Results of an Update of the *Corals of the World* Information Base for the Listing Determination of 66 Coral Species under the Endangered Species Act

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Western Pacific Regional Fishery Management Council
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A report of the Western Pacific Regional Fishery Management Council
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BACKGROUND

The open access website *Corals of the World* (*COTW*) is due for release in 2014. This production, a decade in the making, will give users immediate access to a wealth of information about the taxonomy (in the sub-program *Coral ID*) and distribution (in the sub-program *Coral Geographic*) of extant zooxanthellate Scleractinia. A third sub-program is planned for the future, *Coral Enquirer*, stemming from widespread interest in vulnerability assessments but going well beyond relevance to that subject. *Coral Enquirer* will contain detailed abundance assessments relevant parts of which have been incorporated into this report.

There is a wealth of literature showing that, with rare exception, endangered species are those that have a restricted distribution, are rare, are facing major loss of habitat and/or are biologically sensitive to specific threats. The exceptions are usually disease outbreaks in otherwise non-endangered species. We have every reason to believe that corals are no different—rare species that have limited distributions are clearly vulnerable in a world of changing climate and habitat degradation. In other words, the more diversely widespread a species is the less exposed it will be as a species to regional environmental impacts. Furthermore, abundance is likely to be a major contributor to recovery from mass bleaching and other acute impacts.

Comprehensive accounts of Indo-Pacific species taxonomy, distributions and abundance require extensive field knowledge, time and funding and are fundamentally dependent upon a coherent and consistent taxonomic framework in order to undertake global studies.[1] The great strength of the present work is in the comprehensive coverage and global nature of the authors' original field and taxonomic work which alone covers >68% of all 133 Indo-Pacific ecoregions (see further details below). This coverage has been augmented and expanded to cover almost all of the world's ecoregions through literature searches and the generous assistance of colleagues, photographers and others. There are, however, a number of species and ecoregions for which taxonomic confirmations have not yet been established, and a number of these ecoregions are relevant to the present report. Such confirmation is ongoing and distributions will be updated on the website as these become available.

With rare exceptions, which will be the subject of further clarification and study, the species listed in *COTW* are morphologically distinct both underwater and in skeletal specimens. With the advent and increasing number of molecular studies, most morphological distinctions (irrespective of names) have been supported. There are, however, a number of notable exceptions. In cases where these are clear or simply clarify a known but ignored historical taxonomic issue, they have already been incorporated into *COTW*. In other cases, molecular results are sufficiently surprising to warrant caution before overturning well-established field identifications, or they indicate that future changes will be necessary once problematic issues are clarified (broadly reviewed by Veron 2013). Species and their distributions will be modified in ongoing updates to *COTW* as further evidence confirms or clarifies the relevance of these studies to existing taxonomy.

[1] This report focuses on coral species occurring in the Indo-Pacific ecoregions. Information regarding Caribbean coral species is presented in Linked Documentation B (spreadsheet) and D (maps) but not elaborated in this report. See the "Linked Documentation" section in this report for data categories included in the spreadsheet.

As in virtually all taxonomy, that of corals has been a matter of opinion throughout its history and amongst coral taxonomists today there remain disagreements about a number of species. In *COTW* we have attempted to resolve such disagreements where possible, but the extent of our team's field and taxonomic work can sometimes highlight the distinctiveness of species that are synonymised by others. Some of these species may require further fieldwork, however, given the extent of the fieldwork already undertaken in this study, we believe that changes to the species distinctions we have established (as indicated in other published synonymies) should be adopted with caution.

It is with apologies to colleagues where we have been unable to categorise their field lists as confirmed records (or sometimes even strongly predicted records) in our distribution maps. The process of confirmation is ongoing and the timing of this report is such that many long-standing records still require photographic or other confirmation[2]. This is especially true at the periphery of the known range of species and among others it particularly affects ecoregions of the eastern central Pacific. So far, a relatively small number of photographic or specimen records have been available to assess comparative identifications in this region. A related issue is the existence of a number of recognised field identifications that have not yet been given species status. These are excluded from *COTW* until further clarifications are made. Fieldwork by our team and by others have also highlighted variants of recognised species that may warrant individual species status in their own right. For example we believe that *Pavona diffluens* and *Montipora lobulata*, both subjects of this report, may be restricted to the western Indian Ocean and that Pacific occurrences given these names are likely to be undescribed species. Such issues are always matters of opinion and flag the need for further study.

TAXONOMIC AND DISTRIBUTION DATA

Distribution Data Sources

Data detailed in *COTW* website were obtained from the following sources:

Original field and taxonomic work by the authors: The geographic coverage of taxonomic studies includes (a) detailed fieldwork in >5000 sites in 77 of the Indo-Pacific's 133 ecoregions, a 58% coverage from the Red Sea to Far Eastern Pacific and from the most northern to the most southern latitudes, (b) standardised quantitative studies which include abundance and depth ranges from the Red Sea in the west to Pohnpei in the east, (c) additional work on collections (see below), taking the total coverage to 69% and (d) less detailed or transitory observations in several additional ecoregions.

Globally, original field and taxonomic work by the authors of COTW covers 68% of the world's 150 ecoregions.

Taxonomic literature: Many historical taxonomic studies as well as most taxonomic studies using scuba provide geographic records. Over 500 taxonomic publications cited in *Corals of the World* underpin this report.

[2] There is a fundamental difference between compendia which collate records and revisions which re-assess records. The former are much more common and it is commonplace for the same original record to be repeated in multiple compendia.

Biogeographic literature: Many hundreds of publications cited in *Corals of the World* contain species lists; however these are of very variable value. In principle, species names in any biogeographic publication are only useful if they can be associated with entities that are recognisable in the field. Species which are not recognisable (unstudied 'nominal' species) are not included in this report, nor are unverified records used which cannot be attributed to a recognisable species.

References not included in *COTW* have either been overlooked (unlikely for formal publications but possible for grey literature) or have not presented supportable records.

Ecological literature: Studies involving individual species or groups of species in focussed scientific studies, or in surveys of mass bleaching, *Acanthaster* outbreaks and disease have been used in the present study where authors are known to have appropriate identification skills.

Collections: Collections have been studied in 48 museums, universities and field stations around the world in addition to the author's almost comprehensive collection of some 28,000 specimens.

Images: (a) More than 60 photographers are cited in *COTW* website with the number of location-specific photographs from each varying from one to several hundred. (b) Assessment of *in situ* and skeletal photographs from a wide range of additional sources and colleagues has been used extensively to verify field records where provenance is verified and locations are confirmed.

Field guides: Twenty species-level field guides to corals have been published which usefully illustrate the key characters of living corals in the region they cover.

Personal communications: Verification of distribution records from publications or species lists which do not provide supporting data is ongoing via personal communications using images and descriptions.

Despite the extent of these information sources it is stressed that they can never be up-to-date let alone complete, especially for ecoregions that remain poorly known or are currently under review.

Analyses

As with all biogeography, distribution data can be compiled from studies of specific locations or from studies of individual species.

Ecoregion-based data

Distribution data from combined sources (above) were collated into ecoregion-specific files that compared the various sources. This process, through many reiterations, progressively narrowed decision-making to the point where additional data searches specifically targeted individual species. All data were then transferred to a single matrix and scored as follows.

Occurrence categories

As seen in the example map below (figure 2) and the spreadsheet as "Global occurrences out of 133 Indo-Pacific ecoregions":

0 = No record.

1 = A confirmed record. Only these records are used to delimit species distribution ranges.

2[3] = A strongly predicted record. These are of two kinds; published records yet to be fully confirmed and predicted records based on confirmed occurrences in surrounding ecoregions which have comparable habitats and are upstream of surface currents. Category 1 plus 2 occurrences are the most accurate predictors of ecoregion diversity and are also used in calculation of ecoregion affinity.

3 = A published record considered to warrant further investigation.

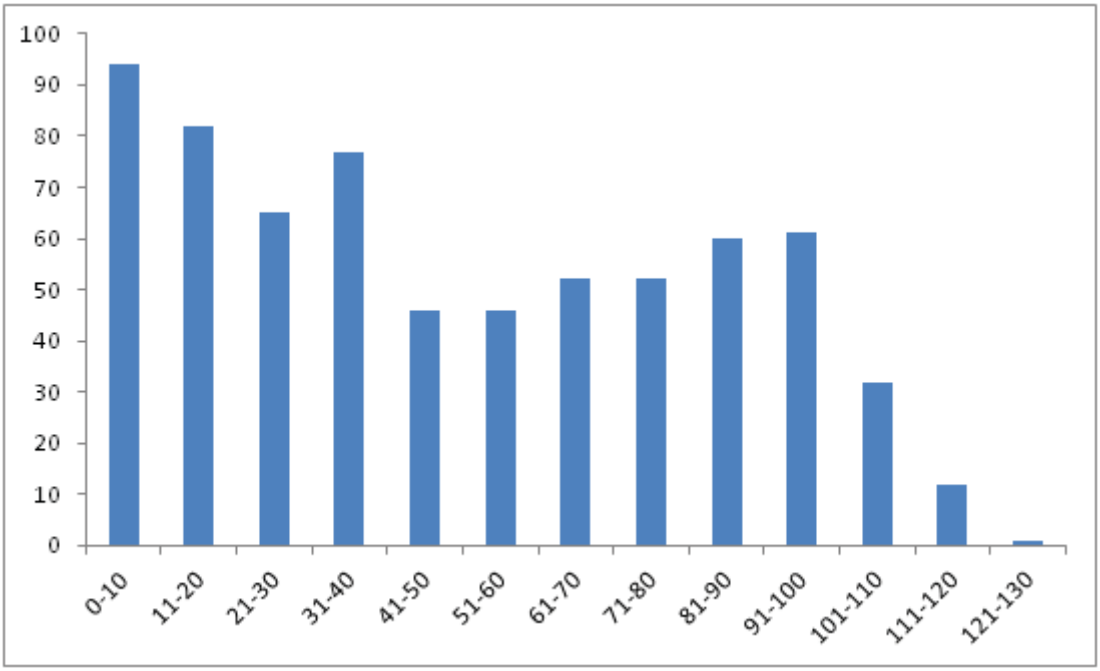

Figure 1: Number of species in ecoregions for all Indo-Pacific species; categories 1 plus 2. Category 3 occurrences are excluded. The x-axis shows global occurrences in number of ecoregions; the y-axis shows number of species.

The above diagram (figure 1) enables categories in the attached spreadsheet to be seen in context.

[3] Many records in the central Pacific listed as "2" will be advanced to "1" when details, identifiable photos and/or specimens, are available. Category 1 records are changed to category 2 if there is minor taxonomic uncertainty.

Species-specific data

Just as ecoregions have far from equal coverage, so have species. Records of all species, irrespective of the ecoregions in which they were recorded, were attributed to one of the three categories described above.

Distribution Maps

All distribution data were amalgamated into a single file and entered into the *Coral Geographic* website. This website allows maps to be generated according to user commands. The figure below is an example, showing ecoregions with the four categories of records (0 to 3) described above. The website also produces maps of different combinations of species and ecoregions.

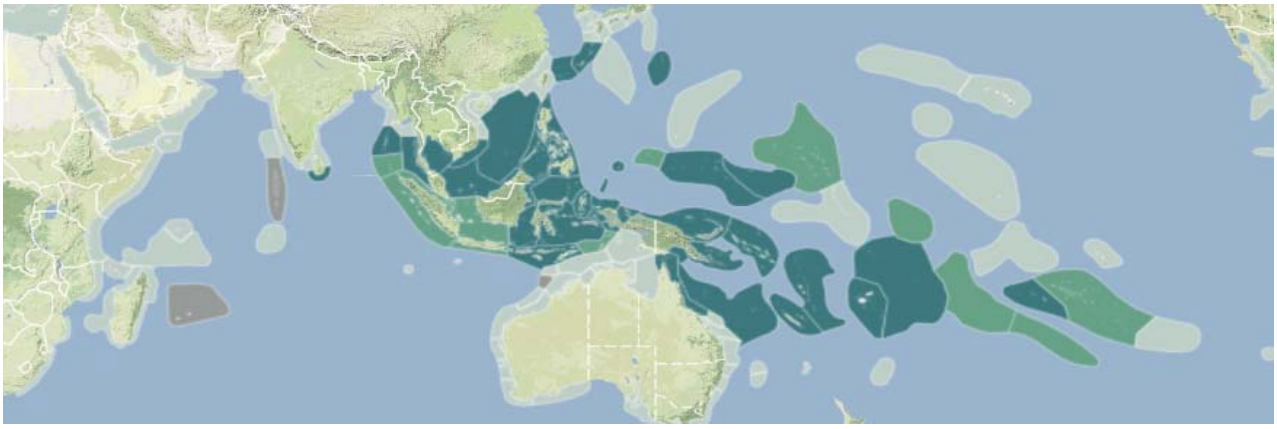

Figure 2: Example of a distribution map from *COTW* showing occurrence categories. Off-white = no record (category 0), dark green = confirmed record (category 1), pale green = predicted record (category 2), tan = published record that needs further investigation (category 3).

Distribution Data Robustness Categories[4]

Three categories of distribution data robustness are given to all species:

1) Species with highly indicative distributions

Substantial gaps (of multiple ecoregions) within the overall range are more likely to be due to non-occurrence rather than omissions. (Approximately 67% of the world's species are in this category.)

2). Species with incomplete but indicative distributions

Gaps in the overall range may have any cause including missing records and non-occurrence. These records are not used to define species boundaries. (Approximately 21% of the world's species are in this category.)

[4] Indicated in bold in the spreadsheet.

3) Species with poorly known distributions

These distribution maps are not suitable for analysis. Gaps in the overall range may be due to taxonomic or identification difficulties, rarity or where the species occurs in seldom studied habitats[5]. (Approximately 11% of the world's species are in this category.)

Specific Reference to Three US Ecoregions

Relevant points:

The Marianas: Our computer analysis of the species composition of these islands indicates a high level of distribution disjunctures. A major revision is currently being undertaken by Randall and Burdick, and we will be assisting with that important undertaking. Only preliminary work is currently available, aided by these colleagues.

American Samoa[6]: What differences there are between our occurrence data and that of Fenner is with a small group of species and should in future be resolved as there is a high level of agreement among us.

Hawaii: The isolation of Hawaii, as with other very isolated ecoregions, creates a spectrum of taxonomic, hence biogeographic, problems. All but a few Hawaiian species show significant differences from their central Indo-Pacific counterparts. Molecular techniques are likely to reveal a high level of complexity in taxonomic affinity between some Hawaiian corals and occurrences of those species in other ecoregions.

ABUNDANCE DATA

The two sets of abundance data described below are from independent sources.

Semi-quantitative Abundance Assessments

Semi-quantitative abundance data are from 2,984 individual survey sites in 30 ecoregions across the Indo-west Pacific from 1994 to 2012 following a standard Rapid Ecological Assessment protocol (DeVantier *et al*. 1998)[7].

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[5] Species that have been described, validated or revised after Veron (2000) commonly have poorly known distributions.

[6] All corals shown in the spreadsheet and maps as occurring (as "1") in the American Samoa ecoregion (which includes Tuvalu and Tonga) have been specifically recorded from American Samoa.

[7] Ecoregions for these studies were not selected in a representative or random manner; rather they were based on the requirements of specific surveys for conservation projects conducted by various government and non-government organizations. Similarly, sampling frequency and intensity were not standardized within or among ecoregions. Some species, particularly endemics, do not occur in any of the 30 surveyed ecoregions. With these constraints, individual survey sites in each ecoregion were selected to provide the broadest range of reef habitat types and environmental conditions.

In each site the relative abundance of each coral species present was scored from one to five, where 1 represents rare, 2 uncommon, 3 common, 4 abundant and 5 dominant. Publication of details of these records is in preparation (DeVantier and Turak in prep).

Analyses

Global abundance of each species was calculated as a three-step process using occurrence and mean abundance:

1. The percentage of the total of 2,984 sites in which each species occurred was determined (Occurrence)[8].

2. The Mean abundance score was determined, being the sum for each species of all its individual abundance scores (1-5) [9] divided by the number of sites in which each species occurred[10].

3. These two numbers (Occurrence x Mean abundance) were multiplied to give the global abundance score[11].

For example, using this metric, a maximum score of 500 is possible (attained if a species occurred in all sites and was dominant in every one of those sites). Actual abundance scores ranged from less than 0.1 to 172.05. This range was divided into six categories, with the range of scores in each category, together with the percentages of species involved, as follows[12]:

Very rare (Score < 0.1). 17 (2.5%) of all encountered species have this score

Rare (Score 0.1 - 1). 126 (18.8%) of all encountered species have this score

Uncommon (Score 1 - 10). 270 (40.2%) of all encountered species have this score

Common (Score 11-50). 193 (28.7%) of all encountered species have this score

Very common (Score 51-100). 59 (8.8%) of all encountered species have this score

Abundant (Score >100). 7 (1.0%) of all encountered species have this score

[8] Indicated in bold in spreadsheet as "% sites present."

[9] Among the subsample of 30 ecoregions where abundance was assessed in detail, the ecoregion(s) in which the species recorded the highest average site abundance when present is indicated in the spreadsheet as "ecoregion with the highest abundance"

[10] Indicated in bold in spreadsheet as "Average abundance when present."

[11] A total of 672 species were assessed using this metric.

[12] Indicated in bold in the spreadsheet as "Semi-quantitative abundance category."

Non-quantitative Abundance Assessments[13]

These are the author's subjective estimates covering a full range of habitats and most ecoregions the author has worked in. Differences between the two estimates are mostly due to species being relatively abundant in specific ecoregions (as these affect semi-quantitative records), with a lesser effect on overall estimates.

Species not occurring in the ecoregions studied by the authors were attributed abundance categories from the literature.

ASSESSMENT OF VULNERABILITY

During the course of this work we have taken into account IUCN's Red List (Carpenter *et al*. 2008, of which three of the four authors of *COTW* are co-authors), the Status Review Report of NOAA (Brainard *et al*. 2011) and Kenyon, Maragos and Fenner's (2011) assessment of that report, the latter two authors having also made valued contributions to *COTW*. It is not our purpose to discuss these publications, but rather to present data about the scleractinian species listed in Kenyon, Maragos and Fenner's (2011)[14] that were not available to these or any other authors. In so doing, we hope that all parties involved will unite to achieve a consensus that will result in strong multi-institutional conservation outcomes.

LINKED DOCUMENTATION

The following documentation is attached to this report and is the substance of it.

A) A spreadsheet covering the Indo-Pacific species of Scleractinia indicated in Kenyon, Maragos and Fenner (2011) and some others that may be of interest. Columns include the following:

1. Coral name.
2. Authority (who described the species).
3. Type locality (the place where the species was originally described).
4. Occurrences globally (as seen on maps). These are divided into the following:
    a. Confirmed records
    b. Strongly predicted records
    c. Total records ("a" plus "b")
5. Occurrences in US territories covered in this report
    a. Marianas
    b. Samoa (also including Tuvalu, Tonga and Samoa)

[13] Indicated in spreadsheet as "Overall estimate." Data are from Veron (2000) with minor subsequent updates.

[14] A small number of additional species are included as these have relevance to other listings.

c. Hawaii

6. Map data robustness category (explained above).
7. Abundance data (as explained above). Records are as follows:
    a. Percent of 2,984 sites where the species was recorded as present
    b. Average abundance when present
    c. Ecoregion with the highest species abundance during surveys
    d. Ecoregions in which available data indicates species presence
    e. Semi-quantitative abundance category
    f. Independent overall abundance estimate
8. Habitat in which the species is most commonly found.
9. Notes.

B) A spreadsheet covering the Caribbean species of Scleractinia proposed for listing by the US National Marine Fisheries Service. Columns are as follows:

1. Coral name.
2. Authority (who described the species).
3. Type locality (the place where the species was originally described).
4. Occurrences globally (as seen on maps). These are divided into the following:
    a. Confirmed records
    b. Strongly predicted records
    c. Total records ("a" plus "b")
5. Map data robustness category (explained above).
6. Independent overall abundance estimate (qualitative data only; explained above).
7. Habitat in which the species is most commonly found.
8. Notes.

C) Global maps from *Coral Geographic* of the Indo-Pacific species indicated above. It should be noted that all maps are being continually updated prior to publication; they are current for the date of this report.

D) Global maps from *Coral Geographic* of the Caribbean species indicated above.

E) Comparison of the updated *COTW* with information contained in the National Marine Fisheries Service's proposal to list 66 species of corals under the Endangered Species Act (Ishizaki *et al.* 2014). The author of this report is not a co-author of Ishizaki *et al.* (2014) but has reviewed the document for accuracy of the *COTW* data and their interpretation. The author

believes the document represents a valuable addition to the coral listing discussion and should be considered alongside the spreadsheets and maps provided here.

CONCLUDING REMARKS

The long history of development of *Coral Geographic* to its point of publication has created significant issues for both user groups and the authors of *COTW*. The necessity of delineating the Coral Triangle before the amalgamation of all relevant records was completed, let alone published, has meant that the process has had to be reiterated. Likewise, IUCN's production of a coral Red List (Carpenter *et al*. 2008, co-authored by three of the present authors) went ahead of necessity using unfinished mapping. It is now common to see two maps of the same species being compared (as for example in Brainard *et al*. 2011) when both are re-worked versions of the same original *Coral Geographic* maps (in Veron 2000) accredited to different sources. In fact digitized versions of these maps were shared with those authors who asked for them and re-digitized by others who didn't. Some authors have considered these maps to be public domain information, and others have claimed them to be their own work. Given the level of taxonomic knowledge and effort required to build detailed species maps the difference between these categories is readily apparent.

Two points of general concern remain that significantly affect the data quality in coral biogeography. (A) The maps of Veron (2000) are thumbnail indicators of broad distributions of coral species as known by the late 1990s; therefore, they do not include most studies relevant to the Coral Triangle, nor do they include any species revealed by molecular techniques, nor do they include the results of fieldwork undertaken during the past 15 years. (B) The spectrum of biogeographic information currently offered on websites is of very variable quality.

As it is important that distribution data used in global vulnerability assessments can be directly compared from one region to another, our goal with *COTW* has been to bridge gaps and attempt to pull all records into a coherent taxonomic framework. It has been and continues to be a very complex and difficult process; compromises must be made and problems remain, not least from the burgeoning molecular literature.

Three factors affect the comprehensiveness of the data in this report: (1) the experience of the fieldworker(s) being foremost, (2) unresolvable taxonomic issues and (3) field-time availability. This has meant that species compilations from earlier studies within the Indo-west Pacific, especially places of high diversity, are normally doubled or trebled when re-visited by an experienced fieldworker. We have attempted to minimize issues of data comprehensiveness by using ecoregion divisions, which allows different data sources relevant to the same region to be pooled with reasonable assuredness, and also by dividing species into the categories described above. Our data for most species and most ecoregions is generally robust; however, for others it is likely to change substantially with future study.

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Linked Documentation A:

Indo-Pacific Species Spreadsheet

This spreadsheet was generated by JEN Veron for the Western Pacific Regional Fishery Management Council and is current as of December 9, 2013. The spreadsheet is open access under the terms of the Creative Commons Attribution-NonCommercial-NoDerivs License, which permits use and distribution in any medium, provided the original work is cited as "from Veron JEN, Stafford-Smith MG, Turak E and DeVantier LM (in prep.) Corals of the World (www.coralsoftheworld.com)" and the use is non-commercial and no modifications or adaptations are made.

Name	Authority	Type Locality	Distribution							Abundance					Principal Habitat	Notes
			Global occurrences (out of 133 Indo-Pacific ecoregions)			Occurrence data category (US territories)			Map robustness category (see Report)	% sites present	Average abundance when present	Ecoregion with the highest abundance	Semi-quantitative abundance category (see Report)	Overall estimate		
			Confirmed (1)	Strongly predicted (2)	Total (1 + 2)	Marianas	Samoa	Hawaii								
Acanthastrea brevis	Milne Edwards and Haime, 1849	Not recorded	29	17	**46**	2	1	0	**1**	**6.53**	**1.49**	Fiji	**Uncommon**	Uncommon	Shallow reef environments	Readily confused with *A. echinata*
Acanthastrea hemprichii	(Ehrenberg, 1834)	Red Sea	47	23	**70**	0	0	0	**1**	**11.39**	**1.47**	Moreton Bay	**Common**	Uncommon	Most reef environments	Unsually distinctive
Acanthastrea ishigakiensis	Veron, 1990	Ryukyu Islands, Japan	25	19	**44**	1	2	0	**1**	**2.68**	**1.30**	Fiji	**Uncommon**	Uncommon but conspicuous	Shallow, partly protected reef environments	Readily confused with *A. hillae*
Acanthastrea regularis	Veron, 2000	Papua New Guinea	17	16	**33**	2	0	0	**2**	**5.13**	**1.21**	Milne Bay	**Uncommon**	Uncommon	Shallow reef environments	Readily confused with *Favia* aspecies
Acropora aculeus	(Dana, 1846)	Fiji	68	16	**84**	1	1	0	**1**	**32.10**	**1.55**	NW Madagascar	**Common**	Usually common in the central Indo-Pacific, uncommon elsewhere	Upper reef slopes and lagoons	Distinctive
Acropora acuminata	(Verrill, 1864)	Gilbert Islands, western Pacific	60	12	**72**	1	1	0	**2**	**4.66**	**1.21**	S Vietnam	**Uncommon**	Sometimes common	Turbid or clear water on upper or lower reef slopes	Distinctive
Acropora aspera	(Dana, 1846)	Fiji	68	17	**85**	1	1	0	**1**	**7.54**	**1.76**	SW Papua	**Common**	Sometimes common	Reef flats and shallow lagoons, also exposed upper reef slopes and occsionally deep water	Distinctive
Acropora dendrum	(Bassett-Smith, 1890)	South China Sea	32	20	**52**	0	2	0	**2**	**2.04**	**1.11**	SW Papua; Milne Bay	**Uncommon**	Rare	Occurs only on upper reef slopes where *Acropora* diversity is high	Distinctive
Acropora donei	Veron and Wallace, 1984	Great Barrier Reef, north-east Australia	50	17	**67**	0	1	0	**2**	**4.66**	**1.16**	Gulf of Aden; Bismarck Sea; Milne Bay	**Uncommon**	Uncommon	Restricted to shallow fringing reefs and upper reef slopes where *Acropora* diversity is high	Distinctive
Acropora globiceps	(Dana, 1846)	Tahiti	22	16	**38**	1	1	0	**2**	**3.22**	**1.95**	Yap; Palau	**Uncommon**	Sometimes common	Upper reef slopes and reef flats	Distinctive
Acropora horrida	(Dana, 1846)	Fiji	61	22	**83**	0	1	0	**1**	**8.85**	**1.70**	Banda Sea	**Common**	Usually uncommon	Turbid water around fringing reefs	Distinctive
Acropora jacquelineae	Wallace, 1994	Papua New Guinea	12	5	**17**	0	0	0	**1**	**1.61**	**1.44**	Sulu Sea	**Uncommon**	Uncommon	Shallow reef slopes protected from wave action	Distinctive when with similar species, not otherwise
Acropora listeri	(Brook, 1893)	Tonga, western Pacific	54	14	**68**	1	1	0	**1**	**5.50**	**1.35**	Fiji	**Uncommon**	Uncommon	Upper reef slopes, especially those exposed to strong wave action	Distinctive
Acropora lokani	Wallace, 1994	Papua New Guinea	14	6	**20**	0	0	0	**1**	**2.75**	**1.44**	Fiji	**Uncommon**	Sometimes common	Shallow reef environments	Distinctive
Acropora microclados	(Ehrenberg, 1834)	Not recorded	56	18	**74**	1	1	0	**1**	**15.18**	**1.51**	Cenderawasih Bay	**Common**	Usually uncommon	Upper reef slopes	Distinctive
Acropora palmerae	Wells, 1954	Marshall Islands	42	17	**59**	1	1	0	**1**	**2.65**	**1.81**	Pohnpei	**Uncommon**	Uncommon	Reef flats exposed to strong wave action and lagoons	Distinctive
Acropora paniculata	Verrill, 1902	? Fiji	51	15	**66**	0	1	1	**1**	**14.31**	**1.43**	Sunda Shelf	**Common**	Uncommon	Upper reef slopes	Distinctive
Acropora pharaonis	(Milne Edwards and Haime, 1860)	Red Sea	11	8	**19**	0	0	0	**2**	**3.62**	**1.80**	North & central Red Sea	**Uncommon**	Common in the Red Sea, uncommon elsewhere	Sheltered reef slopes	Records of this species in the Pacific are believed to be another (probably undescribed) species
Acropora polystoma	(Brook, 1891)	Mauritius, Mascarene Islands	48	19	**67**	1	1	0	**1**	**6.74**	**1.74**	Pohnpei	**Common**	Uncommon	Upper reef slopes exposed to strong wave action	Distinctive
Acropora retusa	(Dana, 1846)	Fiji	23	21	**44**	1	1	0	**2**	**0.47**	**1.21**	Fiji	**Rare**	Common in South Africa, rare elsewhere	Upper reef slopes and reef flats	Readily confused with several other *Acropora*
Acropora rudis	(Rehberg, 1892)	Sri Lanka	7	2	**9**	0	0	0	**2**	**0.13**	**1.25**	Andaman Sea	**Rare**	Uncommon	Shallow to deep rocky foreshores or reef slopes	Readily confused with *Acropora schmitti* in shallow habitats, very distinctive otherwise
Acropora speciosa	(Quelch, 1886)	Tahiti	26	12	**38**	0	3	0	**1**	**8.31**	**1.60**	Bismarck Sea	**Common**	Usually uncommon	Protected reef environments with clear water and a high *Acropora* diversity	Distinctive, however It is likely that this species occurs in central south Pacific ecoregions close to the type locality as well as in Samoa. However, so far, available records and images have been ambiguous or attributable to other species.
Acropora striata	(Verrill, 1866)	Ryukyu Islands, Japan	36	17	**53**	1	1	0	**1**	**3.22**	**1.38**	Banda Sea	**Uncommon**	May be locally dominant in Japan, uncommon elsewhere	Shallow rocky foreshores or shallow reef flats	Easily confused with other *Acropora* with a bushy growth form
Acropora tenella	(Brook, 1892)	South China Sea	18	6	**24**	0	0	0	**2**	**0.40**	**1.25**	Pohnpei; Celebes Sea	**Rare**	Rare	Lower reef slopes below 40 metres	Readily confused with other flattened finely branched *Acropora*
Acropora vaughani	Wells, 1954	Marshall Islands	59	13	**72**	1	1	0	**1**	**7.54**	**1.69**	S Vietnam	**Common**	Uncommon	Turbid water around fringing reefs	Distinctive
Acropora verweyi	Veron and Wallace, 1984	Coral Sea	63	17	**80**	1	1	0	**1**	**4.69**	**1.59**	N Philippines	**Uncommon**	Occasionally common in the western Indian Ocean	Upper reef slopes, especially those exposed to wave action or currents	Distinctive
Alveopora allingi	Hoffmeister, 1925	Samoa	53	27	**80**	1	1	0	**1**	**1.24**	**1.27**	Sunda Shelf; Banda Sea	**Uncommon**	Usually uncommon	Protected reef environments	Distinctive
Alveopora fenestrata	(Lamarck, 1816)	"Southern Ocean" (south Pacific)	39	19	**58**	1	0	0	**2**	**1.98**	**1.29**	North & central Red Sea; Cenderawasih Bay; Milne Bay	**Uncommon**	Uncommon	Shallow reef environments	Easily confused with other *Alveopora* with similar growth form
Alveopora verrilliana	Dana, 1846	Hawaii? (uncertain)	28	30	**58**	1	1	2	**2**	**0.27**	**1.13**	SW Papua	**Rare**	Uncommon	Shallow reef environments	Easily confused with other *Alveopora* with similar growth form. It is impossible to confirm many citations of this species. Note: Hawaii is unlikely to be the type locality as is commonly supposed.
Anacropora puertogalerae	Nemenzo, 1964	Philippines	26	7	**33**	0	0	0	**1**	**4.56**	**2.02**	Banda Sea	**Uncommon**	Uncommon	Shallow reef environments	Sometimes a dominant species where it occurs
Anacropora spinosa	Rehberg, 1892	Palau	13	6	**19**	0	0	0	**2**	**1.47**	**1.84**	Solomon Islands	**Uncommon**	Usually uncommon	Shallow reef environments	Easily confused with the much more common *Anacropora puertogalerae*
Astreopora cucullata	Lamberts, 1980	American Samoa	31	15	**46**	0	1	0	**1**	**6.80**	**1.25**	Pohnpei	**Uncommon**	Rare	Shallow reef environments	Not readily distinguished from some other *Astreopora*
Barabattoia laddi	(Wells, 1954)	Marshall Islands	22	15	**37**	0	3	0	**1**	**5.19**	**1.33**	Celebes Sea	**Uncommon**	Rare	Recorded only from shallow lagoons	Distinctive
Caulastrea echinulata	(Milne Edwards and Haime, 1848)	Singapore	15	12	**27**	0	0	0	**1**	**0.34**	**1.30**	Solomon Islands	**Rare**	Uncommon	Horizontal substrates protected from wave action and with turbid water	Commonly confused with *Caulastrea furcata*. Images we have are all *C. furcata*
Cyphastrea agassizi	(Vaughan, 1907)	Hawaii	28	15	**43**	1	0	1	**1**	**2.58**	**1.14**	Cenderawasih Bay	**Uncommon**	Uncommon	Shallow reef environments	Distinctive

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Name	Authority	Type Locality	Distribution							Abundance					Principal Habitat	Notes
			Global occurrences (out of 133 Indo-Pacific ecoregions)			Occurrence data category (US territories)			Map robustness category (see Report)	% sites present	Average abundance when present	Ecoregion with the highest abundance	Semi-quantitative abundance category (see Report)	Overall estimate		
			Confirmed (1)	Strongly predicted (2)	Total (1 + 2)	Marianas	Samoa	Hawaii								
Cyphastrea ocellina	(Dana, 1846)	Hawaii	27	14	**41**	1	0	1	**2**	**4.29**	**1.24**	Yap; Palau	**Uncommon**	Rare	Upper reef slopes	Distinctive
Euphyllia cristata	Chevalier, 1971	New Caladonia	37	12	**49**	1	0	0	**1**	**12.13**	**1.33**	Pohnpei	**Common**	Uncommon but conspicuous	Shallow reef environments	Sometimes confused with *Euphyllia glabrescens*
Euphyllia paraancora	Veron, 1990	Philippines	19	15	**34**	1	0	0	**1**	**1.88**	**1.46**	Halmahera	**Uncommon**	Uncommon	Shallow to deep reef environments protected from wave action	Very distinctive
Euphyllia paradivisa	Veron, 1990	Philippines	8	8	**16**	0	1	0	**1**	**0.20**	**1.50**	Celebes Sea	**Rare**	Uncommon	Shallow reef environments protected from wave action	Very distinctive
Galaxea astreata	(Lamarck, 1816)	"Indian Ocean"	74	17	**91**	1	1	0	**1**	**23.26**	**1.49**	Pohnpei	**Common**	Common	Reef environments protected from strong wave action	Very distinctive
Isopora crateriformis	(Gardiner, 1898)	Ellice Islands, western Pacific	13	17	**30**	0	1	0	**1**	**0.34**	**1.40**	Birds Head	**Rare**	Occasionally common on reef flats	Shallow reef environments, especially reef flats exposed to strong wave action	Easily confused with *Isopora cuneata*
Isopora cuneata	(Dana, 1846)	Fiji	43	9	**52**	0	1	0	**1**	**5.09**	**1.76**	S Vietnam; Solomon Islands	**Uncommon**	Uncommon	Occurs in all reef environments, especially upper reef slopes and reef flats	Commonly confused with *Isopora palifera* which it closely resembles
Leptoseris incrustans	(Quelch, 1886)	Tahiti	39	21	**60**	1	1	1	**1**	**5.73**	**1.30**	N Philippines; Milne Bay	**Uncommon**	Uncommon	Shallow reef environments	Hawaiian specimens are distinctive
Leptoseris yabei	(Pillai and Scheer, 1976)	Maldive Islands	57	11	**68**	0	1	1	**1**	**6.64**	**1.36**	Birds Head	**Uncommon**	Uncommon but conspicuous	Usually found on flat substrates	Very distinctive
Montipora angulata	(Lamarck, 1816)	"Eastern Indian Ocean"	34	26	**60**	0	3	0	**1**	**0.34**	**1.30**	Sulu Sea; Lesser Sundas	**Rare**	Rare	Fringing reef flats	Distinctive
Montipora australiensis	Bernard, 1897	Houtman Abrolhos Islands, south-west Australia	17	16	**33**	0	0	0	**1**	**0.40**	**1.50**	Sunda Shelf	**Rare**	Usually rare	Shallow reef environments exposed to strong wave action	Easily confused with several other *Montipora*
Montipora calcarea	Bernard, 1897	Tonga	25	24	**49**	0	1	0	**1**	**5.80**	**1.35**	Milne Bay	**Uncommon**	Rare	Shallow reef environments	Easily confused with several other *Montipora*
Montipora caliculata	(Dana, 1846)	Fiji	53	29	**82**	1	1	0	**1**	**12.13**	**1.55**	Pohnpei	**Common**	Uncommon	Most reef environments	Easily confused with several other *Montipora* , however the disjunct distribution between the western Indian Ocean and Pacific is well supported
Montipora dilatata	Studer, 1901	Hawaii	4	0	**4**	0	0	1	**1**	**0.03**	**3.00**	Lesser Sundas	**Rare**	Rare	Subtidal environments	Apparently distinctive
Montipora flabellata	Studer, 1901	Hawaii	3	0	**3**	0	0	1	**2**	**-**	**0.00**	*Not encountered*	*Not encountered*	Uncommon	Shallow reef environments	Apparently distinctive
Montipora lobulata	Bernard, 1897	Diego Garcia, Chagos	10	7	**17**	1	1	0	**3**	**-**	**0.00**	*Not encountered*	*Not encountered*	Rare	Shallow reef environments	This species has never been seen in the central Indo-Pacific or Pacific by the authors of COTW, suggesting that Pacific records indicated in the present maps may be a different species. Nor has it been recorded at its type locality.
Montipora patula	Verrill, 1864	Hawaii	5	2	**7**	0	0	1	**1**	**-**	**0.00**	*Not encountered*	*Not encountered*	Sometimes common	Shallow reef environments	Very similar to *M verrilli*
Montipora turgescens	Bernard, 1897	Great Barrier Reef, north-east Australia	71	30	**101**	0	2	1	**1**	**16.66**	**1.40**	Pohnpei	**Common**	Common	Most reef environments	Very distinctive
Pachyseris rugosa	(Lamarck, 1816)	"Southern Ocean" (south Pacific)	57	17	**74**	0	1	0	**1**	**23.46**	**1.45**	Halmahera	**Common**	Common	May develop into large mound-shaped colonies in shallow water but smaller colonies occur in a wide range of habitats including those exposed to strong wave action	Very distinctive
Pavona bipartita	Nemenzo, 1980	Philippines	34	14	**48**	1	1	0	**1**	**6.90**	**1.28**	N Philippines	**Uncommon**	Uncommon	Shallow reef environments	Usually distinctive
Pavona cactus	(Forskål, 1775)	Red Sea	68	21	**89**	1	1	0	**1**	**17.19**	**1.83**	Fiji	**Common**	Common	Usually found in lagoons and on upper reef slopes, especially those of fringing reefs, and in turbid water protected from wave action, where colonies are sometimes over 10 metres across	Very distinctive
Pavona decussata	(Dana, 1846)	Fiji	75	19	**94**	1	1	0	**1**	**23.93**	**1.60**	Hong Kong	**Common**	Common	Most reef environments	Very distinctive
Pavona diffluens	(Lamarck, 1816)	Not recorded	5	3	**8**	3	3	0	**2**	**0.47**	**1.43**	NW Madagascar	**Rare**	Uncommon	Most reef environments	We believe that Pacific '*P diffluens* ' is likely to be a similar but different species from western Indian Ocean *P diffluens* (the latter having smaller, less plocoid corallites). The type locality is unknown, but as this is a Lamarck species the name almost certainly applies to the Indian Ocean *P diffluens*
Pavona venosa	(Ehrenberg, 1834)	Red Sea	65	23	**88**	1	2	0	**1**	**20.11**	**1.60**	N Philippines; Fiji	**Common**	Sometimes common	Shallow reef environments	Distinctive
Pectinia alcicornis	(Saville-Kent, 1871)	Solomon Islands	39	16	**55**	0	0	0	**1**	**16.59**	**1.56**	S Vietnam	**Common**	Usually uncommon	Turbid water, especially on horizontal substrates	Sometimes confused with other *Pectinia* species
Physogyra lichtensteini	(Milne Edwards and Haime, 1851)	"East Indies" (south-east Asia)	54	18	**72**	0	0	0	**1**	**30.86**	**1.31**	Pohnpei	**Common**	Common in protected habitats	Turbid reef environments	One of the world's most distinctive species
Pocillopora danae	Verrill, 1864	Fiji	28	27	**55**	1	1	0	**2**	**24.10**	**1.80**	North & central GBR	**Common**	Usually uncommon	Partly protected reef slopes	Requires further study and probably a new name
Pocillopora elegans	Dana, 1846	Fiji	26	20	**46**	1	1	0	**2**	**4.12**	**1.74**	Pohnpei	**Uncommon**	Locally common in some regions of the central Indo-Pacific and the far eastern Pacific	Shallow reef environments	A commonly misidentified species
Porites horizontalata	Hoffmeister, 1925	Samoa	28	13	**41**	1	1	0	**1**	**4.16**	**1.62**	Fiji	**Uncommon**	Sometimes common in isolated habitats	Shallow reef environments	Easily confused with the very common *Porites rus*
Porites napopora	Veron, 2000	Ashmore Reef, north-west Australia	13	13	**26**	0	0	0	**1**	**3.15**	**1.79**	Celebes Sea; Halmahera	**Uncommon**	Sometimes common in isolated habitats	Shallow reef environments	Distinctive
Porites nigrescens	Dana, 1846	Fiji	56	18	**74**	0	1	0	**1**	**29.05**	**2.01**	Cenderawasih Bay	**Very common**	Sometimes common	Common on lower reef slopes and lagoons protected from wave action	Easily distinguished from other branching *Porites*

