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Comment

Comment on Arulananthan et al. The Status of the Coral Reefs of the Jaffna Peninsula (Northern Sri Lanka), with 36 Coral Species New to Sri Lanka Confirmed by DNA Bar-Coding. *Oceans* 2021, 2, 509–529

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We are responding to an article by Arulananthan et al. from July 2021 in *Oceans* [1]. Arulananthan et al. [1] report the discovery of 36 coral species new to Sri Lanka, confirmed by DNA barcoding. Hereby, the study provides interesting new information on the coral fauna of the poorly studied reefs of the Jaffna Peninsula, Northern Sri Lanka, and encouragingly reports relatively high coral cover values. The methods used to identify coral species, particularly where it concerns DNA barcoding, appear not suitable for accurately identifying the recorded corals to a species level. Consequently, we argue that it is premature for the authors to claim that they have identified 36 coral species previously not recorded from Sri Lanka and urge caution when using such claims as a basis for making decisions on conservation and management actions. As a solution, we propose a stepwise approach, which one could follow to assess the presence of new coral species with more certainty.

The authors used a combination of skeletal morphology and DNA barcoding, focusing on the Cytochrome Oxidase I marker (COI), to identify coral specimens. Table 1 shows which of these two methods was used by them. However, there are issues with both methods, which render these identifications unreliable. Concerning the morphological characteristics that were used, it is unclear how accurately this was done, as voucher material was not collected for most of the recorded species [2]. This is especially unfortunate in the current study, as most identifications were made primarily using field photos and field identification guides. Even though the cited Indo-Pacific Coral Finder [3] is an excellent tool kit for learning morphological characteristics for coral identification, it is designed for genus-level identification only. To overcome this, the authors indicate that they identified species by comparing characteristics based on species descriptions in *Corals of the World* [4]. To what degree this can accurately be carried out based on photos in the field, in most cases without collecting and preserving voucher material, remains questionable. This is indicated by species like *Acropora gemmifera*, which was recorded at more than 70% of the study sites. As discussed below, the COI sequences of two specimens identified by the authors as this species actually differ by two nucleotides from each other, indicating that these specimens probably belong to two different species. Whether or not these two species were found at all study sites, and which coral species they concern, remains uncertain.

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Table 1. List of species recorded as 'new' by Arulananthan et al. [1], based on their identification and methodology, the availability of voucher material for cross-referencing, and the location of the type specimen repository. Abbreviations used under the repository location are as follows: USNM—United States National Museum of Natural History—Smithsonian Institution, Washington, D.C., USA; NHM—Natural History Museum, London, United Kingdom; NHMTU—Natural History Museum of Tohoku University, Japan; MTQ—Museum of Tropical Queensland, Townsville, Australia; MNHN—Museum National d'Histoire Naturelle, Paris, France; UP—University of the Philippines. Type specimen repositories marked with '?' are based on the assumption that other known type specimens of the same collector/from the same expedition were deposited here.

