Original Article

Establishing historical benthic cover levels for coral reefs of the Western Indian Ocean

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Abstract
Data on coral reef health prior to large-scale disturbances are unavailable in most parts of the world including the Western Indian Ocean (WIO). Robust coral reef health baselines could improve the understanding of changes occurring to reefs in the 21st century and prevent the "shifting baseline" phenomenon, enabling researchers and managers to evaluate the success of management measures, and set achievable targets for new interventions. To make this data accessible to the WIO coral reef community, a literature review was conducted to identify and compile data collected prior to 2008 for two principal measures of reef health; hard coral and fleshy algae cover. Baseline hard coral and algae cover levels were calculated using data from selected sites that were known to be in healthy condition prior to (or just after) the 1998 bleaching event. Mayotte had the highest mean hard coral cover with 80.9 % (95 % bootstrap confidence interval (95 % CI) =65.8-95.9 %), followed by Comoros with 62.1 % (95 % CI=53.2-78.8 %) and Madagascar with 55.6 % (95 % CI=49.8-62.5 %). Mean fleshy algae cover varied from 8.4 % in Mayotte (95 % CI=2.4-17.4 %) to 35.4 % in Mozambique (95 % CI=20.6-50.8 %). At a regional scale, mean baseline hard coral cover is estimated to be between 41 and 47 %; reefs were in a coral-dominant state, with more than double the amount of coral compared to algae.

Keywords: hard coral cover, algae cover, coral bleaching, baseline data, shifting baselines, coral reef health

Introduction
Data on coral reef health prior to large-scale degradation (circa 1970s/pre-industrial era) are unavailable in most parts of the world (Knowlton and Jackson, 2008; Souter *et al.*, 2021), and therefore true coral reef health baselines remain difficult to establish, undermining efforts to fully evaluate the changes occurring to reefs in the 21st century.

Reef monitoring data are scarce prior to the 1990s in the Western Indian Ocean (WIO) (Ateweberhan *et al.*, 2011) with most monitoring programmes established in response to the catastrophic first global coral bleaching event in 1998 (Obura, 2013). This phenomenon marked a turning point in the health of coral reefs globally, particularly in the WIO, thereby setting a distinct 'line in the sand' to approximate pre-disturbance conditions (Wilkinson, 2000). Bleaching events prior to 1998 were localised and less severe (Goreau *et al.*, 2000), and pollution and sedimentation caused by urbanisation, industrialisation and land-use change were less widespread compared to present-day (Salm, 1983). Moderate-to-high levels of artisanal fishing caused localised damage in intensely fished areas (McClanahan, 1994), but fishing had not resulted in large-scale impacts on reef functioning, conceivably due to lag-effects (Graham *et al.*, 2007) or low compounding interactions with other stressors, which have since accelerated (Ban *et al.*, 2014; Harvey *et al.*, 2018). Therefore, the limited data from 'healthy' sites before 1998 can be used to estimate consistent and robust hypothetical baseline levels of conditions prior to

1970, before large-scale disturbance and degradation. These baselines can support multiple research and management applications. Baseline levels can be compared with current conditions to improve the understanding of status and trends in reef health, and evaluate the success of management measures (Bruno *et al*., 2014). Reliable baselines can also help set ambitious and achievable conservation targets that are within natural ranges, thereby solving issues associated with shifting-baselines (Knowlton and Jackson, 2008).

Recent regional and global reef status reports (Obura *et al*., 2017; Gudka *et al*., 2018; Souter *et al*., 2021) and vulnerability assessments (Obura *et al*., 2021) framed their analysis around two key benthic indicators of reef health; hard coral cover and fleshy algae cover. These variables have been recognised as Essential Ocean Variables (EOVs) because of their importance as standard measures of coral reef functioning, and their extensive historical monitoring records (Miloslavich *et al*., 2018; Obura *et al*., 2019). Hard corals construct the reef framework, but sensitivity to marine heat waves, pollution and sedimentation threatens these reef engineers. Fleshy algae (which may include turf, macro and calcareous algae) are an increasingly important taxonomic group to monitor as the main competitor to hard corals for space, particularly following a disturbance event (Nyström *et al*., 2008; Jouffray *et al*., 2015; Mora *et al*., 2016; Brown *et al*., 2017).