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Name	Authority	Type Locality	Distribution							Abundance					Principal Habitat	Notes
			Global occurrences (out of 133 Indo-Pacific ecoregions)			Occurrence data category (US territories)			Map robustness category (see Report)	% sites present	Average abundance when present	Ecoregion with the highest abundance	Semi-quantitative abundance category (see Report)	Overall estimate		
			Confirmed (1)	Strongly predicted (2)	Total (1 + 2)	Marianas	Samoa	Hawaii								
Porites pukoensis	Vaughan, 1907	Hawaii	1	3	**4**	0	3	1	**2**	**-**	**0.00**	*Not encountered*	*Not encountered*	Usually uncommon	Shallow protected reef environments, especially lagoons	Easily confused with other sub-massive *Porites.* The type locality is eastern Hawaii but other records are currently uncertain
Psammocora stellata	(Verrill, 1866)	Panama	24	15	**39**	1	0	1	**2**	**0.34**	**2.00**	N Philippines	**Rare**	Usually rare	Shallow wave washed rock	Distinctive
Seriatopora aculeata	Quelch, 1886	Indonesia	19	7	**26**	1	0	0	**2**	**10.29**	**1.70**	Sunda Shelf	**Common**	Uncommon	Shallow reef environments	Sometimes confused with *Seriatopora stellata*
Turbinaria mesenterina	(Lamarck, 1816)	"Indian Ocean"	84	21	**105**	0	1	0	**1**	**18.83**	**1.46**	N Philippines	**Common**	Common	May be a dominant species in shallow turbid environments	A very distinctive species. Most old references to *Turbinaria crater* are probably this species
Turbinaria peltata	(Esper, 1794)	China Sea	80	20	**100**	0	1	0	**1**	**24.10**	**1.46**	Moreton Bay	**Common**	Common and may be a dominant species	Protected environments, especially shallow rocky foreshores with turbid water. Also occurs on shallow reef slopes	One of the world's most distinctive species
Turbinaria reniformis	Bernard, 1897	Great Barrier Reef, north-east Australia	77	23	**100**	1	1	0	**1**	**26.24**	**1.36**	Palau	**Common**	Sometimes common	May form large stands on fringing reefs where the water is turbid	A very distinctive species
Turbinaria stellulata	(Lamarck, 1816)	? Fiji	70	23	**93**	1	1	0	**1**	**16.55**	**1.25**	Socotra	**Common**	Usually uncommon	May form conspicuous dome-shaped colonies on upper reef slopes. Unlike other *Turbinaria* this species is seldom found in turbid waters	Sometimes confused with *Turbinaria radicalis*

Linked Documentation B:

Caribbean Species Spreadsheet

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Name	Authority	Type Locality	Distribution				Abundance	Principal Habitat	Notes
			Global occurrences (out of 15 Atlantic ecoregions)			Map robustness category (see Report)	Overall estimate		
			Confirmed (1)	Strongly predicted (2)	Total (1 + 2)				
Acropora cervicornis	(Lamarck, 1816)	Caribbean	7	0	7	**1**	Sometimes common	Upper to mid reef slopes and lagoons with clear water	Well defined species
Acropora palmata	(Lamarck, 1816)	Caribbean	8	0	8	**1**	Usually common	Shallow outer reef slopes exposed to wave action	Well defined species
Agaricia lamarcki	Milne Edwards and Haime, 1851	Caribbean	7	1	8	**1**	Common	Shallow reef environments	Well defined species
Dendrogyra cylindrus	(Ehrenberg, 1834)	Caribbean	7	0	7	**1**	Uncommon	Most reef environments	Well defined species
Dichocoenia stokesi	Milne Edwards and Haime, 1848	Caribbean	9	0	9	**1**	Usually uncommon	Most reef environments	Well defined species
*Montastraea annularis**	(Ellis and Solander, 1786)	Not recorded	9	0	9	**1**	Very common	Most reef habitats	Historically confused with M. faveolata and M. franksi
*Montastraea faveolata**	(Ellis and Solander, 1786)	Caribbean	5	3	8	**1**	Sometimes common	Most reef habitats	A technically invalid species historically confused with M.annularis and M. franksi
*Montastraea franksi**	(Gregory, 1895)	Barbados	6	3	9	**1**	Sometimes common	Most reef habitats	Historically confused with M.annularis and M. faveolata
Mycetophyllia ferox	Wells, 1973	Caribbean	7	0	7	**1**	Usually uncommon	Shallow reef environments	Well defined species

* The genus name will be changed to *Orbicella* in *Corals of the World*

Linked Documentation C:

Coral Geographic Global Maps for the Indo-Pacific Species

Acanthastrea brevis

CORALS of the World

Summary

Distribution

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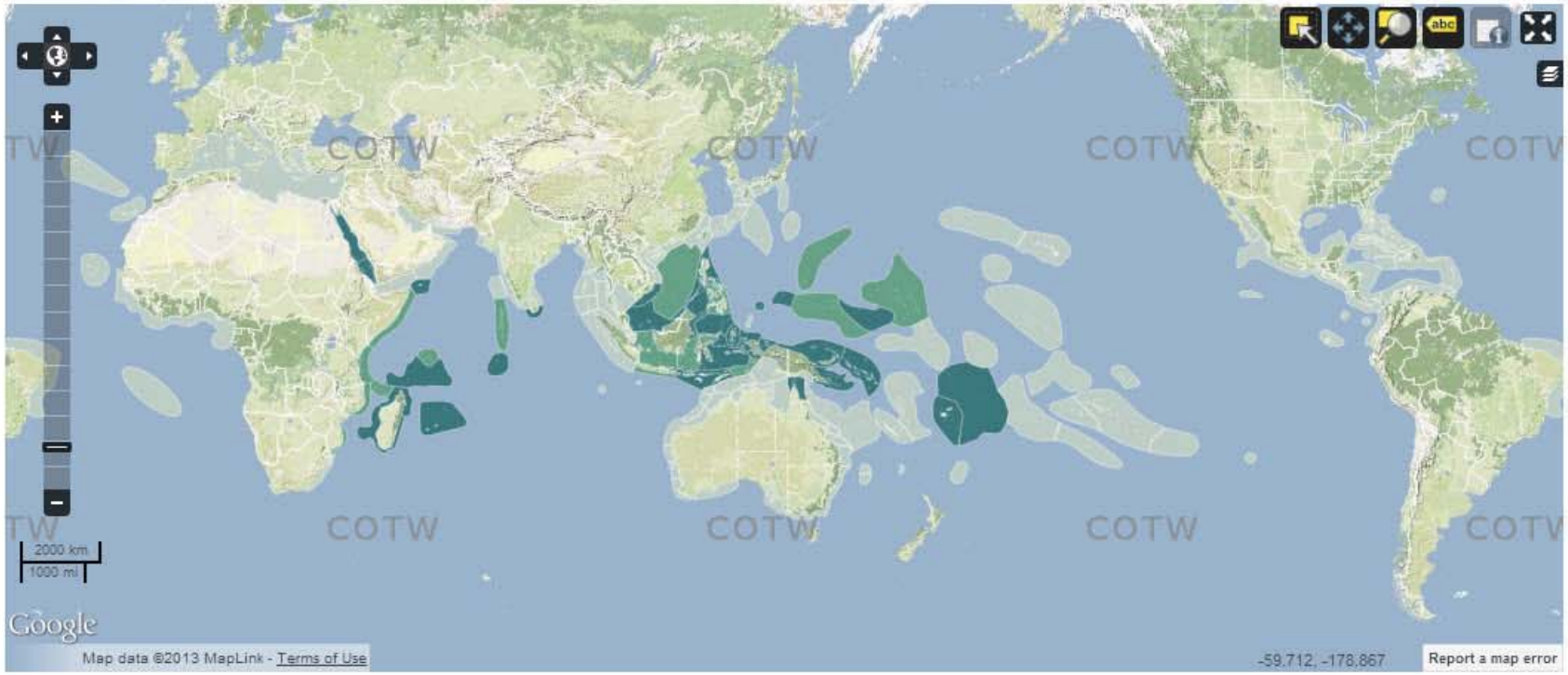

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Acanthastrea hemprichii

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Summary

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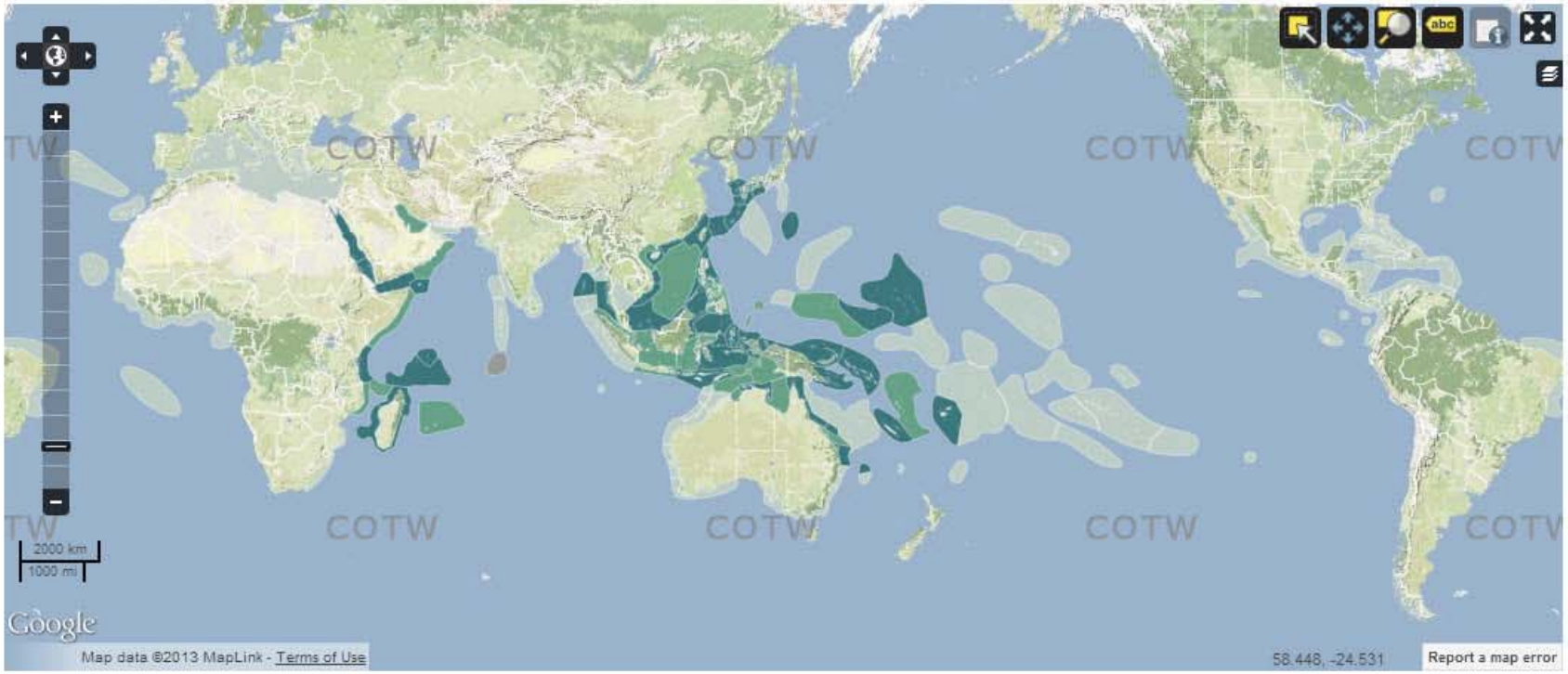

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Acanthastrea ishigakiensis

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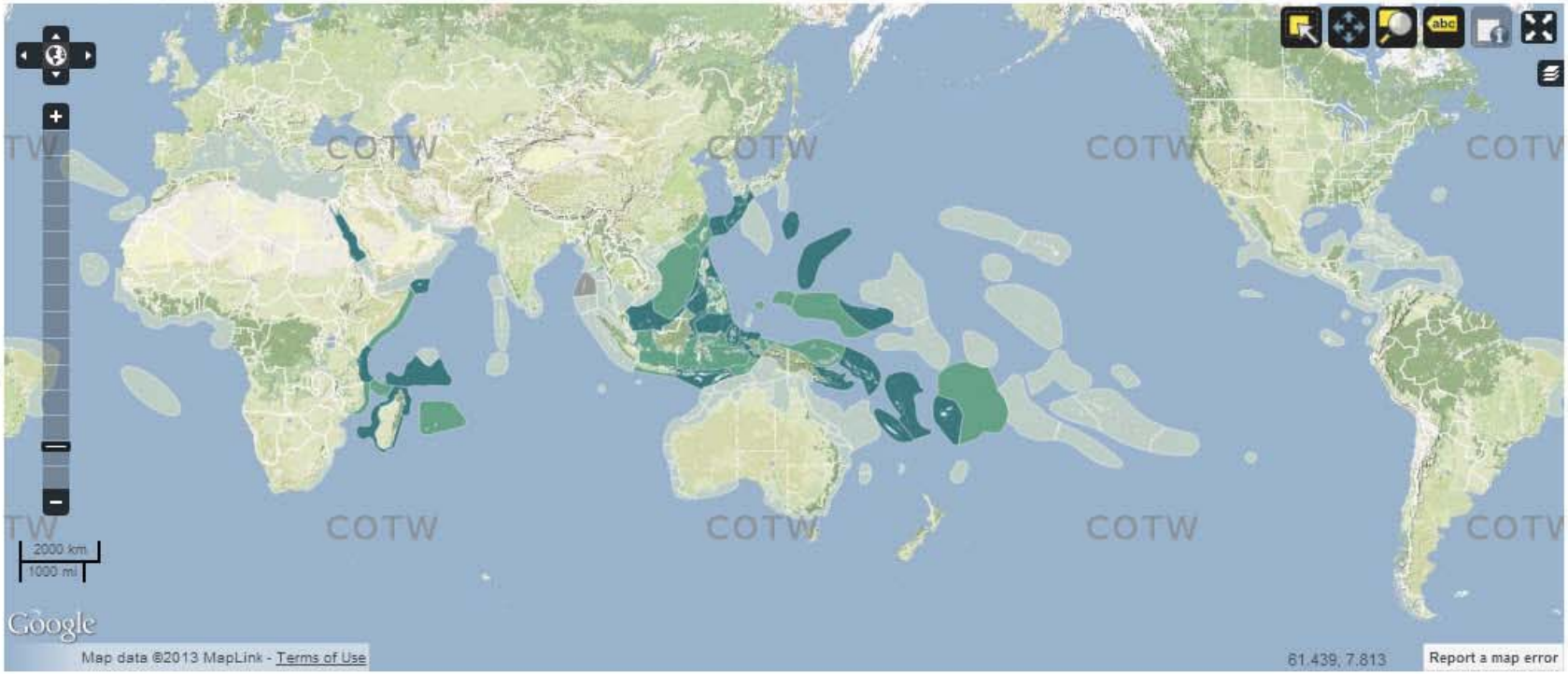

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Acanthastrea regularis

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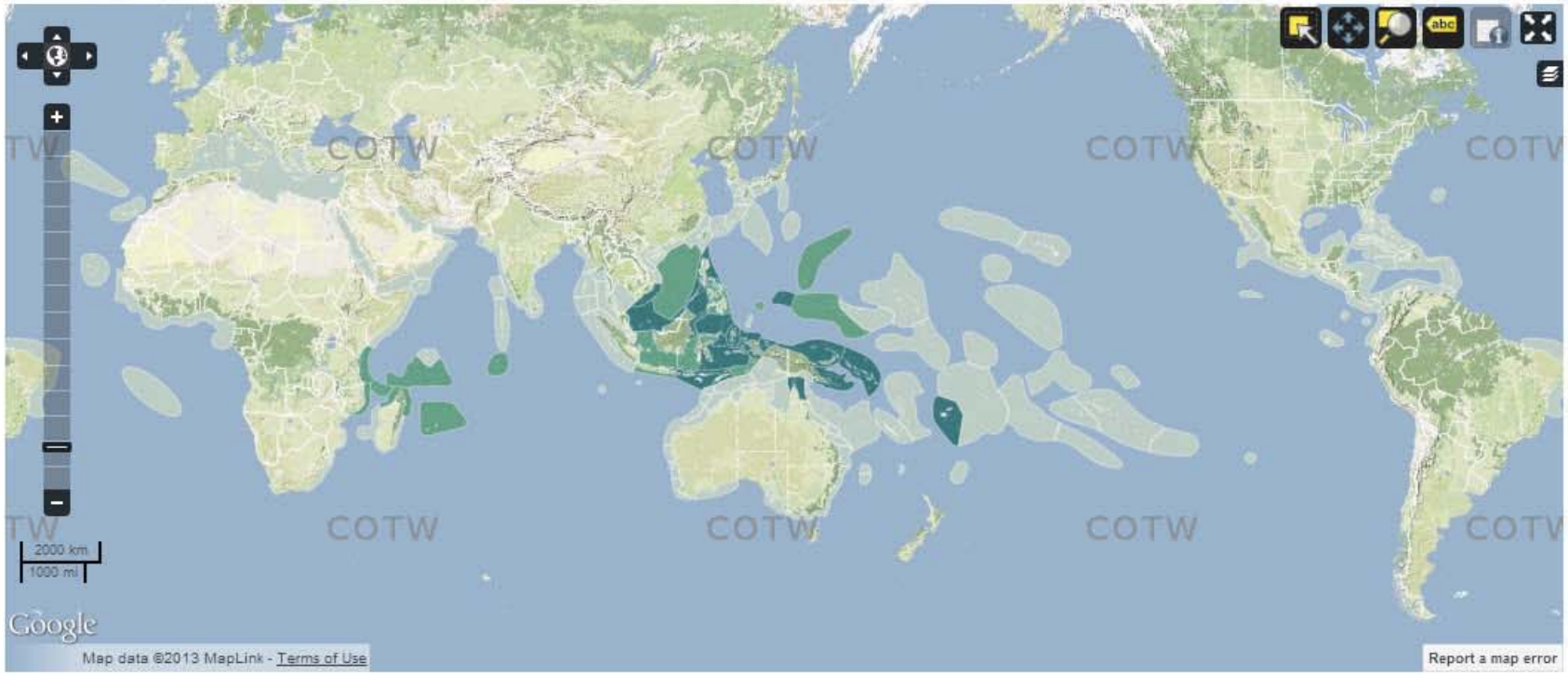

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Acropora aculeus

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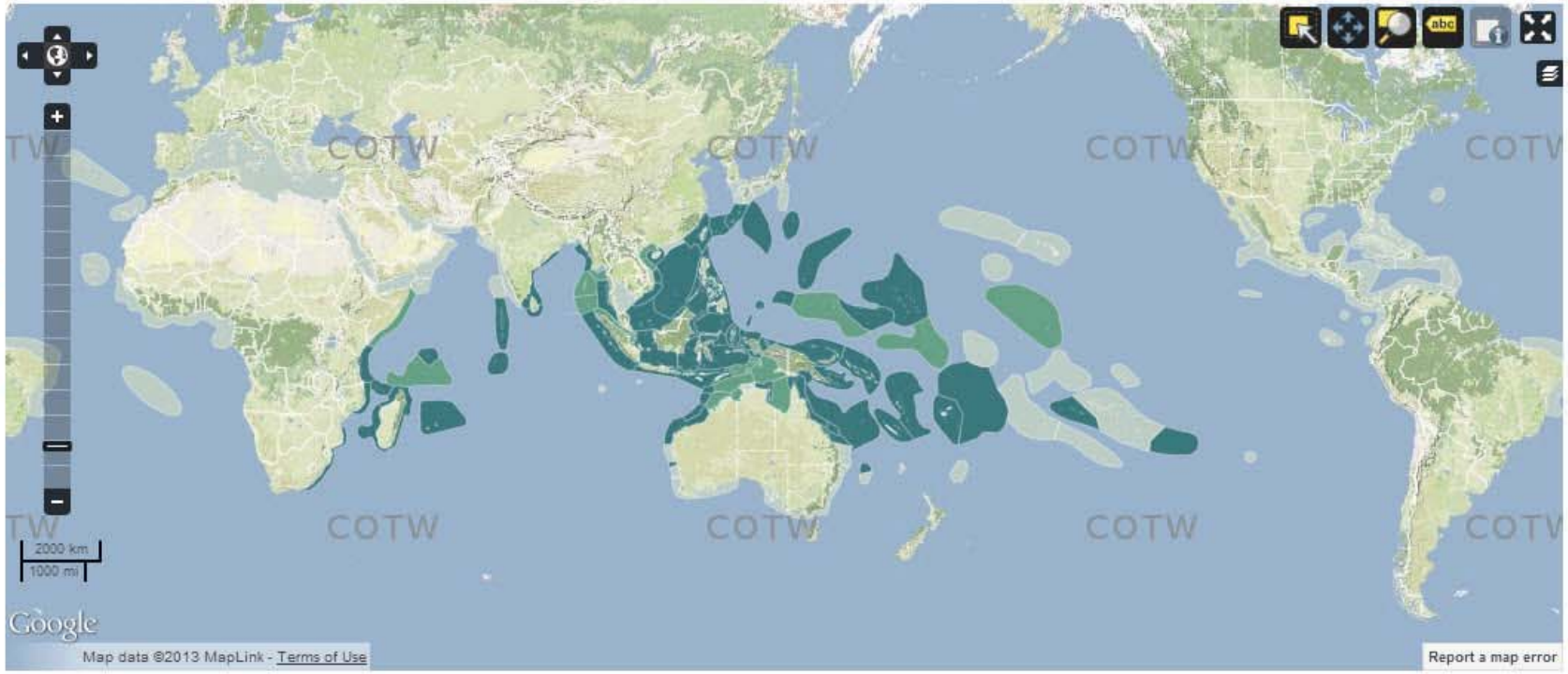

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Acropora acuminata

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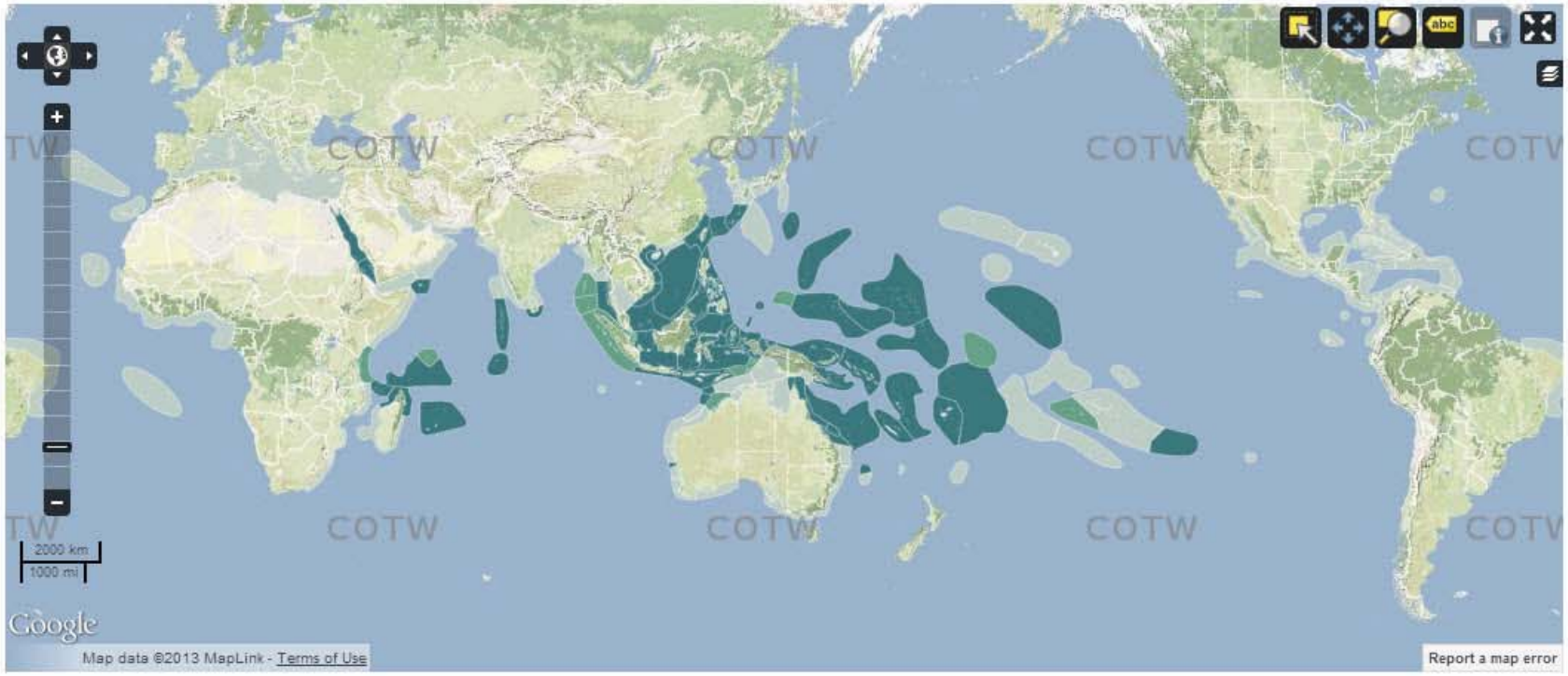

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Acropora aspera

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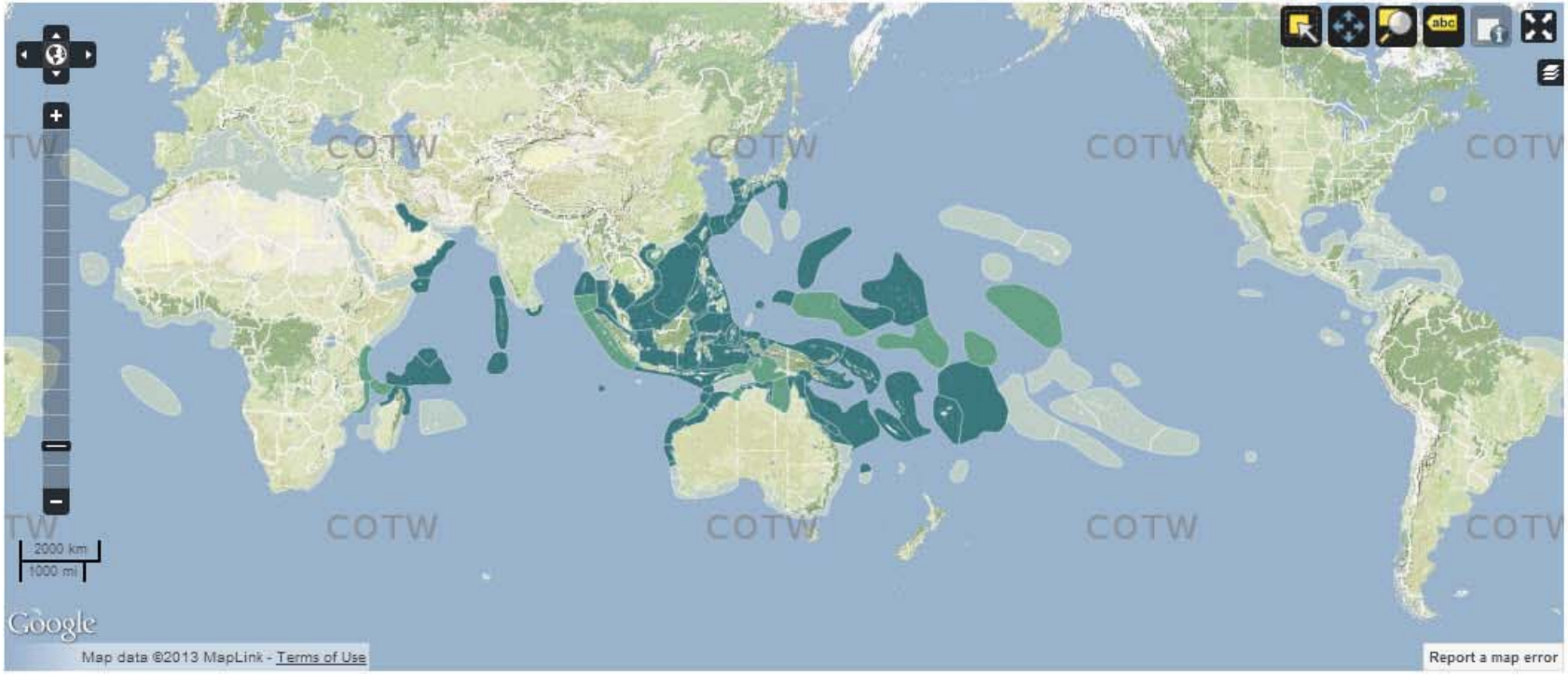

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Acropora dendrum

CORALS of the World

Summary

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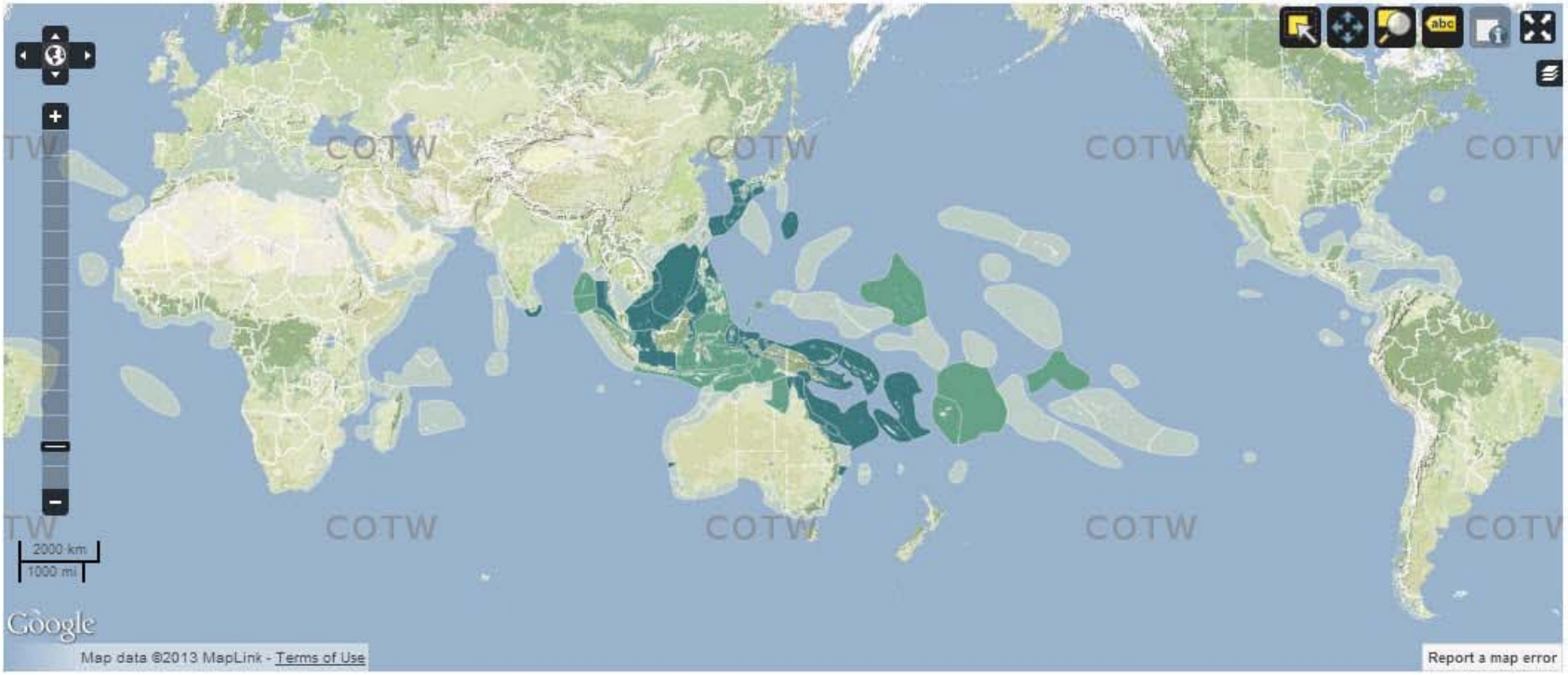

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Acropora donei

CORALS of the World

Summary

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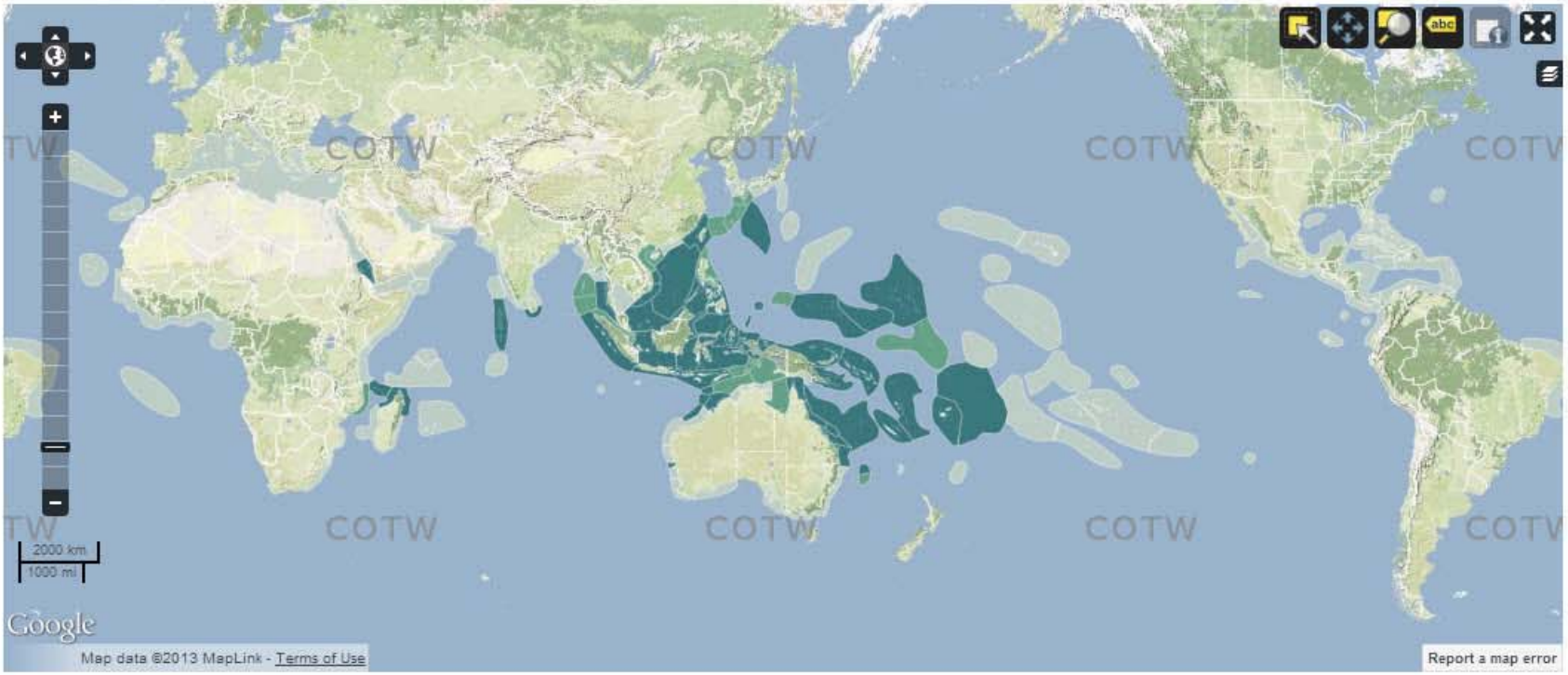

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Acropora globiceps

CORALS of the World

Summary

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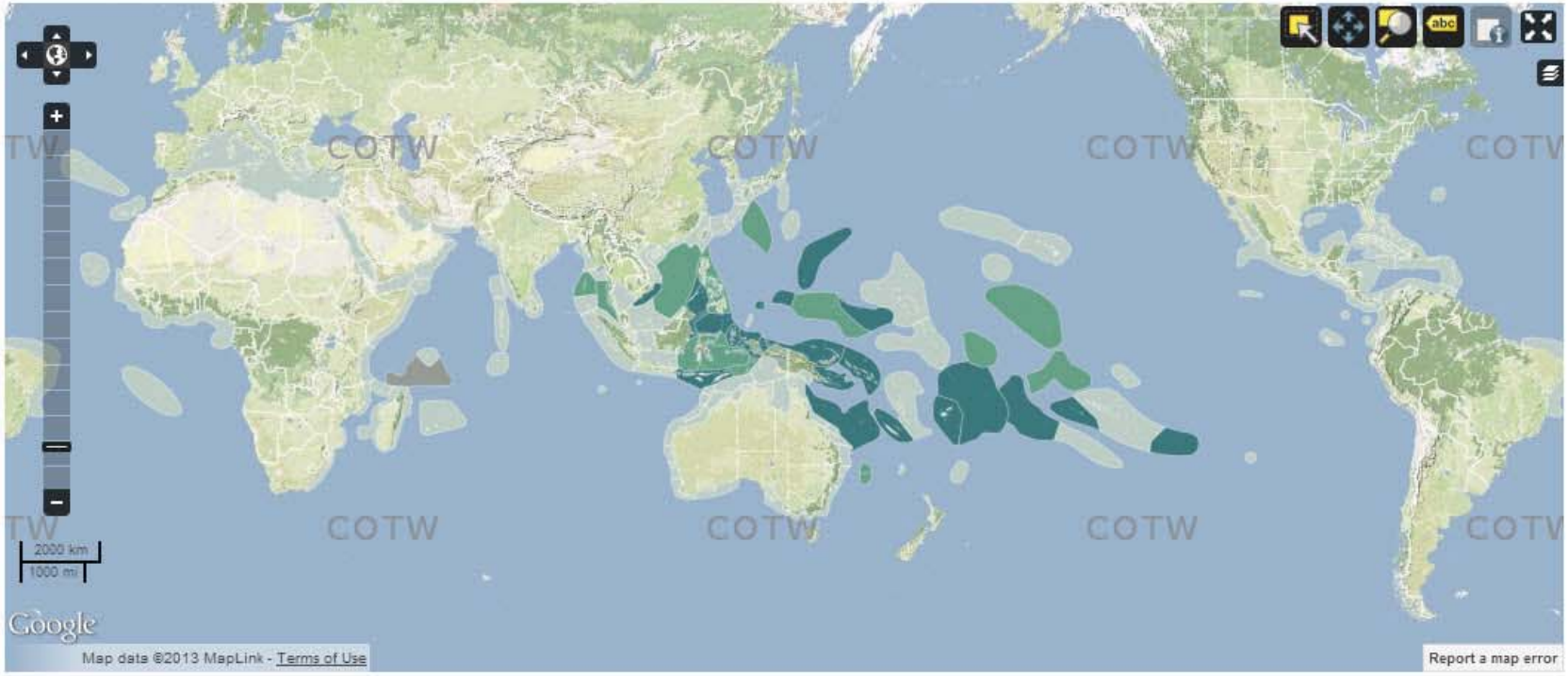

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Acropora horrida

CORALS of the World

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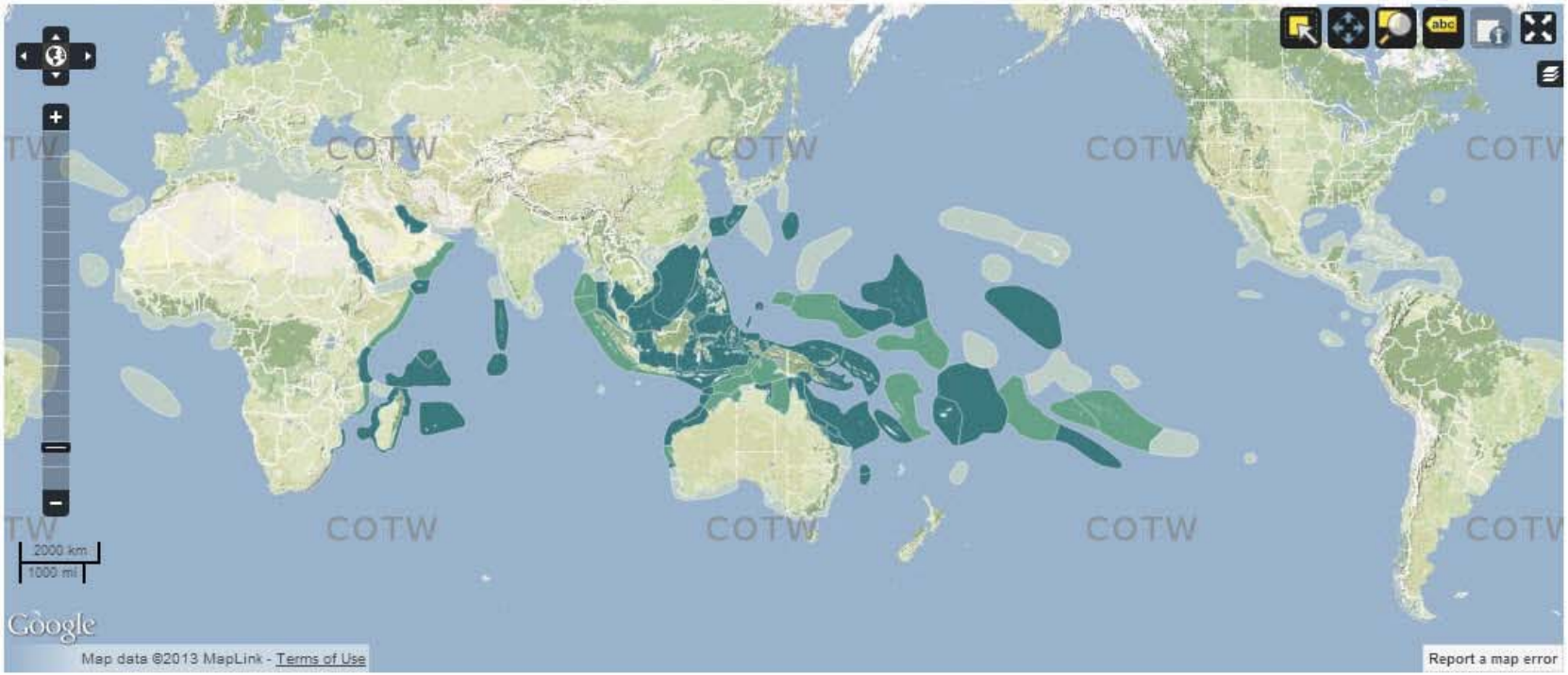

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Acropora jacquelineae

CORALS of the World

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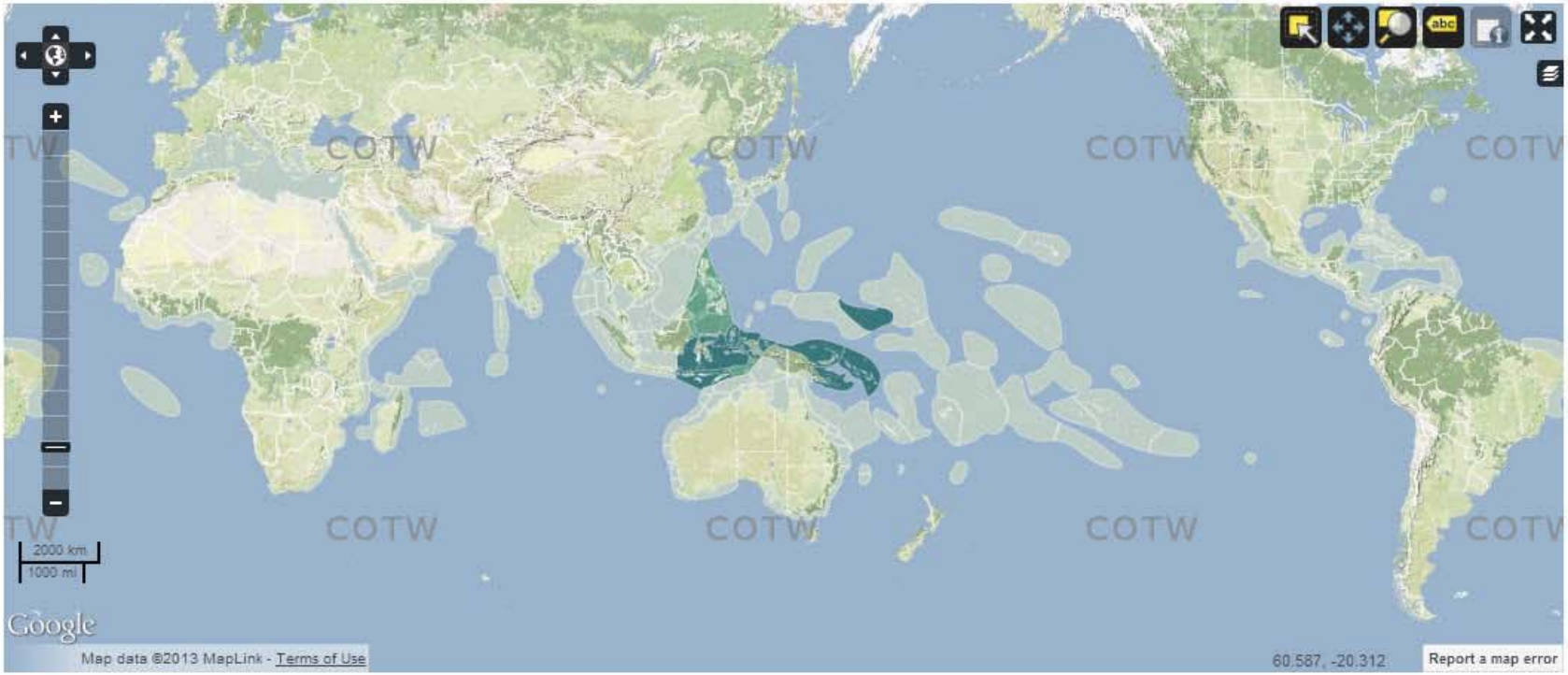

