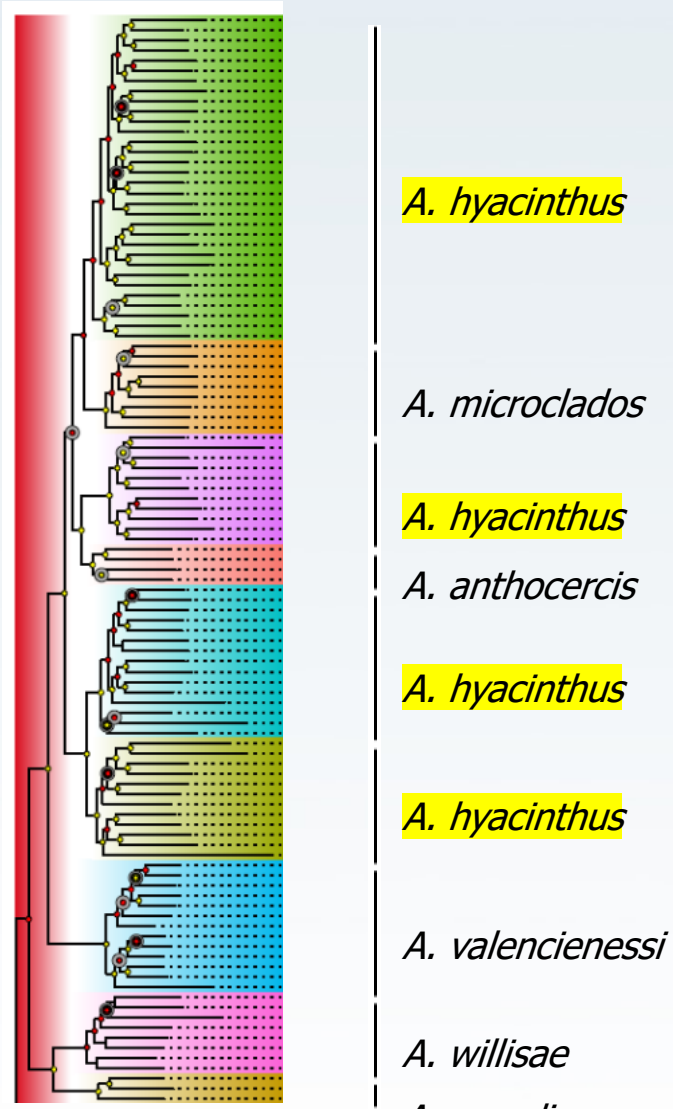




Lectotype USNM_256

Acropora subulata sensu Veron 2000

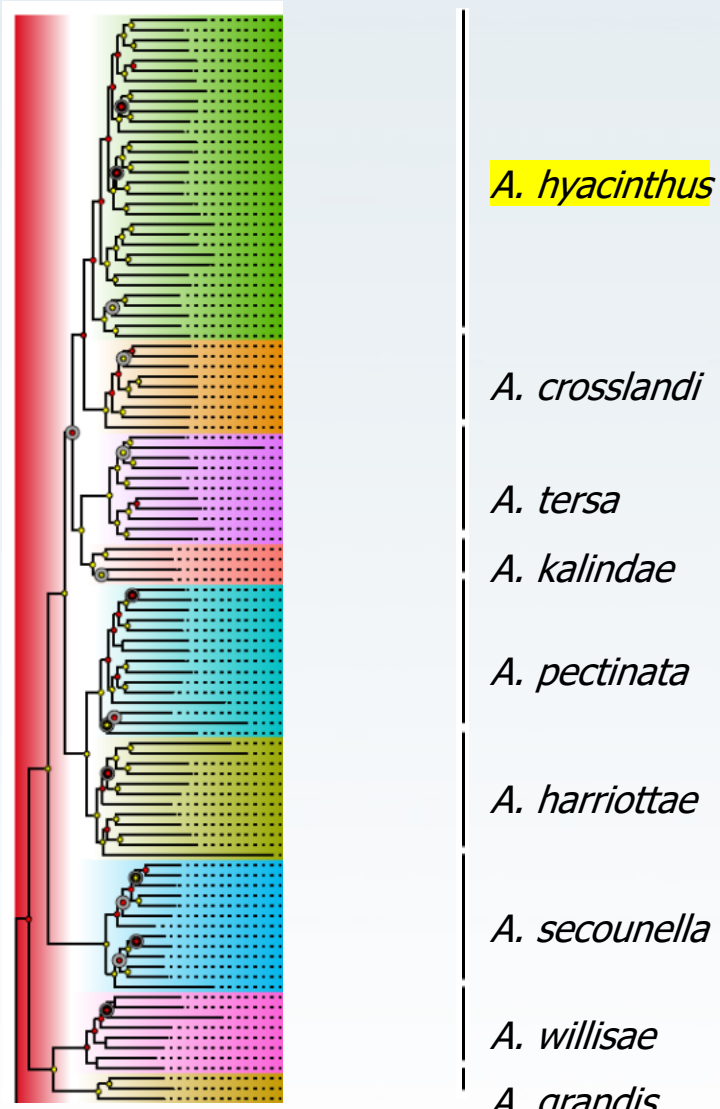
Reticulate evolution or poor taxonomy?



