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Case Study

Measuring conservation success with missing Marine Protected Area boundaries: A case study in the Coral Triangle

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ABSTRACT

The on-going loss of biodiversity calls for assessing the performance of conservation strategies. In the case of marine protected areas (MPAs), a common indicator of success is the amount of biodiversity protected within them. However, there are many cases where the information for the official MPA boundary is not available, making it difficult to precisely measure the indicator. A solution to this problem is to create circular buffers around the centre location of MPAs for which boundaries are missing, equivalent in area to that reported officially for the MPA. The Coral Triangle Atlas provides the opportunity to quantify more precisely the validity of using buffers as proxies for MPA boundaries both at national and regional scales in the Coral Triangle. We used 612 existing MPA boundaries, converted them into point data at their centroids and then created circular buffers of area equal to that of the MPAs' original polygons. Errors in estimated area of protected coral reefs were used to measure the bias created by the centroid buffers. We obtained an underestimation of protected coral reef area, both at the scale of the Coral Triangle region and at a national scale when using centroid buffers, with a larger underestimation as more MPA boundary proxies were used. We found that the size of MPA does not have a significant effect on the percentage of bias when MPAs are smaller than 100 km^2 at a national level, and smaller than 1000 km^2 at a regional level. With less than 15% of the total MPAs in the CT region larger than 100 km^2, these results suggest that using buffers at a national scale for small MPAs may be a good solution to missing boundaries and cheaper than trying to collect exact information if working at a national or multinational scale. However, for countries with large MPAs such as Indonesia, using this proxy system will tend to create a larger error. At a regional scale, such as the Coral Triangle region, an estimation of total protected coral reef using buffers as MPA boundaries proxies will produce a small underestimation, thus, producing conservative results of protected coral reef area. This study shows the importance of assessing the bias introduced by using proxies for MPA boundaries when measuring indicators of conservation target achievement for coastal and marine areas.

1. Introduction

Marine protected areas (MPAs) are a fundamental conservation tool (Green et al., 2012; Halpern and Warner, 2002; Roberts et al., 2005). This has resulted in global and regional efforts to establish ecologically representative and effectively managed MPA networks (Mora, 2011a). These networks are encouraged at a global level through the Convention on Biological Diversity and the Aichi Targets (Balmford et al., 2005), and at regional levels through initiatives such as the Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security (CTI-CFF) (CTI-CFF, 2009; White et al., 2014).

Planning, implementing and managing such MPA networks is costly. According to Balmford et al. (2004) an estimated \$5 billion to \$19 billion annually would be needed to run a global MPA network that would protect 20–30% of the world's oceans. In order to justify these levels of investment, indicators that measure MPAs' effectiveness in protecting marine resources are necessary. A common indicator of MPA effectiveness is the percentage of biodiversity

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(e.g. species, area of particular habitats, biogeographic classifications) present within its boundaries (Barr et al., 2011). Whether these indicators reach the targeted percentage of protection or not will have a major role in deciding where and how resources are invested.

Indicators of conservation effectiveness with a spatial dimension are often measured using Geographic Information Systems (GIS) (Chape et al., 2005; Wood et al., 2008). However, these types of analyses are often hampered by incomplete or poor quality spatial data (Chape et al., 2005; Cros et al., 2014b; Visconti et al., 2013; Wabnitz et al., 2010). In the case of quantifying the amount of biodiversity protected by MPAs, a common problem is the absence of the protected area boundaries, and therefore the lack of polygons to overlay with biodiversity layers such as coral reefs, seagrass or mangroves which hinders its precise quantification in a GIS. An approach to solve this (both in the marine and the terrestrial realms) has been to create a circular polygon from a buffer around a point representing the location of the protected area (Brooks et al., 2004; Coad et al., 2013; Hoekstra et al., 2004; Jenkins and Joppa, 2009; Jenkins et al., 2013; Mora, 2011b; Mora et al., 2006; Rodrigues et al., 2004; Soutullo et al., 2008; Spalding et al., 2013; Venter et al., 2014; Wu et al., 2011). This point is assumed to be the centroid of the MPA, and the buffer is proportional to the area officially designated as protected.