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Acropora listeri

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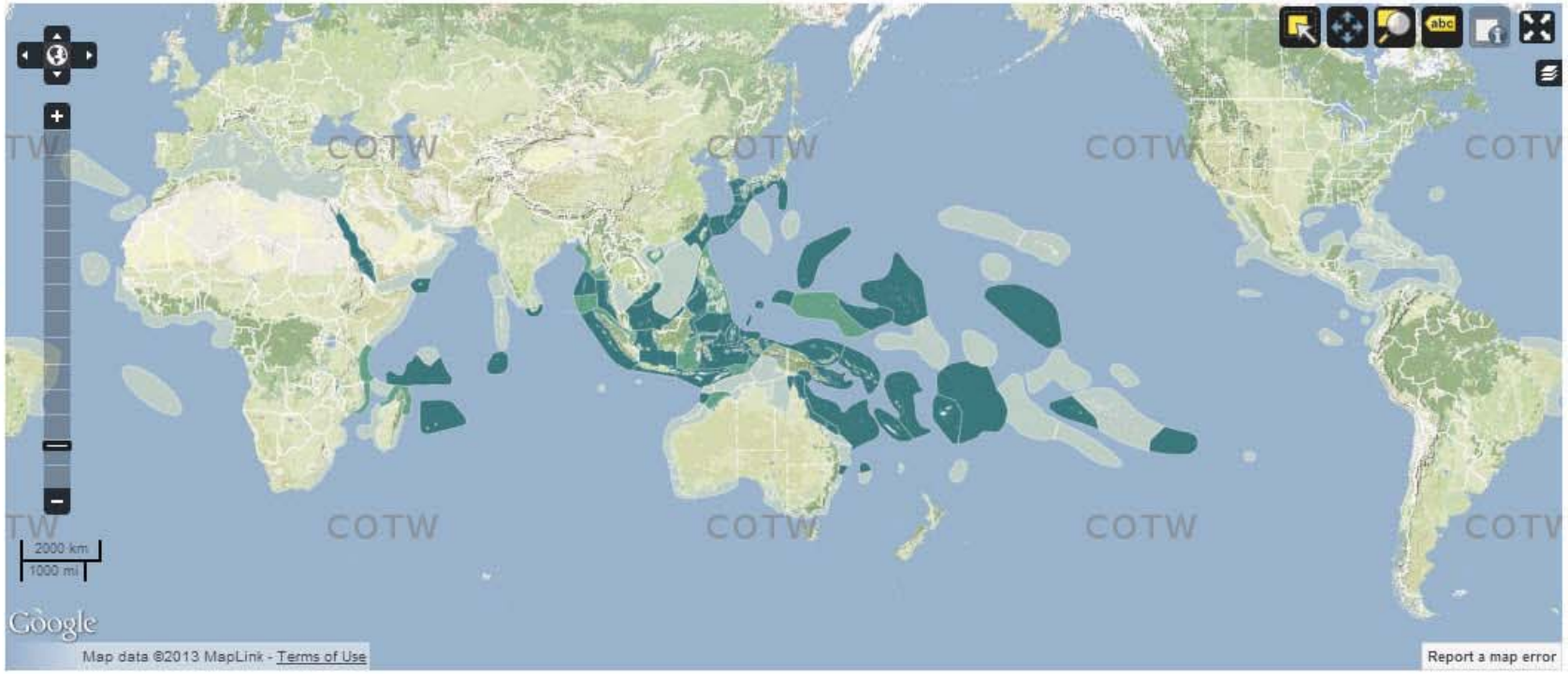

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Acropora lokani

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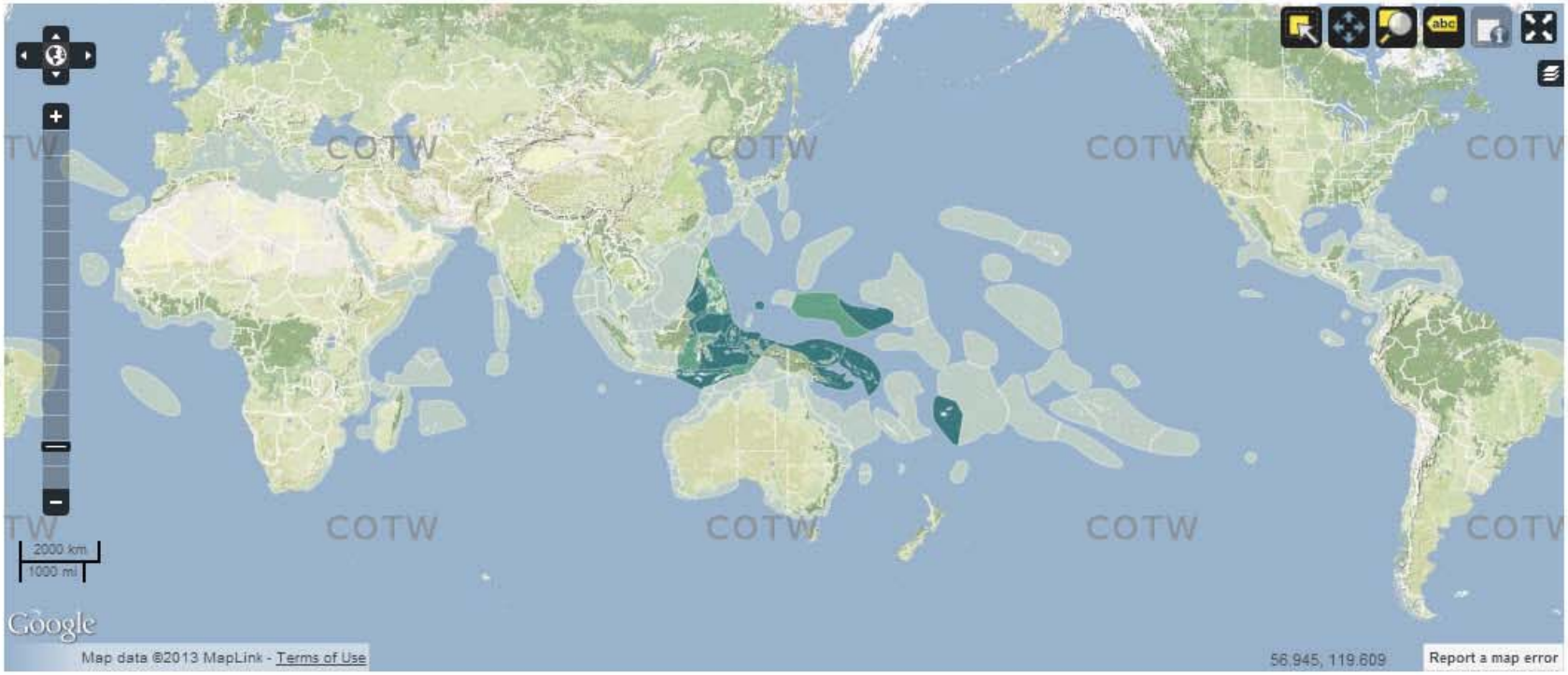

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Acropora microclados

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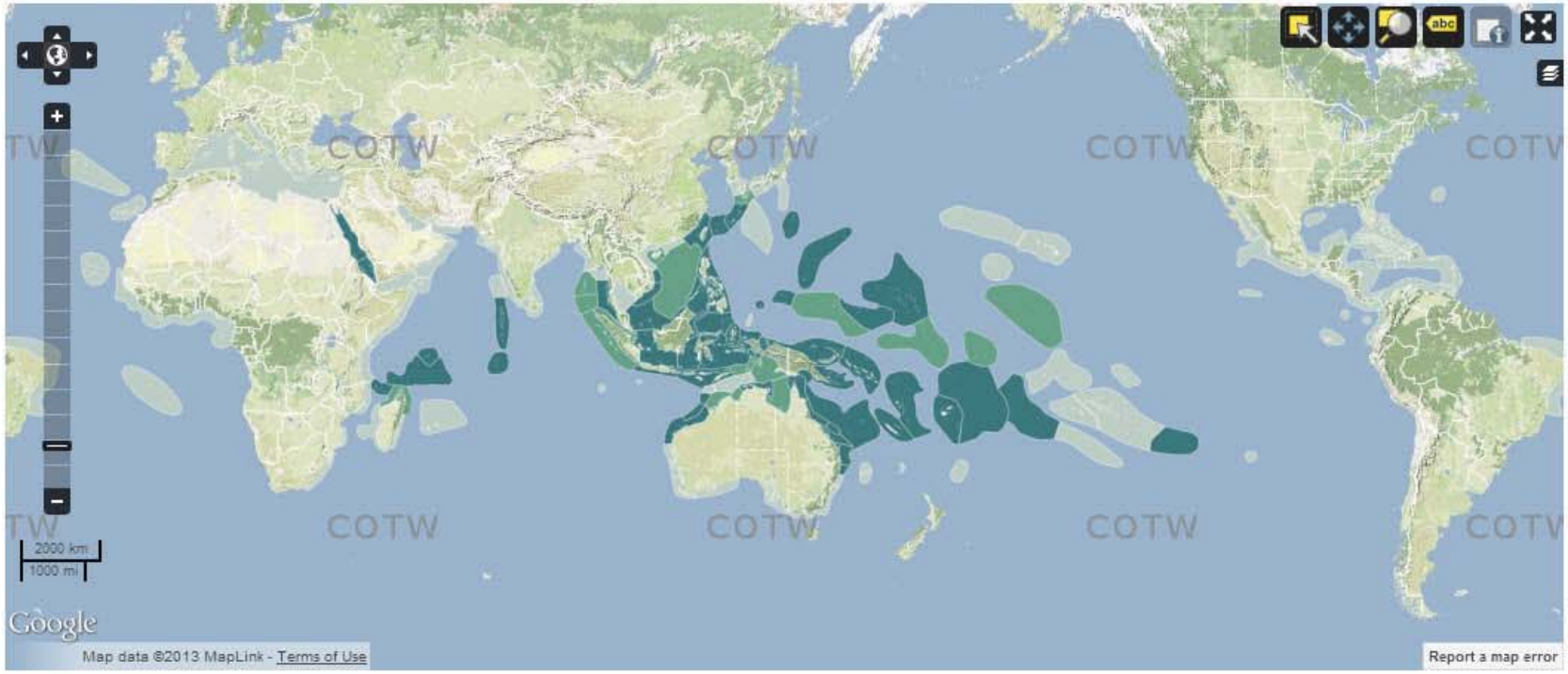

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Acropora palmerae

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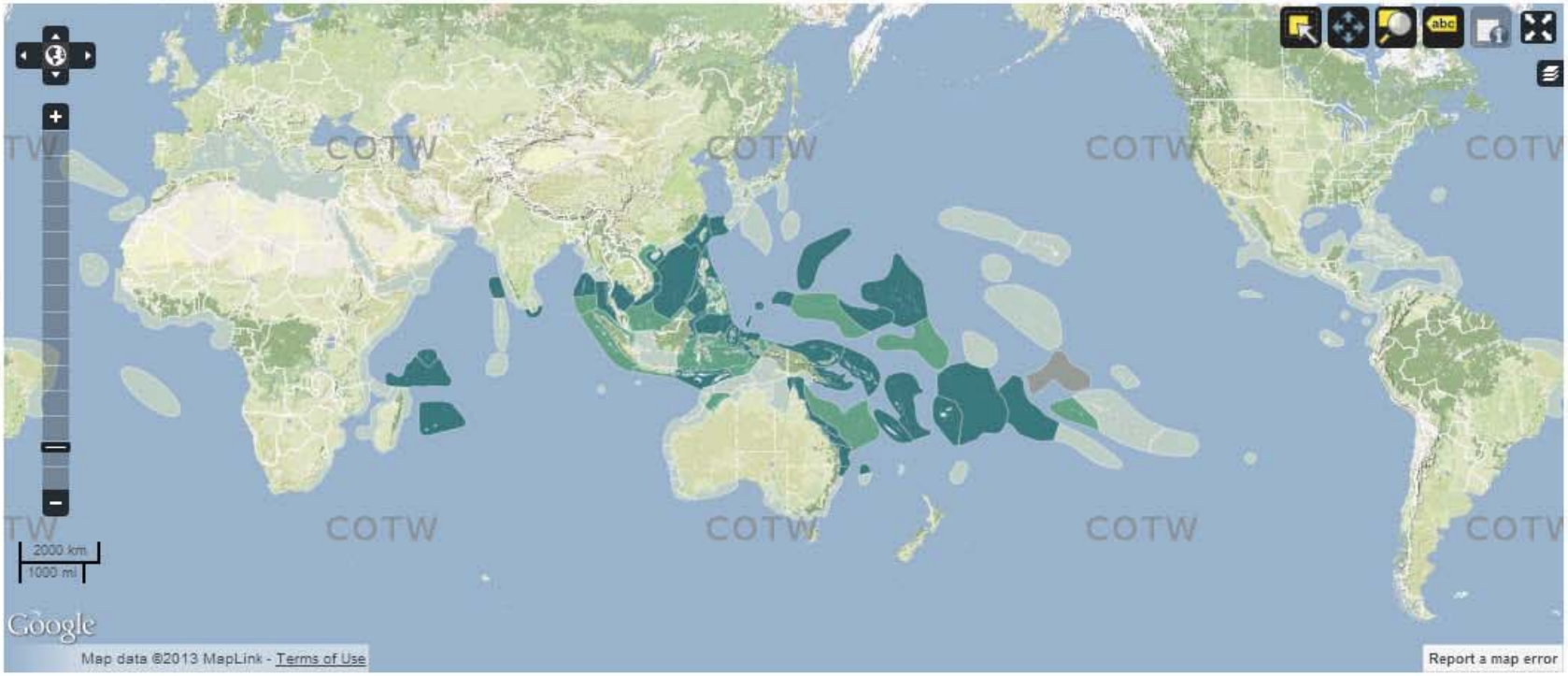

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Acropora paniculata

CORALS of the World

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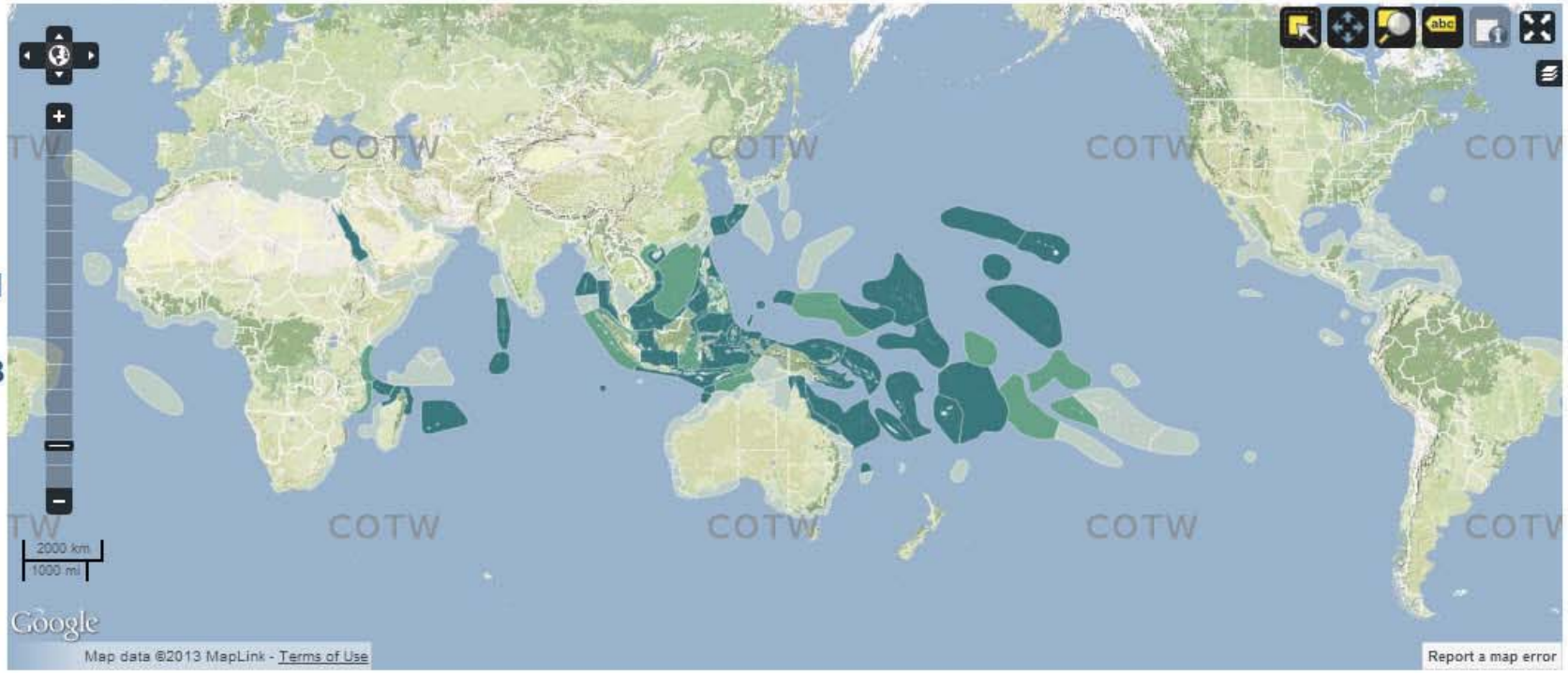

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Acropora pharaonis

CORALS of the World

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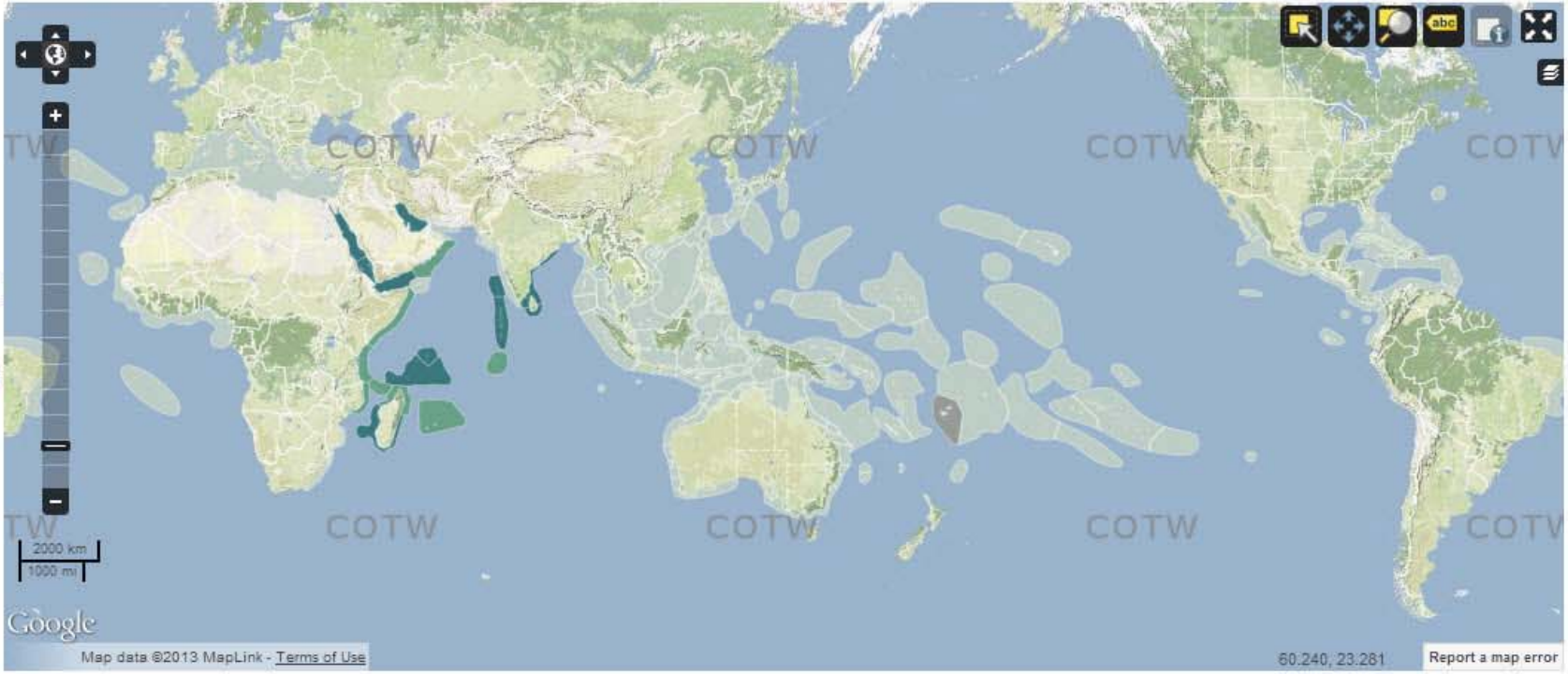

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Acropora polystoma

CORALS of the World

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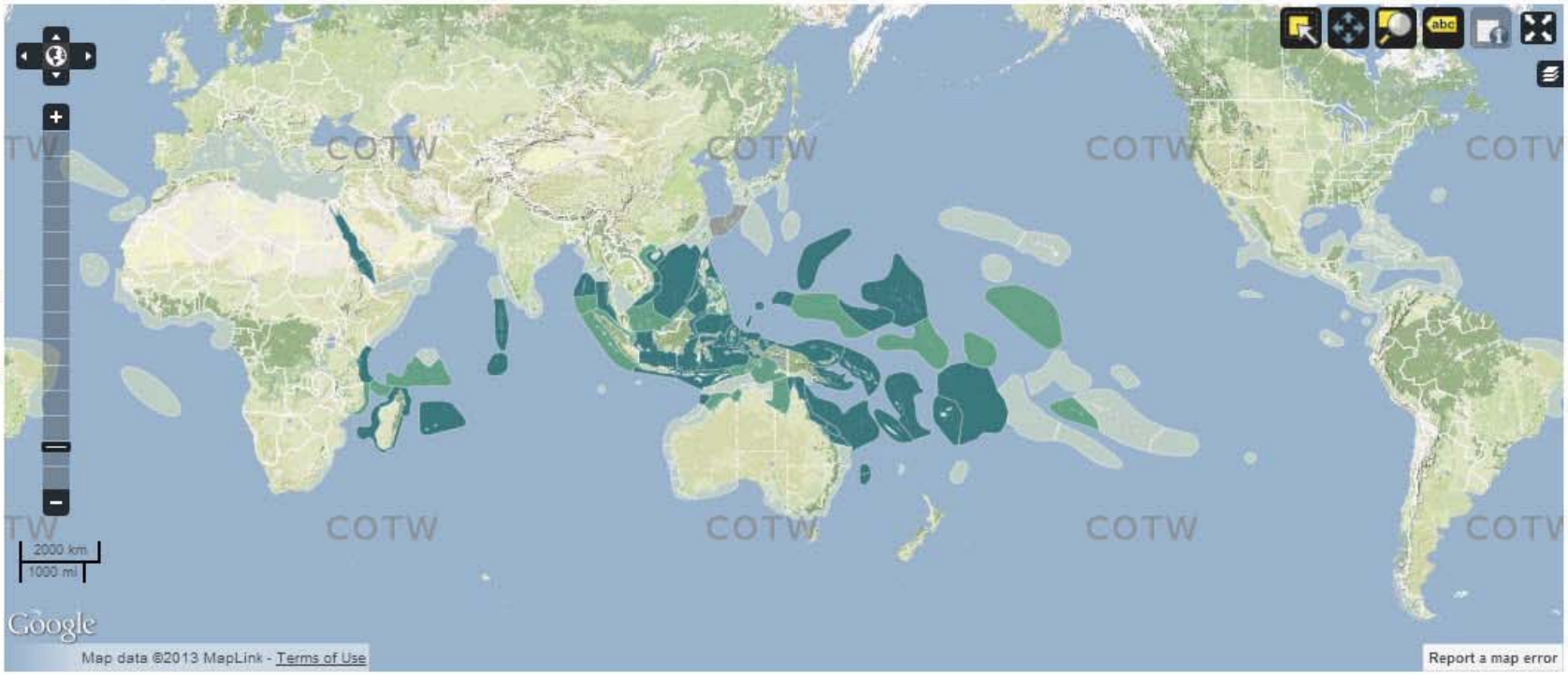

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Acropora retusa

CORALS of the World

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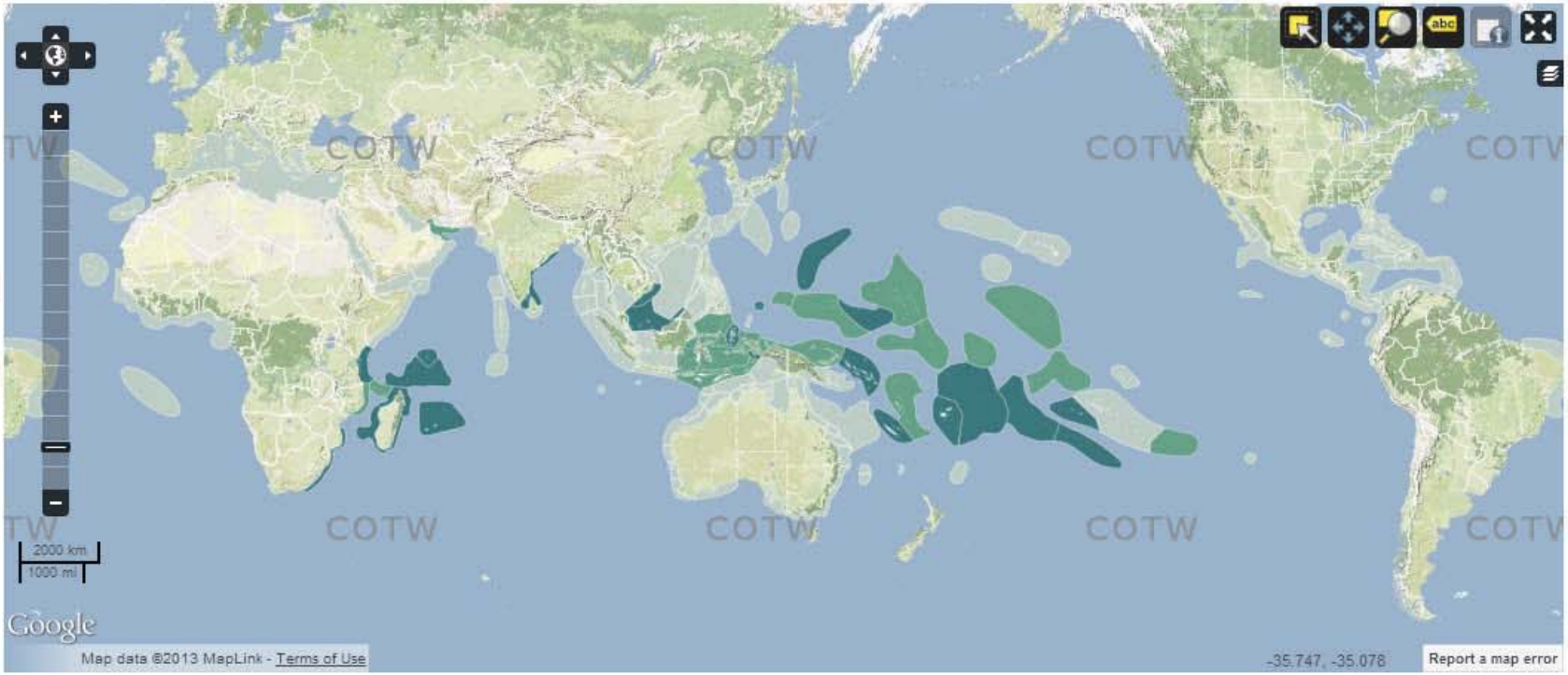

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Acropora rudis

CORALS of the World

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Acropora speciosa

CORALS of the World

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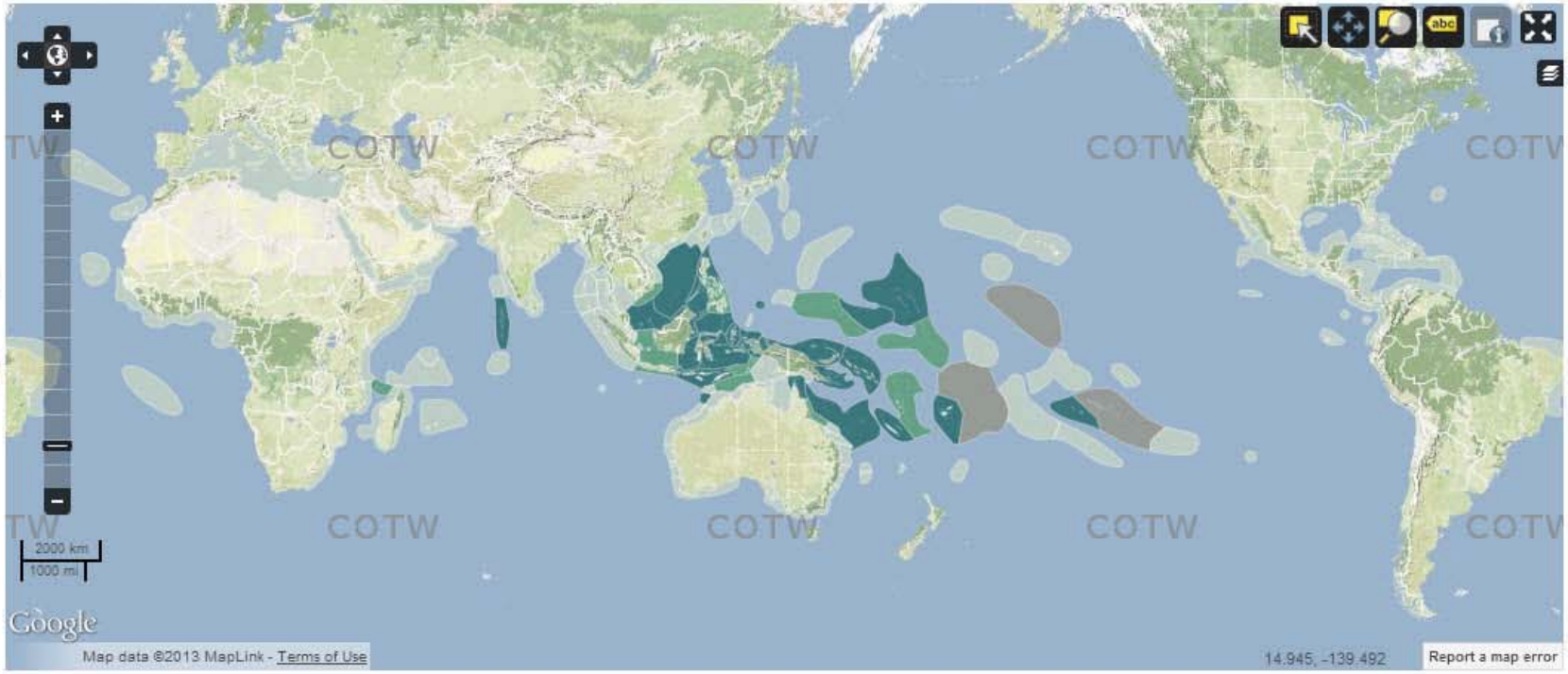

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Acropora striata

CORALS of the World

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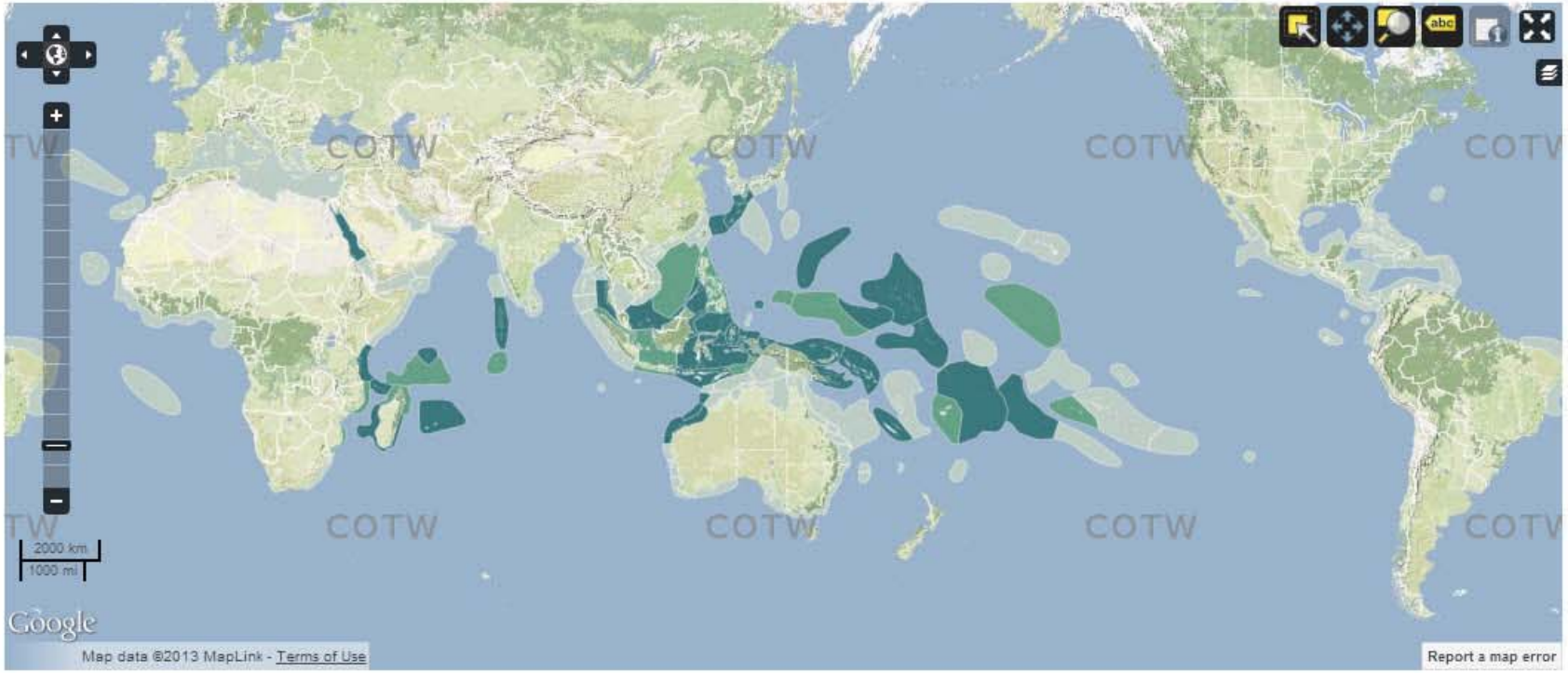

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Acropora tenella

CORALS of the World

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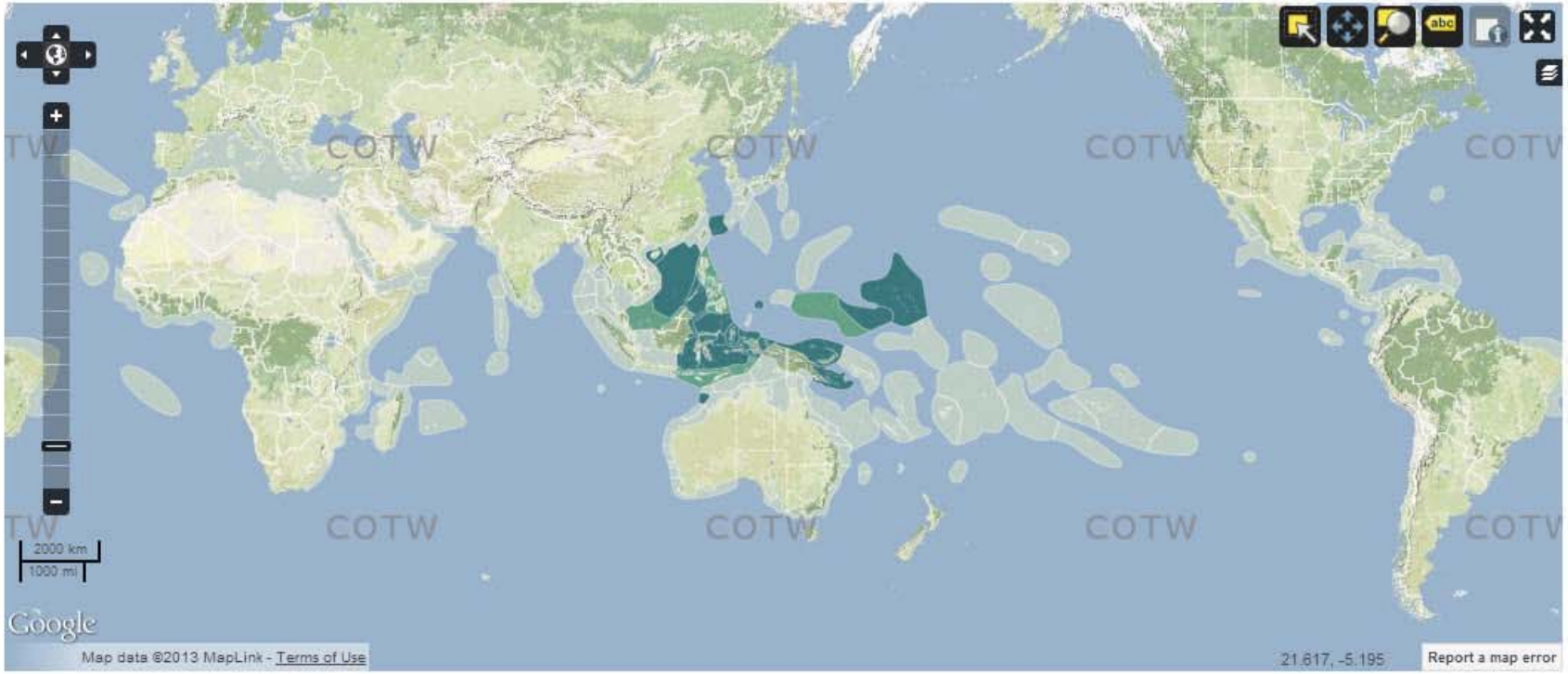

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Acropora vaughani

CORALS of the World

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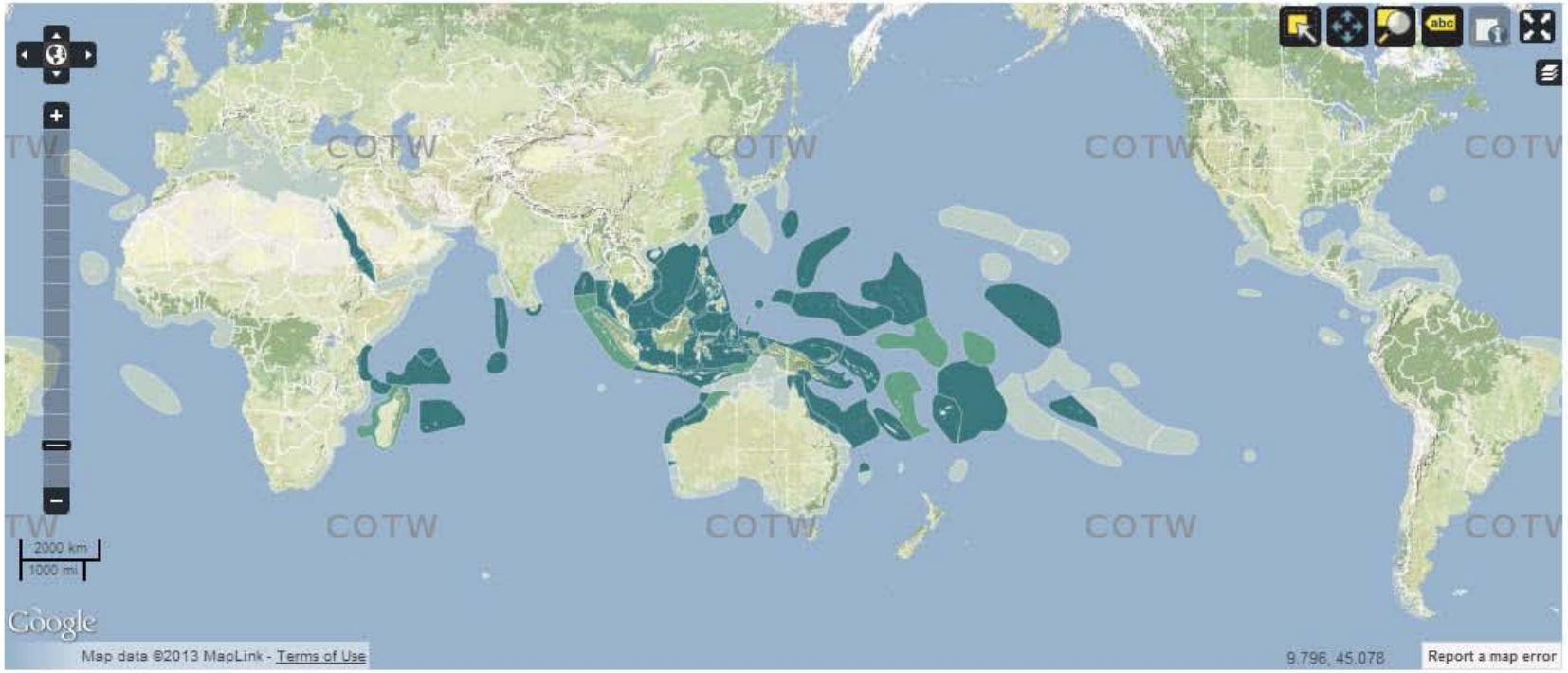