Clade VI HA

Crosbie et al in review

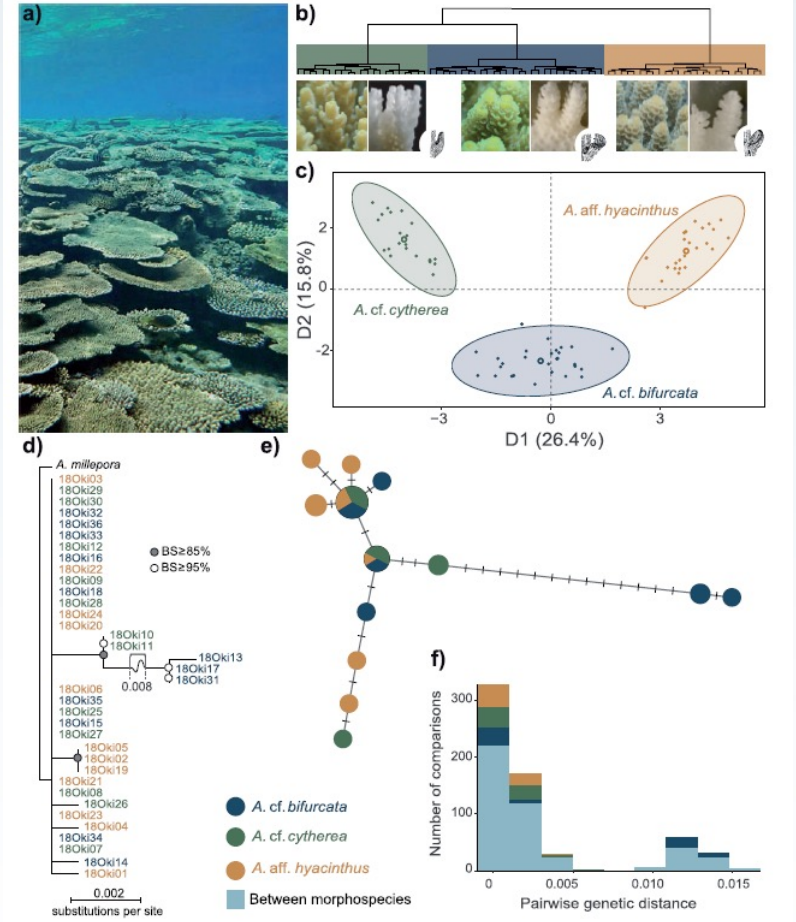
Reticulate evolution or poor taxonomy?