Although this approach is widely accepted and commonly used, only three studies have actually quantified the difference in the area of biodiversity protected by MPAs when calculated using the real boundaries and this method (Jenkins and Joppa, 2009; Mora et al., 2006; Visconti et al., 2013). Mora et al. (2006) found that circular buffers tend to underestimate the coral reef area protected by the global network of MPAs by 23%, although the underestimation was reduced to 7% if the largest eight MPAs were removed, thus, negligible at a global scale. Jenkins and Joppa (2009), found that representing terrestrial park boundaries with circular buffers is a relatively minor problem at large scales (such as ecoregions and biomes), but that it could induce serious inaccuracies at finer scales (such as the actual land cover contained in individual parks). Visconti et al. (2013) found that the frequency of protected areas with unknown boundaries can cause large over or underestimation of the extent of protection of terrestrial neotropical mammals.

These disparities in the extent of errors introduced by using buffered MPA boundaries highlight the need for additional tests at different scales. This is especially true for regions like the Coral Triangle (CT), where current conservation efforts have to rely on spatial data that are often lacking and where the management scale oscillates from national boundaries to regional boundary. Despite efforts to build a regional MPA database for the Coral Triangle, only one third of MPAs have boundary data available (Cros et al., 2014a, 2014b; White et al., 2014); this dataset is used in regional spatial analysis to assess conservation effectiveness, as the best data available. In this study we quantify the potential error obtained by using buffered MPA centroids as proxies of MPA boundaries at regional and national levels in the estimation of total protected area of coral reefs in the CT region, and discuss potential consequences in conservation decisions.

2. Methodology

We assessed the bias introduced when using buffered MPA centroids by quantifying the difference of coral reef area obtained within the real MPA boundary and its proxy, for the Coral Triangle region. We followed an approach similar to Mora et al. (2006), Jenkins and Joppa (2009) and Visconti et al. (2013). All the GIS operations were carried out on ArcGIS 10.1 (ESRI 2012).

2.1. MPA and coral reef data

The MPA data was downloaded from the Coral Triangle Atlas (ctatlas.reefbase.org) MPA database (version 07/23/2012), regarded at the moment as the most complete for the region (Cros et al., 2014b). There are 612 polygons in the dataset, which represent the boundaries of approximately 30% of the total 1972 MPAs reported in the CT region (White et al., 2014). Approximately 95% of the missing boundaries (that is, 1308 out of 1360) are associated with small locally marine managed areas (LMMAs) in the Philippines (White et al., 2014), and less than 5% represent missing MPA boundaries for the other five countries (Fig. 1).

We selected coral reef as the major habitat type to measure within MPAs since its protection is a milestone in the CTI-CFF (CTI-CFF 2009), as evidenced by two indicators in the Regional Plan of Action: (1) percentage area of coral reef within protected areas in the Coral Triangle, and (2) percentage area of coral reefs within no-take replenishment zones. We used the Global Distribution of Coral Reefs dataset (UNEP-WCMC et al., 2010), distributed in vector format, with a spatial resolution of 30 m for the majority of the region.

2.2. Buffered MPA centroids: circular and square shaped polygons

The 612 available polygons in the CT Atlas representing real MPA boundaries were converted into points at its centroid using the "feature to point" tool. These points were then either converted into circular shapes using the "buffer" tool, or square shape, using the "buffer" and the "feature to envelope polygon" tools, both with an area equal to the original polygon. The latter shape was used by UNEP/WCMC World Database on Protected Areas as a proxy when the real MPA boundaries were unknown. The 2015 dataset no longer use this method (UNEP-WCMC, 2015), it represents MPAs with missing boundaries as point data.

2.3. Reef area inside MPA polygons

The 3 sets of boundaries (the original MPA boundaries, the circular boundaries, and the square boundaries) were clipped with the coral reef dataset to extract the coral reef area within. The resulting polygons represented the coral reef area inside each set of the MPA boundaries. Very similar results were obtained when using square and circular boundaries as proxies, thus from this step onwards only the circular buffer boundary will be used as a proxy.

2.4. Scales

Regional scale describes the Exclusive Economic Zones (EEZ) of the six countries in of the Coral Triangle region (Cros et al., 2014b), which includes Indonesia, Malaysia, Philippines, East Timor, Solomon Islands and Papua New Guinea and measures approximately 12.3 million km^2.

National scale describes the boundaries of individual countries, ranging from 77,256 km^2 to 6 million km^2. Site level corresponds to individual MPAs or LMMAs.

2.5. Bias measurement

The first step was to determine if there was a difference in the protected coral reef area when all of the original boundaries were substituted by circular buffers at national and regional scale (i.e. representing a situation in which no MPA boundaries are available), creating a bias in the estimation of protected biodiversity.