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Acropora verweyi

CORALS of the World

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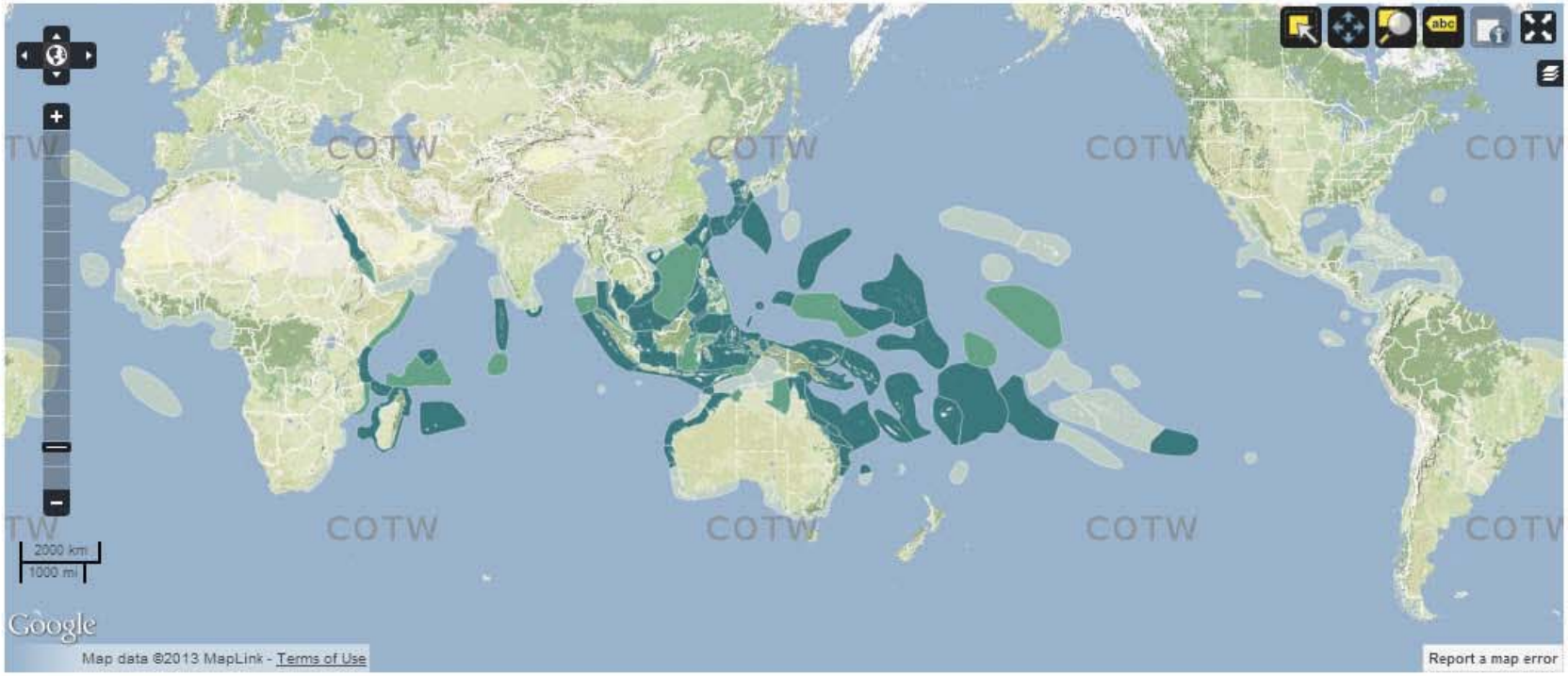

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Alveopora allingi

CORALS of the World

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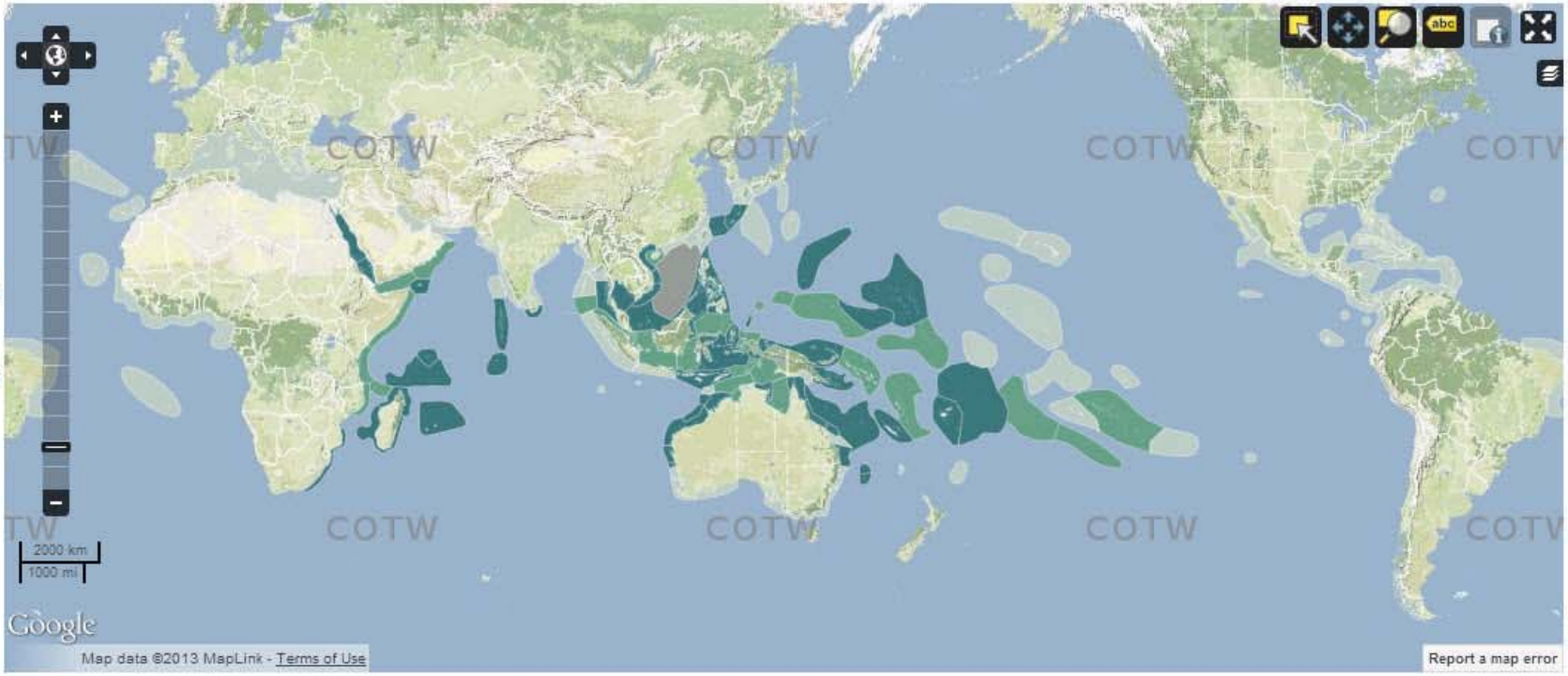

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Alveopora fenestrata

CORALS of the World

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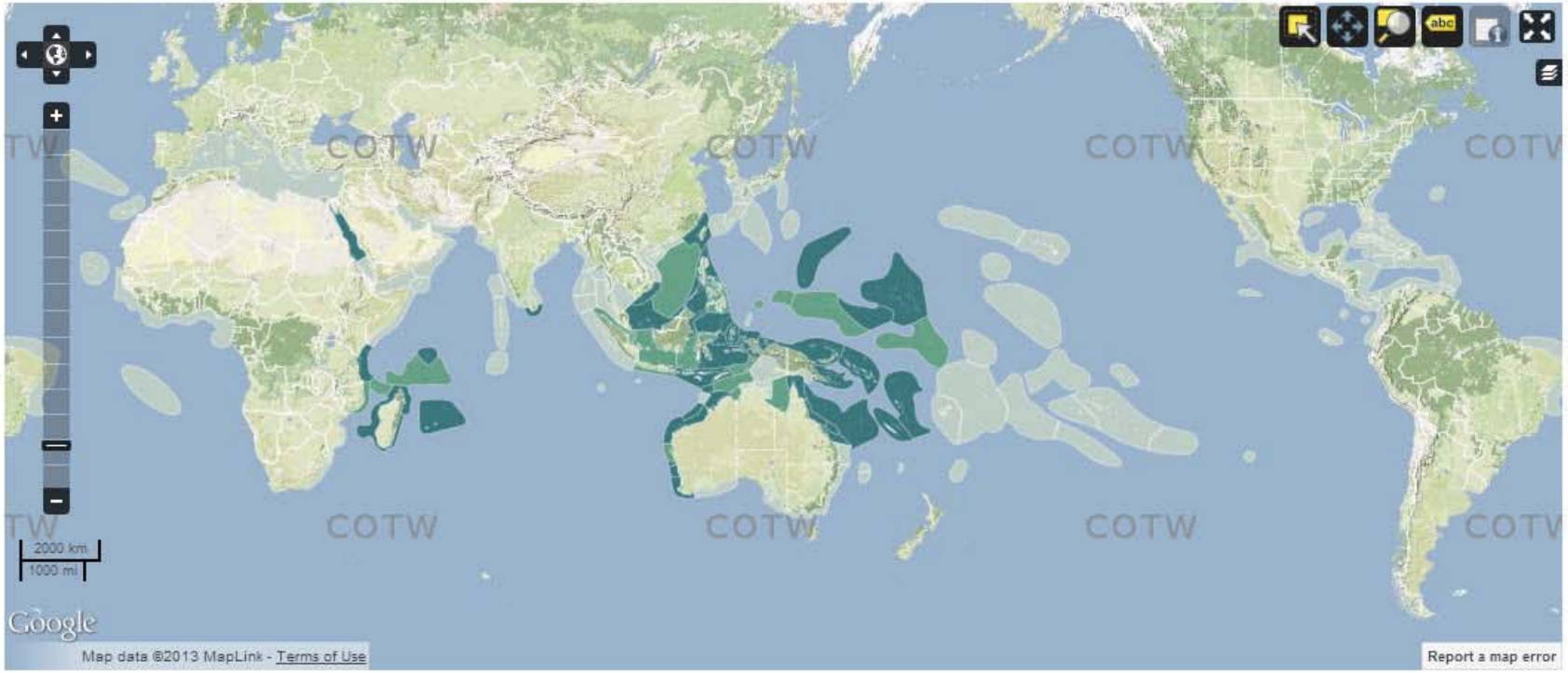

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Alveopora verrilliana

CORALS of the World

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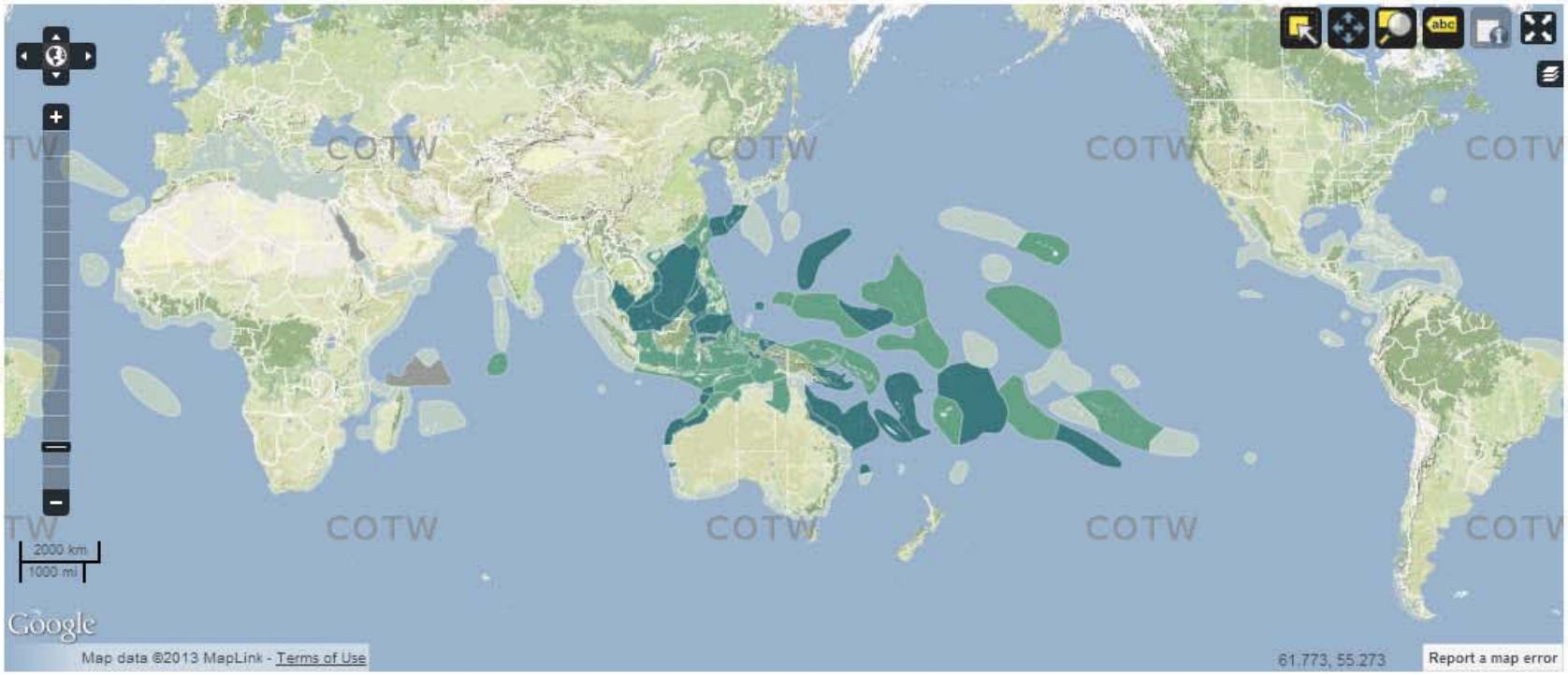

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Anacropora puertogalerae

CORALS of the World

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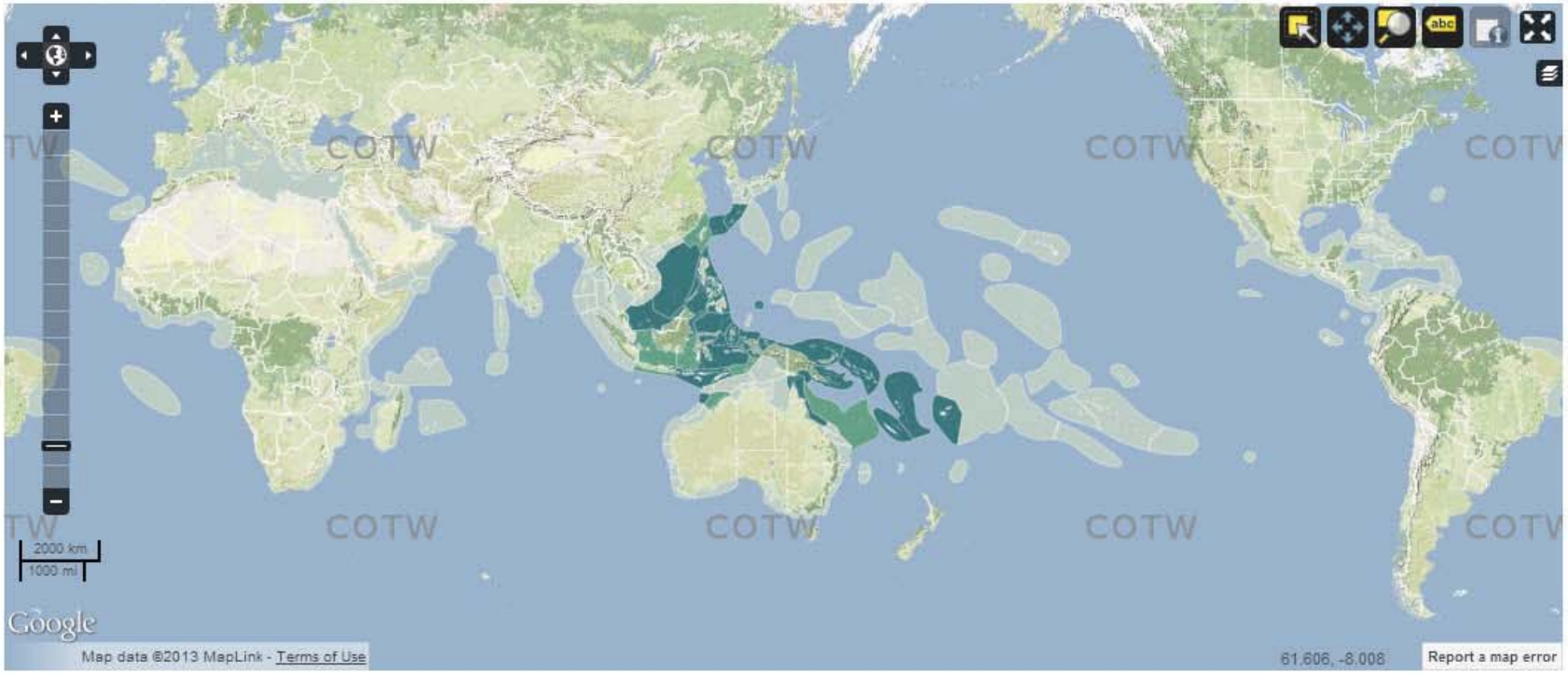

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Anacropora spinosa

CORALS of the World

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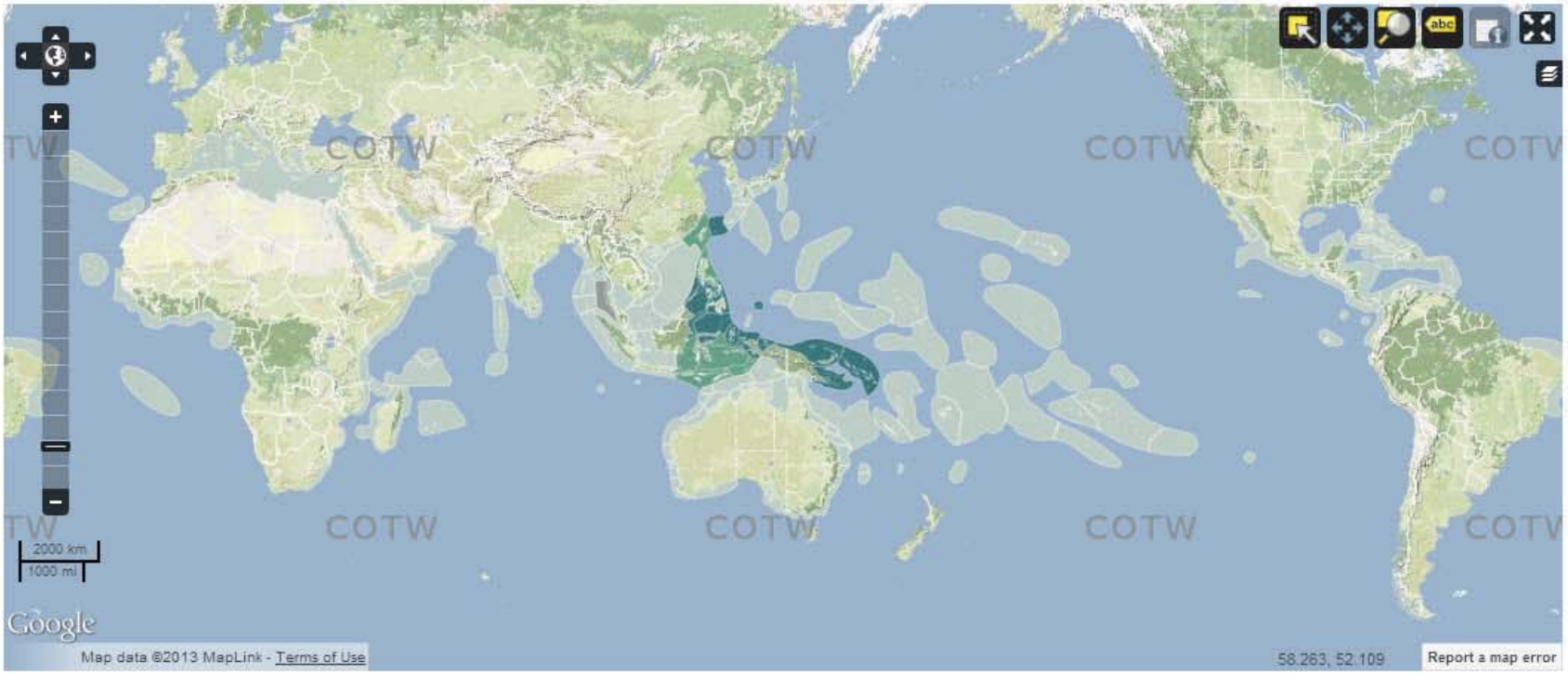

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Astreopora cucullata

CORALS of the World

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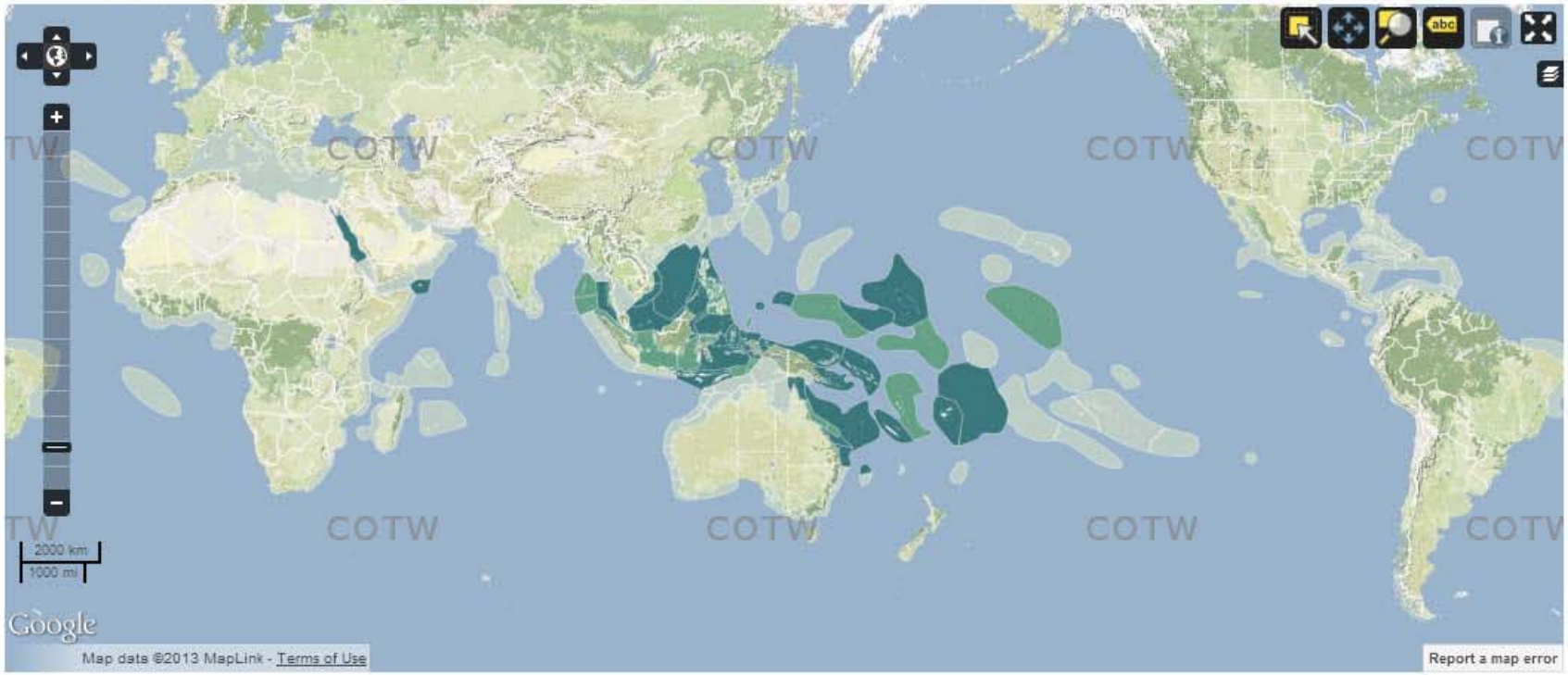

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Barabattoia laddi

CORALS of the World

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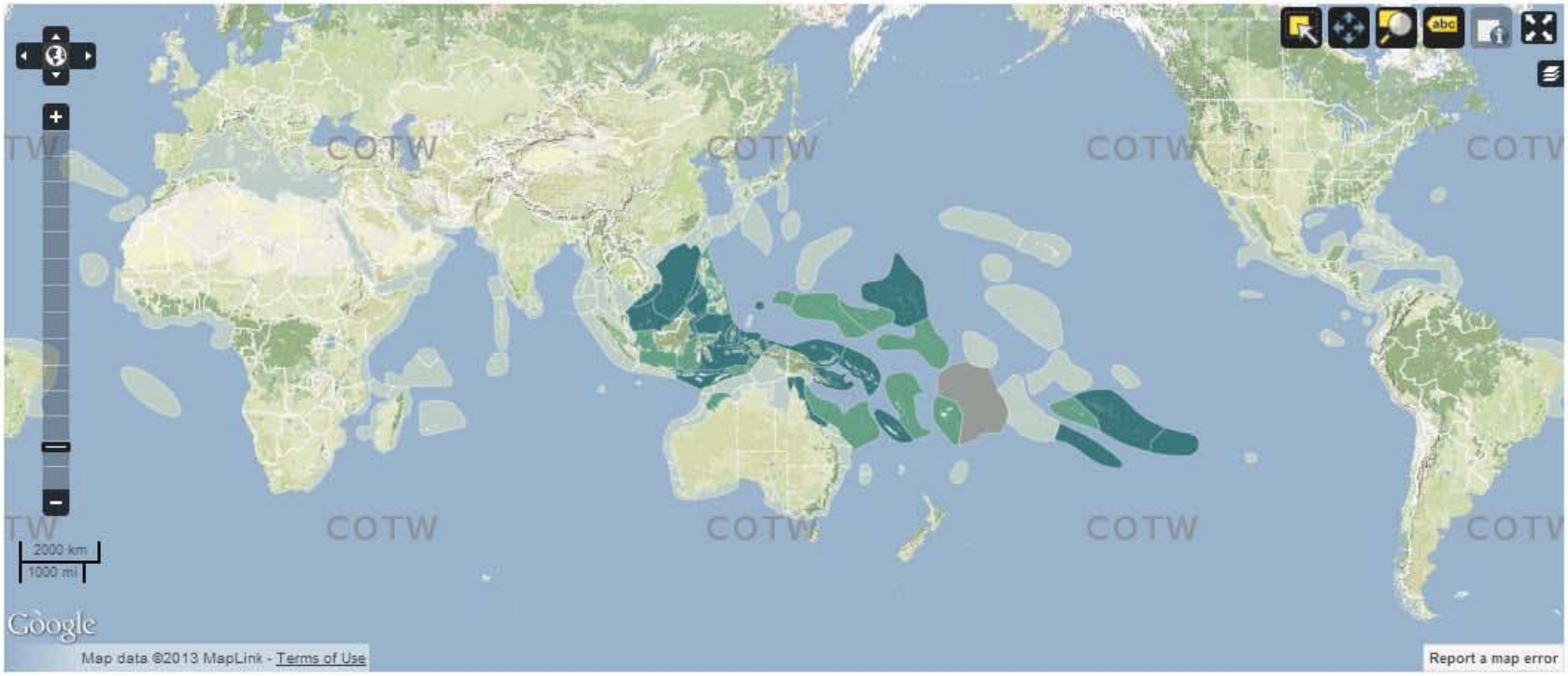

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Caulastrea echinulata

CORALS of the World

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Cyphastrea agassizi

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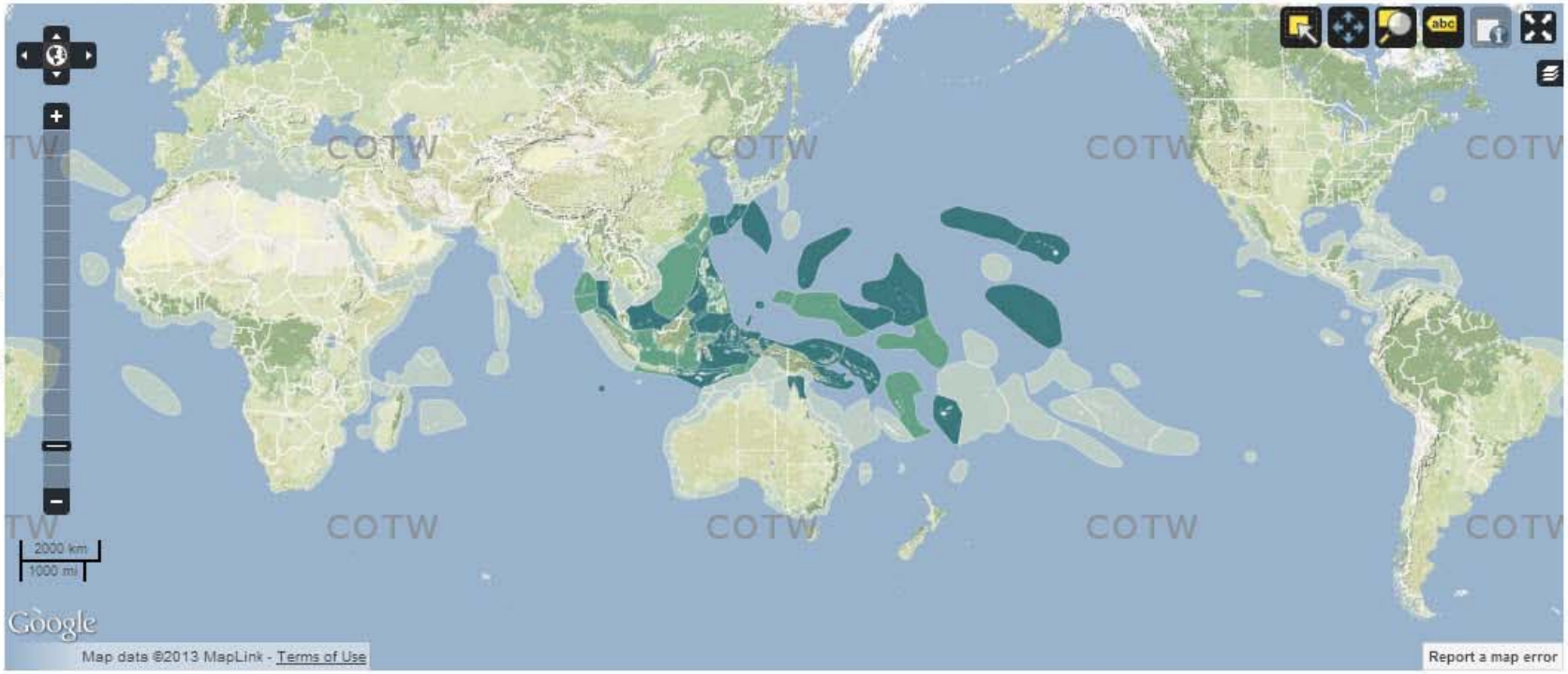

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Cyphastrea ocellina

CORALS of the World

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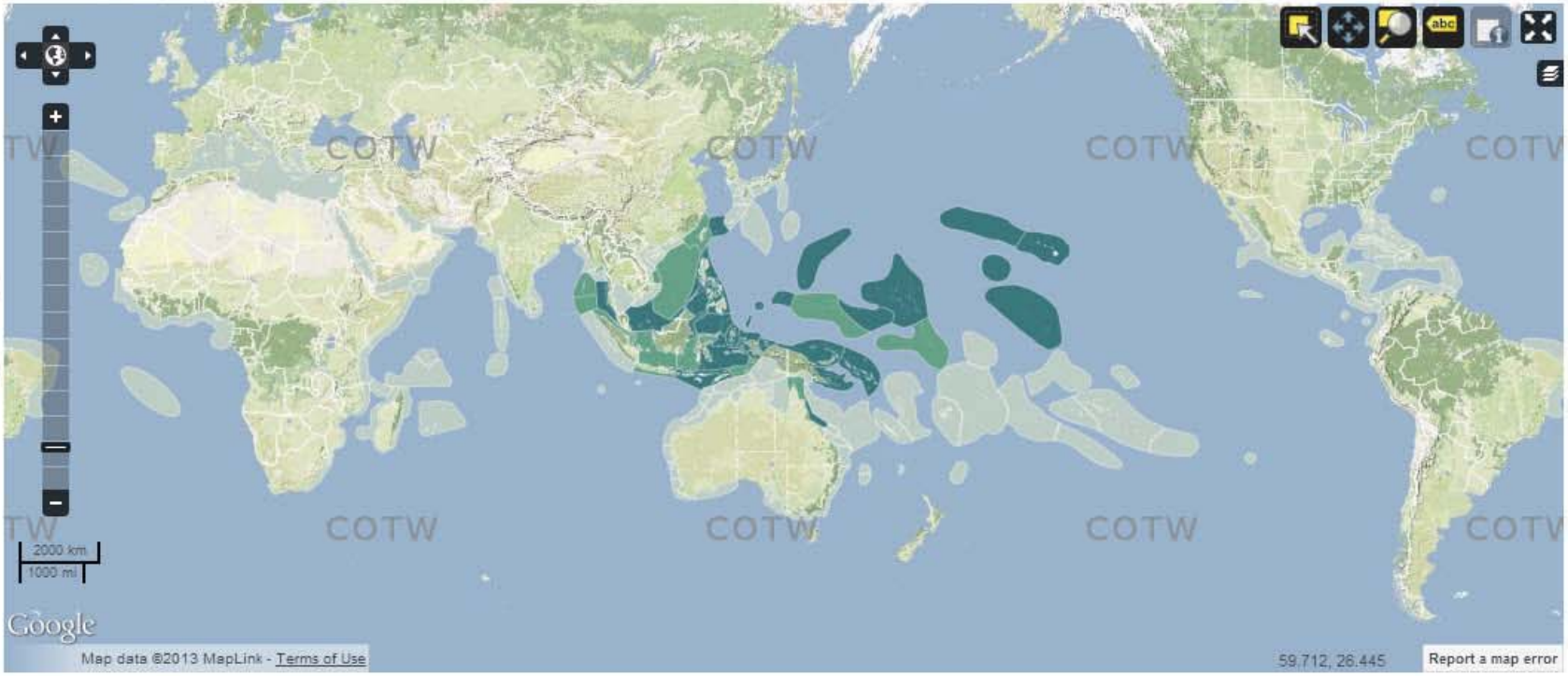

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Euphyllia cristata

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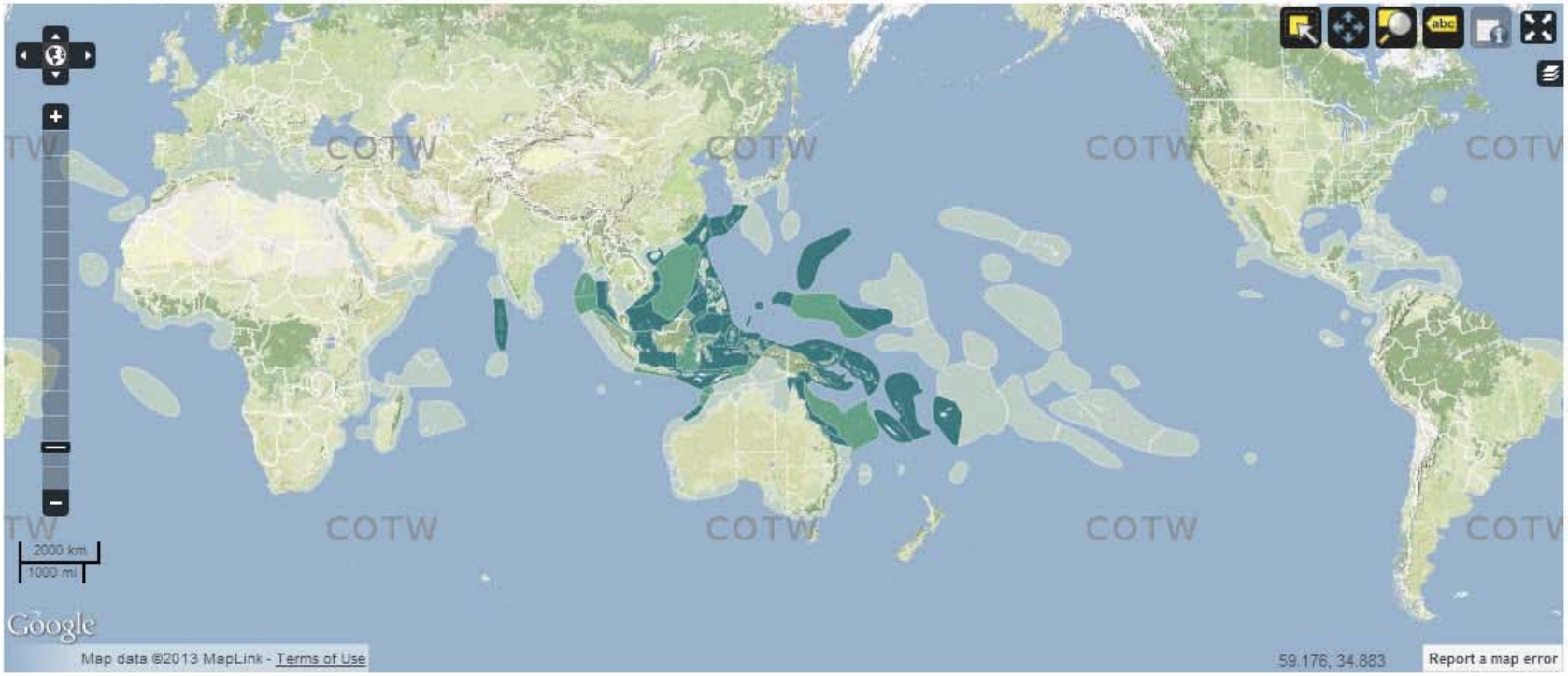

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Euphyllia paraancora

CORALS of the World

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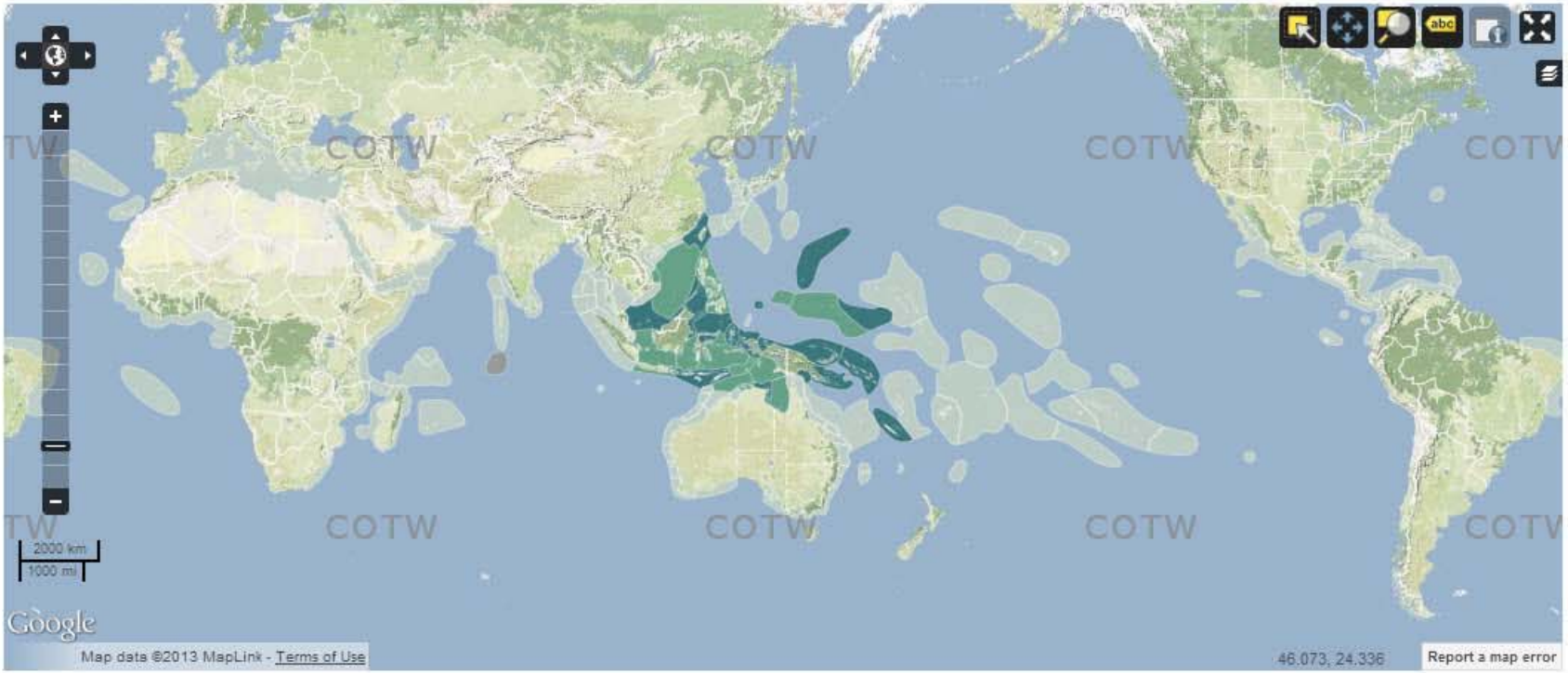

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Euphyllia paradivisa

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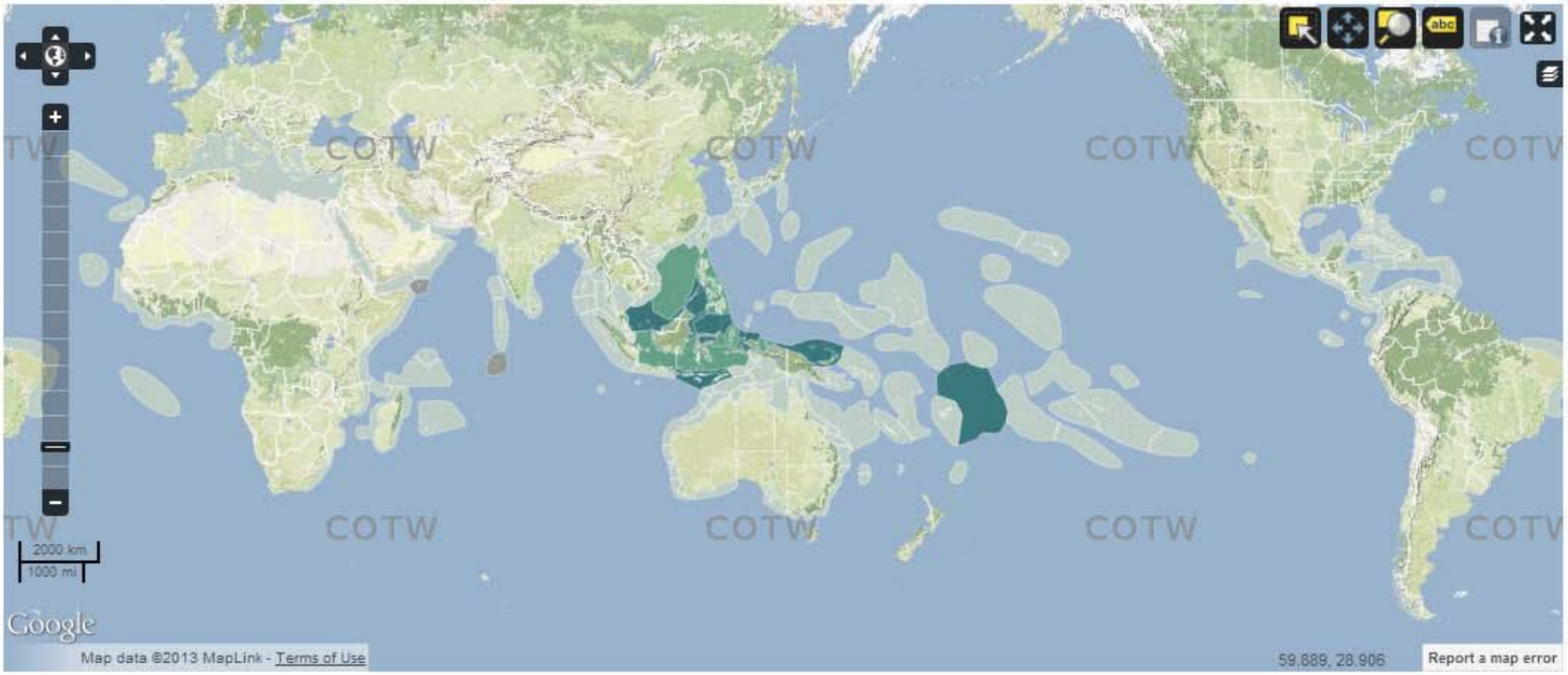