Species Names with Authorities	Basis of the Identification	Availability of Voucher Material for Cross-Checking	Type Specimen Repository	Code/ Type No
Acroporidae Verrill, 1901				
Acropora aspera Dana, 1846	DNA marker COI	Not collected	USNM	287
Acropora digitifera Dana, 1846	DNA marker COI	Not collected	MTQ	G37980
Acropora gemmifera Brook, 1892	DNA marker COI	Not collected	NHM	1892.6.8.114
Acropora latistella Brook, 1891	Morphology based on [4]	Not collected	NHM	1892.6.8.275
Acropora pulchra Brook, 1891	Morphology based on [4]	Not collected	NHM	1884.2.16.1
Alveopora allingi Hoffmeister, 1925	Morphology based on [4]	Not collected	USNM	62494
Astreopora myriophthalma Lamarck, 1816	Morphology based on [4]	Not collected	MNHN	219c
Astreopora listeri Bernard, 1896	Morphology based on [4]	Not collected	NMH	1891-3-6-20
Astreopora ocellata Bernard, 1896	Morphology based on [4]	Not collected	NHM	1892-12-1-150
Montipora flabellata Studer,1901	DNA marker COI	Not collected	N/A	Not available
Montipora informis Bernard, 1897	Morphology based on [4]	Not collected	NHM	1885-6-30-3
Merulinidae Verrill, 1865				
Coelastrea palauensis Yabe & Sugiyama, 1936	Morphology based on [4]	Not collected	NHMTU	56631
Cyphastrea japonica Yabe & Sugiyama, 1936	Morphology based on [4]	Not collected	NHMTU	40323
Cyphastrea microphthalma Lamarck, 1816	Morphology based on [4]	Not collected	MNHN?	Not available
Platygyra acuta Veron, 2000	Morphology based on [4]	Not collected	MQT	G55845
Echinopora gemmacea Lamarck, 1816	DNA marker COI	Not collected	MNHN?	Not available
Dipsastraea amicorum Milne Edwards & Haime, 1850	Morphology based on [4]	Not collected	MNHN?	Not available
Dipsastraea lizardensis Veron, Pichon & Wijsman-Best, 1977	Morphology based on [4]	Not collected	NHM	1977.1.1.2
Pachyseridae Benzoni & Hoeksema, 2023				
Pachyseris gemmae Nemenzo, 1955	Morphology based on [4]	Not collected	UP	UP C-123
Oulastreidae Vaughan,1919				
Oulastrea crispata Lamarck, 1816	Morphology based on [4]	Not collected	MNHN	scle15
Poritidae Gray, 1842				
Porites evermanni Vaughan, 1907	Morphology based on [4]	Not collected	USNM	21627
Porites murrayensis Vaughan, 1918	Morphology based on [4]	Not collected	USNM	47237
Porites pukoensis Vaughan, 1907	Morphology based on [4]	Not collected	USNM	22236
Goniopora lobata Milne Edwards, 1860	Morphology based on [4]	Not collected	MNHN?	Not available
Goniopora minor Crossland, 1952	Morphology based on [4]	Not collected	NHM	56
Goniopora somaliensis Vaughan, 1907	Morphology based on [4]	Not collected	MNHN	Not available
Goniopora tenuidens Quelch, 1886	Morphology based on [4]	Not collected	NHM	Not available
Dendrophylliidae Gray, 1847				
Turbinaria frondens Dana, 1846	Morphology based on [4]	Not collected	USNM	214
Turbinaria reniformis Bernard, 1896	Morphology based on [4]	Not collected	NHM	Not available
Turbinaria stelluta Lamarck, 1816	Morphology based on [4]	Not collected	MNHN	Not available
Lobophylliidae Dai & Horng, 2009				
Acanthastrea ishigakiensis Veron, 1990	Morphology based on [4]	Not collected	MTQ	G32484
Micromussa amakusensis Veron, 1990	Morphology based on [4]	Not collected	MTQ	G32485
Euphylliidae Milne Edwards & Haime, 1857				
Coeloseris mayeri Vaughan, 1918	Morphology based on [4]	Not collected	USNM	45546 (syntype series (a series of multiple types) but no holotype)
Siderastreidae Vaughan & Wells, 1943				
Siderastrea savignyana Milne Edwards & Haime, 1849	Morphology based on [4]	Not collected	NHM	Not available

The modern application of molecular methods in coral taxonomy in recent years has consistently shown that many of the characteristics used to delineate species and genera, as described in *Corals of the World* [4], which was first published over 20 years ago, are not homologous. This can be partially attributed to the fact that the bulk of the work described was undertaken before molecular sequencing became available and because it primarily concentrated on macromorphological characteristics and undervalued the significance of micromorphological characteristics.