The second step was to assess if there was a change in the bias as we decreased the number of real MPA boundaries replaced by buffers (i.e. representing a situation with varying levels of

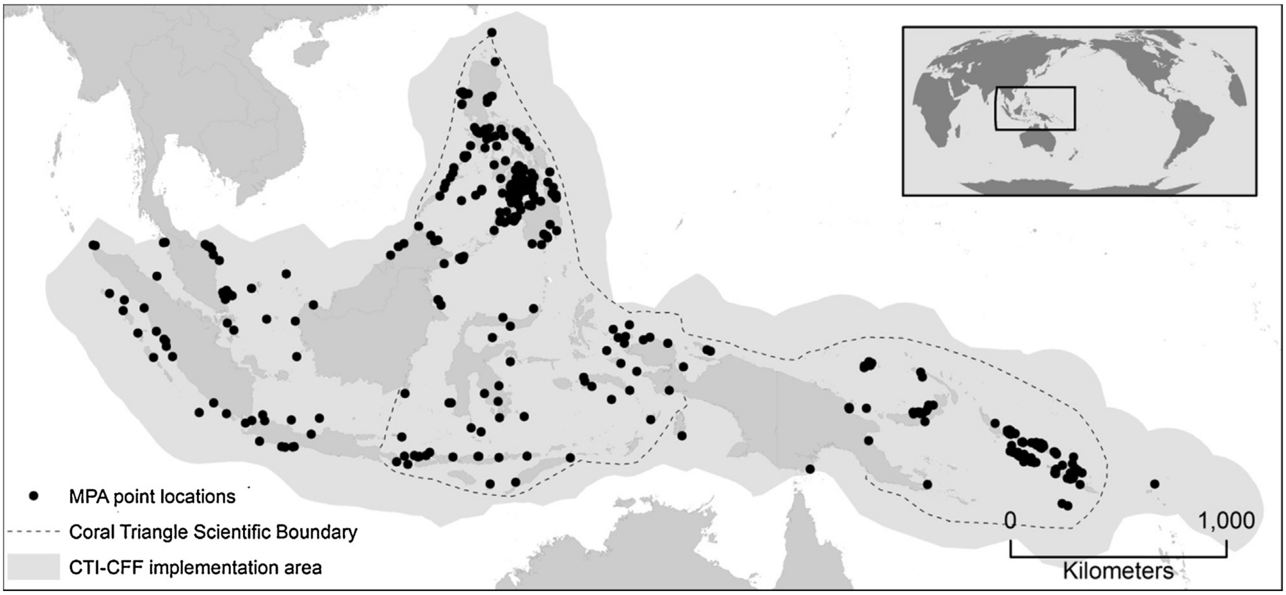

Fig. 1. Map of the Coral Triangle and the 612 MPA locations downloaded from the Coral Triangle Atlas (version 07/23/2012).

MPA boundary availability). In order to do this, we followed an approach similar to Visconti et al. (2013), in which dummy protected area datasets representing varying combinations of original boundaries and buffered centroids were created. Three sets of combinations were created with 75%, 50% or 25% of the original boundaries replaced with circular MPA boundaries. We did 60 replicates for each combination set, randomly selecting the polygons to be replaced (using Hawth's Analysis tools version 3.27). We applied these scenarios at two scales: at the Coral Triangle region scale and at the national scale.

The third step was to quantify differences in protected coral reef area according to the size of the MPA boundaries being converted to a circular buffer. To do this, we categorized MPAs in different size categories: (a) >10,000 km^2, (b) 10000–1000 km^2, (c) 1000–100 km^2, (d) 100–10 km^2, (e) 10–1 km^2, (f) <1 km^2. We created six scenarios by replacing all of the original MPA boundaries in one size category at a time.

The last step was to evaluate the difference in protected coral reef areas for individual MPAs when using the real MPA boundaries versus buffered centroids, and if this varied by sizes.

2.6. Statistical tests

We used a *t*-test to determine: (a) if the percentage error of protected coral reef area obtained was different when using a circular shape polygon and a square shape polygon to represent MPA boundaries and (b) if there was a difference between the protected area of coral reefs within the real MPA boundaries and the circular buffers in the Coral Triangle region. A single factor ANOVA was used to test whether: (c) there was a difference of error obtained between the countries of the Coral Triangle and (d) there was a difference in the estimated error of protected coral reef area when different percentages of true MPA boundaries are replaced with circular buffers.