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Galaxea astreata

CORALS of the World

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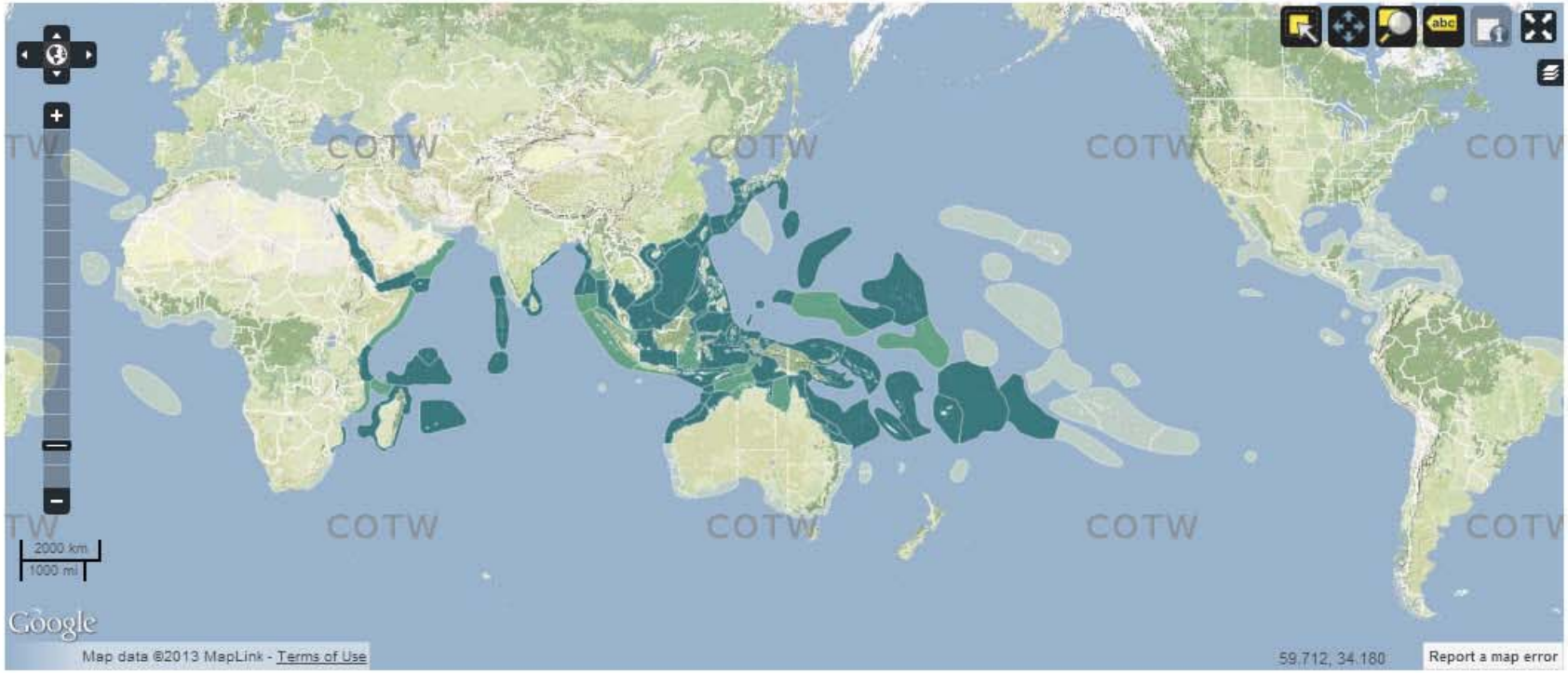

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Isopora crateriformis

CORALS of the World

Summary

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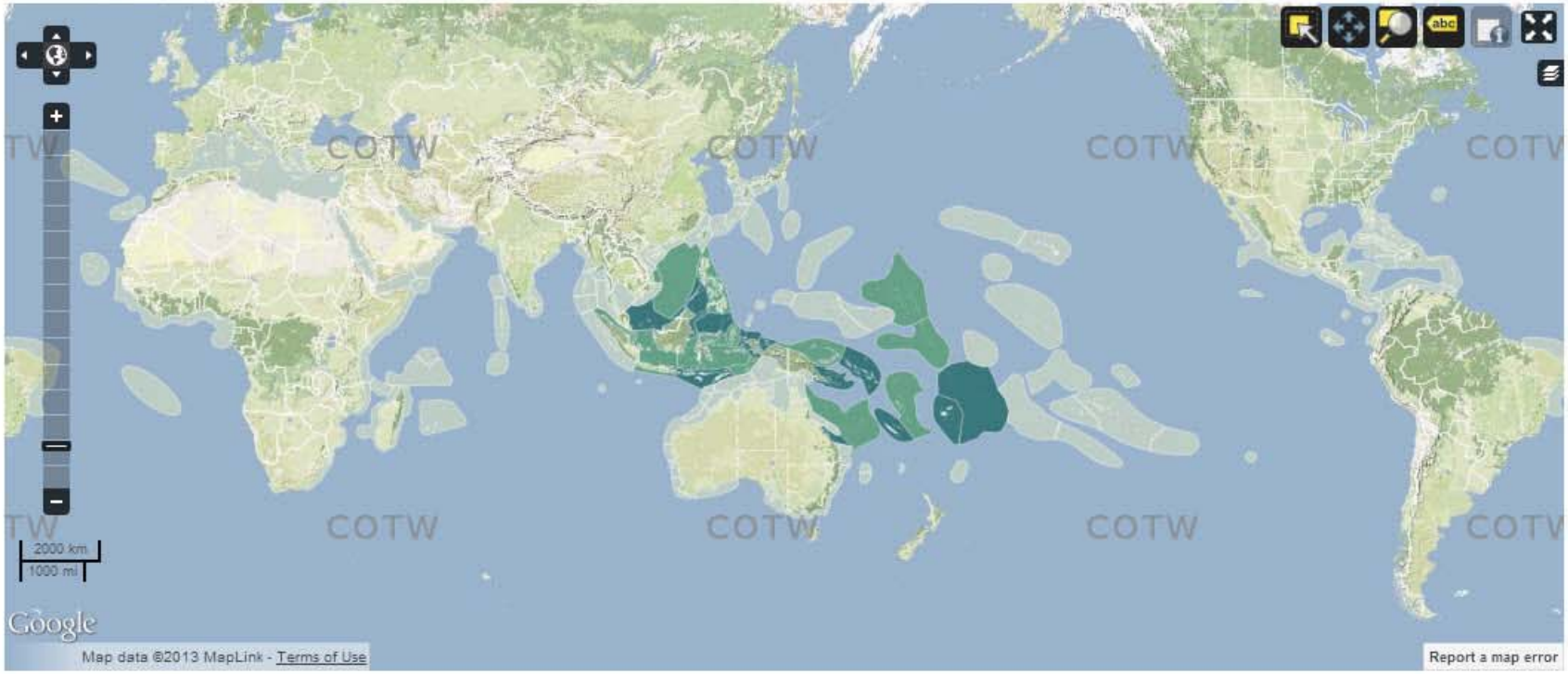

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Isopora cuneata

CORALS of the World

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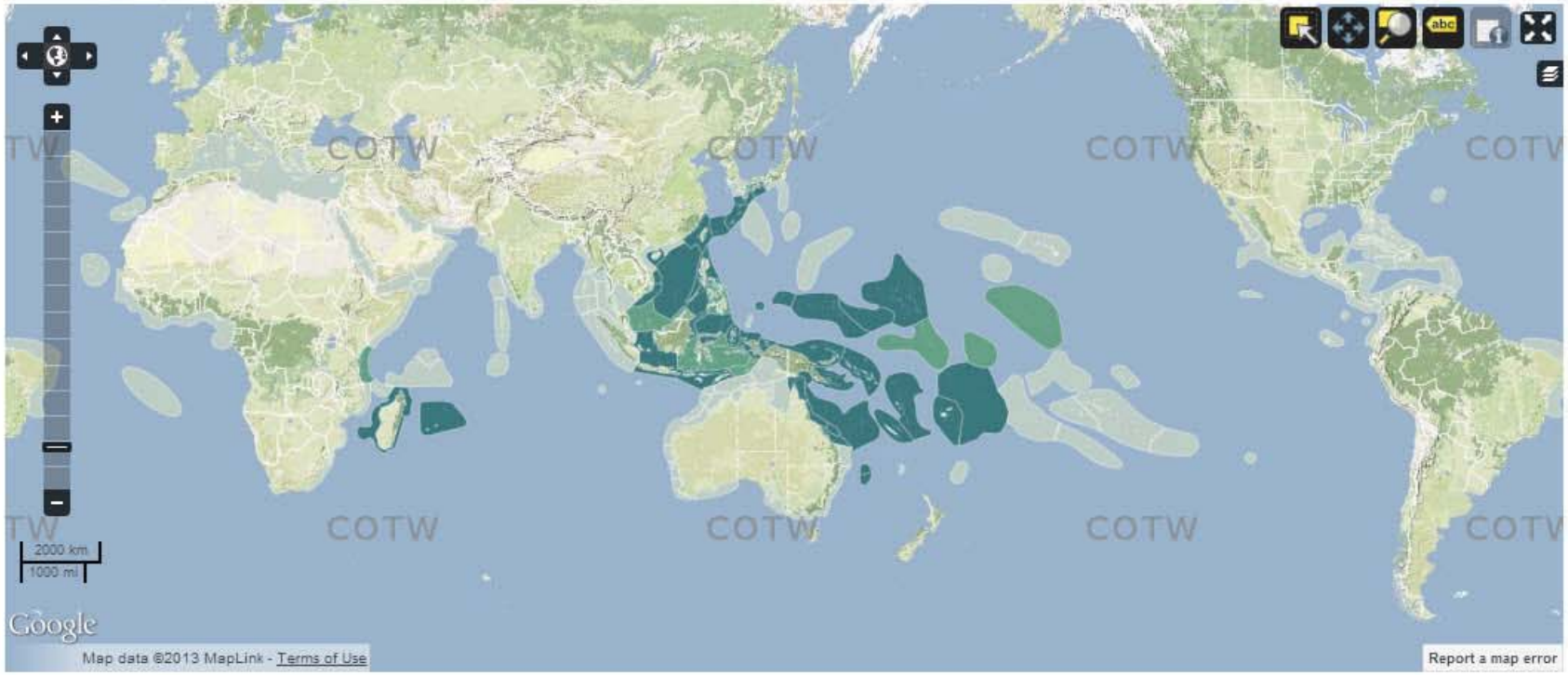

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Leptoseris incrustans

CORALS of the World

Summary

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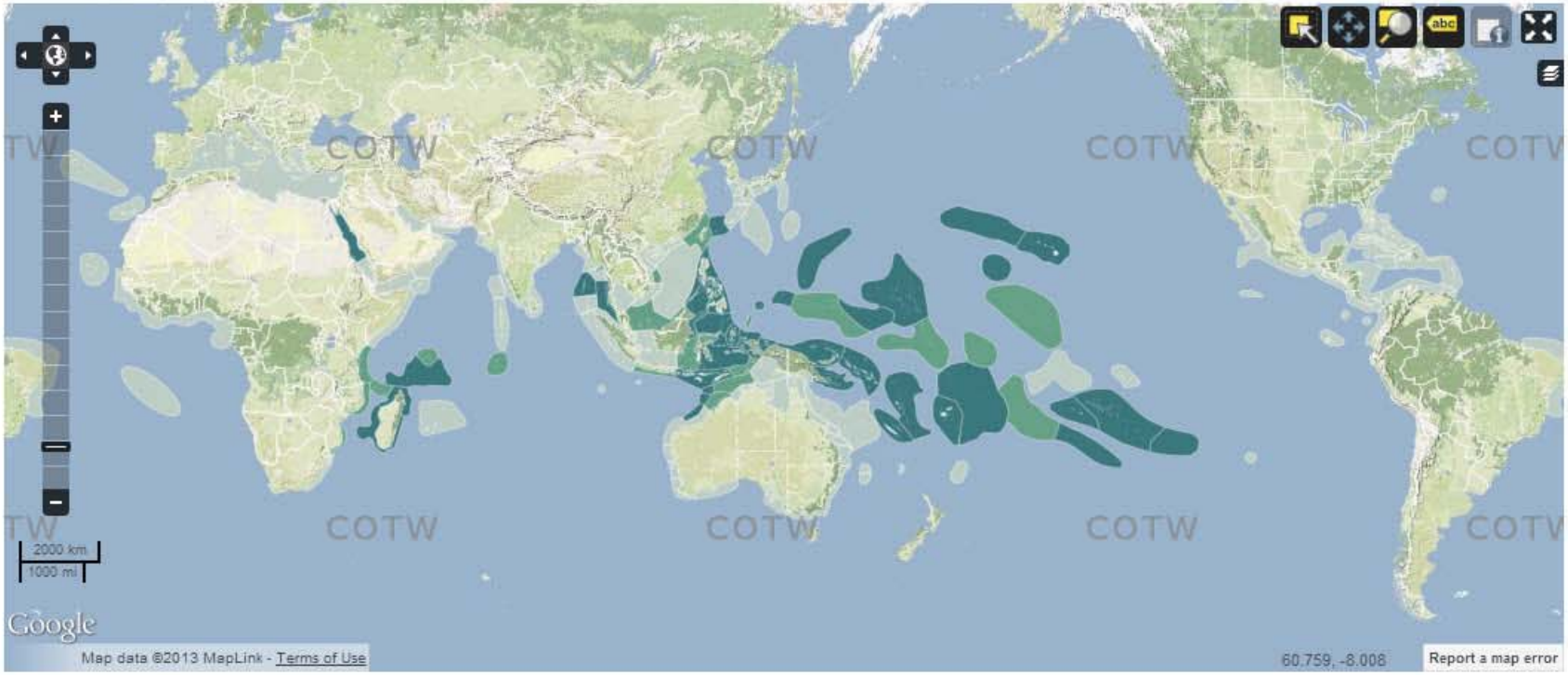

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Leptoseris yabei

CORALS of the World

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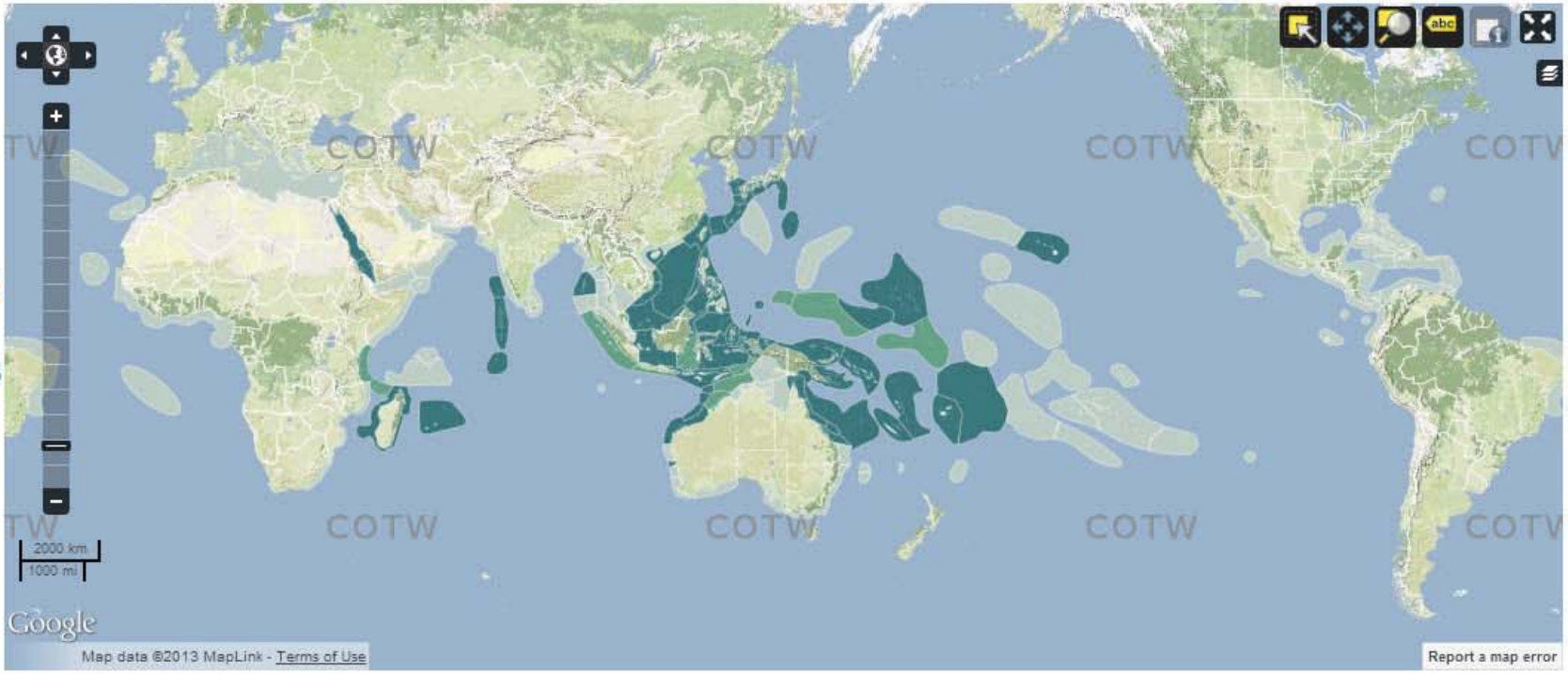

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Montipora angulata

CORALS of the World

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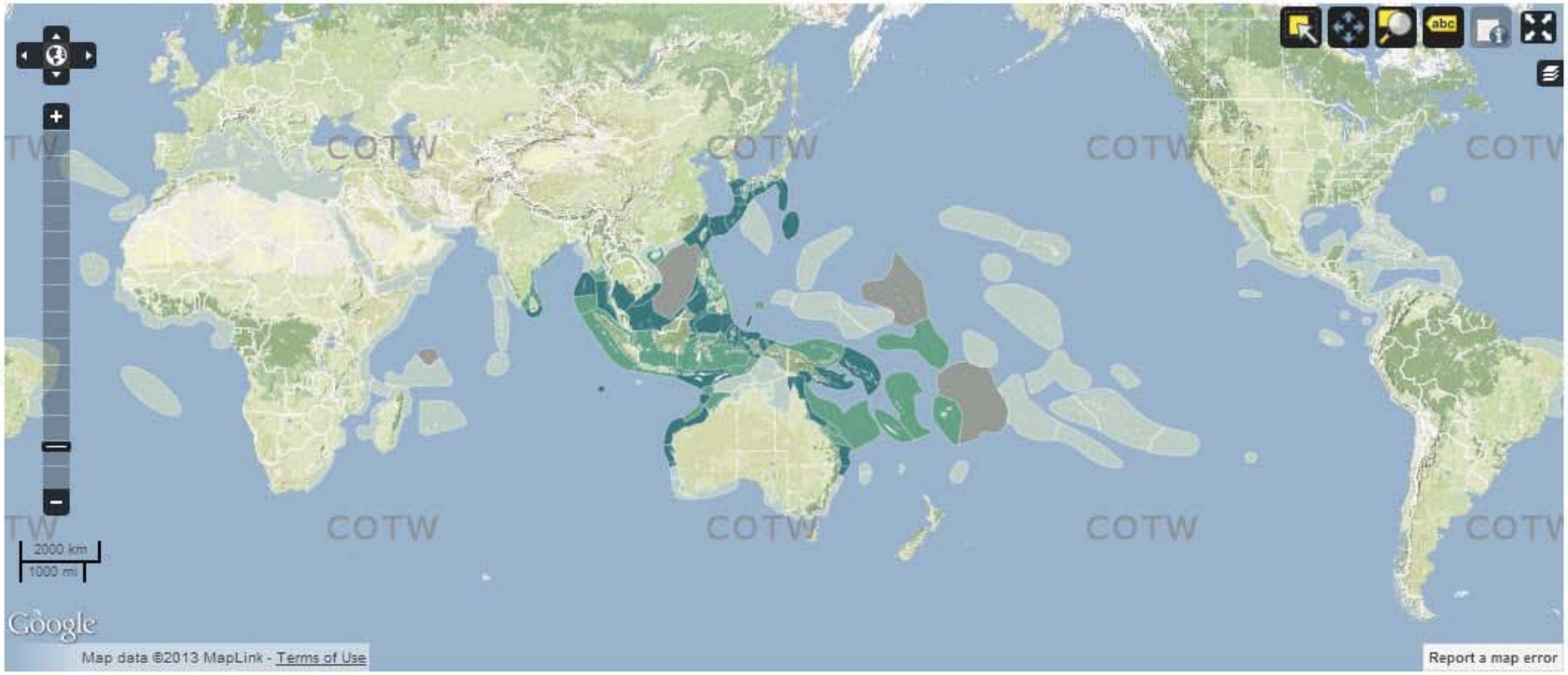

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Montipora australiensis

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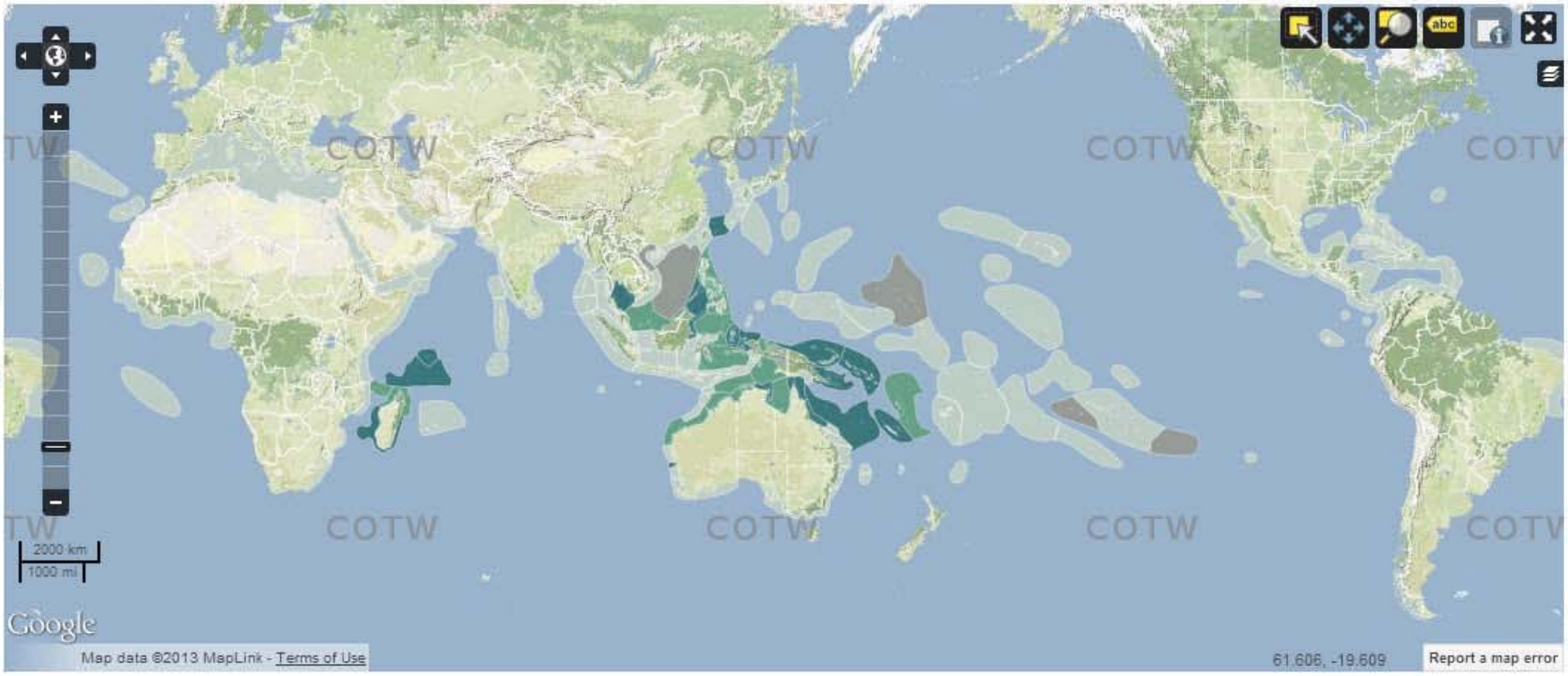

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Montipora calcarea

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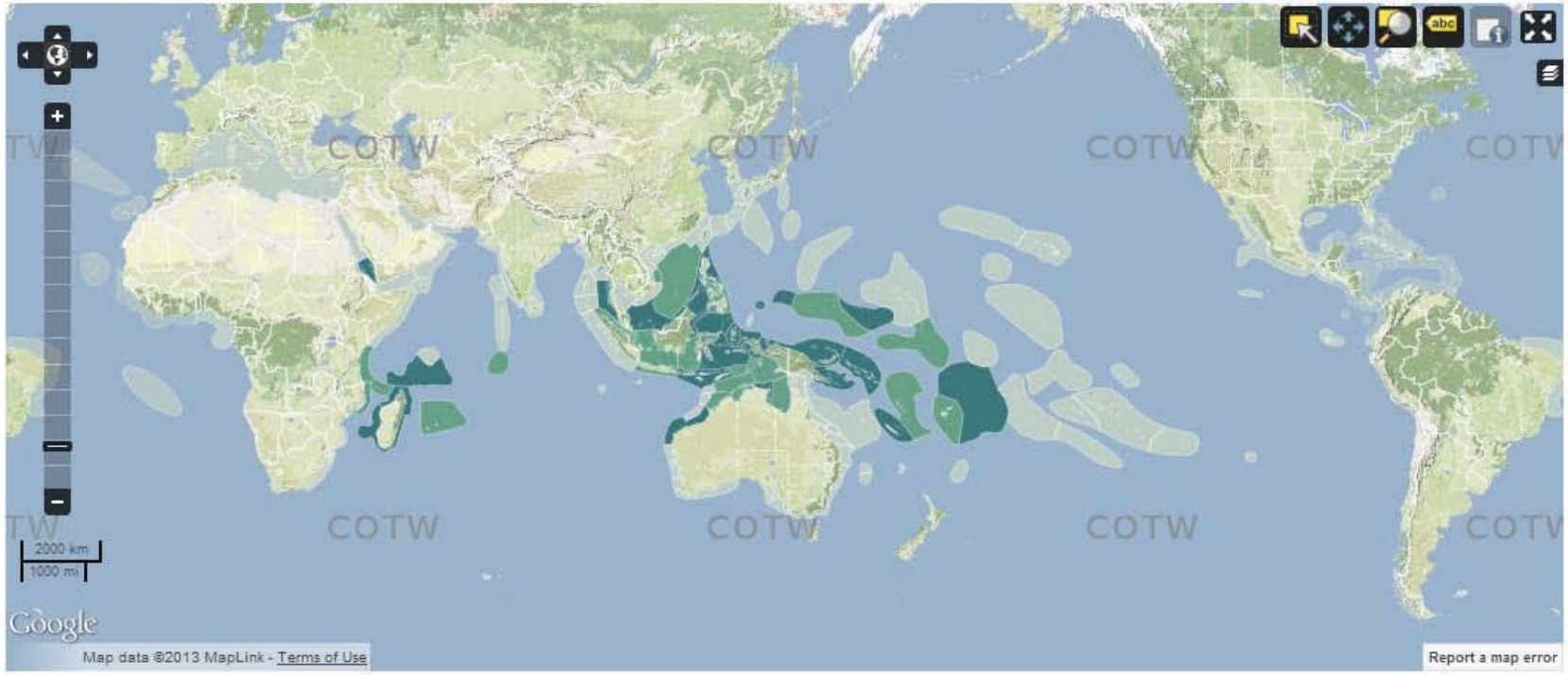

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Montipora caliculata

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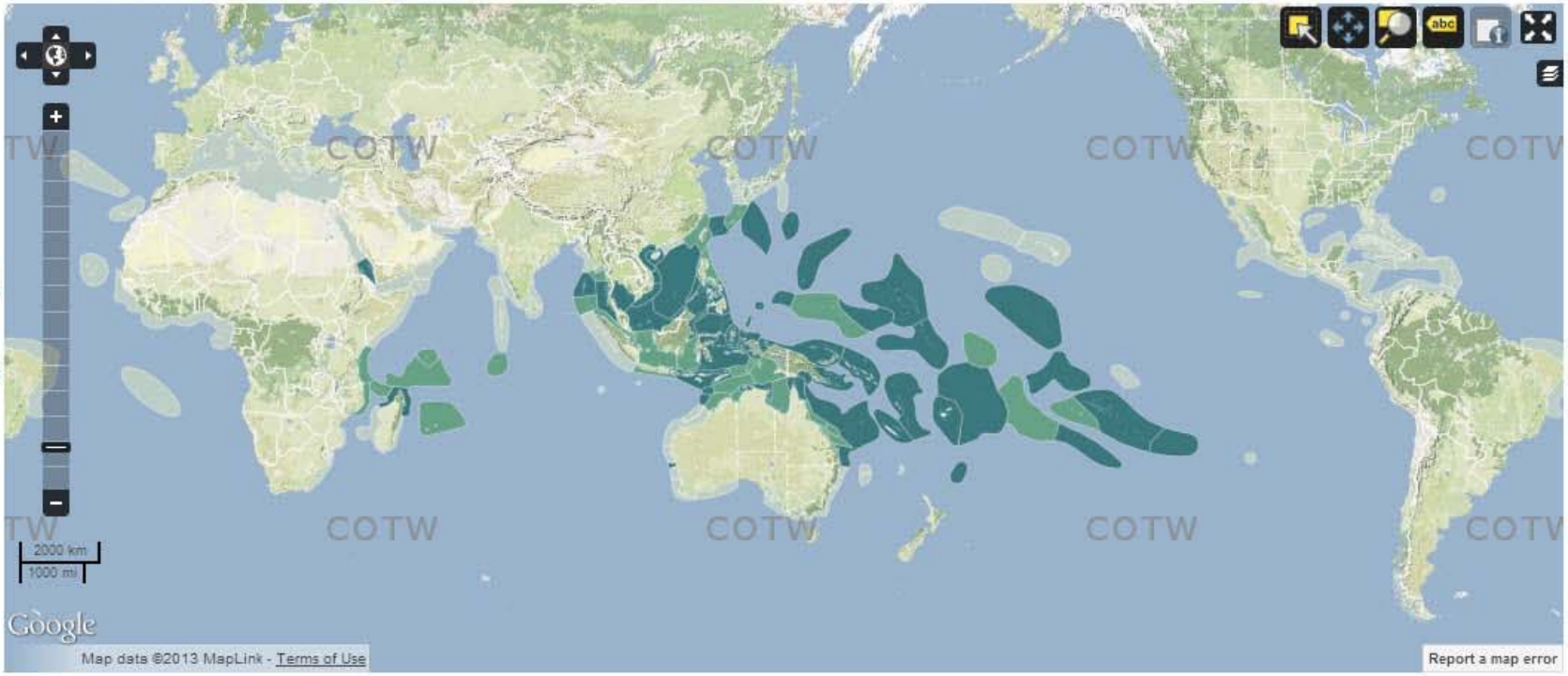

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Montipora dilatata

CORALS of the World

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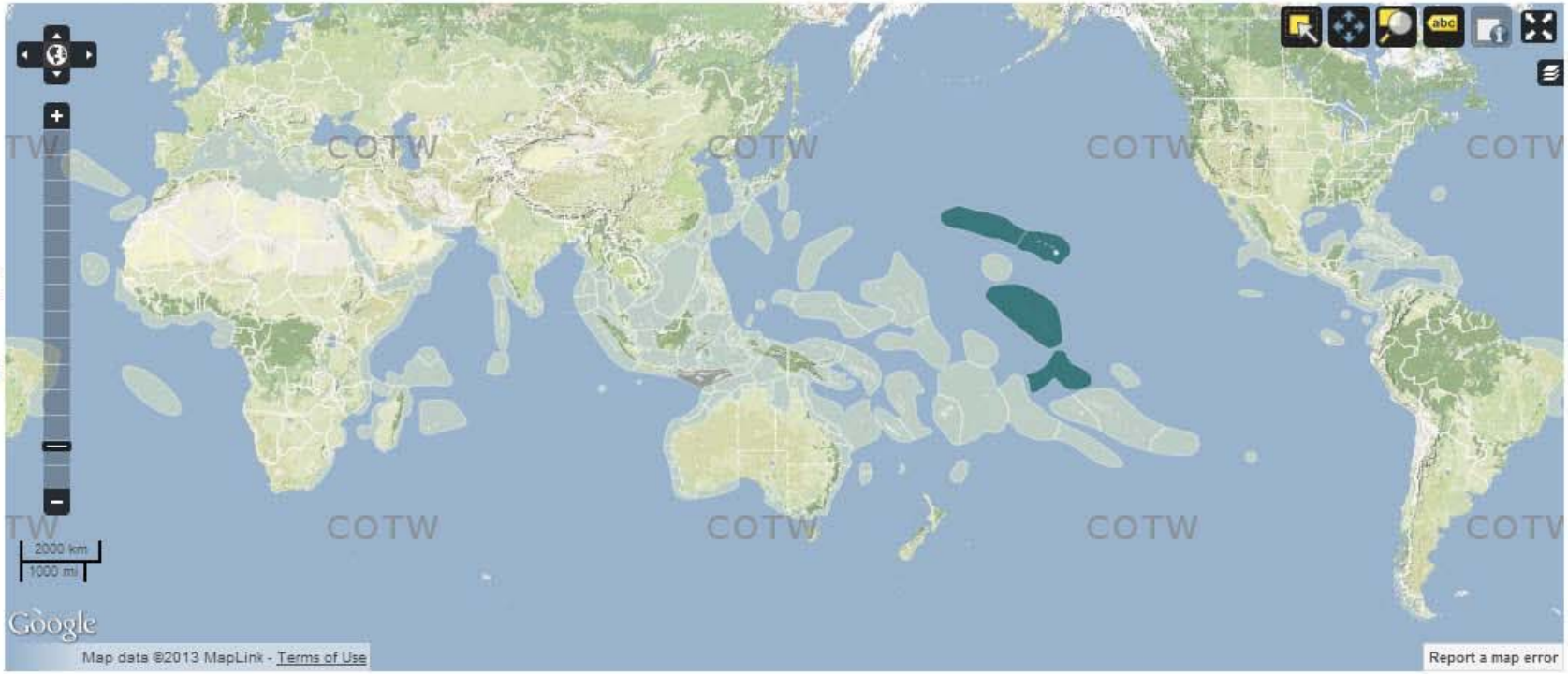

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Montipora flabellata

CORALS of the World

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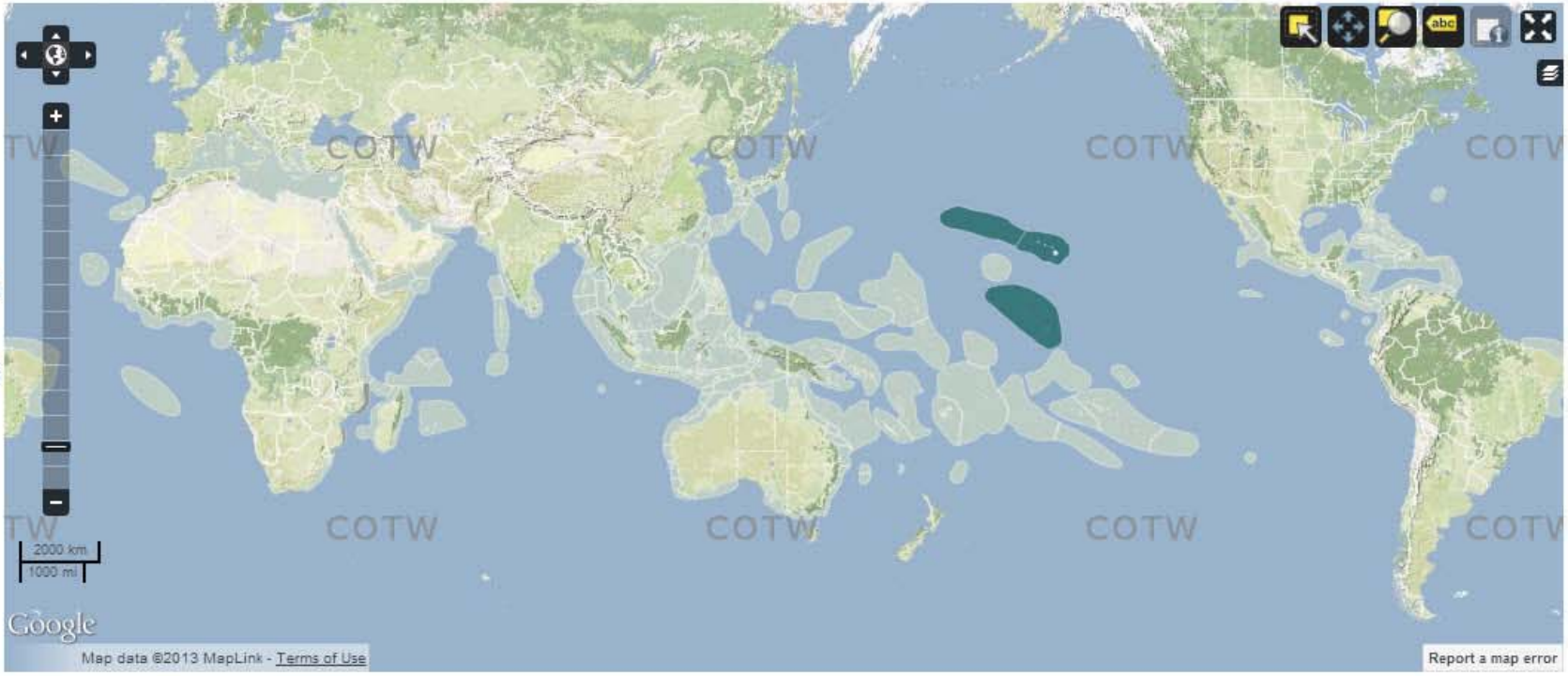

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Montipora lobulata

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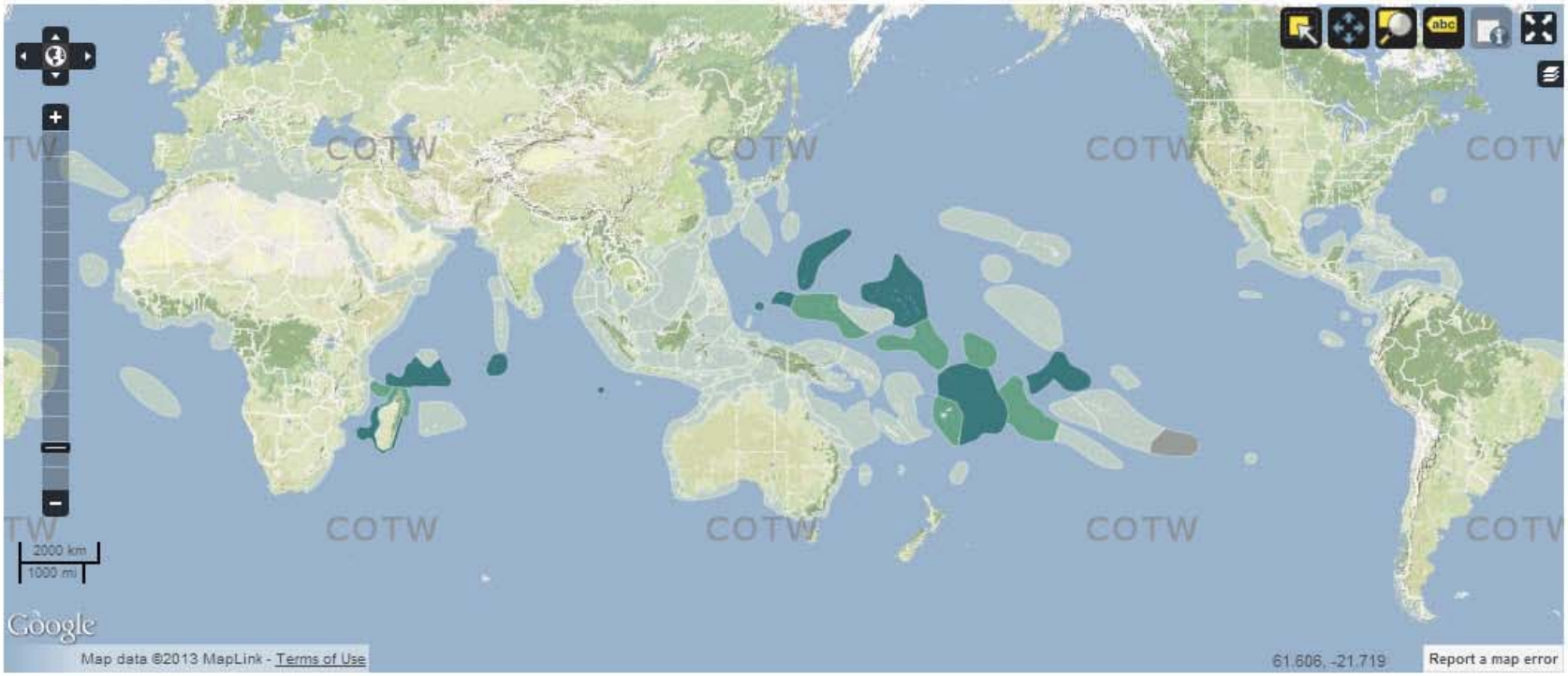

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Montipora patula

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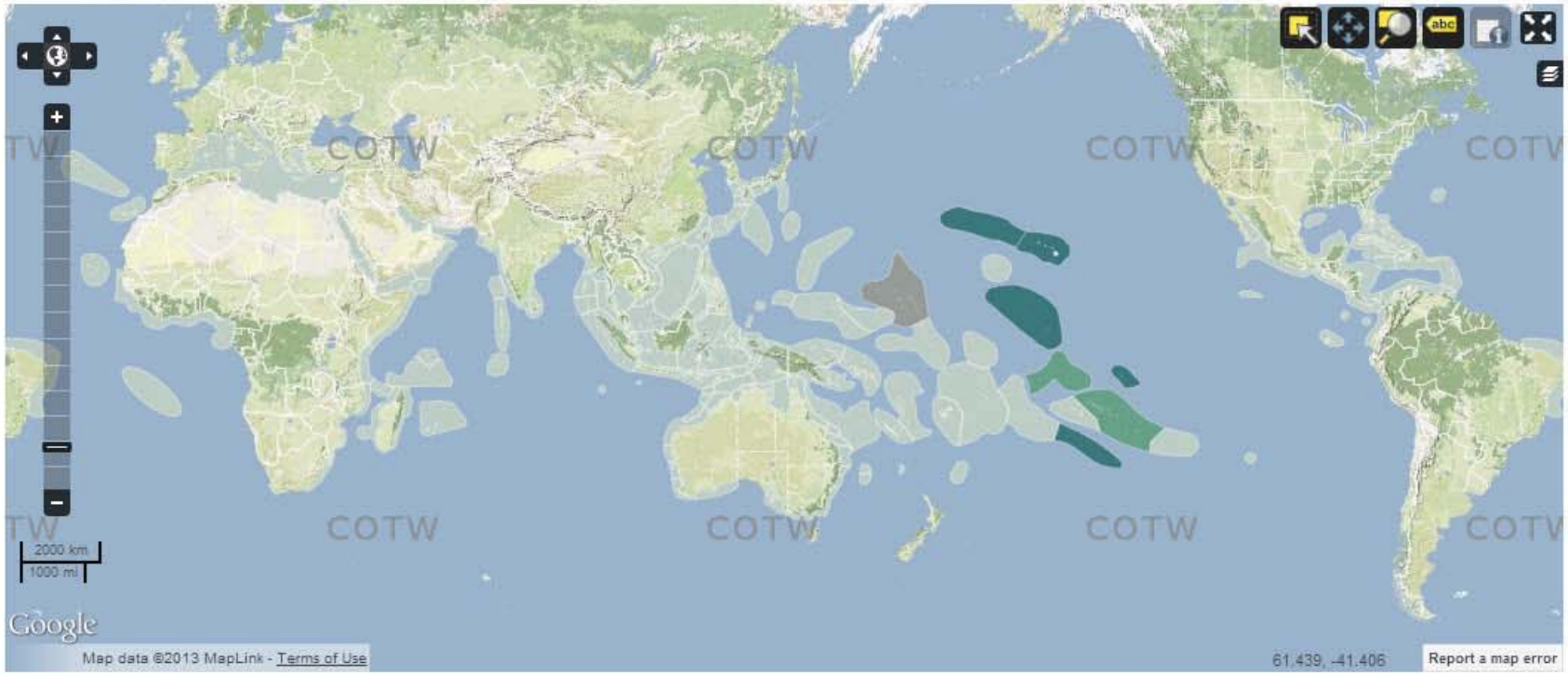