It is now well established that a combined analysis of morphological (informative characteristics determined at each taxonomic level by macromorphological, micromorphological, and microstructural examinations), molecular characteristics, and other sources of evidence (reproductive isolation, spawning synchronization, geographical boundaries, etc.) is key to establishing robust and reliable coral phylogenies [5–8]. Fukami et al. [9], for example, illustrate that one can assess *Acropora* diversity through DNA analyses of the mitochondrial marker mtCR (generally considered diagnostic for these coral species) in combination with present-day knowledge of their colony form, skeletal morphology, and spawning season [10]. This is also reflected, for example, by the newly released edition of the Coral Finder [11], which "*no longer follows the* Corals of the World *framework. . ..but instead a new synthesis based on individual research publications*", using a robust taxonomic approach to delineate species boundaries in a range of coral clades.

Concerning the molecular methods used, Arulananthan et al. [1] imply in the title of their paper that the identities of all 36 species were recorded as new to Sri Lanka, confirmed by DNA barcoding. The paper only gives seven COI sequences, supposedly belonging to six different coral species. To identify these species, the authors used BLAST searches in GenBank to assess which sequences match most closely. The closest match of each sequence was then assumed to provide the identification. This "molecular identification" method can result in errors being made. Downloading the seven sequences of Arulananthan et al. [1] from GenBank (MN689059.2- MN689062.2, MN689065.2, MN689067.2, and MN689068.2) and aligning them in BioEdit [12] shows, for example, that the three sequences MN689059.2, MN689060.2, and MN689067.2 match each other for 100% in the regions where they overlap and can be aligned with each other. One cannot therefore conclude based on these sequences that they concern different species at all. These three sequences differ only in sequence length, i.e., having lengths of, respectively, 709, 717, and 715 nucleotides. These length differences explain why blasting on GenBank gave different results and let Arulananthan et al. [1] wrongfully believe that the three sequences concerned three different coral species, i.e., *Acropora aspera*, *A. gemmifera*, and *A. hyacinthus*.

Where the COI marker can be used as a barcode for most animal species, this marker is known to be unsuitable for resolving systematic relationships at a species level in Anthozoans because it is not variable enough [13–16]. It is certainly not appropriate for identifying species within species-rich groups such as *Acropora* [8]. Aligning GenBank sequences MN689060.2 and MN689062.2 with each other, both identified as *A. gemmifera* by Arulananthan et al. [1], two nucleotide differences become apparent. As genetic differences between coral species within COI are minimal, it is in this case quite likely that these sequences belong to two different species. This is confirmed by the fact that running the BLAST analysis on the matched sequence of *A. gemmifera* (MG383839.1) on GenBank shows that its COI sequence differs by only one nucleotide from the COI sequences of other *Acropora* species like *A. valida*, *A. tenuis*, and *A. awi*. It can be generally concluded that Arulananthan et al. unfortunately made two mistakes in their approach to identifying corals using DNA sequences: (1) The marker that was used is not variable enough to reliably identify the corals concerned to a species level. (2) One should not identify species based solely on the first or best match sequence resulting from a BLAST search on GenBank without considering that a BLAST search result is not only dependent on how similar sequences are but also on the query cover and therefore potentially the sequence length.

It is well established that the delimitation of closely related species in scleractinian genera such as *Acropora* is not possible using markers like COI [7,8,17–19]. Molecular analyses can aid in the identification of corals at the species level [8,20–23]. For example, Ramírez-Portilla et al. [8] examined three closely related, co-occurring tabular *Acropora* species in Japan and clearly demonstrated that these species can be distinguished from each other by using multiple lines of evidence: investigating their morphologies, carrying out cross-breeding trials, and using target capture-derived markers in conjunction with haplowebs [24]. As recent molecular studies [25,26] and cross-breeding trials [27] have indicated, a wider taxonomical structure linked to the geographical distribution of species across oceans is not evident for most coral species. Therefore, the identification of species may require a comparison to the original holotype specimen and other specimens collected at the type locality. To do this, Table 2 was made based on a search in WoRMS, the World list of Scleractinia [28], to cross-check the taxonomic descriptions and relevant authorities and locate the type localities [28] of the species recorded by Arulananthan et al. [1]. Considering these type localities, 10 out of the 36 species listed by Arulananthan et al. [1] appear to have subjective junior synonyms [28] (denoted by * in Table 2), which appear more likely to occur in Sri Lanka.