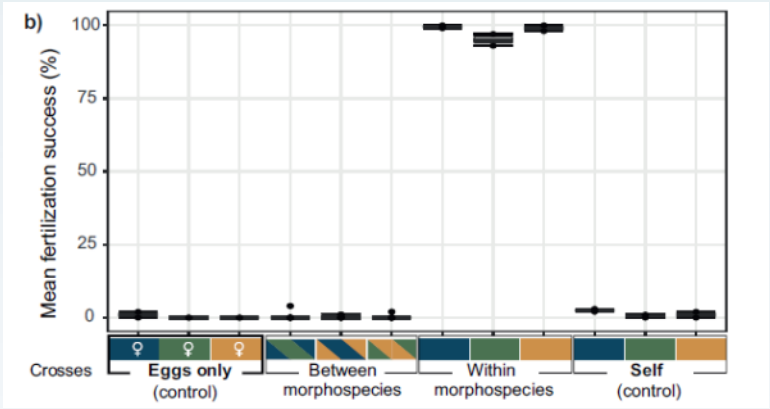


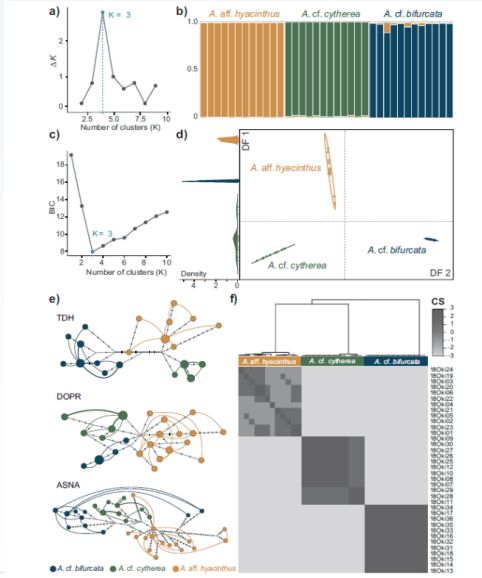
Clade VI HA

Crosbie et al in review

Reproductive isolation despite introgression in some genes