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Montipora turgescens

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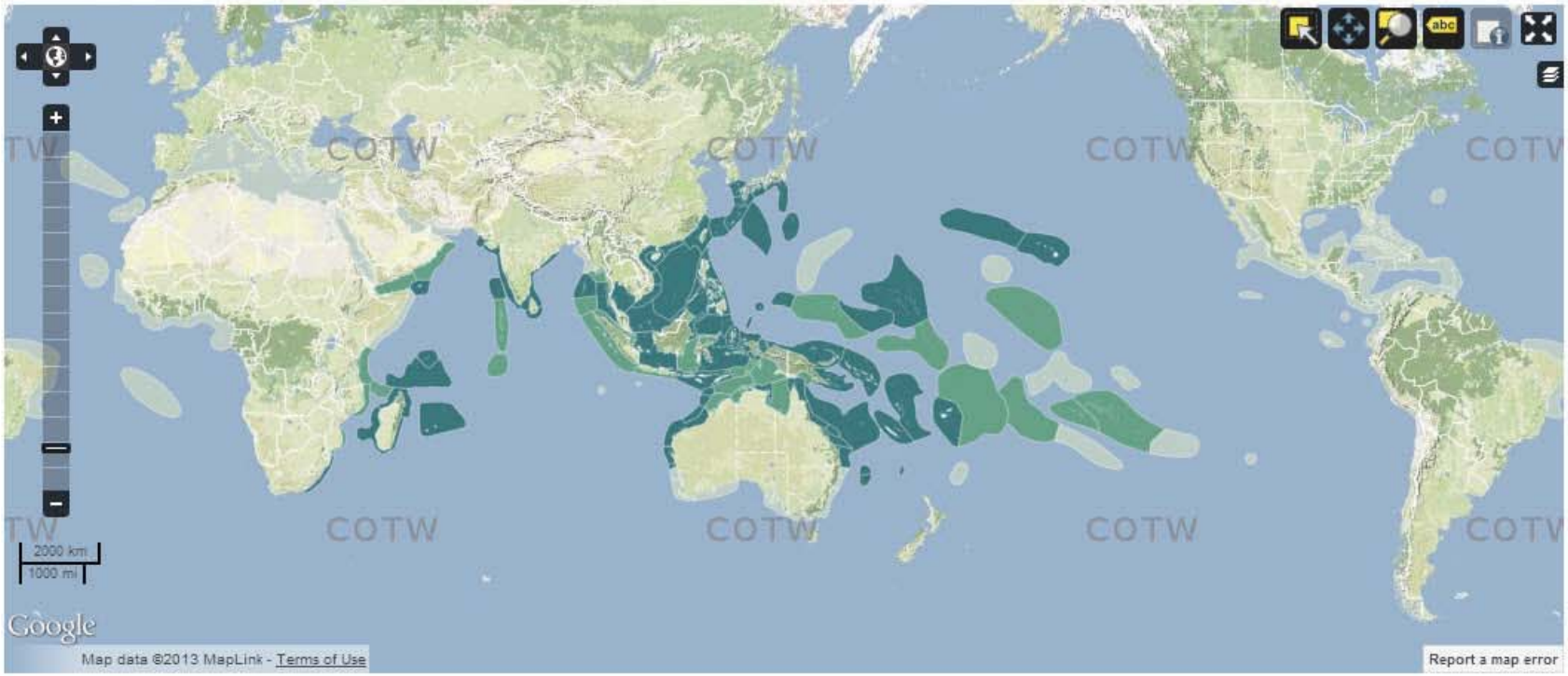

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Pachyseris rugosa

CORALS of the World

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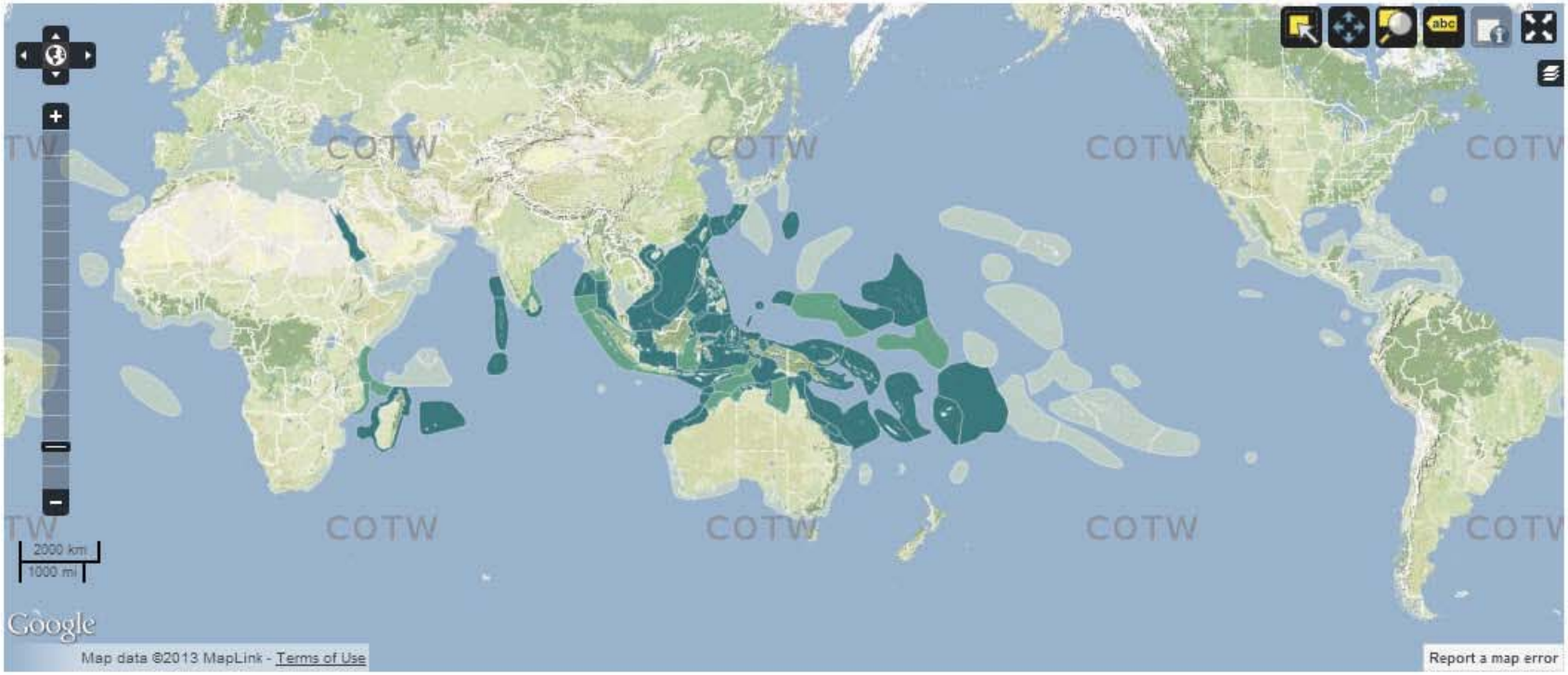

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Pavona bipartita

CORALS of the World

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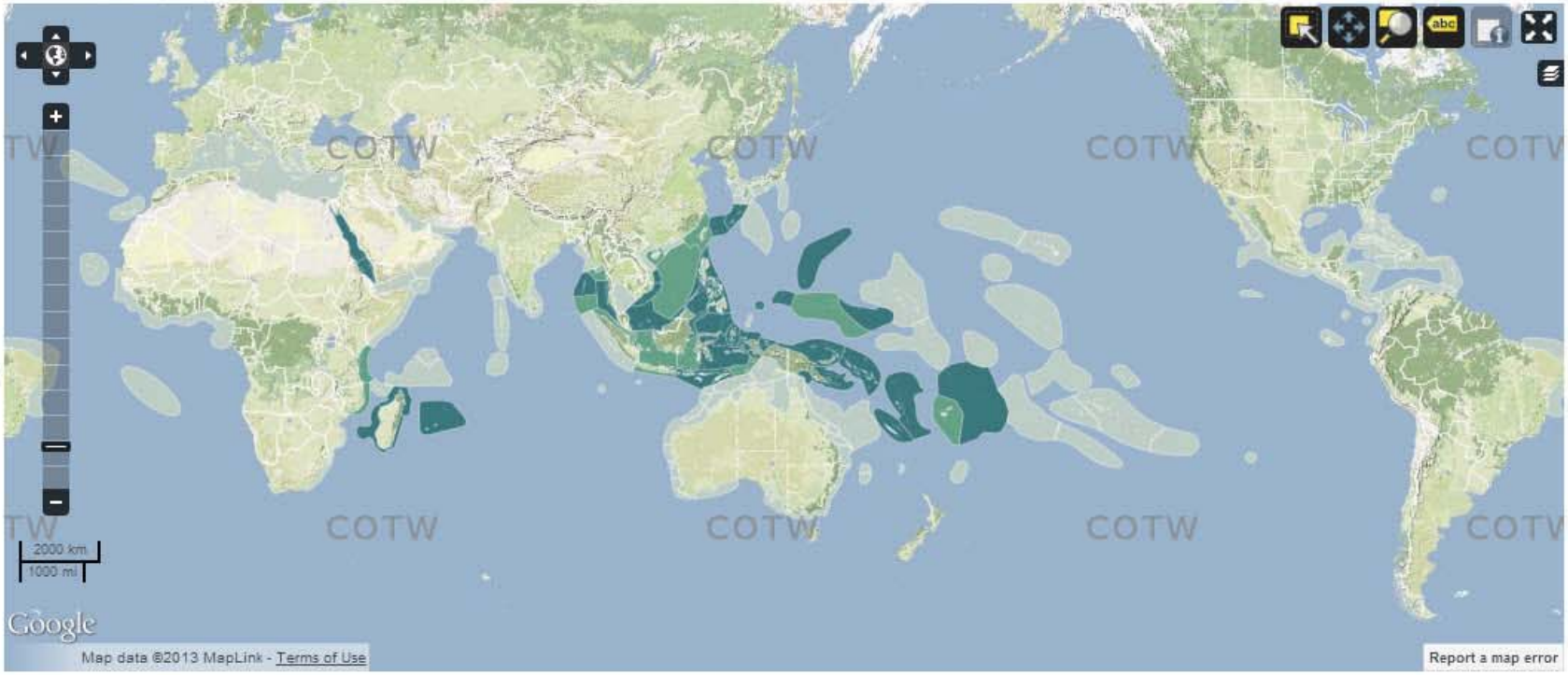

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Pavona cactus

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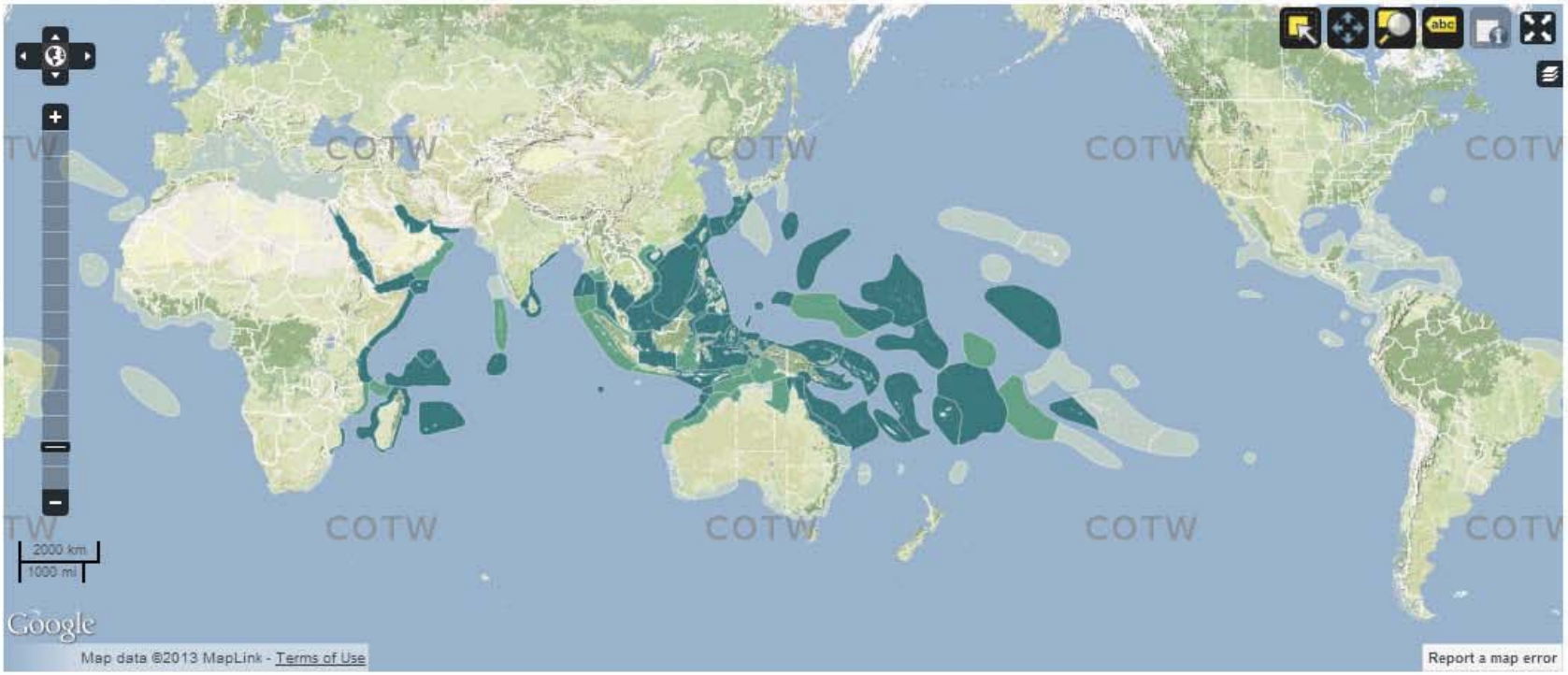

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Pavona decussata

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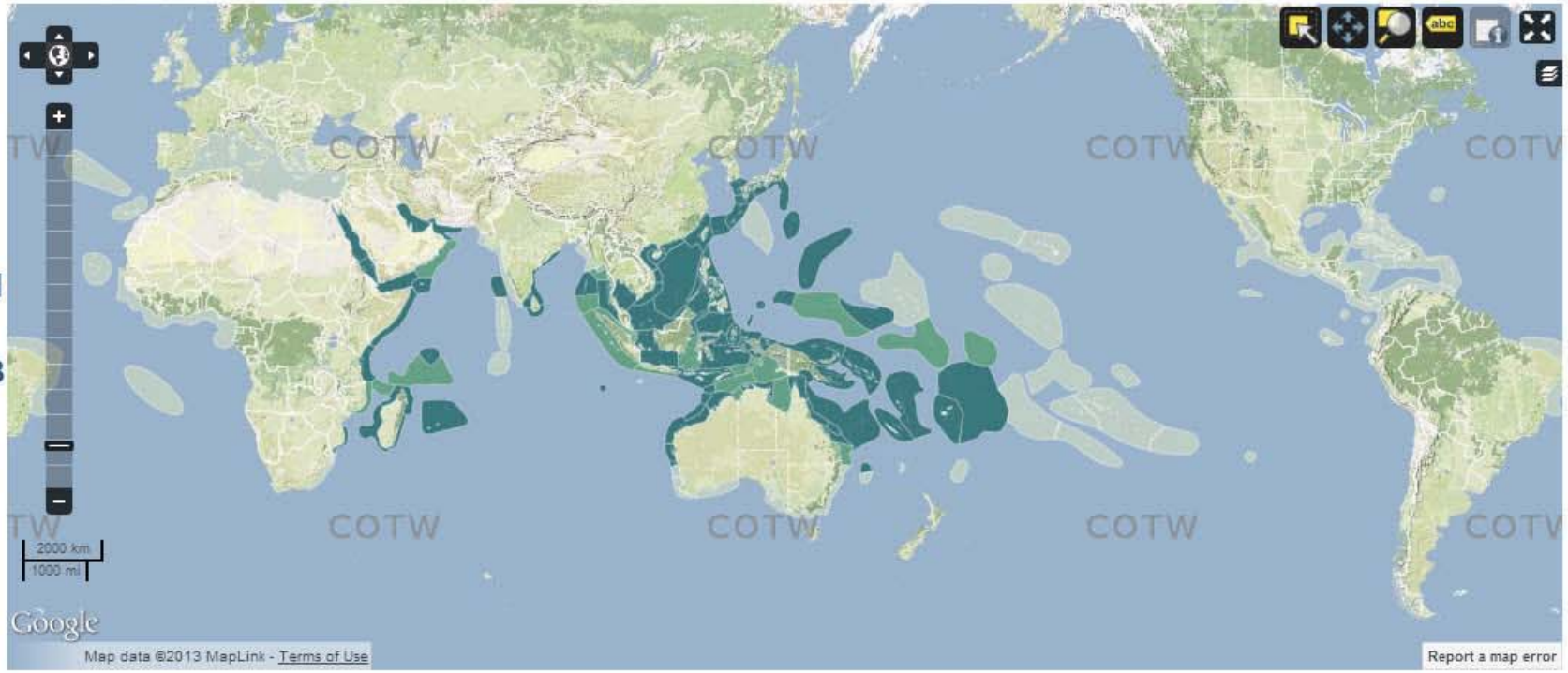

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Pavona diffluens

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Pavona venosa

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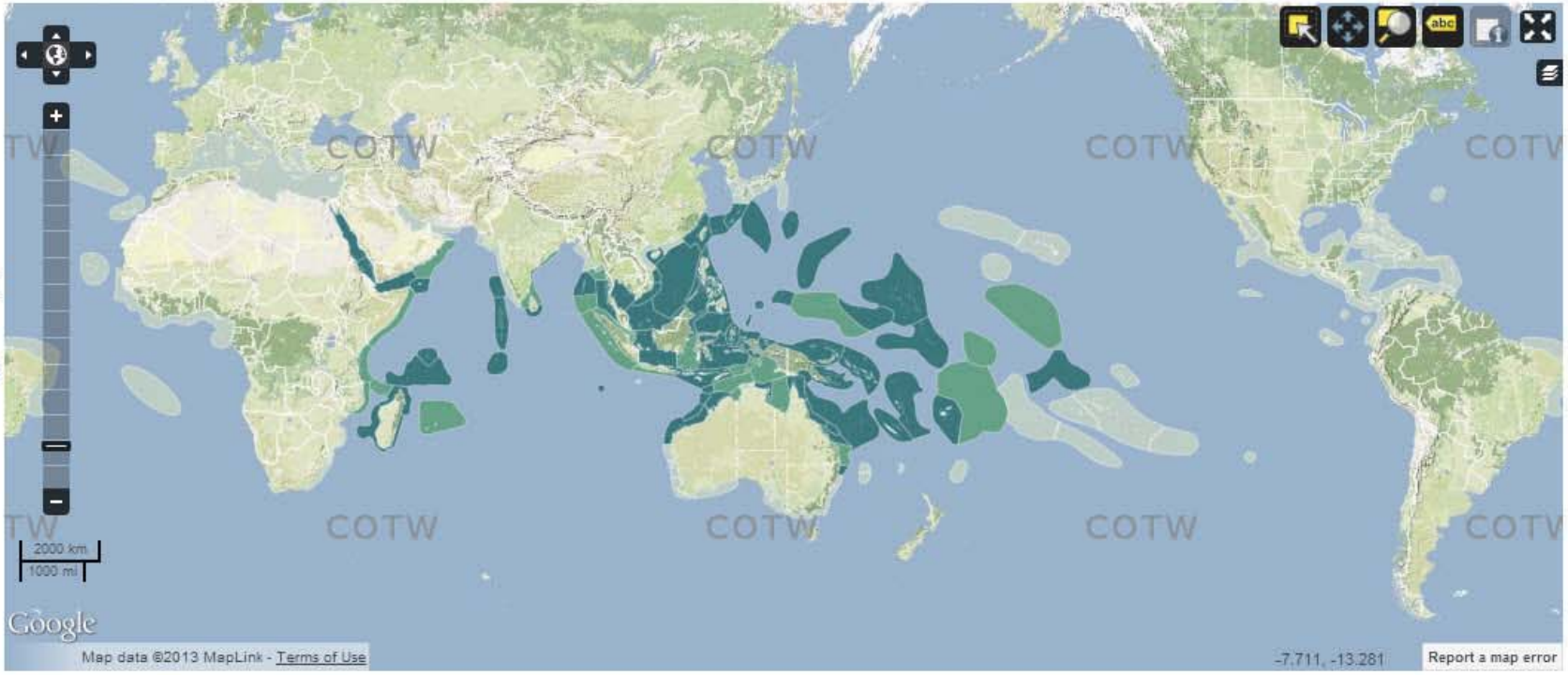

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Pectinia alcicornis

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Physogyra lichtenstein

CORALS of the World

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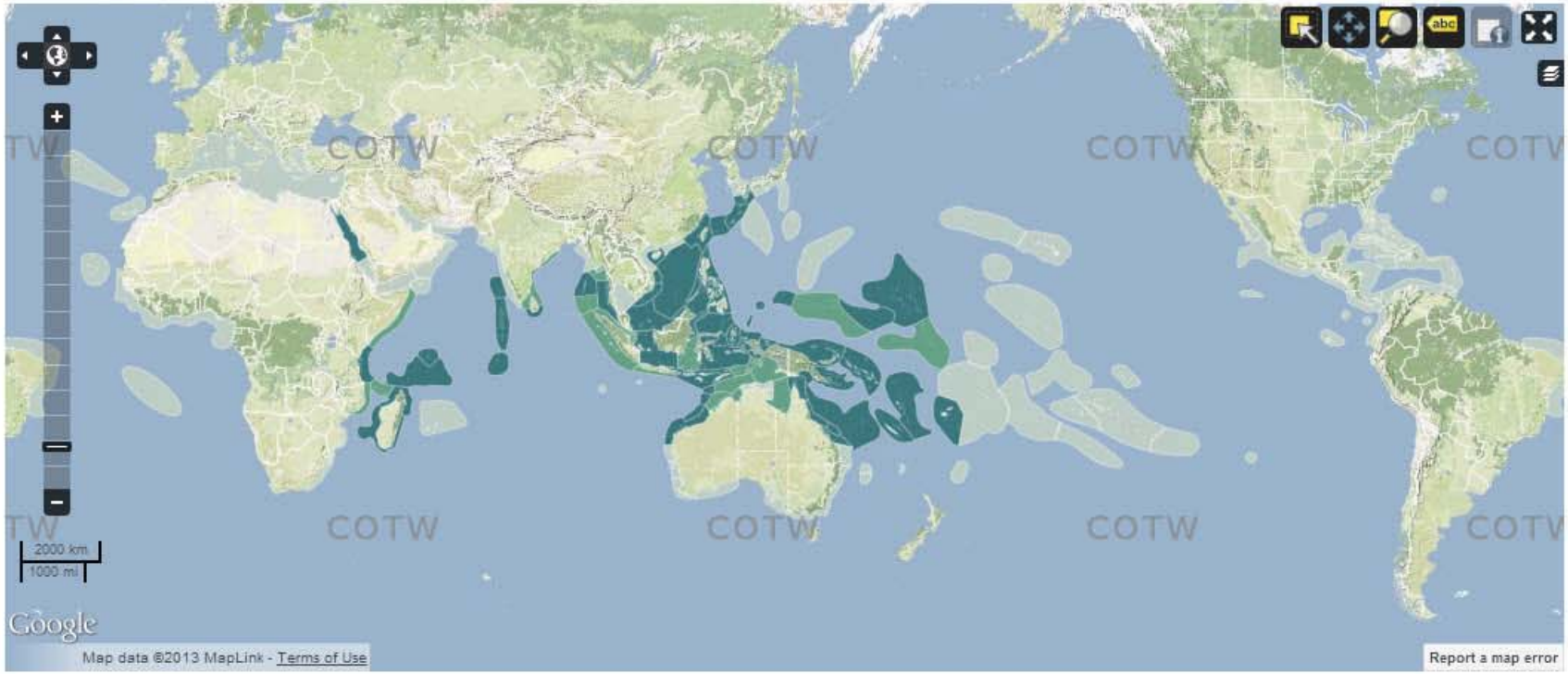

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Pocillopora danae

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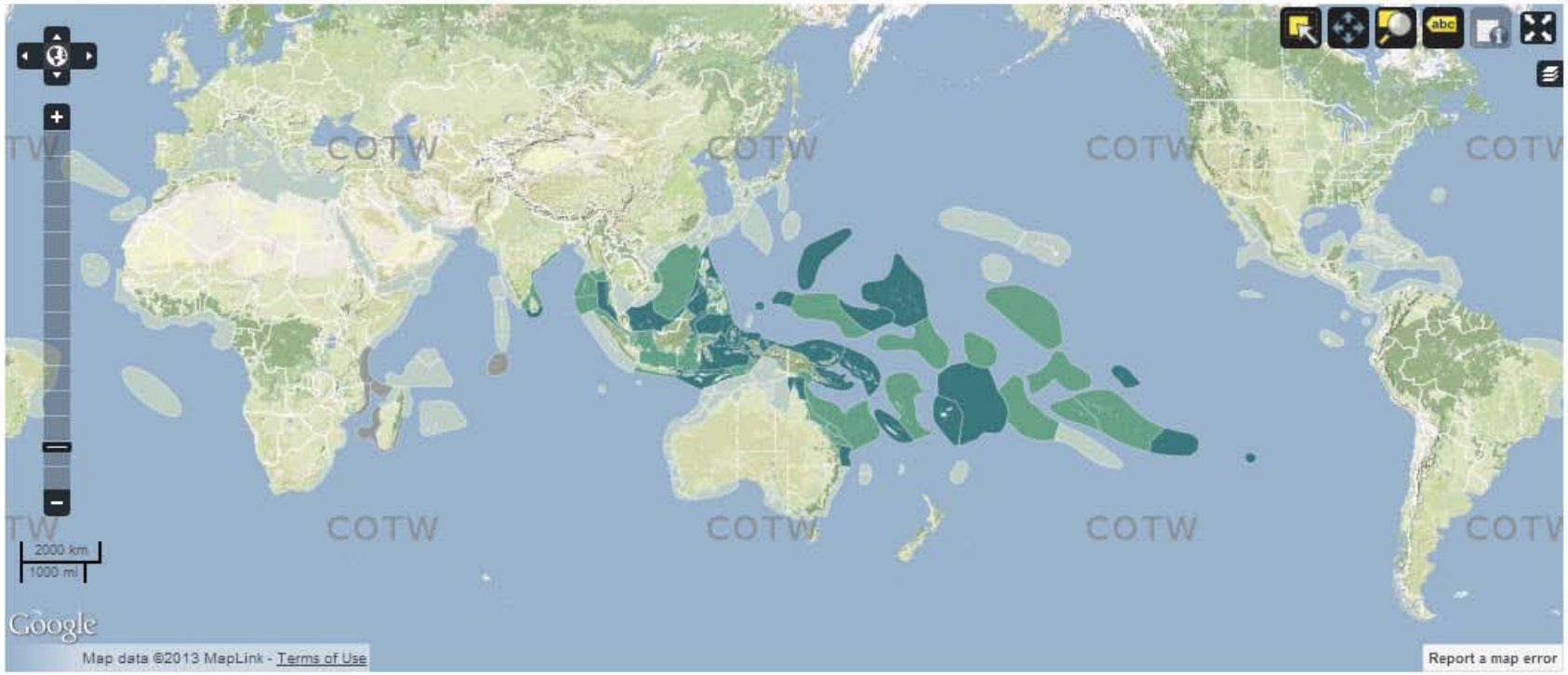

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Pocillopora elegans

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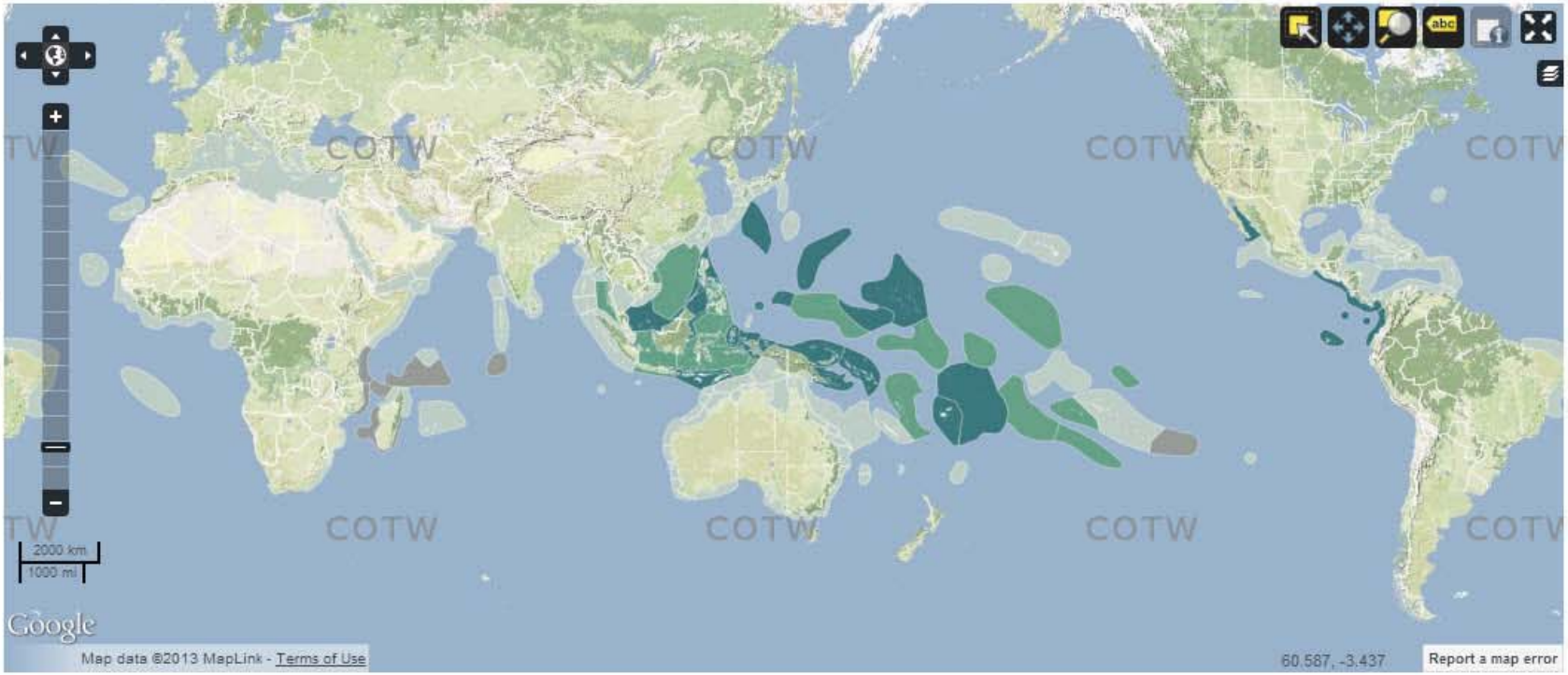

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Porites horizontalata

CORALS of the World

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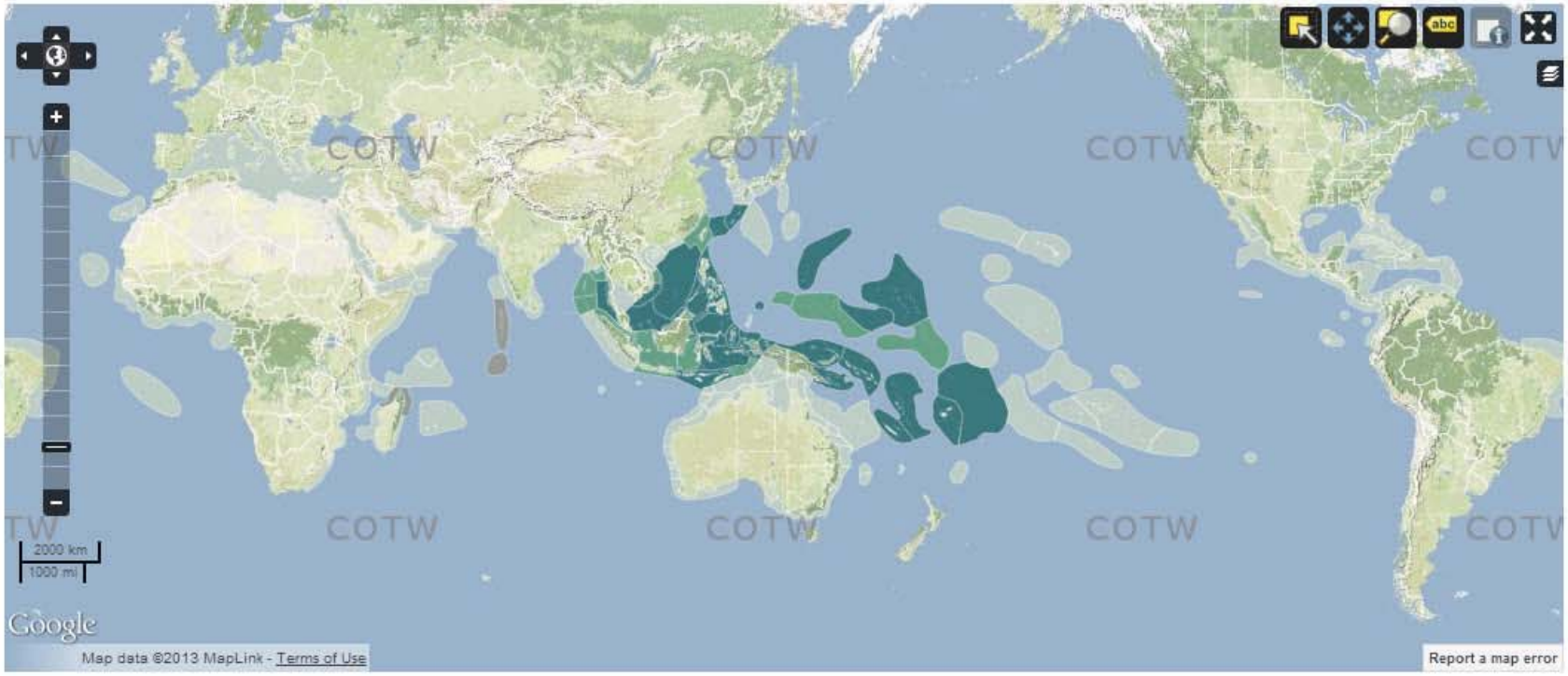

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Porites napopora

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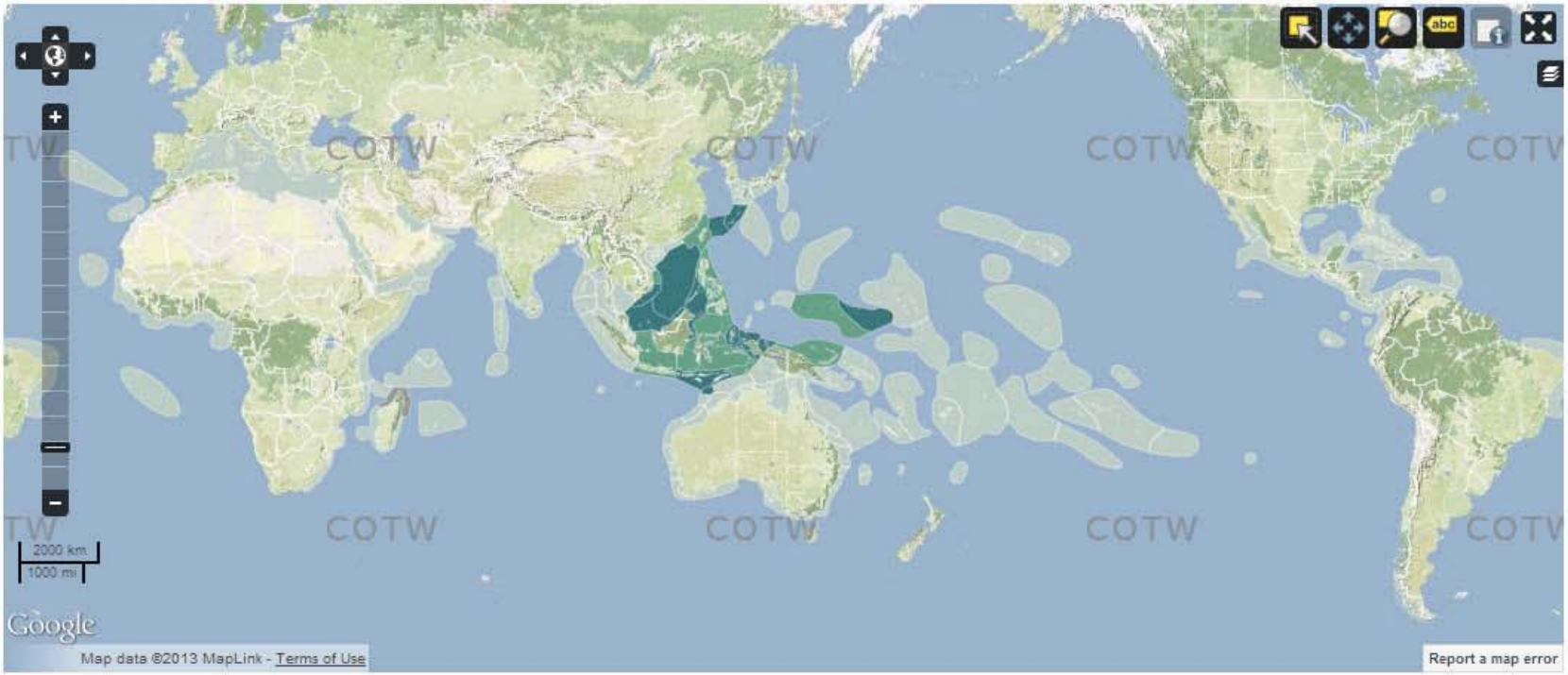

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Porites nigrescens

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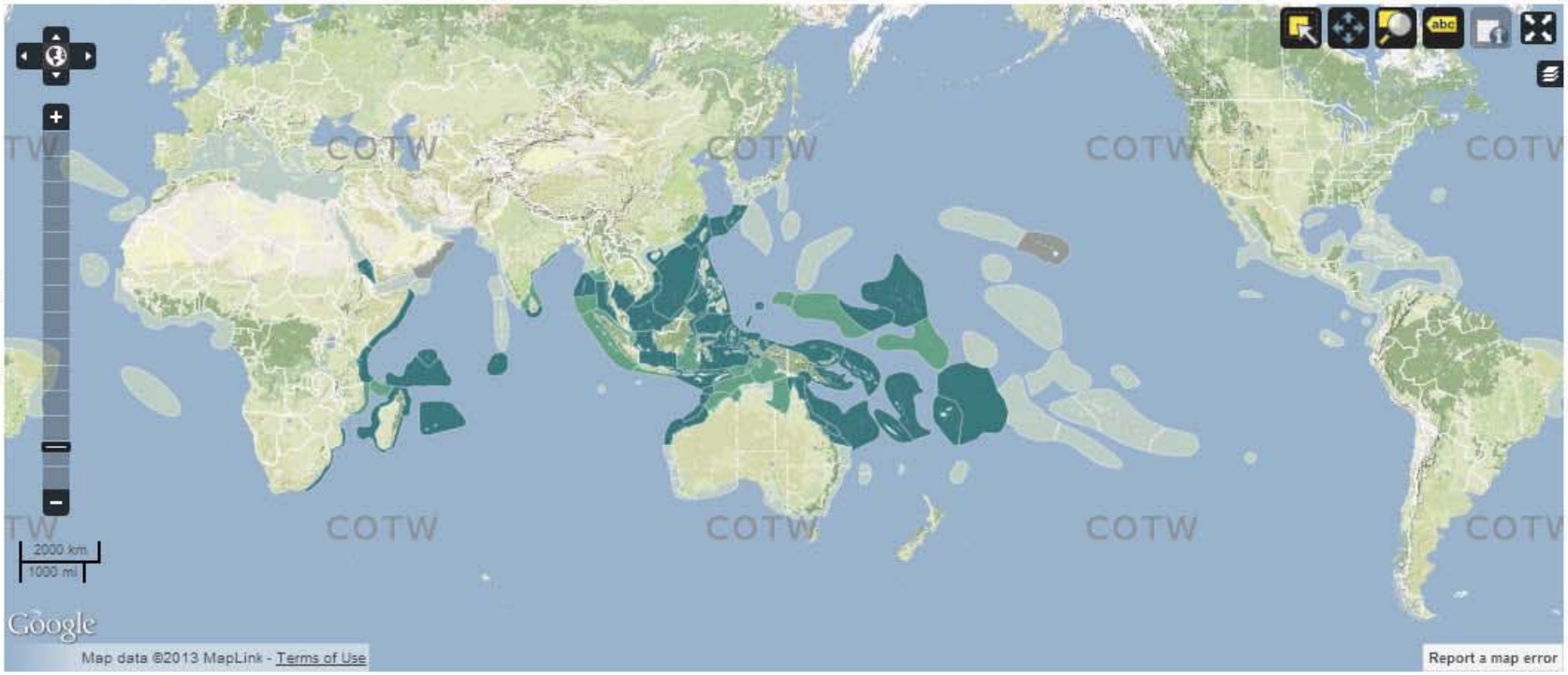