Long term coral reef monitoring in the WIO began in the 1980s and early 1990s. A significant amount of data from this period were either not digitised, remain unpublished, are archived on personal and institutional databases (principally Non-Government Organizations), or are scattered across the grey literature. Efforts to secure this data in coral reef databases, e.g. Coral Reef Monitoring Database (CoReMo) and the Coral Reef Information System (CRIS), unintentionally led to significant losses in access to historical (early) data in the region as these databases became non-operational (Obura, 2013). These factors have led to very few coral reef datasets from the WIO being freely available and accessible, reducing the utility of the data. Renewed efforts to compile regional data and contribute it into regional and global outputs began around 2015 (Obura *et al*., 2017; Gudka *et al*., 2018; Souter *et al*., 2021; Obura *et al*., 2021), nevertheless, large data gaps still exist, particularly prior to 1998 (as illustrated in Obura *et al*., 2017). To make historical data accessible to the wider WIO coral reef research and management community, a literature review was conducted to identify, compile and consolidate available (published) data from sites across the WIO for two key indicators; hard coral and fleshy algae cover. The aim of this exercise is to establish a baseline that reflects the state of reefs around 1970, before widespread degradation occurred in the WIO region. Because of the lack of monitoring data from that time, data collected from reefs known to be healthy prior to 2000 were used to approximate this. The main objectives of this paper are to: a) compile site-level historical hard coral and algae cover data in the WIO into a single dataset; b) estimate pre-disturbance baseline levels of hard coral and fleshy algae cover for countries and ecoregions in the WIO; and c) quantify the magnitude of coral mortality in the WIO due to coral bleaching in 1998 using data from reefs monitored before, during and soon after the event.

Materials and methods

Literature review

A systematic literature review was conducted to locate and extract benthic cover data (percent cover) collected through quantitative coral reef surveys (e.g., Line or Point-Intercept-Transects, photo or visual quadrats) and visual estimates. Data were invariably reported as summarised mean cover values. Sources included grey literature (technical reports, books, and book chapters), scientific journal papers (articles and reviews) and project reports (Fig. S1).

Particular attention was given to extracting live hard coral cover and macro and turf algae cover data due to their importance as principal measures of coral reef health, with hard corals recognised as keystone reef builders and fleshy algae as their main competitors for space. These Essential Ocean Variables (EOVs) are used in national, regional and global biodiversity reporting on coral reefs (Bruno *et al*., 2014; Jouffray *et al*., 2015; Mora *et al*., 2016; Gudka *et al*., 2018; Miloslavich *et al*., 2018; Bang *et al*., 2021). Benthic cover data for the following benthic groups was also extracted: dead coral/recently dead coral (publications recorded these differently); calcareous algae (mainly *Halimeda*) and bleached coral; as well as combinations of these categories where reported and relevant (e.g., rock + algae and dead coral + algae).

Most effort was focused on locating data from as early as possible, ideally prior to 1998. However, since significant data gaps still exist for the early 2000s, data was also compiled from surveys conducted up until 2008. The primary focus was to extract site level data, but data aggregated at broader geographic scales was also included (e.g., “northern Kenya”), or other classes (e.g., “unspecified 9 sites (protected)”). In such cases, the number of sites included was noted. Where available, site coordinates were also included in the compiled dataset.

The systematic literature review was conducted through open-access search engines, Google and Google Scholar, using the following search words and terms: coral cover; status of coral reefs; coral monitoring reports; coral abundance; coral bleaching; coral and 1998 El-Nino; coral mortality; and coral communities. Scientific literature databases such as Scopus were not used due to access constraints, and because a significant amount of literature for this region is in grey literature sources not covered by the international scientific resources. The keywords were further refined by including the following additional search criteria:

- Surveyed areas: Global, Western Indian Ocean, Country (e.g., Tanzania), Location (e.g., Pemba Island) and site (e.g., Misali Island)

- Publication period: documents with data that were published between 1960 to 2008.

Publications were reviewed, and data were obtained from tables or in-line text in the main sections as well as supplementary materials and appendices. During the search process, if the data provided by the document was from secondary sources, the source reference with the primary data was located and used instead. A total of over 70 documents were reviewed, from which 58 documents were found to provide relevant data for this study (Table S3, Supplementary Information), with the other publications either having no useful data or data was provided in a way which could not be extracted efficiently, such as in graphs or figures (e.g. van Katwijk *et al*., 1993; Ballesteros and Afonso-Carrillo, 1995; Johnstone *et al*., 1998; Muthiga *et al*., 1998; Wilkinson *et al*., 1999; McClanahan, 1999). Data were obtained for 10 WIO countries and territories: Kenya, Seychelles, Tanzania, Mozambique, Comoros, Mayotte, Madagascar, Reunion, Mauritius and South Africa (Table 1). No data from Somalia was available.