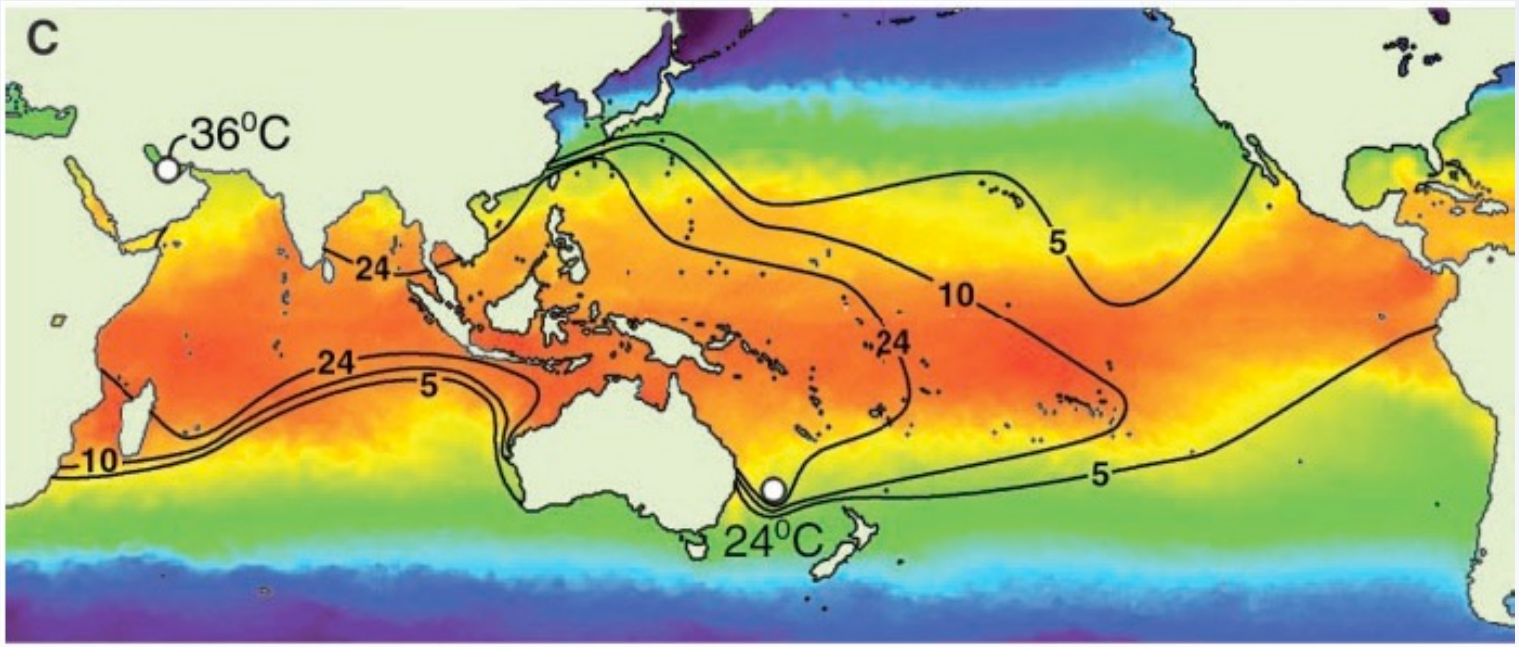




Ramirez-Portilla et al 2022

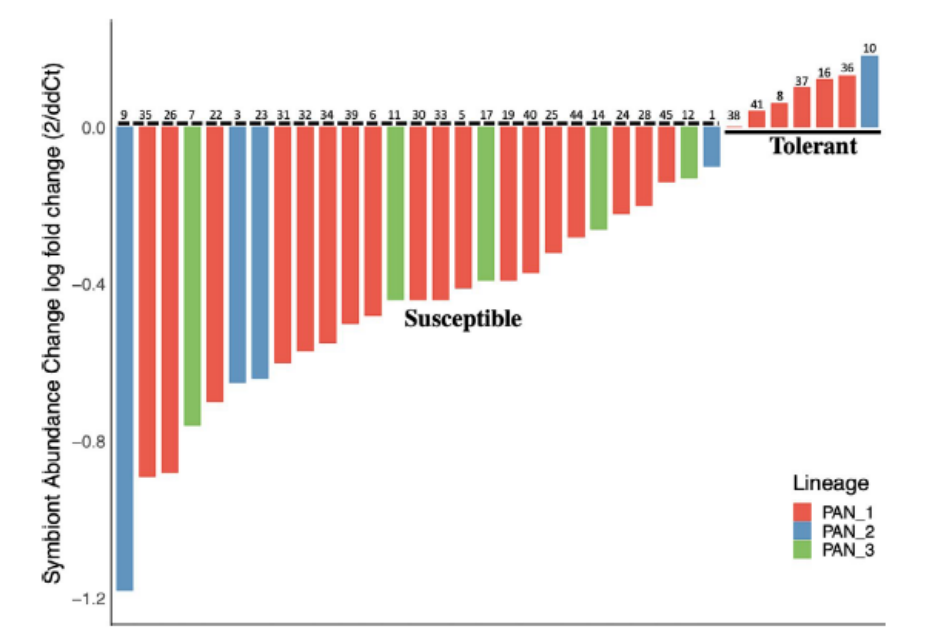
What are some of the implications of a flawed taxonomic framework?