3. Results

3.1. Square vs. circular

We found no statistical difference, $t(480) = 0.03$, $p = 0.97$, in the protected coral reef area obtained when we replaced 100% of the real MPA boundaries with the circular buffer and the square buffer. For simplicity, we only present the results using circular shapes from here onward.

3.2. Effect of the number of replaced boundaries on percentage protected coral reef area at the regional and national scale

At the CT regional scale, we found that when 100% of the original MPA boundaries are replaced with circular buffers, the area of protected coral reef is underestimated by 19.2%. This underestimation decreases as the percentage of replaced polygon decreases (Fig. 2) [$F(2,177) = 210.5$, $p < 0.001$]. Furthermore, the dispersion of the results suggests that replacing particular polygons have a considerable effect in the bias of estimated coral reef within MPAs. For example, from the 10 randomly generated dummy datasets in which 50% of the MPA boundaries were represented by a buffered centroid, we obtained a minimum and maximum protected coral reef area underestimation of 4.21% and 14.84%.

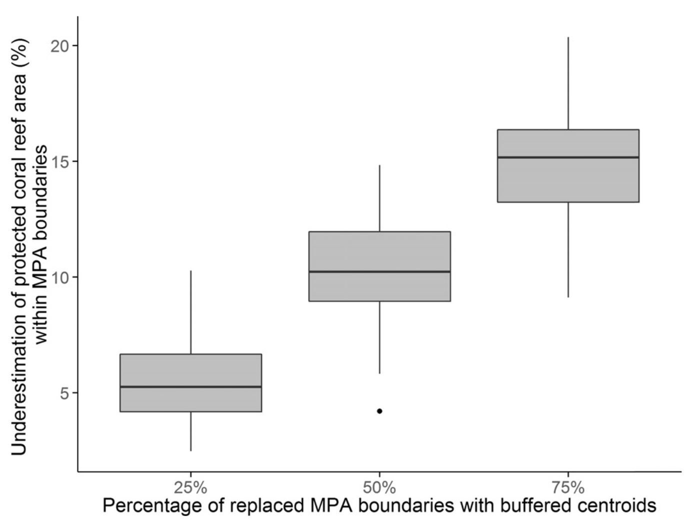

Fig. 2. Regional error of estimated protected coral reef area calculated using different combinations of original MPA boundaries and circular MPA buffers for the Coral Triangle.

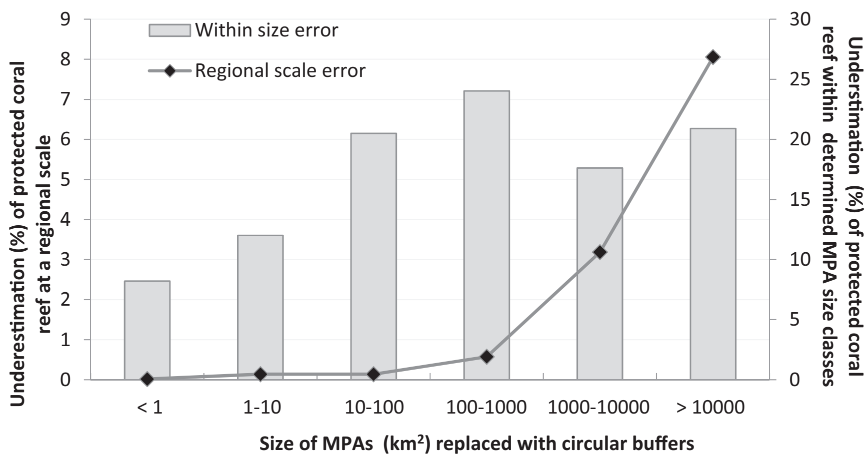

Fig. 3. Underestimation (%) of protected coral reef area when converting the original MPA polygons into circular buffers for different MPA sizes and its effect at a regional scale.

At the national scale a similar pattern was observed (Table 1) [$F(2,147) = 28.1$, $p < 0.001$]. Interestingly, the underestimations are different between countries for the different scenarios: 25% [$F(4,45) = 47.7$, $p < 0.001$], 50% [$F(4,45) = 8.6$, $p < 0.001$] or 75% [$F(4,45) = 6.7$, $p < 0.001$]. The Philippines, the Solomon Islands and Indonesia have the greatest underestimation when replacing 75% of the real boundaries with buffers. Malaysia is an exception, in which the error of using buffered MPA boundaries could be considered negligible at 25% (0.12% ± 0.50), at 50% (0.51% ± 1.14) and at 75% (0.27% ± 0.91). A plausible explanation for this is that in Malaysia most declared marine parks correspond to the 2 nautical miles around specific islands, thus their boundaries are close to circular in shape and similar to the buffered boundaries.