In general, we would like to propose the adoption of a stepwise integrated approach (Figure 1) when assigning names to corals in ecological and conservation studies, especially when labeling them as species new to a geographical area. This would make greater use of an open nomenclature, as indicated in the blue section, with specimens being labeled as closely familiar or having an affinity to a named species or as potentially a new record before being reported with apparent certainty.

It is unfortunate that Arulananthan et al. [1] (1) missed the present-day best available scientific knowledge, (2) used a marker that is considered not to be diagnostic at a species level for corals, and (3) relied on visual comparisons with *Corals of the World* [3] for their identifications at the species level without collecting voucher specimens. This strongly reduces the credibility of their results. While Veron's work [4] can serve as an initial reference, it is important to exercise caution in confirming the identity of many individual species. The study in its present form at most gives an indication of coral species that may be present at the reefs of the Jaffna Peninsula, Northern Sri Lanka, and for which further research, for example, for conservation purposes, is necessary to confirm their presence.

As Arulananthan et al. [1] stated, geographically distinct and long-neglected coastal regions can conceal remarkable biodiversity and therefore may provide a reservoir of genes that are capable of withstanding climate change-driven impacts. We agree that understanding the diversity of corals in Sri Lanka is important for the conservation of Sri Lanka's coral fauna. It is critical that taxonomic identifications are conducted in a robust way. Failure to correctly identify species can lead to misidentifying patterns of diversity and biogeography and potentially to the misdirection of scarce conservation resources. However, given the serious problems with both the morphological and molecular methods used to identify coral species by Arulananthan et al. [1], it is clearly premature to declare with certainty that this study reports on coral species previously not recorded in Sri Lanka.

Table 2. List of species recorded as 'new' by Arulananthan et al. [1], with type locality and potential subjective junior synonyms in Sri Lanka. Type localities marked with '?' are based on the assumption that the collectors/authors of the older monographs have ambiguity over the type locality or the label attached to the type specimen.

Species Name with Authorities	Type Locality	Potential Junior Synonyms in Sri Lanka
Acroporidae Verrill, 1901		
Acropora aspera Dana, 1846 *	Fiji	*Acropora yeayamaensis* (Eguchi & Shirai, 1977), Japan; *Madrepora manni* (Quelch, 1886), Zamboanga, Philippines
Acropora digitifera Dana, 1846 *	Marshall Islands	*Acropora schmitti* (Wells, 1950), Cocos (Keeling) Islands,
Acropora gemmifera Brook, 1892	Rocky Islands, Great Barrier Reef, Australia	
Acropora latistella Brook, 1891 *	Port Denison, Great Barrier Reef, Australia	*Acropora imperfecta* (Nemenzo, 1971), Puerto Galera, Philippines; *Acropora loricata* (Nemenzo, 1967), Cebu, Philippines
Acropora pulchra Brook, 1891	Cocos (Keeling) Islands, Indian Ocean	
Alveopora allingi Hoffmeister, 1925	Pago Pago Harbour, American Samoa	
Astreopora myriophthalma Lamarck, 1816 *	Red Sea	*Astreopora stellae* (Nemenzo, 1964), Cebu, Philippines; *Astreopora horizontalis* (Bernard, 1896), Seychelles
Astreopora listeri Bernard, 1896 *	Tonga	
Astreopora ocellata Bernard, 1896	Torres Strait	
Montipora flabellata Studer,1901	Hawaii	
Montipora informis Bernard, 1897	Torres Strait	
Merulinidae Verrill, 1865		
Coelastrea palauensis Yabe & Sugiyama, 1936	Palau	
Cyphastrea japonica Yabe & Sugiyama, 1936	Tanabe-wan, Wakayama-ken, subtropical Japan	
Cyphastrea microphthalma Lamarck, 1816 *	the Ocean around New Holland—possibly Western Australia	*Cyphastrea minuta* (Nemenzo & Ferraris, 1982), Cebu, Philippines
Platygyra acuta Veron, 2000	Mahe, Seychelles	
Echinopora gemmacea Lamarck, 1816	Indian Ocean?	
Dipsastraea amicorum Milne Edwards & Haime, 1850 *	Tonga	*Barabattoia modesta* (Nemenzo, 1971), Cebu, Philippines
Dipsastraea lizardensis Veron, Pichon & Wijsman-Best, 1977	Lizard Island, Great Barrier Reef	
Pachyseridae Benzoni& Hoeksema, 2023 (Authors have listed Pachyseris gemmae Nemenzo, 1955 under Scleractinia incertae sedis but it is now under Pachyseridae Benzoni& Hoeksema, 2023 [28])		
Pachyseris gemmae Nemenzo, 1955	Bohol, Philippines	
Oulastreidae Vaughan, 1919		
Oulastrea crispata Lamarck, 1816	Indian Ocean	
Poritidae Gray, 1842		
Porites evermanni Vaughan, 1907	Oahu, Hawaii	
Porites murrayensis Vaughan, 1918	Mer Island, Torres Strait	
Porites pukoensis Vaughan, 1907	Molokai, Hawaii	
Goniopora lobata Milne Edwards, 1860	Red Sea	
Goniopora minor Crossland, 1952 (Considered as a junior subjective synonym of *G. pedunculata* Quoy and Gaimard, 1833 [28])	Great Barrier Reef	
Goniopora somaliensis Vaughan, 1907	French Somaliland	
Goniopora tenuidens Quelch, 1886	Zamboanga, Philippines	