After reviewing the literature and compiling the data, data were cross-checked for errors, duplication and missing information. Entries with no coral cover values were deleted and those with incomplete information were updated. Data found in more than one publication were highlighted and cross-referenced to the other sources. Locations were ordered hierarchically by Country, Sector, Site and Station. In some cases, the same site or station may have multiple entries for the same year because of surveys of different reef zones or depths, and this information is provided to enable a distinction to be made. The exact date or year of survey was not clear in a few publications, and this has been recorded in the *Year* column as either combined years, e.g. 1998/99, general time period, e.g. mid - 1990s, or if no information is available, as ‘n.d’. The full benthic cover dataset is available online (10.5281/zenodo.7949598).

Establishing baseline cover values

Baseline (pre-disturbance) hard coral and algae cover levels were calculated for each country/territory as well as for 10 ecoregions conceptualised by Obura *et al*.,

Table 1. Summary of the percent cover data extracted through a systematic literature review for 10 Western Indian Ocean countries/territories including the total number of data points, sites, literature sources and time-period.

Territory	Literature sources	Sites	Hard coral data points	Algae data points	Date range
Comoros	5	15	27	15	1997-2002
Kenya	23	84	120	24	1970-2004/05
Madagascar	7	25	41	17	1998-2008
Mauritius	3	43	51	52	1999-2002
Mayotte	2	12	27	6	1998-2001
Mozambique	6	37	62	10	1999-2005
Reunion	9	36	73	40	1985-2004/05
Seychelles	8	28	50	19	1994-2004/05
South Africa	6	10	17	-	1993-2005
Tanzania	9	74	94	10	1987-2004/05

2021 (see Fig. 1 for details; there was no data for Madagascar South). First, specific sites and time points were selected as representative of baseline conditions based on the following criteria:

- sites were characteristic of other reefs in the country/eco-region. This meant data from atypical reef habitats were excluded e.g., deeper algal/invertebrate reefs in Lamu, northern Kenya.

- known to be in healthy condition prior to (or just after) the 1998 mass bleaching event, applying the assumption that there were only minor changes in reef benthic composition before the 1998 bleaching event. Data from sites that were known to have been degraded prior to 1998, as reported in the source study or indicated by the data, were excluded.

- only pre-1998 data were used, unless sites sampled shortly after the 1998 bleaching event (1998-2000) had recent dead coral (and/or bleached) cover data collected and there was confidence that the monitoring was conducted using verified quantitative survey methods, and by experienced surveyors able to accurately distinguish and classify these categories at the necessary resolution. Adding the recent dead coral cover to the living cover values enabled estimation of the pre-1998 hard coral cover level.

- care was taken to ensure that where possible there was equal distribution of sites within a country or ecoregion (herein referred to as a geo-unit) and each site was only represented once in the calculation of the baseline.

Using the filtered dataset, the mean hard coral and algae baseline cover was calculated by averaging across all the selected site mean values within an ecoregion or country/territory (geo-unit). Baseline averages are not disaggregated by reef zone, as zonal information was not reported for several sites, and disaggregating by zone would result in too few data points per zone for some geo-units. Most geo-units did not meet normality and symmetry assumptions