Biogeography: thermal tolerance



Flawed data on distributions leads to false hope with respect to the thermal tolerance of species

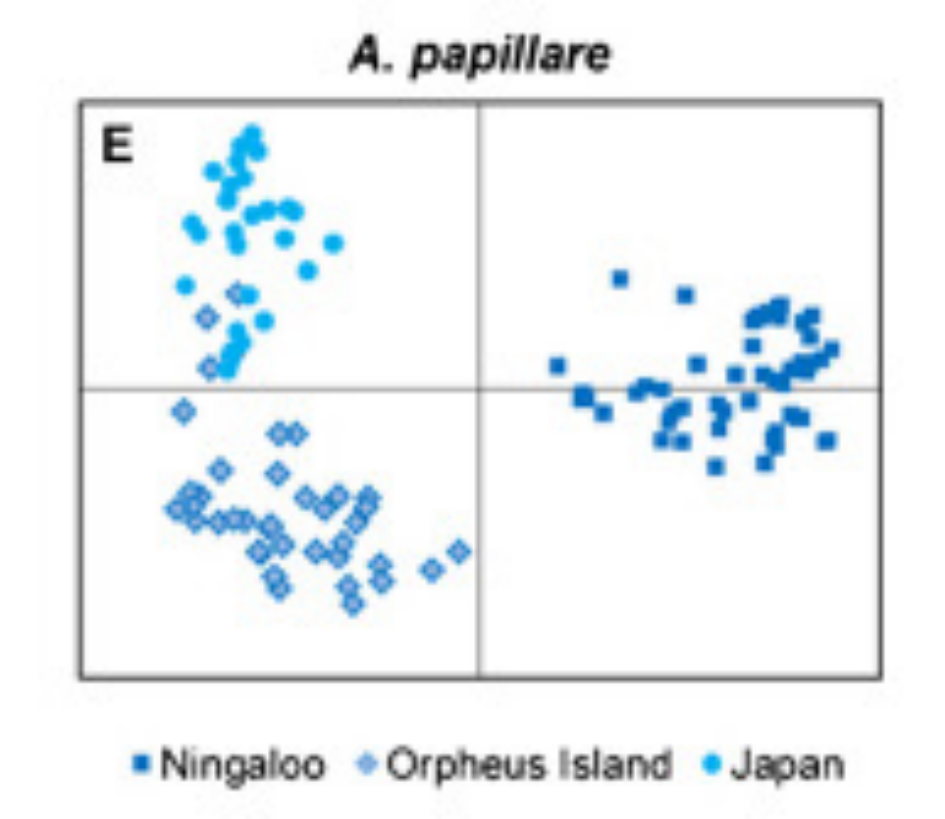
Thermal tolerance of *Orbicella faveolata*

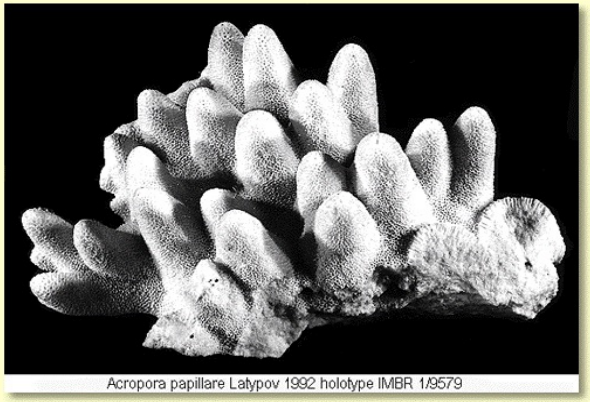


Misidentification of experimental samples, results in overestimates of thermal tolerance and false conclusions on adaptive potential

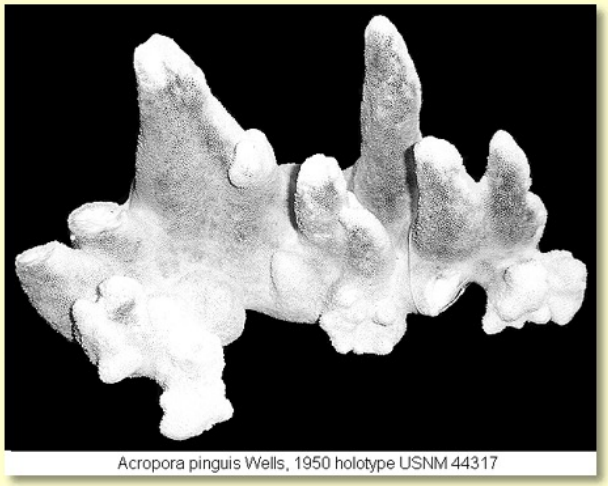
Gomez-Corrales and Prada (2020) reanalysed data from Dziedzic et al (2019)

Cryptic species or poor taxonomy?