3.3. Errors obtained through buffering boundaries for certain MPA size classes

Protected coral reef area was underestimated within all the MPA size classes that were tested (Fig. 3), ranging between 8.21% and 24.03%. However at a regional scale, there was a noticeable underestimation only when replacing boundaries for MPAs larger than 1000 km^2.

Similarly, at the national scale, a noticeable underestimation of protected coral reef is only evident when replacing boundaries of MPAs larger than 100 km^2 (Table 2). The Solomon Islands is an exception, where an underestimation of protected coral reef is obtained even when using buffered centroids for MPAs between 1 and 10 km^2. This may be due to the fact that MPAs with a size between 1 km^2 and 100 km^2 represent a large proportion (approximately 30%) of the protected area of this country, which might have a significant weight on the obtained bias.

These results suggest that although the size of the missing boundaries has an effect on the bias, the difference in protected coral reef habitat between real and buffered MPA boundaries at a national scale is also dependent on the proportion of MPAs being replaced.

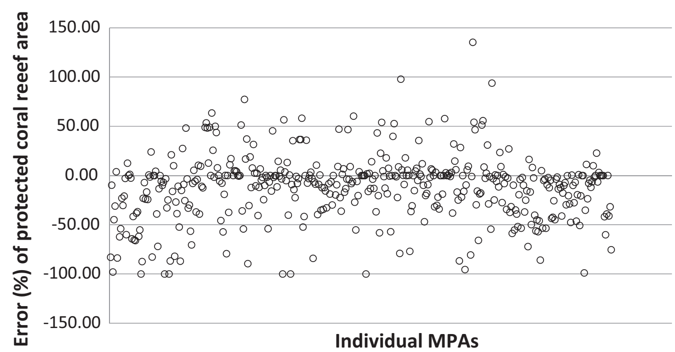

Fig. 4. Percentage error of protected coral reef area for individual MPAs in the Coral Triangle when their boundaries are replaced with a circular shape MPA polygon.

3.4. Site level

At individual site level we obtained both under and overestimation of protected coral reef area. The biases ranged between −100% and 489.97%, as shown in Fig. 4. Only 6 MPAs presented values higher than 150%, therefore they are not represented in the figure for clarity. There was a non-significant correlation of 0.05 ($p = 0.23$) between the size of individual MPAs and the percentage error of protected coral reef obtained when MPA centroids are buffered.

4. Discussion

The estimation of protected coral reef area within MPA boundaries presents considerable errors when buffered centroids are used to substitute missing boundaries. The magnitude of these errors at

Table 1
Underestimation of protected coral reef area obtained using different percentages and combinations of original MPA boundaries and circular MPA buffers in the Coral Triangle countries (Timor Leste only has one MPA, therefore it is not included here).

	Buffered centroids – original boundaries (25–75%)		Buffered centroids – original boundaries (25–75%)		Buffered centroids – original boundaries (75–25%)	
	Average (%)	S.D. (±%)	Average (%)	S.D. (±%)	Average (%)	S.D. (±%)
Indonesia	4.40	3.13	9.48	2.63	16.09	2.13
Malaysia	0.12	0.50	0.51	1.14	0.27	0.91
Papua New Guinea	5.54	4.54	6.55	4.98	12.57	3.90
Philippines	3.55	3.59	11.91	10.02	23.71	7.52
Solomon Islands	6.78	2.06	12.82	3.39	18.43	1.95

Table 2
Percentage of underestimated protected coral reef area per country by size category of replaced MPA boundaries.

	Marine Protected Area size categories					
	<1 km^2	1–10 km^2	10–100 km^2	100–1000 km^2	1000–10000 km^2	>10,000 km^2
Indonesia	0.00	0.00	0.21	2.61	7.80	10.26
Malaysia	N/A	N/A	0.22	0.86	0.07	N/A
Papua New Guinea	0.10	0.01	1.99	8.47	6.60	N/A
Philippines	0.17	0.30	0.08	8.39	20.68	N/A
Solomon Islands	0.15	5.51	14.67	5.92	N/A	N/A
Timor Leste	N/A	N/A	N/A	N/A	31.61	N/A

the national and regional scale is dependent both on the proportion and the size of MPAs with buffered centroid. These findings are similar to those from Mora et al. (2006) at the global scale, who obtained a total underestimation of 23% when all of the MPAs where represented by buffered centroids, but which was lowered to 7% when the original boundaries of the 8 larger MPAs were used.