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Porites pukoensis

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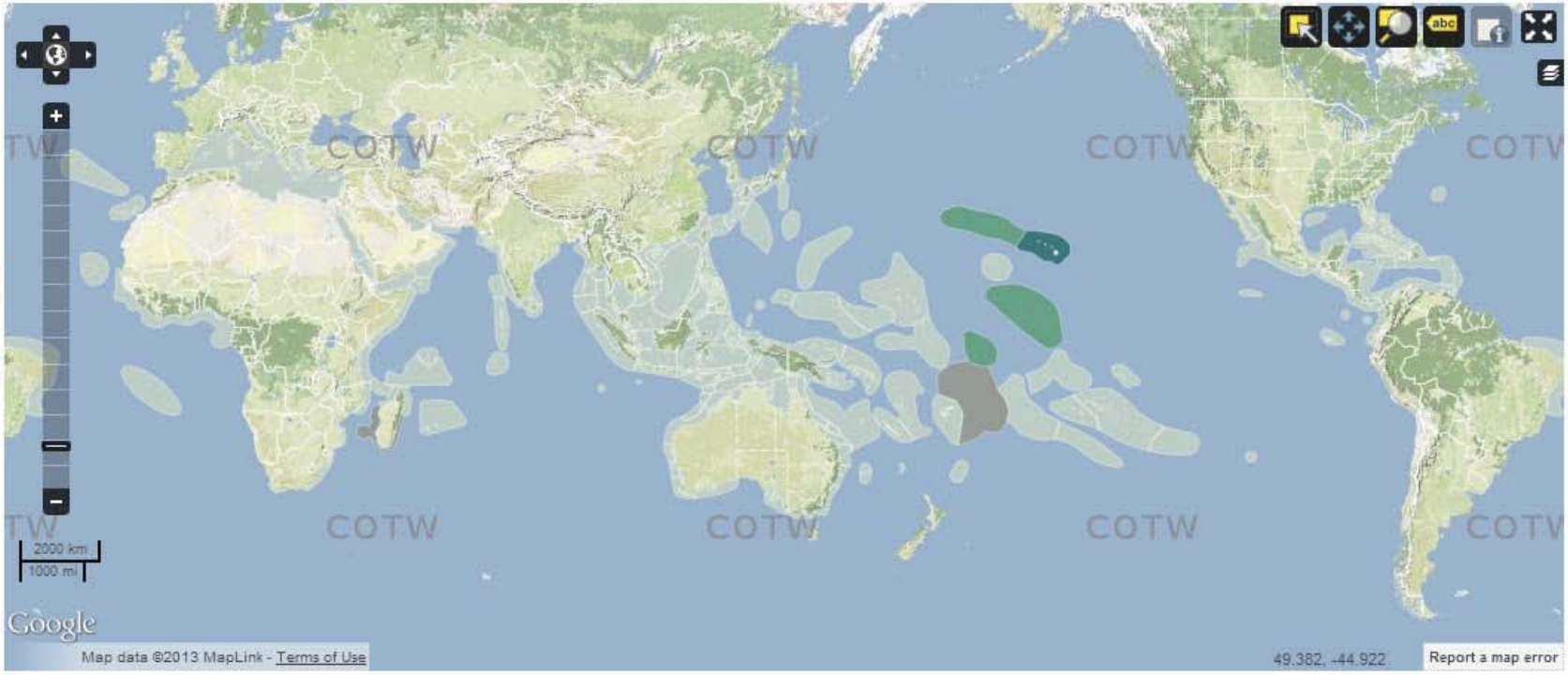

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Psammocora stellata

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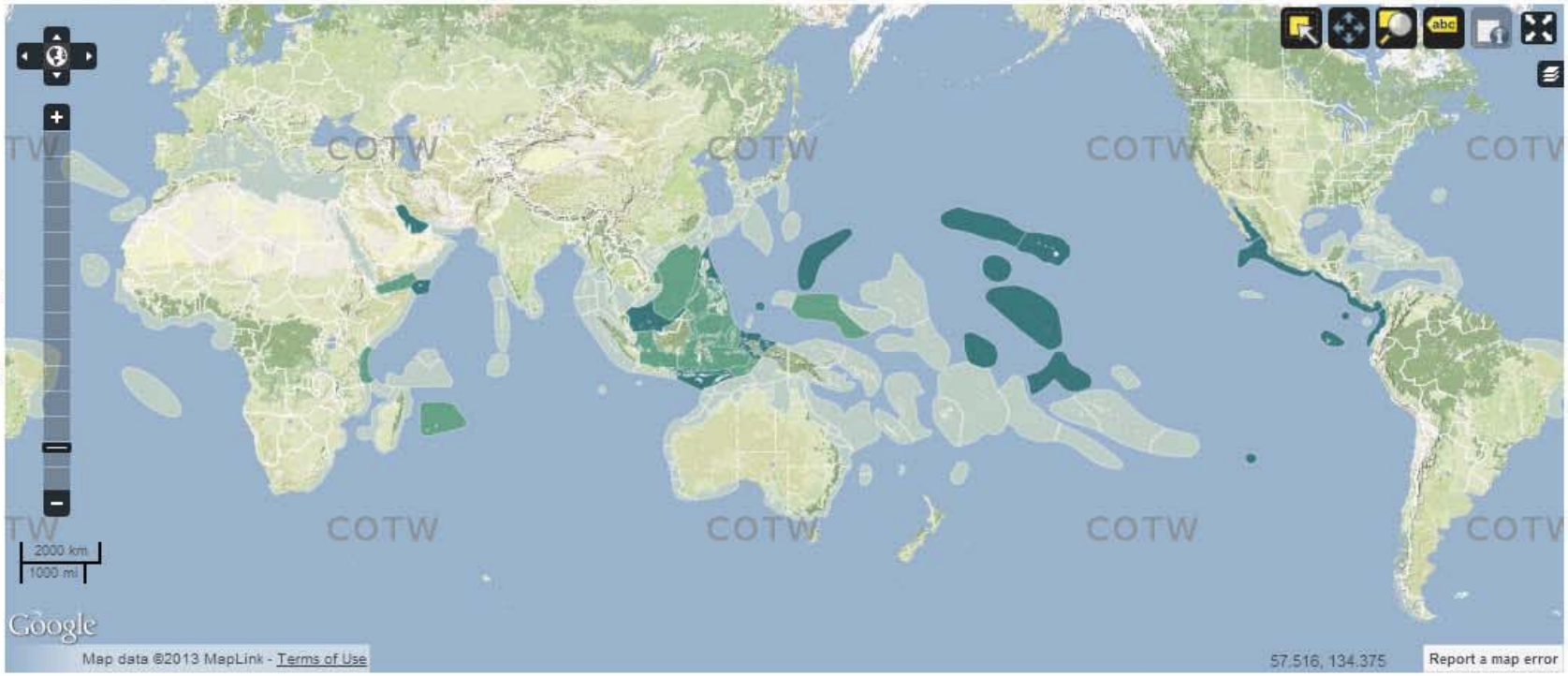

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Seriatopora aculeata

CORALS of the World

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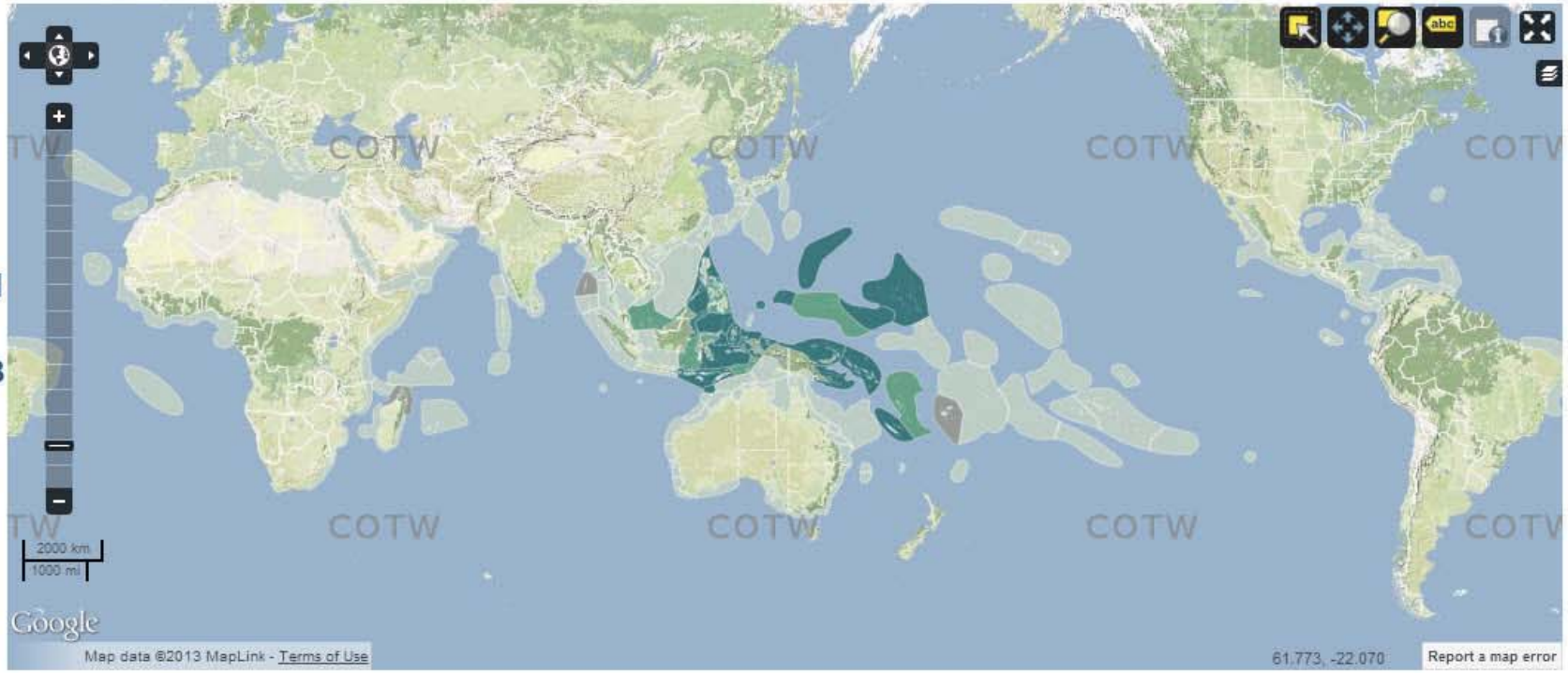

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Turbinaria mesenterina

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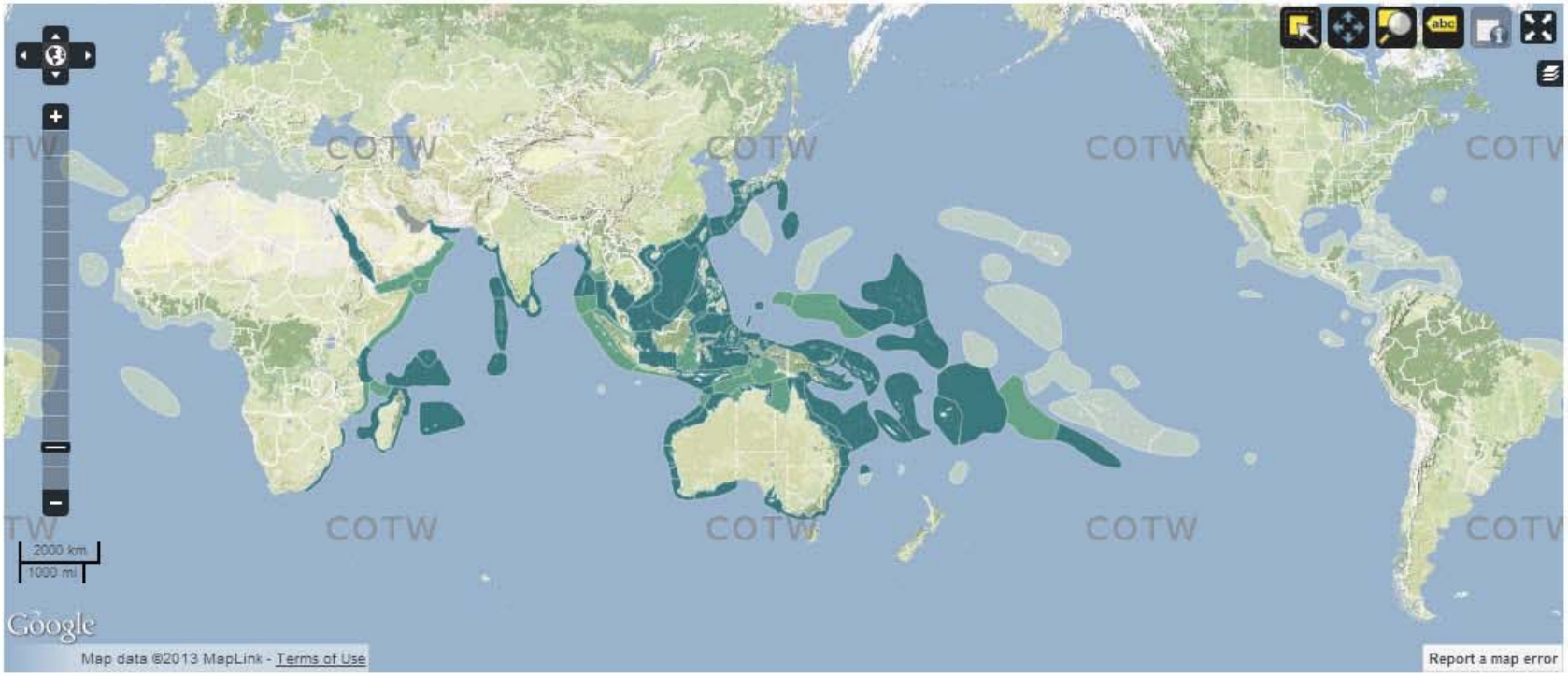

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Turbinaria peltata

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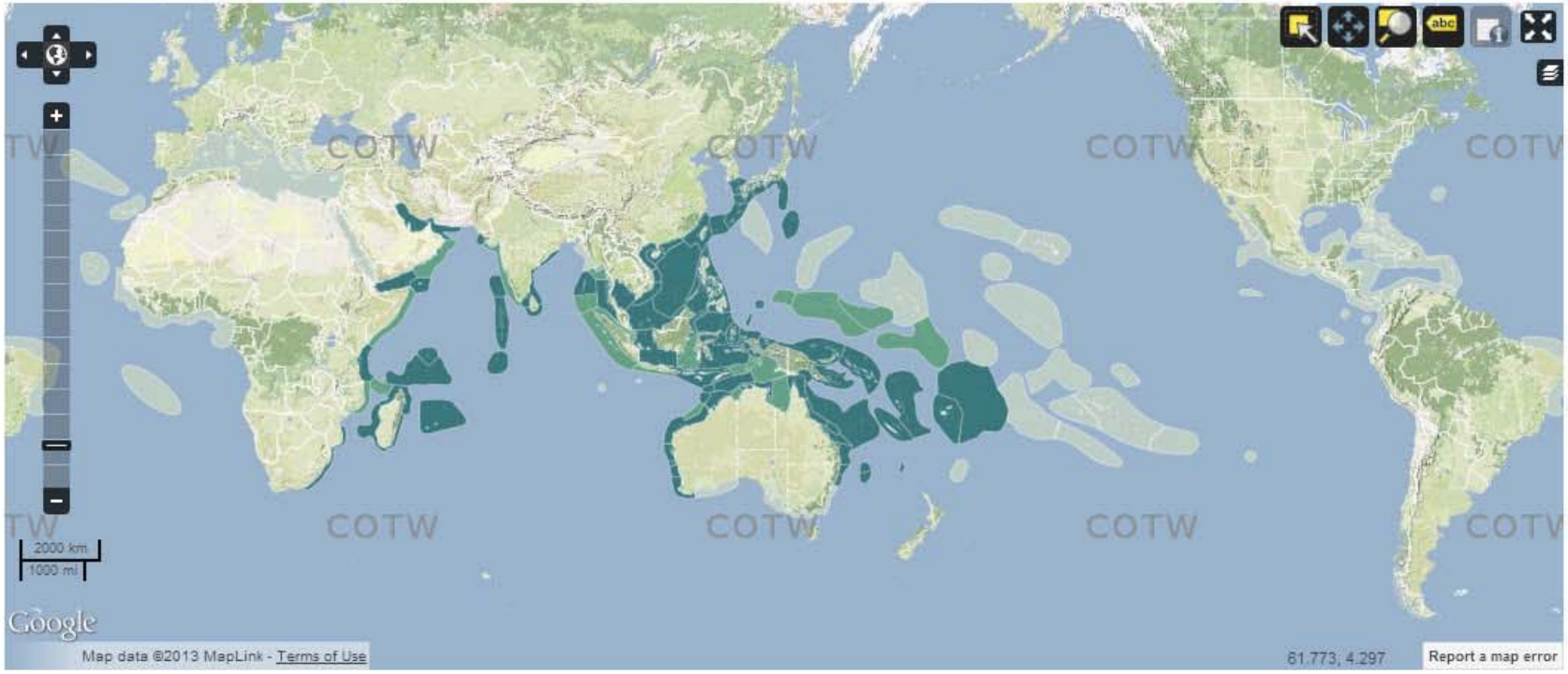

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Turbinaria reniformis

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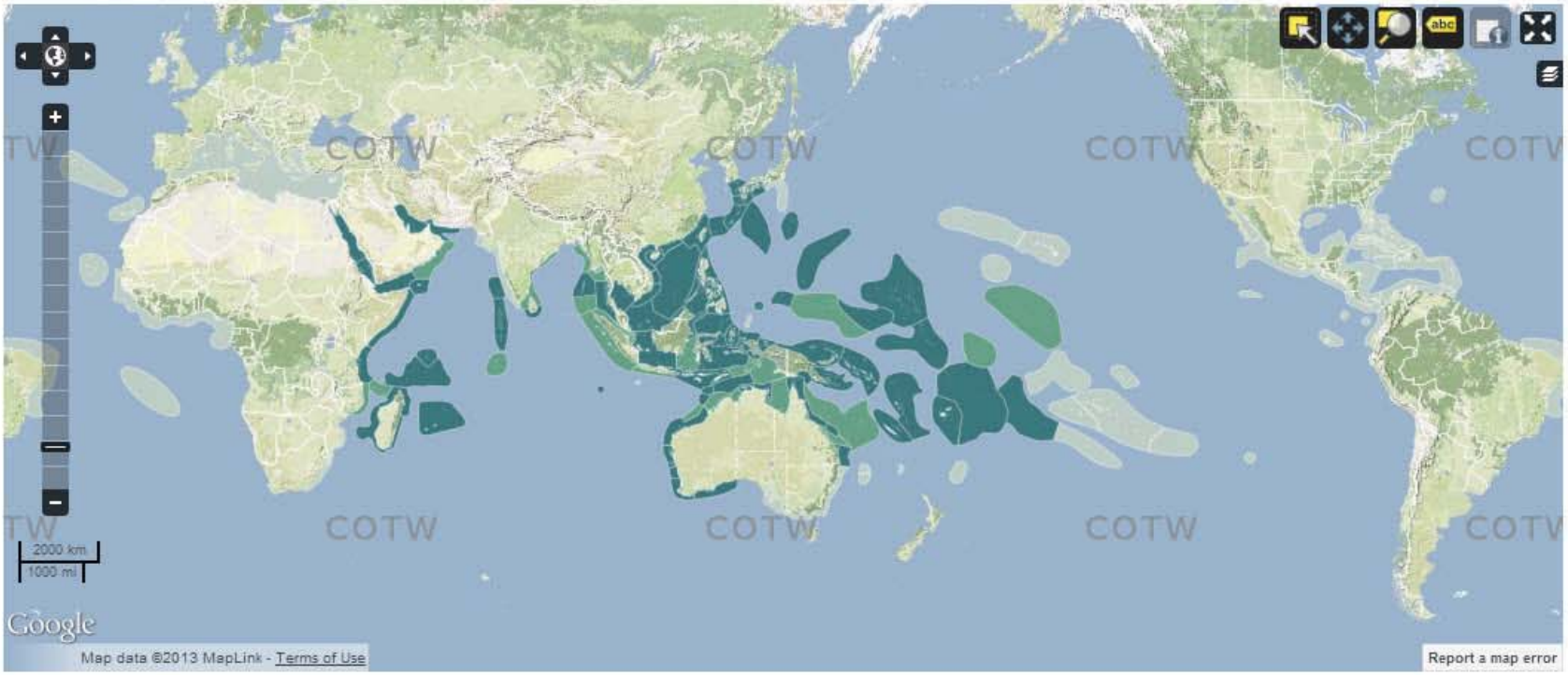

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Turbinaria stellulata

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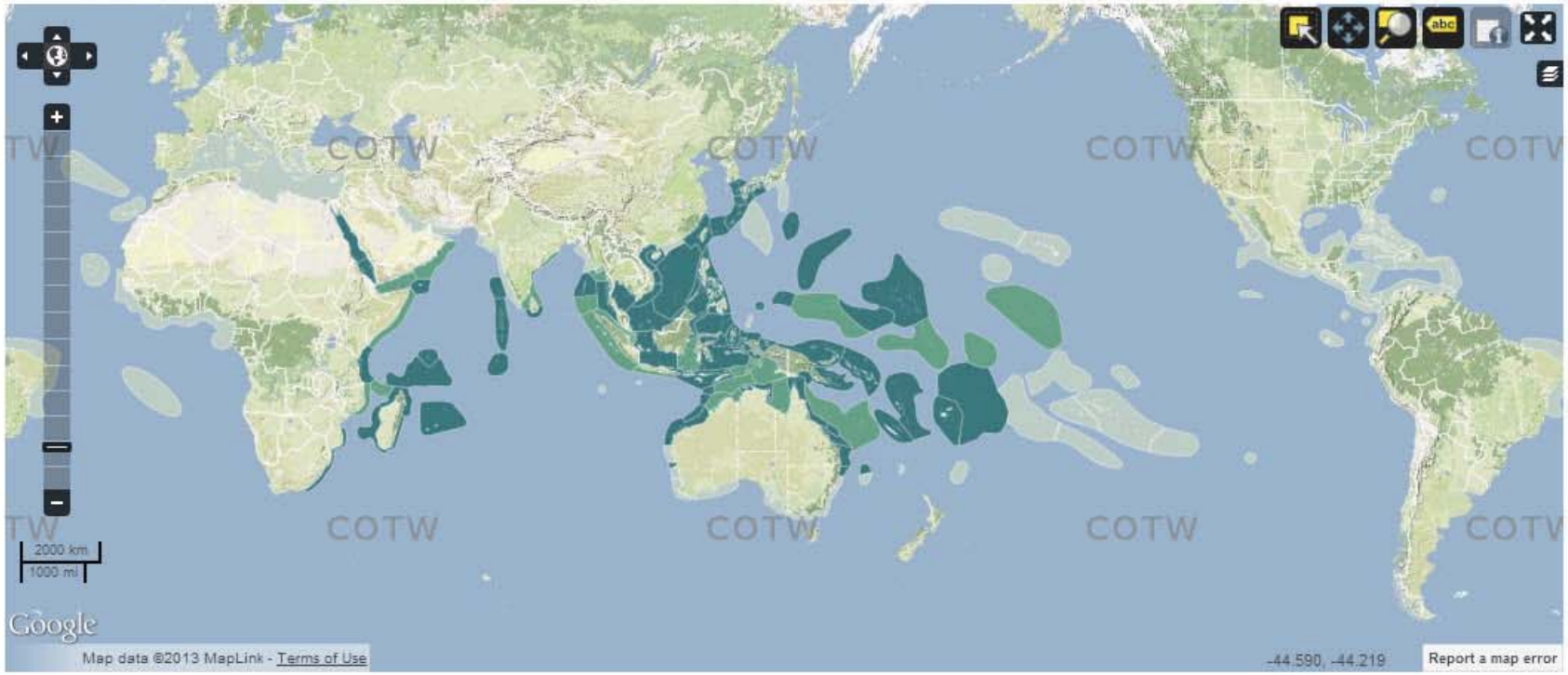

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Veron JEN, Stafford-Smith MG, Turak E and DeVantier LM (in prep.) Corals of the World www.coralsoftheworld.com

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Linked Documentation D:

Coral Geographic Global Maps for the Caribbean Species

Acropora cervicornis

CORALS of the World

Summary

Distribution

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Acropora palmata

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Agaricia lamarcki

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Dendrogyra cylindrus

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Dichocoenia stokesi

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Montastraea annularis

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Montastraea faveolata

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Montastraea franksi

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Mycetophyllia ferox

CORALS of the World

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Linked Documentation E:

Comparison of Veron's updated *Corals of the World* Database and Information in the Proposed Rule to list 66 Species under the Endangered Species Act (Ishizaki et al. 2014)

Comparison of Veron's Updated Corals of the World Database and Information in the Proposed Rule to List 66 Species under the Endangered Species Act

Report Jointly Prepared by

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Executive Summary

The proposed listing of 66 species of reef-building corals as either endangered or threatened under the Endangered Species Act (ESA) relied heavily on family- and genus-level vulnerability to threats due to the lack of species-specific information. This report provides a summary of previously unpublished distribution and abundance data for coral species proposed for ESA listing and a comparison of the new data with information available to the National Marine Fisheries Service (NMFS) at the time of the proposed rule publication.

Semi-quantitative distribution and abundance data, along with updated distribution maps, were made available by J.E.N. Veron. The data represent a significant update to the three-volume book *Corals of the World*, published in 2000, and are based primarily on comprehensive and extensive surveys conducted by Veron and colleagues. Veron's data contain both Indo-Pacific and Caribbean species; however this report focuses on the Indo-Pacific species proposed for ESA listing.

Veron's distribution data are compiled as confirmed and strongly predicted occurrence in each of the 133 Indo-Pacific ecoregions. These data show the following:

- Coral species included in NMFS' proposed list are mostly broadly distributed across the Indo-Pacific, occurring on average in 50 ecoregions;
- Compared to all species in the Corals of the World database, NMFS' proposed list of species contains disproportionately fewer species occurring in less than 10 ecoregions, indicating that NMFS' proposed list of species did not select out the most narrowly distributed species;
- Evaluation of NMFS' distribution categories using Veron's data suggests NMFS' use of older maps and the lack of standardized quantitative measures of distribution led to inconsistent assignment of species in "narrow", "moderate" or "wide" distribution categories;
- Nearly all of the Indo-Pacific species proposed for ESA listing have "moderate" or "wide" distributions when reassigned to NMFS' distribution categories using Veron's ecoregion data; and
- Veron's species occurrence data for ecoregions containing U.S. waters show discrepancies with NMFS' data, especially for American Samoa where Veron's data show 12 fewer species occurring in its waters than NMFS' data, suggesting that NMFS' occurrence data for U.S. waters contained unverified records or misidentified species.

Veron provided two measures of abundance based on survey protocols with differing spatial and depth coverage. The semi-quantitative abundance provides a standardized measure across the 2,984 sites surveyed across 30 ecoregions by Veron's Corals of the World co-authors, whereas the qualitative overall estimates provide localized abundance observed during Veron's extensive fieldwork covering over 5,000 sites in 77 ecoregions. These two measures of abundance are not directly comparable but provide different dimensions of abundance for each species. These data show the following:

- The proportions of species in "rare", "uncommon" and "common" semi-quantitative abundance categories are comparable between NMFS' proposed list of species and all

species assessed in the Corals of the World database, indicating that NMFS' proposed list did not select out species with "very rare" or "rare" abundance;

- Of the ten proposed species with "rare" semi-quantitative abundance, five species were evaluated under Veron's qualitative overall estimate as having "uncommon" localized abundance and two species were found to have "common" localized abundance in some portion of their range; and
- All but two species contained in Veron's data have an average relative abundance of less than 2 on a 5-point scale, indicating that a relative abundance of "rare" or "uncommon" is a common attribute in coral species and thus may not in itself be a useful indicator of species vulnerability.

Combined distribution and abundance data offer a more holistic measure of species-specific resilience to threats than evaluating these data separately:

- Species with "rare" semi-quantitative abundance are not necessarily narrowly distributed, with species in this abundance category occurring in as few as eight ecoregions and as broadly as 60 ecoregions; and
- Only two species out of the Indo-Pacific species proposed for ESA listing have a combination of "rare" semi-quantitative abundance and "narrow" distribution;
- Additional information in Veron's dataset on the two species with "rare" semi-quantitative abundance and "narrow" distribution indicate that these species are locally "uncommon" and have distribution ranges that span substantial geographic distances.

Veron's data provide substantial species-specific information not available at the time of NMFS' proposed rule. These data indicate that corals proposed for ESA listing occur in large and diverse geographic areas, providing a potential buffer against extinction risks. Nevertheless, the best available abundance data presented here do not provide population estimates or abundance trends for the Indo-Pacific coral species proposed for ESA listing, and additional survey work is needed to assess these trends over time.

Acknowledgements

The authors thank Dr. John "Charlie" Veron for making available the data and maps in advance of the *Corals of the World* website completion and for reviewing this report for accuracy of our data interpretation. The authors also thank Milani Chaloupka, Samuel Kahng and Domingo Ochavillo for their review and comments, which substantially improved this report.

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Introduction

In December 2012, the National Marine Fisheries Service (NMFS**)** proposed to list 66 species of reef-building corals as either endangered or threatened under the Endangered Species Act (ESA)[1]. The proposal relied on a range of scientific studies on coral taxonomy, reproductive behaviors, and response to stressors such as disease or climate impacts. However, NMFS acknowledged that the proposal suffers from the lack of species-specific information, and relied heavily on family- and genus-level vulnerability to ocean warming and acidification to arrive at proposed listing determinations.

Veron's three-volume book *Corals of the World* (2000) was one of the primary sources in NMFS' proposed rule for species-specific information such as taxonomy, distribution and habitat. Since the late 1990s when the Corals of the World (COTW) was first compiled, Veron and his colleagues have continued to conduct extensive and detailed fieldwork and gathered additional coral data from published literature and unpublished data sources. These unpublished data are currently being incorporated into an interactive and searchable website.

Distribution and abundance information on Indo-Pacific and Caribbean coral species relevant to NMFS' proposed coral listing were compiled by Veron and made available in advance of the COTW website (Veron 2014). Veron provided distribution and abundance data as well as updated distribution maps for 73 Indo-Pacific species included in NMFS' Status Review Report (SRR), excluding the two *Millepora* species. Combined species clades proposed by NMFS (i.e., *Montipora dilatata/flabellata(/turgescens)* and *Montipora patula(/verrilli)*) are treated as separate species in Veron's data. Veron also provided data for the seven Caribbean species proposed for ESA listing and two additional Caribbean species already listed under the ESA.

This report provides a summary of these data in the context of the NMFS' proposed listing of 66 coral species, with a particular focus on the Indo-Pacific species. Additional details on the data sources and methodologies for the Indo-Pacific species are available in Veron (2014) and Linked Documentation A (spreadsheet) and C (maps). Data on Caribbean species are not elaborated in this report, but information provided by Veron is available under Linked Documentation B (spreadsheet) and D (maps) in Veron (2014).

For purpose of discussion below, Veron's data for species combined within NMFS' larger clade (*Montipora dilatata*, *Montipora flabellata*, and *Montipora patula*) were excluded from the summary to allow for direct comparison with NMFS' proposed rule, unless otherwise noted.

A comparison of data sources in NMFS' proposed rule and Veron (2014) is provided in Appendix 1 of this report.

[1] See 77 Fed. Reg. 73220 (December 7, 2012)

Ecoregions

Data provided in Veron (2014) are compiled by ecoregions. An ecoregion is defined as an area which is internally cohesive (i.e., areas with similar habitats share similar species complements) but externally distinct from neighboring regions (J.E.N. Veron, *pers. comm.*, January 2014; Veron 2009). Ecoregions are widely used in biogeography because they incorporate a substantial amount of background knowledge, are a good platform for statistical analysis and allow the pooling and comparison of different datasets from the same ecoregion (J.E.N. Veron, *pers. comm.*, January 2014). Veron has identified 150 ecoregions to date (Figure 1).

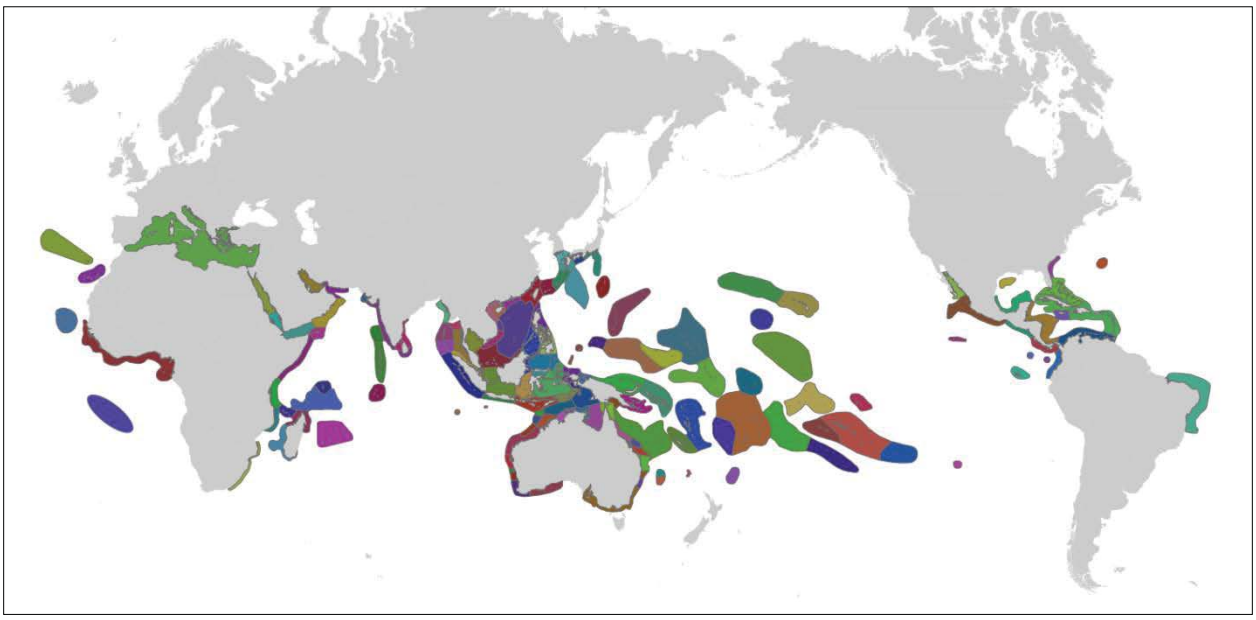

Figure 1. Outline of the 150 ecoregions currently identified by Veron. (Source: J.E.N. Veron *pers. comm..*, January 2014)

Robustness of Data

Veron's distribution maps have an associated data robustness category as follows[2]:

1) Species with highly indicative distributions;
2) Species with incomplete but indicative distributions; and
3) Species with poorly known distributions.

Maps with robustness category 3 are not suitable for analysis. *Montipora lobulata* is the only species contained in the Veron spreadsheet that falls in this category. Veron further notes:

> This species has never been seen in the central Indo-Pacific or Pacific by the authors of COTW, suggesting that Pacific records indicated in the present maps may be a different

[2] See Veron (2014) for additional details on the robustness categories.

species. Nor has it been recorded at its type locality. (Linked Documentation A in Veron 2014)

This species has been included in the analysis for the purposes of discussion in this report, but Veron's map robustness category suggests that information on *Montipora lobulata* may not be sufficient for ESA listing determination at this time.

Of the remaining 72 Indo-Pacific species included in Veron's dataset, 52 species (71.2%) are in data robustness category 1 and 20 species (27.4%) are in category 2. Distribution maps for species with data robustness category 2 are sufficient for providing a general indication of the species range, but are subject to change with verification of additional records or surveys as existing gaps may have any cause including missing records and non-occurrence.

Distribution

Veron's dataset includes distribution data in terms of the total number of ecoregions in which a species has been confirmed or strongly predicted to occur. There are a total of 133 ecoregions in the entire Indo-Pacific. The Coral Triangle contains 16 ecoregions within its boundaries (Veron et al. 2009). Combined with the maps[3], Veron's data provide both semi-quantitative and spatial measures of distribution.

Coral Distribution in Veron's Data

Global occurrences of the Indo-Pacific corals proposed for listing under the ESA, excluding those species grouped in a larger clade by NMFS, range from 8 to 101 ecoregions (Figure 2). *Pavona diffluens* (proposed threatened) had the lowest number of ecoregions and *Montipora turgescens* (proposed threatened) had the highest number of ecoregions. On average, the species proposed for listing were distributed broadly across 50 ecoregions.

Figure 3 compares the global occurrence of the proposed species with 680 species in the full COTW database (Veron unpublished data). Nearly 14% of the species contained in the COTW database have limited distributions occurring in less than 10 ecoregions, whereas only two species (3.6%) of the Indo-Pacific species proposed for listing fall in this category. Furthermore, NMFS' proposed list of corals contains a substantially greater proportion of species that have wide-spread occurrences in the 41-80 ecoregion range than all species in the COTW.

[3] See Veron (2014) Linked Documentation C.

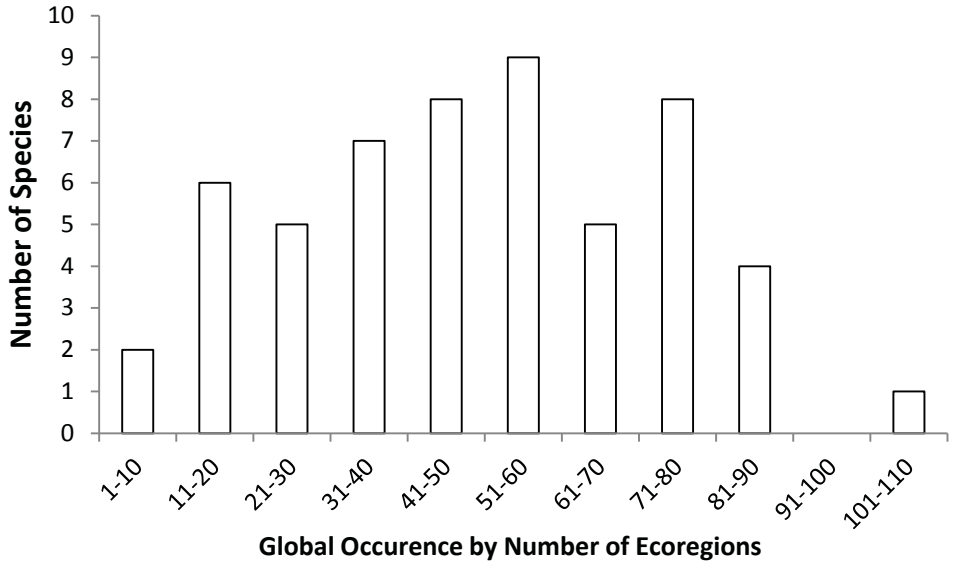

Figure 2. Global occurrences of the Indo-Pacific coral species proposed for ESA listing. Species are categorized by the number of ecoregions in which they occur.

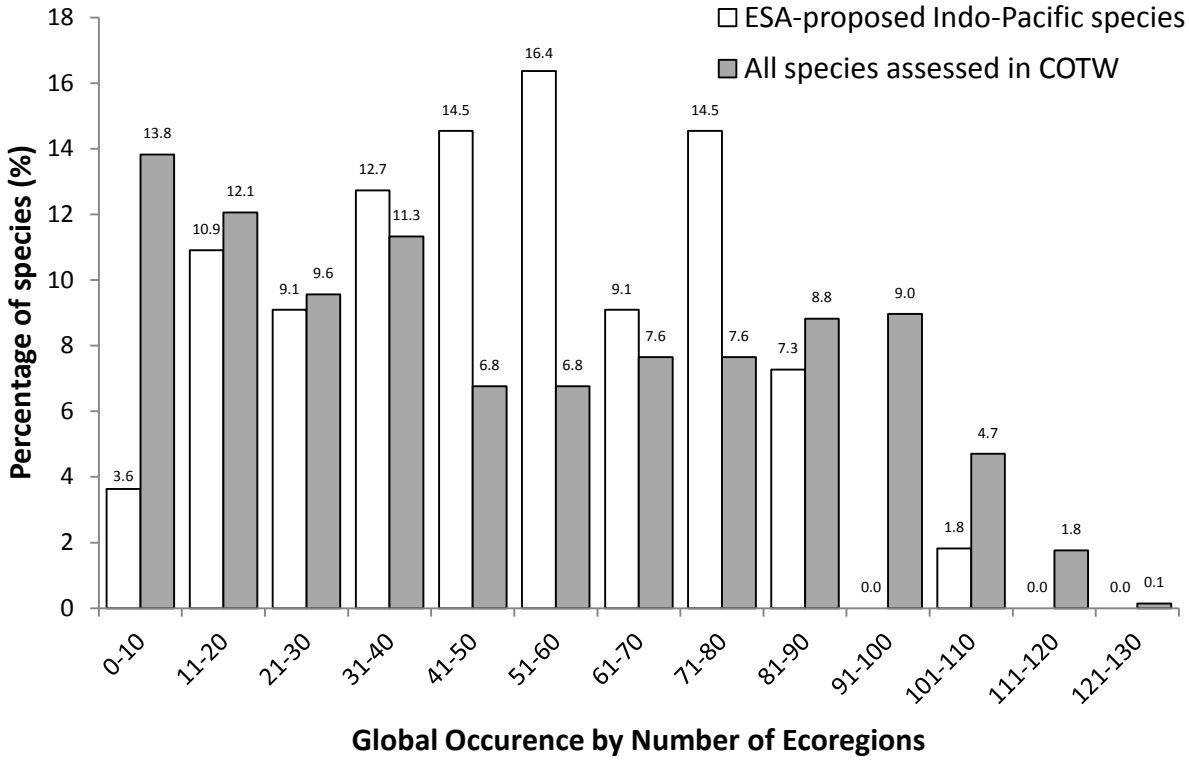

Figure 3. Comparison of global occurrences between ESA-proposed and 680 Indo-Pacific coral species contained in the Corals of the World database (Unpublished data in Veron 2014).

Comparison of Coral Distribution with NMFS Proposed Rule Information

In the proposed rule, NMFS categorized geographic distribution using a three-point scale ranging from narrow to wide (Table 1). Based on this scale, NMFS categorized the 59 Indo-Pacific coral species proposed for listing as follows:

- 12 species as having narrow distributions
- 17 species as having moderate distributions
- 30 species as having wide distributions

Table 1. NMFS' geographic distribution scale used in the Determination Tool for the proposed rule[4].

Scale	Category Name	Description
1	Narrow	Caribbean or restricted to a portion of the Coral Triangle, or the eastern Pacific, or the Hawaiian archipelago, or a similarly small portion of the Indian and Pacific Oceans
2	Moderate	Somewhat restricted latitudinally or longitudinally in the Indo-Pacific, but not as much as the narrow species (e.g., species distributed throughout the Coral Triangle are rated as moderate, not narrow)
3	Wide	Broadly distributed latitudinally or longitudinally throughout most of the Indo-Pacific

Evaluation of NMFS' distribution categories using Veron's ecoregion occurrences suggest that NMFS was inconsistent in applying its own distribution scale (Table 2). The lowest and highest number of ecoregions within each of NMFS' distribution category overlap substantially, especially between the "moderate" and "wide" categories, indicating that a clear cut-off point was not determined in assigning the categories to each of the species. Furthermore, species categorized as having "moderate" distributions have an average occurrence of 43.5 ecoregions. According to NMFS' own description of a "moderate" distribution, this category should apply to species that are "somewhat restricted latitudinally or longitudinally in the Indo-Pacific, but not as much as the narrow species (e.g., species distributed throughout the Coral Triangle[5] are rated as moderate, not narrow)". The Coral Triangle contains 16 ecoregions (Veron et al. 2009), and thus substantially less than the average number of ecoregions for species categorized as moderate.

[4] See 77 Fed. Reg. 73220 (December 7, 2012)

[5] In this report, we refer to the Coral Triangle boundary as defined in Veron et al. (2009). The Coral Triangle Initiative (CTI) identifies this boundary as the "Scientific Boundary" to distinguish between its CTI Coral Reefs, Fisheries, and Food Security (CFF) Implementation Area. See: http://www.coraltriangleinitiative.org/cti-cff-regional-map

Table 2. Comparison of NMFS' geographic distribution categories in the proposed rule to Veron's occurrence in number of ecoregions.

NMFS Distribution Category	Number of Species	Average occurrence (# of ecoregions)	Range of occurrence (# of ecoregions)	
			Lowest	Highest
Narrow	8*	16.9	8	27
Moderate	17	43.5	24	85
Wide	30	62.3	17	101

* Excludes 2 Millepora species not included in Veron data and 3 Montipora species combined with a larger clade.