Acropora papillare Latypov 1992 holotype IMBR 1/9579


Acropora indiana Wallace, 1994 holotype MTQ G46445


Acropora pinguis Wells, 1950 holotype USNM 44317

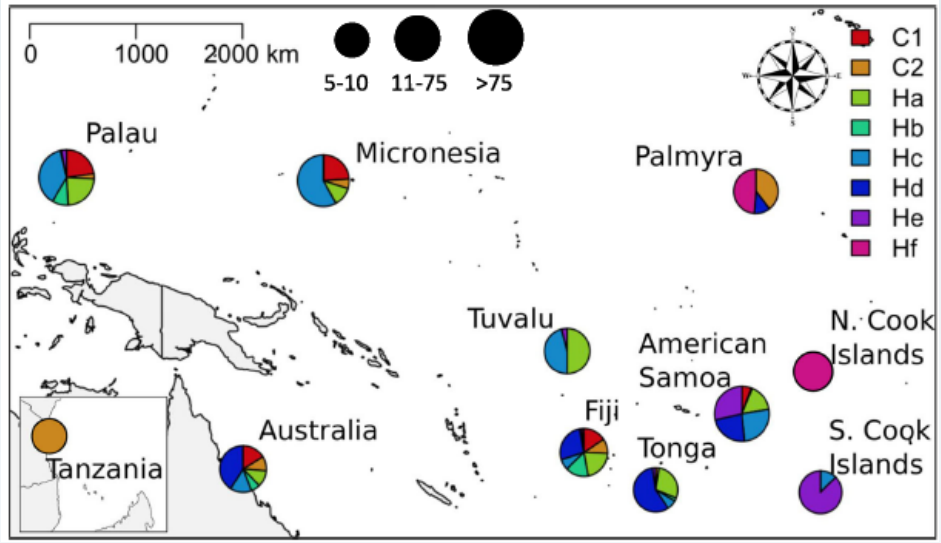
"Cryptic" lineages of *A. papillare* identified by Richards et al (2016) are good nominal species previous synonymized by "The Great" Carden Wallace.

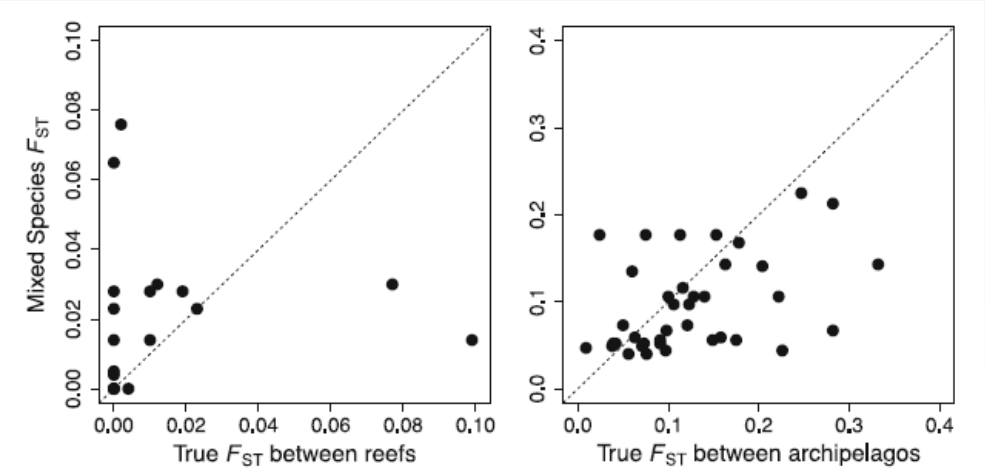
Connectivity

"Accurate population genetic measurements require cryptic species identification in corals."