Table 2. *Cont.*

Species Name with Authorities	Type Locality	Potential Junior Synonyms in Sri Lanka
Dendrophylliidae Gray, 1847		
Turbinaria frondens Dana, 1846 *	Fiji	*Turbinaria carcarensis* (Nemenzo, 1971), Cebu, Philippines; *Turbinaria contorta* (Bernard, 1896), South China Seas; *Turbinaria ramosa* (Yabe & Sugiyama, 1941), Meitu Minami-Naka-gun, Miyazaki-ken, Japan; *Turbinaria rugosa* (Bernard, 1896), Formosa
Turbinaria reniformis Bernard, 1896 *	Palm Islands, Great Barrier Reef	*Turbinaria disparata* (Bernard, 1896), Basay, Oriental Negros, Philippines; *Turbinaria globularis* (Bernard, 1896), Diego Garcia;
Turbinaria stelluta Lamarck, 1816 *	American Ocean?	*Turbinaria titizimaensis* (Yabe & Sugiyama, 1941), Ogasawa Islands, Japan; *Turbinaria nitida* (Nemenzo, 1960), Quezon, Philippines
Lobophylliidae Dai & Horng, 2009		
Acanthastrea ishigakiensis Veron, 1990 (Basionym *Acanthastrea ishigakiensis* is now accepted as *Lobophyllia ishigakiensis* [28])	Ishigaki Island, Japan	
Micromussa amakusensis Veron, 1990	Amaku Island, Japan	
Euphylliidae Milne Edwards & Haime, 1857 (Authors have listed *Coeloseris mayeri* Vaughan, 1918 under the Family Agariciidae Gray, 1847 but it should be Euphylliidae Milne Edwards & Haime, 1857 [28])		
Coeloseris mayeri Vaughan, 1918	Mer Island, Torres Strait	
Siderastreidae Vaughan & Wells, 1943 (Siderastreidae Vaughan & Wells, 1943 is now accepted as Rhizangiidae d'Orbigny, 1851 [28])		
Siderastrea savignyana Milne Edwards & Haime, 1849	Red Sea	