Closer examination of several proposed species highlight NMFS' inconsistent application of the distribution scale. For example, NMFS categorized *Acropora jacquelieae* as "narrow" with justification that the species' distribution is "limited to part of the Coral Triangle". However, the species map used in NMFS' SRR indicates that the species is distributed throughout most of the Coral Triangle. Veron's updated map confirms that the species is distributed throughout the Coral Triangle and occurs in 17 ecoregions, similar to the number of ecoregions within the Coral Triangle boundary.

Similarly, NMFS categorized *Caulastrea echinulata* as "narrow" indicating that its distribution is "limited to the Coral Triangle". However, maps used in the SRR show that the species is distributed throughout and extending beyond the Coral Triangle. Veron's updated map shows a similar distribution of the species range extending over 27 ecoregions including all of the Coral Triangle and out to southern Japan, northern Australia, Fiji and Sumatra. The designation of *Caulastrea echinulata* as having a narrow distribution is contrary to NMFS' designation of *Acropora tenella* as having a "moderate" distribution despite the latter having a very similar range, described by NMFS as "somewhat broadly distributed latitudinally (Japan to Indonesia) and longitudinally (Sumatra to Fiji)"[6] and covering a slightly smaller number of ecoregions (24 ecoregions) than the former.

The inconsistencies likely resulted from the use of older distribution maps and the lack of quantitative measures of distribution available to NMFS at the time the proposed rule was drafted. NMFS's distribution categories can be reassigned more objectively using Veron's measure of distribution in terms of the number of ecoregions (Table 3). Given that the Coral Triangle contains 16 ecoregions and a "narrow" distribution is restricted to a portion of the Coral Triangle, species occurring in 10 or less ecoregions could be assigned to this category. Similarly, given that a species distributed throughout the Coral Triangle is to be rated as "moderate", 11-20 ecoregions could be assigned to this category. Species occurring in 21 or more ecoregions would therefore be assigned to the "wide" category.

Using this revised category, most (85.5%) of the Indo-Pacific species proposed for ESA listing are classified as having wide distributions, whereas only two species are assigned to the narrow

[6] See Justification for Values in the Determination Tool available online at: http://www.nmfs.noaa.gov/stories/2012/11/docs/82_corals_determination_tool_web.xlsx

distribution category (Table 3, Figure 4). The reassigned distribution category is used for the remained of this report.

Table 3. Reassigned distribution categories based on Veron's quantitative measure of distribution.

Category Name	Description	Veron's distribution by ecoregion	Number of species
Narrow	Caribbean or restricted to a portion of the Coral Triangle, or the eastern Pacific, or the Hawaiian archipelago, or a similarly small portion of the Indian and Pacific Oceans	Equal to or less than 10 ecoregions	2
Moderate	Somewhat restricted latitudinally or longitudinally in the Indo-Pacific, but not as much as the narrow species (e.g., species distributed throughout the Coral Triangle are rated as moderate, not narrow)	11-20 ecoregions	6
Wide	Broadly distributed latitudinally or longitudinally throughout most of the Indo-Pacific	Equal to or more than 21 ecoregions	47

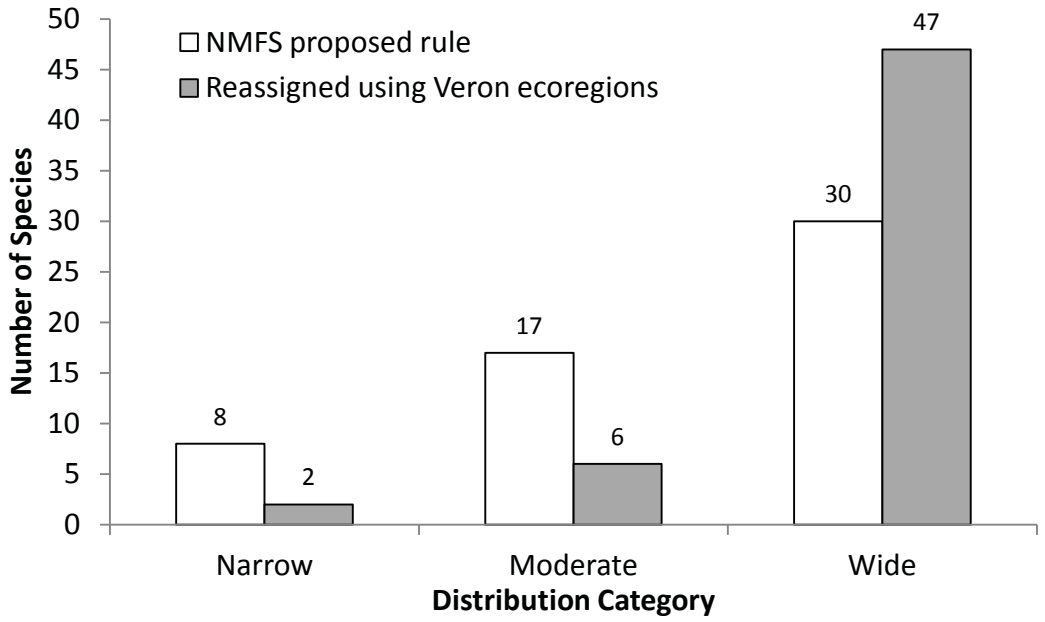

Figure 4. Comparison of NMFS' distribution categories and reassigned categories using Veron's ecoregion data.

Occurrence of Proposed Coral Species in American Samoa, CNMI, Guam and Hawaii

Table 4 shows a comparison of the Indo-Pacific coral species proposed for ESA listing identified by NMFS and Veron's updated database as occurring in U.S. waters of American Samoa, Commonwealth of the Northern Mariana Islands (CNMI), Guam and Hawaii[7]. Occurrence in Veron's database are identified by ecoregions, combining CNMI and Guam into a single ecoregion and including Tuvalu, Tonga and Western Samoa with American Samoa. The two *Millepora* species were excluded from this comparison as they are not included in Veron's database. Veron's occurrence data for the *Montipora dilatata/flabellata/turgescens* species were combined to match NMFS' clade. NMFS combined occurrence data for *Montipora patula* and *Montipora verrilli*; however, Veron (2014) does not cover *M. verrilli* and thus only occurrence for *M. patula* is shown in columns under Veron's list.

The comparison shows discrepancies between the two lists. According to the Veron's occurrence data, of the Indo-Pacific coral species proposed as threatened or endangered, four occur in Hawaii (compared to 3 in NMFS list), 26 in Guam and CNMI combined (29 and 27, respectively, in NMFS list), and 33 in American Samoa and surrounding areas (45 in NMFS list). In total, 16 species and species units show discrepancies in occurrences in Hawaii, Guam, CNMI, and American Samoa between the two lists (noted in Table 4 with an asterisk next to the species name). The discrepancy likely resulted from misidentified species or unverified records in NMFS' dataset. Veron's current information also indicate that at least five species have published records that are still pending confirmation by the COTW team. Occurrence information will likely change in the near future as additional records are reviewed by the COTW team, especially for species that have map robustness categories of 2 and 3.

Veron's updated occurrence list additionally support the conclusions of Luck (2013) that *Acropora jacquelineae* and *Acropora rudis* were incorrectly documented as occurring in American Samoa due to misidentification.

Table 4. Comparison of NMFS and Veron occurrence lists for American Samoa, Hawaii and the Mariana Archipelago.

Species (purple = Proposed Endangered; orange = Proposed Threatened)	**NMFS List (0 = absent; 1 = present)**				**Veron List (0 = absent; 1 = confirmed present; 2 = strongly predicted; 3 = warrant further investigation)**		
	Hawaii	Guam	CNMI	AS	Hawaii (two eco-regions)	Guam and Northern Marianas	Tuvalu, Samoa and Tonga
Acanthastrea brevis	0	1	1	1	0	2	1
****Acanthastrea hemprichii***	0	0	0	1	0	0	0
****Acanthastrea ishigakiensis***	0	0	0	1	0	1	2
Acanthastrea regularis	0	1	0	0	0	2	0
Acropora aculeus	0	1	1	1	0	1	1
Acropora acuminata	0	1	1	1	0	1	1

[7] NMFS' list of corals occurring in American Samoa, CNMI, Guam and Hawaii were derived from species fact sheets available online at: http://www.fpir.noaa.gov/PRD/prd_coral.html

Species (purple = Proposed Endangered; orange = Proposed Threatened)	NMFS List (0 = absent; 1 = present)				Veron List (0 = absent; 1 = confirmed present; 2 = strongly predicted; 3 = warrant further investigation)		
	Hawaii	Guam	CNMI	AS	Hawaii (two eco-regions)	Guam and Northern Marianas	Tuvalu, Samoa and Tonga
Acropora aspera	0	1	1	1	0	1	1
Acropora dendrum	0	0	0	1	0	0	2
Acropora donei	0	0	0	1	0	0	1
Acropora globiceps	0	1	1	1	0	1	1
Acropora horrida	0	0	0	1	0	0	1
**Acropora jacquelineae*	0	0	0	1	0	0	0
Acropora listeri	0	1	1	1	0	1	1
Acropora lokani	0	0	0	0	0	0	0
Acropora microclados	0	1	1	1	0	1	1
Acropora palmerae	0	1	1	1	0	1	1
**Acropora paniculata*	1	1	1	1	1	0	1
**Acropora pharaonis*	0	0	0	1	0	0	0
Acropora polystoma	0	1	1	1	0	1	1
Acropora retusa	0	1	0	1	0	1	1
**Acropora rudis*	0	0	0	1	0	0	0
Acropora speciosa	0	0	0	1	0	0	3
Acropora striata	0	1	1	1	0	1	1
**Acropora tenella*	0	0	0	1	0	0	0
Acropora vaughani	0	1	1	1	0	1	1
Acropora verweyi	0	1	1	1	0	1	1
Alveopora allingi	0	1	1	1	0	1	1
Alveopora fenestrata	0	1	1	0	0	1	0
**Alveopora verrilliana*	0	1	1	1	2	1	1
Anacropora puertogalerae	0	0	0	0	0	0	0
Anacropora spinosa	0	0	0	0	0	0	0
Astreopora cucullata	0	0	0	1	0	0	1
Barabattoia laddi	0	0	0	1	0	0	3
**Caulastrea echinulata*	0	0	0	1	0	0	0
**Euphyllia cristata*	0	1	1	1	0	1	0
Euphyllia paraancora	0	1	1	0	0	1	0
Euphyllia paradivisa	0	0	0	1	0	0	1
Isopora crateriformis	0	0	0	1	0	0	1
**Isopora cuneata*	0	0	1	1	0	0	1
Montipora angulata	0	0	0	1	0	0	3
**Montipora australiensis*	0	0	0	1	0	0	0
Montipora calcarea	0	0	0	1	0	0	1
Montipora caliculata	0	1	1	1	0	1	1

Species (purple = Proposed Endangered; orange = Proposed Threatened)	NMFS List (0 = absent; 1 = present)				Veron List (0 = absent; 1 = confirmed present; 2 = strongly predicted; 3 = warrant further investigation)		
	Hawaii	Guam	CNMI	AS	Hawaii (two eco-regions)	Guam and Northern Marianas	Tuvalu, Samoa and Tonga
Montipora dilatata/flabellata/turgescens	1	0	0	0	1	0	2
Montipora lobulata	0	1	1	1	0	1	1
Montipora patula(/verrilli) (note: Veron occurrence only for M. patula)	1	1	1	0	1	0	0
Pachyseris rugosa	0	0	0	1	0	0	1
Pavona diffluens	0	1	1	1	0	3	3
Pectinia alcicornis	0	1	0	0	0	0	0
Physogyra lichtensteini	0	0	0	0	0	0	0
Pocillopora danae	0	1	1	1	0	1	1
Pocillopora elegans	0	1	1	1	0	1	1
Porites horizontalata	0	1	1	1	0	1	1
Porites napopora	0	0	0	1	0	0	0
Porites nigrescens	0	0	0	1	0	0	1
Seriatopora aculeata	0	1	1	0	0	1	0
Total number of species present (note: only includes occurrence categories 1+2 for Veron's data)	**3**	**29**	**27**	**45**	**4**	**26**	**33**

Abundance

Veron's dataset includes two sets of abundance data[8]:

1) Semi-quantitative abundance assessments: Six "semi-quantitative abundance categories" ranging from "very rare" to "abundant", based on a "global abundance score" calculated as a factor of percent of the total number of surveyed sites in which the species was present ("% site present") and "average relative abundance" across those sites. Data for this measure are derived from 2,984 individual survey sites in 30 ecoregions across the Indo-Pacific, collected by the authors of COTW from 1994 to 2012 (DeVantier and Turak in prep). The global abundance score is standardized across all 2,984 sites surveyed, whereas the average relative abundance represents abundance across sites where the species was found present. Publication of detailed data is currently in preparation.

2) Overall estimate: Veron's qualitative estimates based on his extensive field observations and are either the same as or slightly updated since Veron (2000) referenced extensively in NMFS' proposed rule to derive generalized rangewide abundance.

[8] See Veron (2014) for additional details on the abundance data.

The two abundance measures are based on survey protocols with differing spatial and depth coverage, and are not directly comparable. The "semi-quantitative abundance" provides a standardized measure across the 2,984 sites surveyed across 30 ecoregions, whereas the "overall estimates" provide localized abundance observed by Veron in his extensive fieldwork covering over 5,000 sites in 77 ecoregions, including rarer locations and deeper dives than those conducted for the semi-quantitative abundance.

Veron's overall estimates are descriptive in nature and vary by species[9]; therefore we do not provide a detailed analysis of this measure in this report. However, both measures of abundance should be considered in NMFS' final determination of coral listing under the ESA or any other assessment of coral species as they provide different dimensions of abundance for each species.

The semi-quantitative abundance data represent the most comprehensive standardized abundance measure currently available for Indo-Pacific corals, but nevertheless should be interpreted with caution for the reasons outlined in Veron (2014):

- Ecoregions for the surveys were not selected in a representative or random manner;
- Sampling frequency and intensity were not standardized within or among ecoregions; and
- Some species, particularly endemics, do not occur in any of the 30 ecoregions.

For example, *Alveopora verrilliana* has been confirmed or strongly predicted to occur in 58 ecoregions according to Veron's distribution data, but was only found present at 0.27% (n = 8) of 2,984 sites covered in the semi-quantitative abundance survey. The average relative abundance of this species where present was 1.13, resulting in a global abundance score of 0.30, making the semi-quantitative abundance category for this species "rare". However, the overall estimate indicates that this species is locally "uncommon", suggesting that the semi-quantitative abundance survey may not have focused on sites or ecoregions where *A. verrilliana* is more commonly found.

It should also be noted that the semi-quantitative abundance is based on each taxon's relative abundance of individuals, rather than contribution to benthic cover, at each of the survey sites, and are subjective assessments rather than quantitative counts (DeVantier et al. 1998). The rapid ecological assessment approach used in deriving semi-quantitative abundance does not produce population size estimates or abundance trends for each species.

Coral Abundance in Veron's Data

Numbers of species in each of the semi-quantitative abundance categories are shown in Table 5. Excluded from this table are those species grouped in a large clade by NMFS as well as *Montipora lobulata* for which semi-quantitative abundance was not calculated[10]. Ten (18.5%) of the Indo-Pacific species proposed for ESA listing have a "rare" semi-quantitative abundance, 26 species (48.1%) have an "uncommon" abundance, 17 species (31.5%) have a "common" abundance, and one species (1.9%) has a "very common" abundance. The proportion of these

[9] Overall estimate for a given species may simply be noted as "rare", while for another species it may be noted in more detail (e.g., "Common in South Africa, rare elsewhere).
[10] See notes in Veron (2014) Linked Documentation A.

species across the abundance categories are comparable to all species assessed in the COTW database (Table 5, Figure 5).

Of the ten species with "rare" semi-quantitative abundances, five species were evaluated under the overall estimate as having "uncommon" overall abundance and two species were found to have "common" abundance in some portion of their range. The additional details gleaned from Veron's qualitative overall estimates indicate that localized abundance of these species may be more common than suggested by the semi-quantitative abundance measures.

Table 5. Number and percentage of ESA-proposed Indo-Pacific coral species and all 627 assessed species in each of the semi-quantitative abundance categories.

Semi-quantitative abundance categories (range of global abundance scores)	ESA-proposed Indo-Pacific Species[1]		All 627 species assessed[2]	
	n	%	n	%
Very rare (<0.1)	0	0.0%	17	2.5%
Rare (0.1-1)	10	18.5%	126	18.8%
Uncommon (1-10)	26	48.1%	270	40.2%
Common (11-50)	17	31.5%	193	28.7%
Very common (51-100)	1	1.9%	59	8.8%
Abundant (>100)	0	0.0%	7	1.0%

[1] Excludes 2 Millepora species not included in Veron data and 3 Montipora species combined with a larger clade.
[2] Unpublished data reported in Veron (2014).

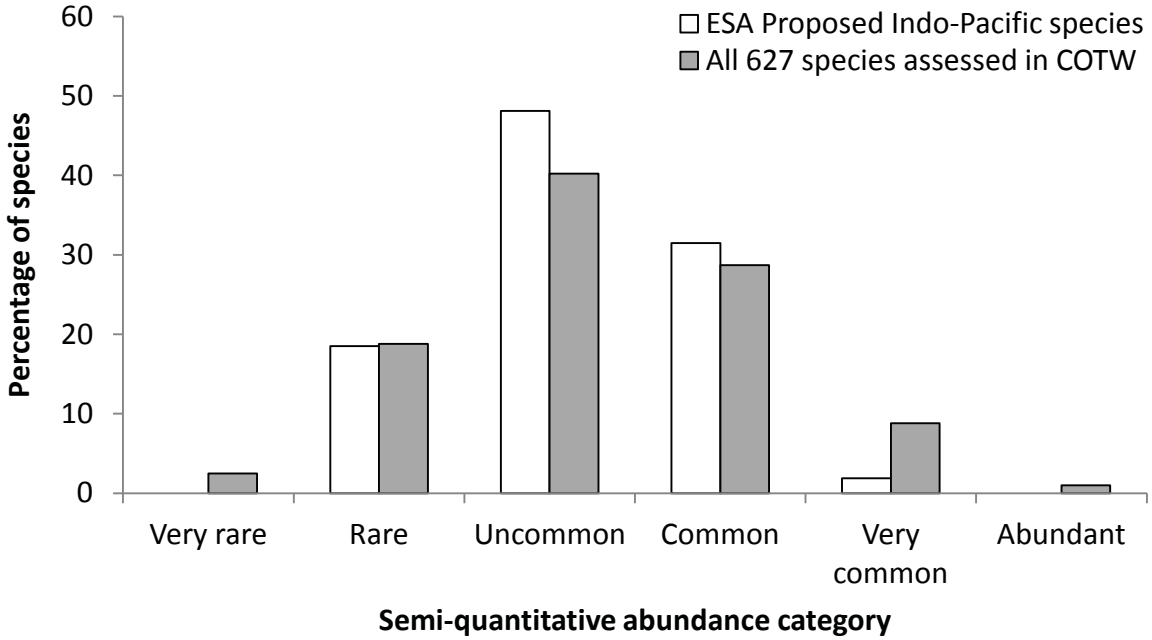

Figure 5. Comparison of the percentage of species in each semi-quantitative abundance category for ESA-proposed species and all 627 species assessed in Corals of the World.

Examination of the two components used to calculate the global abundance scores, "% sites present" and "average relative abundance", reveal that the semi-quantitative abundance is largely driven by "% sites present" rather than the "average relative abundance" where species were found present in the surveys (Table 6). Mean % sites present for species categorized as "rare", "uncommon" and "common" were substantially different from one another, with species being recorded on average at 0.34%, 3.78%, and 15.19% of the 2,984 sites surveyed, respectively. However, the means of each species' average relative abundance across the semi-qualitative abundance categories were not substantially different from one another, with "rare" species having an overall average abundance score of 1.33 out of 5, "uncommon" species having a score of 1.50 out of 5, and "common" species having a score of 1.56 out of 5. In fact, all but two of the 73 Indo-Pacific species contained in Veron (2014), including those species NMFS determined as not warranted for listing, had average relative abundance of less than 2 out of 5 (i.e., "rare" or "uncommon" average relative abundance where species are found). This suggests that a relative abundance of "rare" or "uncommon" is a common attribute in coral species and thus may not in itself be a useful indicator of species vulnerability.

Table 6. Mean and range of occurrence and average relative abundance for ESA-proposed Indo-Pacific coral species in each of the semi-quantitative abundance category

Semi-quantitative abundance category (n)	% Sites Present[1]			Average Relative Abundance[2]		
	Mean	Lower range	Upper range	Mean	Lower range	Upper range
Very rare (n = 0)	-	-	-	-	-	-
Rare (n = 10)	0.34	0.13	0.47	1.33	1.13	1.50
Uncommon (n = 26)	3.78	1.24	6.80	1.50	1.11	2.02
Common (n = 17)	15.19	6.74	32.10	1.56	1.31	1.80
Very common (n = 1)	29.05	29.05	29.05	2.01	2.01	2.01
Abundant (n = 0)	-	-	-	-	-	-

[1] % sites present was determined as the percentage of the total 2,984 abundance survey sites in which each species occurred.
[2] Average relative abundance score was determined as the sum for each species of all its relative abundance scores (1-5) divided by the number of sites in which each species occurred. Relative abundance of each species present was scored as follows: 1 = rare; 2 = uncommon; 3 = common; 4 = abundant; and 5 = dominant.

Comparison of Coral Abundance with NMFS Proposed Rule Information

NMFS used qualitative abundance estimates coded as "common", "uncommon", or "rare" based on information presented in the SRR and the Supplemental Information Report (SIR). Most of the information sources for abundance were derived from Veron (2000). The breakdown of abundance for the 59 proposed Indo-Pacific species were as follows:

- 3 species have "rare" abundance
- 39 species have "uncommon" abundance
- 17 species have "common" abundance

Veron's "overall estimate" is a comparable measure to NMFS' qualitative abundance estimate, as the overall estimate is based on the same or slightly updated information from the Veron

(2000) publication. However, as previously indicated, Veron's overall estimate and NMFS' qualitative abundance estimate are not directly comparable to the "semi-quantitative abundance" presented in Veron's spreadsheet because the former is a qualitative measure that is descriptive of localized abundance and the latter is a standardized quantified measure of abundance throughout its surveyed range. Therefore, we do not provide a comparative analysis of the semi-quantitative abundance and NMFS' abundance estimates. A table comparing NMFS' generalized rangewide abundance with the semi-quantitative and Veron's qualitative measures of abundance is included for reference in Appendix 2.

Combined Distribution and Abundance

NMFS evaluated measures of abundance and distribution separately in the Determination Tool used in the proposed rule. Specifically, abundance was considered at the second tier of the Determination Tool, with both "rare" and "uncommon" species directed toward the Endangered outcome. Distribution was considered at the third tier after abundance, and "narrow" distribution species were directed toward the Endangered outcome.

Distribution plays a significant role in coral resilience to extinction, especially in light of climate change impacts which have a spatial component (e.g., Hoegh-Guldberg et al. 2007). It is likely that a species will be less vulnerable to climate change impacts if it is distributed across a wide range of ecoregions latitudinally and longitudinally (Veron 2014). Abundance alone will not provide a sufficient measure of vulnerability in the absence of distribution data, but is likely to be a major contributor to recovery from impacts (Veron 2014). Assessment of vulnerability should therefore consider both distribution and abundance simultaneously rather than evaluating them linearly with abundance considered first and distribution second as it was done by NMFS in its Determination Tool.

Figure 6 shows the range of distribution for each of the semi-quantitative abundance category for the Indo-Pacific species proposed for ESA listing, excluding those species grouped in a large clade by NMFS as well as *Montipora lobulata* for which semi-quantitative abundance was not calculated. Species with rare semi-quantitative abundance have distributions ranging from 8 ecoregions ("narrow") to 60 ecoregions ("wide"), species with uncommon abundance have distributions ranging from 17 ecoregions ("moderate") to 80 ecoregions ("wide"), and species with common abundance have distributions ranging from 26 ecoregions ("wide") to 101 ecoregions ("wide"). The figure clearly illustrates that rare abundance species are not necessarily narrowly distributed, although there is a general linear relationship of a wider distribution with more common abundance.

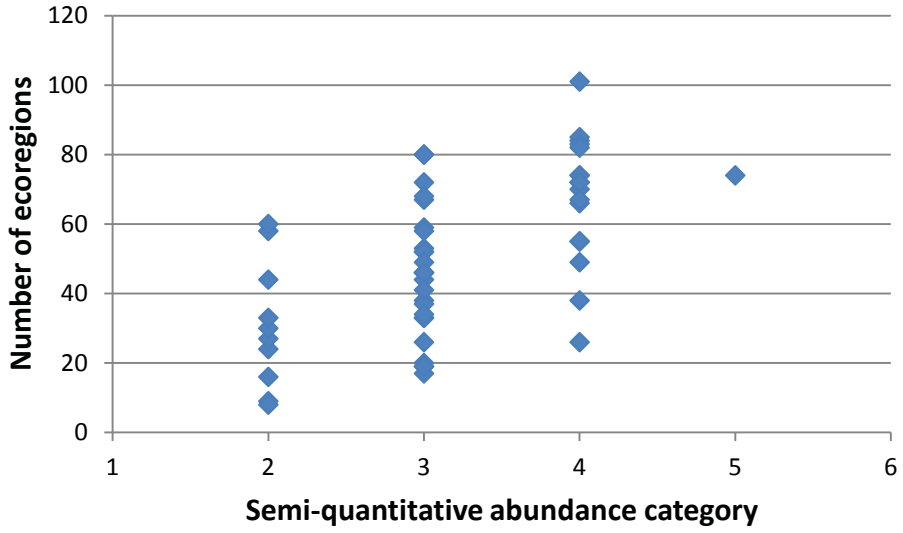

Figure 6. Range of distribution in number of ecoregions by semi-quantitative abundance category. (Semi-quantitative abundance categories: 1 = very rare; 2 = rare; 3 = uncommon; 4 = common; 5 = very common; 6 = abundant)

Only two species out of the Indo-Pacific species proposed for ESA listing have "rare" semi-quantitative abundance and "narrow" distribution (Table 7). These are:

- *Acropora rudis* (occurs in 9 ecoregions & has rare semi-quantitative abundance)
- *Pavona diffluence* (occurs in 8 ecoregions & has rare semi-quantitative abundance)

Only one species, *Euphyllia paradivisa* has "rare" abundance and "moderate" distribution (16 ecoregions). All other species with rare abundance have "wide" distributions (occurring in more than 20 ecoregions).

Additionally, four species have a combination of "uncommon" abundance and "moderate" distribution (Table 7). These are:

- *Acropora jacquelineae* (17 ecoregions)
- *Acropora lokani* (20 ecoregions)
- *Acropora pharaonis* (19 ecoregions)
- *Anacropora spinosa* (19 ecoregions)

None of the Indo-Pacific species proposed for ESA listing has an "uncommon" abundance coupled with "narrow" distribution. All other species not listed above have "wide" distributions and either "uncommon" or "common" abundance (Table 7).

The matrix in Table 7 illustrates the gradient of distribution and abundance attributes across the Indo-Pacific coral species proposed for listing under the ESA. However, additional information in Veron's dataset portrays a more nuanced picture of these species. For example, the three species with "rare" semi-quantitative abundance and "narrow" or "moderate" distribution, *Acropora rudis*, *Pavona diffluence* and *Euphyllia paradivisa* have "uncommon" localized

abundance according to Veron's qualitative overall estimate. This suggests that the species are not rare within their distribution ranges. Furthermore, the latitudinal and longitudinal distribution of the species may provide a buffer for climate change impacts for "narrow" or "rare" species. An example of this is *Pavona diffluence*, which has a latitudinal distribution extending from the Gulf of Oman to northern Madagascar, a distance similar to the western coast of North America from the border of Alaska and Canada to the southern tip of Baja California, Mexico.

Table 7. Matrix of the Indo-Pacific coral species proposed for ESA listing based on Veron's data of distribution and abundance. The full list of species is included in Appendix 2.

	Semi-quantitative abundance					
Distribution[1]	Very Rare	Rare	Uncommon	Common	Very Common	Abundant
Narrow	None	*Acropora rudis* *Pavona diffluence*	None	None	None	None
Moderate	None	*Euphyllia paradivisa*	*Acropora jacquelineae* *Acropora lokani* *Acropora pharaonis* *Anacropora spinosa*	None	None	None
Wide	None	*Acropora retusa* *Acropora tenella* *Alveopora verrilliana* *Caulastrea echinulata* *Isopora crateriformis* *Montipora angulata* *Montipora australiensis*	3 *Acanthastrea* spp. 8 *Acropora* spp. 2 *Alveopora* spp. 1 *Anacropora* spp. 1 *Astreopora* spp. 1 *Barabattoia* spp. 1 *Euphyllia* spp. 1 *Isopora* spp. 1 *Montipora* spp. 1 *Pocillopora* spp. 2 *Porites* spp.	1 *Acanthastrea* spp. 8 *Acropora* spp. 1 *Euphyllia* spp. 2 *Montipora* spp. 1 *Pachyseris* spp. 1 *Pectinia* spp. 1 *Physogyra* spp. 1 *Pocillopora* spp. 1 *Seriatopora* spp.	*Porites nigrescens*	None

[1] The distribution used here refers to the reassigned categories shown in Table 3.

Conclusions

NMFS had limited species-specific information on exposure and susceptibility to climate change impacts in developing the proposed rule to list 66 species of corals under the ESA. As a result, the Biological Review Team (BRT) relied on expert opinion to assess extinction risk, and all species considered in the status review were rated as having a high to moderate exposure to ocean warming and acidification in the Determination Tool (scored 1.5 on a scale of 1-3). However, a widely distributed species is more likely to be buffered against ocean warming and acidification than narrowly distributed species, and abundance is likely to be a contributor to recovery (Veron 2014).

Veron's updated species-specific distribution and abundance information represent a previously unpublished, robust dataset based on extensive scientific surveys and should be a central component in assessing vulnerability and extinction risk moving forward. Data provided by Veron indicate that the Indo-Pacific coral species proposed for ESA listing occur across a large and diverse geographic area, providing a potential buffer against various threats. Classification of

species as “rare” or “uncommon” semi-quantitative abundance does not necessarily accurately portray extinction risk because such species may have not been frequently observed in dedicated abundance surveys, but are confirmed as occurring across a number of ecoregions, and in large coral reefs within ecoregions. Even assuming such “rare” or “uncommon” characterizations do suggest extinction risk, it is clear that NMFS’ conclusions in the proposed rule are inconsistent with Veron’s updated distribution and abundance data.

Finally, it is important to note that the abundance surveys used to derive the semi-quantitative abundance estimates do not allow projection of abundance trends over time, nor does it estimate overall species abundance within and across all or a representative sample of ecoregions within each species’ known distribution range. At most, these data allow for a semi-quantitative assessment of relative species abundance, providing some insight as to the geographic distribution of species across a range of diverse ecoregions. Additional survey work is needed in order to assess actual species abundance within and across ecoregions, and to assess species abundance and distribution trends over time.

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Appendix 1: Comparison of Data Properties between NMFS' Proposed Rule and Veron (2014)

Data property	NMFS Proposed Rule	Veron Updated Information
Geographic Distribution		
Type of data	• Categorization of narrow, moderate and wide based on latitudinal and longitudinal extent derived from information in the SRR and SIR • No standardized quantified measure of distribution	• Species-specific *semi-quantitative measure* of global occurrences, in number of ecoregions in which the species has been confirmed or strongly predicted to occur (out of 133 Indo-Pacific ecoregions) • Distribution maps for each species, showing occurrence in each ecoregion using four categories of records (no record; confirmed; strongly predicted; or warrant further investigation) • Distribution data robustness category for each species (highly indicative distributions; incomplete but indicative distributions; or poorly known distribution)
Data source	• Distribution in the SRR were based on the following (p.90, SRR): o Distribution maps from Veron (2000) o Distribution maps from IUCN o Evaluation of U.S. distribution of candidate coral species (Kenyon et al. 2010) o Personal communication of observation from BRT members, BRT-solicited subject matter experts and other researchers • Personal communications of reports of occurrence are cited in the SRR but do not appear to be verified by taxonomic experts	• Original field and taxonomic work by the authors o Detailed fieldwork in >5,000 sites in 77 of Indo-Pacific's 133 ecoregions, representing 58% coverage from the Red Sea to Far Eastern Pacific from the most northern to the most southern latitudes o Standardized quantitative studies which include abundance and depth ranges from the Red Sea in the west to Pohnpei in the east o Additional work on collections, taking the total coverage to 69% o Less detailed or transitory observations in several additional ecoregions • Taxonomic, biogeographic and ecological literature • Collections from 48 museums, universities and field stations in addition to Veron's comprehensive collection of nearly 28,000 specimens • Images from over 60 photographers cited in the COTW website and from a wide range of sources used to verify field records • Field guides – 20 published species-level field guides to corals • Personal communications for verification of distribution records

Data property	NMFS Proposed Rule	Veron Updated Information
Abundance		

Type of data	• Species-specific *qualitative* abundance estimates
	  o Coded as "common", "uncommon" or "rare" based on information in SRR and SIR
		• Species-specific *semi-quantitative* abundance assessments
		  o Data presented in six categories ranging from "very rare" to "abundant" based on a global abundance score calculated as a factor of percent of the total number of surveyed sites in which the species was present and mean abundance across those sites
		• Overall estimates (Veron's qualitative estimates)
		Note: The two measures of abundance are not directly comparable due to differences in survey protocol and coverage (spatial and depth)

Data source	• Abundance information in the SRR were most commonly based on the following (p.89, SRR):
	  o Veron (2000)
	  o Carpenter et al. (2008)
	  o Online IUCN species accounts
	Note: Most of the IUCN species accounts are based on the same series of workshops that produced Carpenter et al. (2008). Most of the abundance estimates in Carpenter et al. are from the authors of the Corals of the World, including Veron.
		• Semi-quantitative abundance assessments were based on:
		  o Data from 2,984 individual survey sites in 30 ecoregions across the Indo-Pacific from 1994-2012 following a standard Rapid Ecological Assessment protocol (DeVantier & Turak, in prep)
		• Overall estimates were based on:
		  o Veron's extensive field observations and are either the same as or slightly updated since Veron (2000)

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Appendix 2: Comparison of Distribution and Abundance Data between Veron (2014) and NMFS Proposed Rule.

Note: The table includes Indo-Pacific coral species proposed for listing under the ESA but excludes species grouped in a larger clade by NMFS (*Montipora dilatata*, *Montipora flabellate*, and *Montipora patula*). Veron's information suggests currently available information on *Montipora lobulata* is not robust and may not be suitable for analysis. Cell color for Veron's data correspond to that of Table 7. For the full dataset, see Linked Documentation A in Veron (2014).

Species Name	Veron Data							NMFS Proposed Rule		
	Distribution		Abundance							
	Number of Ecoregions confirmed or strongly predicted	Distribution Category[1]	% sites present	Average relative abundance when present[2]	Global Abundance Score[3]	Semi-quantitative abundance category	Overall estimate	Proposed Listing Category[4]	Geographic Distribution	Generalized Rangewide Abundance
Pavona diffluens	8	narrow	0.47	1.43	0.67	Rare	Uncommon	T	narrow	uncommon
Acropora rudis	9	narrow	0.13	1.25	0.17	Rare	Uncommon	E	narrow	uncommon
Montipora lobulata	17	moderate	-	n/a	n/a	*Not encountered*	Rare	T	wide	uncommon
Euphyllia paradivisa	16	moderate	0.20	1.50	0.30	Rare	Uncommon	E	narrow	uncommon
Acropora jacquelineae	17	moderate	1.61	1.44	2.31	Uncommon	Uncommon	E	narrow	rare
Anacropora spinosa	19	moderate	1.47	1.84	2.71	Uncommon	Usually uncommon	E	narrow	uncommon
Acropora pharaonis	19	moderate	3.62	1.80	6.50	Uncommon	Common in the Red Sea, uncommon elsewhere	T	narrow	common
Acropora lokani	20	moderate	2.75	1.44	3.95	Uncommon	Sometimes common	E	narrow	rare
Acropora tenella	24	wide	0.40	1.25	0.50	Rare	Rare	T	moderate	uncommon
Caulastrea echinulata	27	wide	0.34	1.30	0.44	Rare	Uncommon	T	narrow	uncommon
Isopora crateriformis	30	wide	0.34	1.40	0.47	Rare	Occasionally common on reef flats	T	moderate	common
Montipora australiensis	33	wide	0.40	1.50	0.60	Rare	Usually rare	T	wide	uncommon
Acropora retusa	44	wide	0.47	1.21	0.57	Rare	Common in South Africa, rare elsewhere	T	wide	uncommon
Alveopora verrilliana	58	wide	0.27	1.13	0.30	Rare	Uncommon	T	wide	uncommon
Montipora angulata	60	wide	0.34	1.30	0.44	Rare	Rare	T	wide	uncommon

Species Name	Veron Data							NMFS Proposed Rule		
	Distribution		Abundance							
	Number of Ecoregions confirmed or strongly predicted	Distribution Category[1]	% sites present	Average relative abundance when present[2]	Global Abundance Score[3]	Semi-quantitative abundance category	Overall estimate	Proposed Listing Category[4]	Geographic Distribution	Generalized Rangewide Abundance
Porites napopora	26	wide	3.15	1.79	5.63	Uncommon	Sometimes common in isolated habitats	T	moderate	common
Acanthastrea regularis	33	wide	5.13	1.21	6.20	Uncommon	Uncommon	T	moderate	uncommon
Anacropora puertogalerae	33	wide	4.56	2.02	9.22	Uncommon	Uncommon	T	moderate	uncommon
Euphyllia paraancora	34	wide	1.88	1.46	2.75	Uncommon	Uncommon	T	moderate	uncommon
Barabattoia laddi	37	wide	5.19	1.33	6.90	Uncommon	Rare	T	moderate	uncommon
Acropora globiceps	38	wide	3.22	1.95	6.27	Uncommon	Sometimes common	T	moderate	common
Porites horizontalata	41	wide	4.16	1.62	6.74	Uncommon	Sometimes common in isolated habitats	T	wide	common
Acanthastrea ishigakiensis	44	wide	2.68	1.30	3.49	Uncommon	Uncommon but conspicuous	T	wide	uncommon
Acanthastrea brevis	46	wide	6.53	1.49	9.75	Uncommon	Uncommon	T	wide	uncommon
Astreopora cucullata	46	wide	6.80	1.25	8.51	Uncommon	Rare	T	wide	uncommon
Pocillopora elegans	46	wide	4.12	1.74	7.17	Uncommon	Locally common in some regions of the central Indo-Pacific and the far eastern Pacific	T	wide	common
Montipora calcarea	49	wide	5.80	1.35	7.84	Uncommon	Rare	T	wide	uncommon
Acropora dendrum	52	wide	2.04	1.11	2.28	Uncommon	Rare	T	moderate	rare
Isopora cuneata	52	wide	5.09	1.76	8.95	Uncommon	Uncommon	T	wide	common
Acropora striata	53	wide	3.22	1.38	4.42	Uncommon	May be locally dominant in Japan, uncommon elsewhere	T	moderate	uncommon
Alveopora fenestrata	58	wide	1.98	1.29	2.55	Uncommon	Uncommon	T	wide	uncommon

Species Name	Veron Data							NMFS Proposed Rule		
	Distribution		Abundance							
	Number of Ecoregions confirmed or strongly predicted	Distribution Category[1]	% sites present	Average relative abundance when present[2]	Global Abundance Score[3]	Semi-quantitative abundance category	Overall estimate	Proposed Listing Category[4]	Geographic Distribution	Generalized Rangewide Abundance
Acropora palmerae	59	wide	2.65	1.81	4.79	Uncommon	Uncommon	T	moderate	uncommon
Acropora donei	67	wide	4.66	1.16	5.40	Uncommon	Uncommon	T	moderate	uncommon
Acropora listeri	68	wide	5.50	1.35	7.41	Uncommon	Uncommon	T	wide	uncommon
Acropora acuminata	72	wide	4.66	1.21	5.63	Uncommon	Sometimes common	T	wide	uncommon
Acropora verweyi	80	wide	4.69	1.59	7.44	Uncommon	Occasionally common in the western Indian Ocean	T	wide	common
Alveopora allingi	80	wide	1.24	1.27	1.58	Uncommon	Usually uncommon	T	wide	uncommon
Seriatopora aculeata	26	wide	10.29	1.70	17.49	Common	Uncommon	T	moderate	uncommon
Acropora speciosa	38	wide	8.31	1.60	13.30	Common	Usually uncommon	T	moderate	uncommon
Euphyllia cristata	49	wide	12.13	1.33	16.15	Common	Uncommon but conspicuous	T	moderate	uncommon
Pectinia alcicornis	55	wide	16.59	1.56	25.94	Common	Usually uncommon	T	wide	uncommon
Pocillopora danae	55	wide	24.10	1.80	43.43	Common	Usually uncommon	T	moderate	uncommon
Acropora paniculata	66	wide	14.31	1.43	20.44	Common	Uncommon	T	wide	uncommon
Acropora polystoma	67	wide	6.74	1.74	11.70	Common	Uncommon	T	wide	uncommon
Acanthastrea hemprichii	70	wide	11.39	1.47	16.72	Common	Uncommon	T	wide	uncommon
Acropora vaughani	72	wide	7.54	1.69	12.73	Common	Uncommon	T	wide	uncommon
Physogyra lichtensteini	72	wide	30.86	1.31	40.48	Common	Common in protected habitats	T	wide	common
Acropora microclados	74	wide	15.18	1.51	22.99	Common	Usually uncommon	T	wide	uncommon
Pachyseris rugosa	74	wide	23.46	1.45	33.91	Common	Common	T	wide	common
Montipora caliculata	82	wide	12.13	1.55	18.77	Common	Uncommon	T	wide	uncommon

Species Name	Veron Data							NMFS Proposed Rule		
	Distribution		Abundance							
	Number of Ecoregions confirmed or strongly predicted	Distribution Category[1]	% sites present	Average relative abundance when present[2]	Global Abundance Score[3]	Semi-quantitative abundance category	Overall estimate	Proposed Listing Category[4]	Geographic Distribution	Generalized Rangewide Abundance
Acropora horrida	83	wide	8.85	1.70	15.08	Common	Usually uncommon	T	wide	uncommon
Acropora aculeus	84	wide	32.10	1.55	49.77	Common	Usually common in the central Indo-Pacific, uncommon elsewhere	T	wide	common
Acropora aspera	85	wide	7.54	1.76	13.30	Common	Sometimes common	T	moderate	common
Montipora turgescens	101	wide	16.66	1.40	23.29	Common	Common	T	wide	common
Porites nigrescens	74	wide	29.05	2.01	58.28	Very common	Sometimes common	T	wide	common

[1] Distribution category was derived from the quantitative distribution measure (number of ecoregions) using NMFS' definitions as follows: narrow = equal to or less than 10 ecoregions; moderate = 11-20 ecoregions; wide = equal to or more than 21 ecoregions. See Table 3 for additional details.
[2] Average relative abundance is calculated as the sum for each species of all its individual relative abundance scores (1 = rare; 2 = uncommon; 3 = common; 4 = abundant; and 5 = dominant) divided by the number of sites in which each species occurred.
[3] Calculated as a product of the % sites present and average relative abundance.
[4] E = Endangered; T = Threatened

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