- In other words, you need to be sampling within a single species to get meaningful estimates of connectivity.

Sheets et al 2018





Are tropical corals on the move?

No.

Suzuki et al (2016) show that is a sub-tropical species that is moving north in Japan

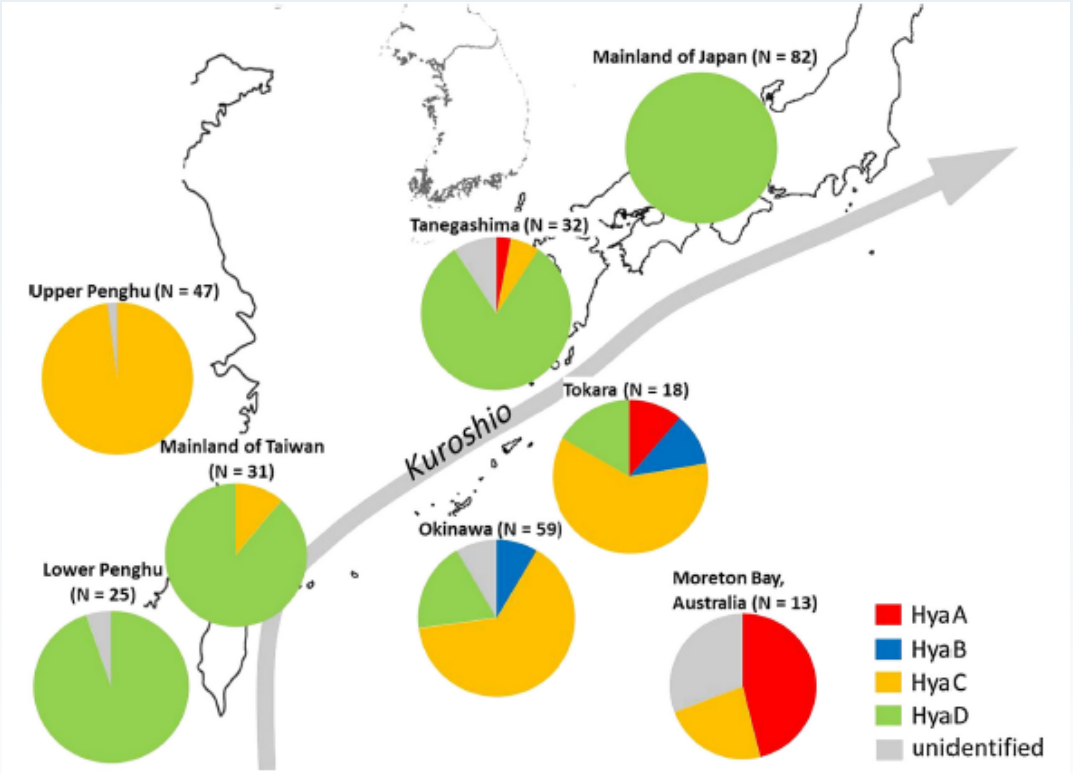


Fig. 5 *Acropora hyacinthus* cryptic lineage composition in each region. Grouping of locations for the mainland of Japan is shown in Fig. 3. For Ryukyu Islands, Tanegashima and Tokara are independently illustrated and other locations are integrated as "Okinawa." For Taiwan, upper and lower Penghu Islands are shown independently

Suzuki et al 2016 Coral Reefs

The way forward

- Stop using the “accepted” taxonomy and *Corals of the World* to identify your species. Up to 70% of coral species are not in CoTW
- Need to test *all* the *nominal* species i.e. resurrect all species in synonym that pre-date the use of molecular approaches
- Need to be aware that there are lots of undescribed species.

Project Phoenix: a new beginning

- Curate the type material and make it freely available
- Collect topotypes to test all the *nominal* species
- Use an integrated and quantitative approach that combines molecules, morphology, ecology etc

https://coralprojectphoenix.org/

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