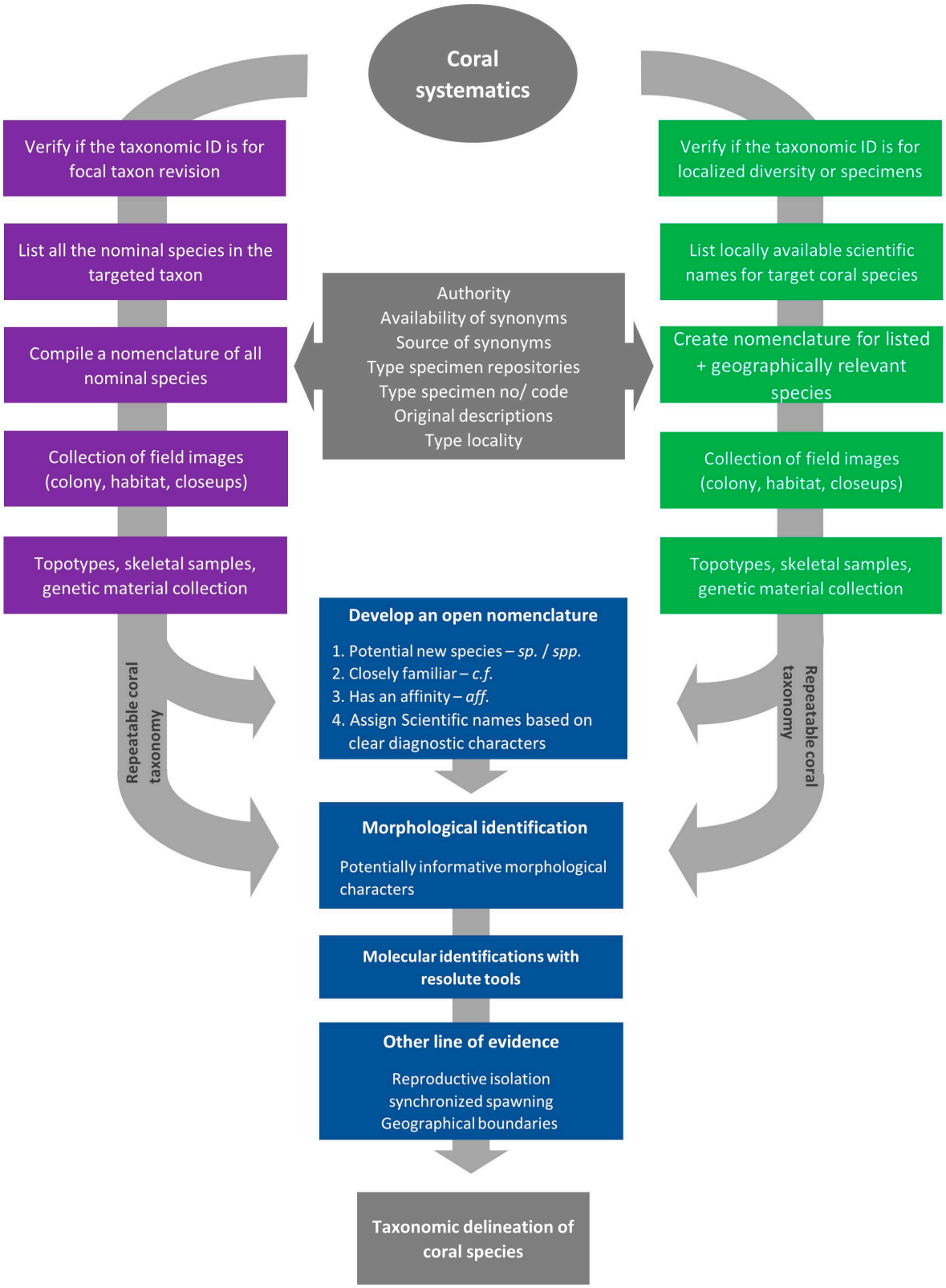

Figure 1. A schematic diagram illustrating a systematic, stepwise approach to coral taxonomy aimed at ensuring robustness, repeatability, and scalability. The two primary processes in coral taxonomy are indicated by distinct colors: purple represents taxonomic identification for focal taxon revisions, and green signifies taxonomic identification for localized diversity or specific specimens. The process indicated in blue is shared by both primary procedures.

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