Given the results of this study and the present MPA boundary data available for the Coral Triangle, we think that at a regional scale, buffering centroids as a proxy for missing MPA boundaries is a good solution to estimate total protected area of specific coastal habitats such as coral reefs. The present MPA dataset available for the region through the CT Atlas contains boundaries for approximately 83% of the total MPAs from Indonesia, Malaysia, Papua New Guinea, Solomon Islands and Timor Leste. For the Philippines approximately 66% of the total MPA boundaries are missing, all for Locally Managed Marine Areas (LMMAs), which have a median size of 0.12 km^2 (Weeks et al., 2010). At a regional scale those missing polygons, if buffered, would cause an underestimation no larger than 1% (Fig. 3). Furthermore, boundaries for MPAs larger than 1000 km^2 are all available, meaning that the underestimation would be no greater than 3%. This highlights the importance of regional efforts to build strong MPA datasets (Cros et al., 2014b; White et al., 2014).

At a national scale, the decision to use buffered centroids is not as straightforward as at a regional scale, and should be considered on a case-to-case basis. For Indonesia, the Philippines, Papua New Guinea and the Solomon Islands, 18% or more of the MPA polygons are missing, which would introduce a considerable amount of error according to Table 1; nonetheless, if the missing polygons were smaller than 100 km^2 the underestimation of protected coral reef (Table 2) would be negligible with the exception of the Solomon Islands. Therefore, there is a clear indication that for these countries obtaining missing boundaries for MPAs larger than 100 km^2 is a priority.

At site level, we can observe from the omission and commission errors that using buffers to represent MPA boundaries is not advisable, as the errors would range between −100% and 490%. This is important when calculating the indicator of success "area of coral reef protected" for individual MPAs. If management or investment decisions need to be taken at the site level, real boundaries are necessary to understand the level of protection the individual MPA provides to biodiversity. Therefore, it is important that even if at a regional or even national scale a certain level of data availability would be enough to assess progress towards conservation objectives, the need of having complete and good quality data for individual sites should not be underestimated.

These results also show the importance of improving spatial databases in terms of inclusion of all protected areas and in terms of improved articulation of management objectives for particular zones within protected areas. For the Coral Triangle countries, the CT Atlas is the one means of consolidating spatial information to track progress against the goals and indicators set out in the Coral Triangle Regional Plan of Action (CTI-CFF, 2009) and for the MPA goal, one indicator is critical marine habitat within "no-take areas" of MPAs. In this regard, it is essential that spatial databases begin to include a more refined data set so that these indicators can be accurately tracked. The CT Atlas has defined a set of data fields for MPAs that includes area in "no-take" zones and refined inputs on what constitute MPA "management effectiveness" which the Coral Triangle countries have agreed to and thus sets the stage for a much improved information base for the region. In the last 5 years, the CT Atlas built upon the WDPA and local efforts (e.g. Govan et al., 2009) to improve the MPA database for the region, achieving the collection of 231 new MPA boundaries and updating approximately other 150 records (Cros et al., 2014b). These records include large MPA boundaries which, as shown by this analysis, decreases the bias generated by buffering missing polygons.

This study assumes good data quality regarding the location of the centroid and the size of the MPA, which otherwise would introduce larger errors to the estimations of protected coral reefs. The point locations provided by WDPA are interpreted as centroids of the MPA by researchers; nonetheless this is not always the case (e.g. many of the points provided for the Philippines are in fact one of the corners of the MPA). Furthermore, when an MPA has two different areas (thus more than one polygon representing it), only one point record is provided in databases. The errors introduced by these situations were not quantified in this study.

5. Conclusions

Given the fact that the CT Atlas has boundary data for most of the largest MPAs in the region, buffering centroids to represent missing MPA boundaries is a good solution to estimate the protected area of coastal habitat at a regional scale. At a national scale, an effort should be made to gather boundary information for all polygons of MPAs larger than 100 km^2. Finally, at a site level (individual MPAs), buffering centroids is not recommended to estimate the total area of coral reef that a certain MPA protects.

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