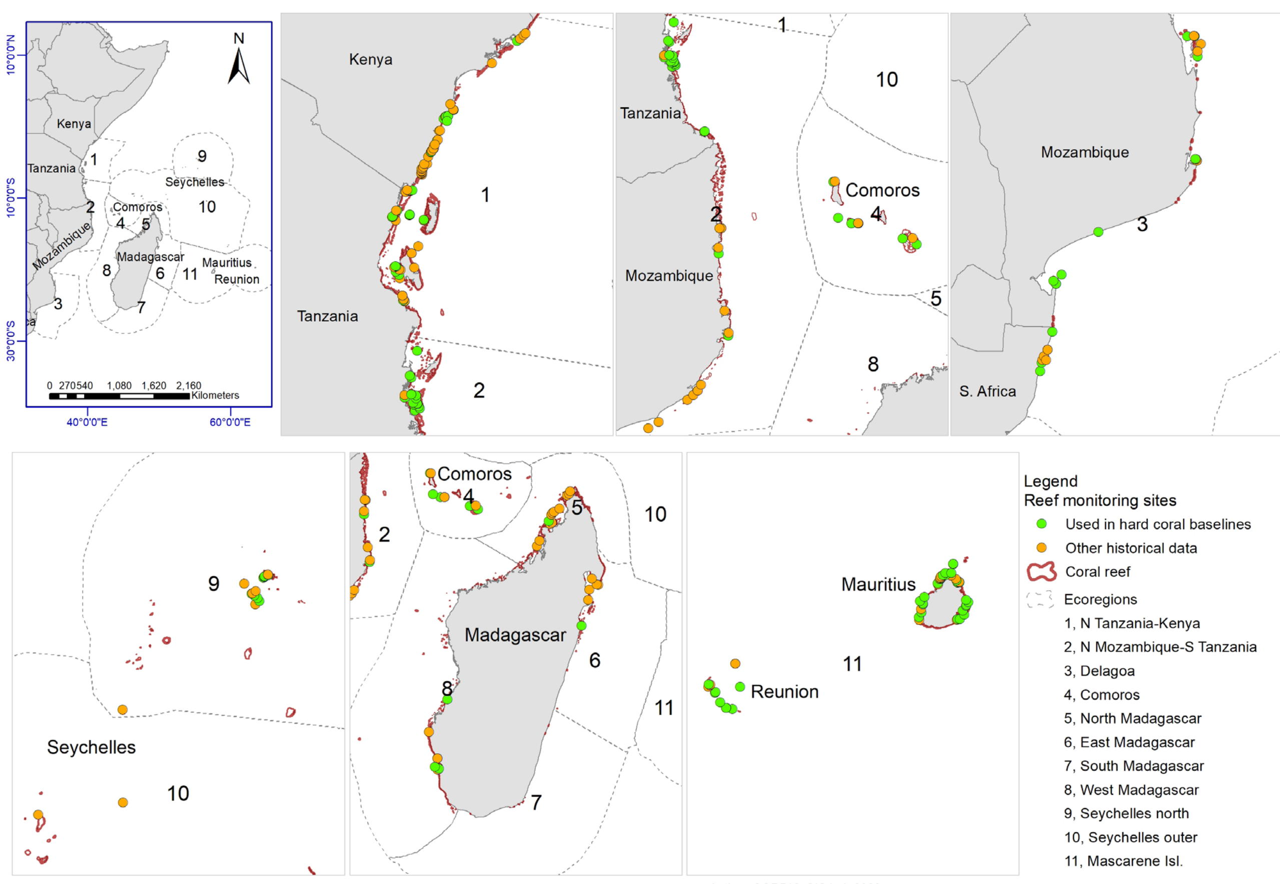

Figure 1. Monitoring sites across the Western Indian Ocean for which data was extracted from the literature review (orange and green circles). Sites used to calculate baseline averages are shown as green circles. Sites without published location information were assigned approximate coordinates.

and had low sample size, therefore data variability is reported using standard deviation, coefficient of variation (CV, ratio of standard deviation to the mean) and inter-quartile range (Rowland *et al*., 2021). As an inferential statistic, bootstrap resampling of the indicator mean was performed to provide a 95 % confidence interval using 10,000 iterations (Rowland *et al*., 2021). The regional mean range (95 % CI) for the WIO was calculated using the same bootstrap resampling method across all the data.

There was less algae data available than hard coral cover, with 162 sites for corals and 101 for algae. All countries/territories and ecoregions (except Madagascar South) had data for hard coral cover calculations, with some of the ecoregions only having a single data point (Madagascar East, and Madagascar North). There was no algae data for South Africa. Where site data was presented as a range (Hardman, 1999), the median value was used for calculations.

For sites with both hard coral and algae data, the algae-coral ratio (ACR) was calculated as ACR = Algae cover/ (Algae + Coral cover) (Bajjouk *et al*., 2019), and selected site values were averaged to calculate baseline ACR values per geo-unit. This metric provides a useful index for describing the relationship between the competing corals and algae. Using this formula, the values are bound between zero and one, simplifying its interpretation. For this analysis, the percent cover of fleshy algae was a combination of any or all three erect algae types reported in a study (turf, macro and calcareous algae (not including crustose coralline algae)). This follows the regional practice in (Obura *et al*., 2017; Gudka *et al*., 2018; Obura *et al*., 2021) to overcome inconsistencies in the identification and recording of different algae categories across monitoring programmes. Though the algae types have varied ecological functions and interactions with hard coral, with some not always having a competitive role (e.g. algal turfs (< 2 mm)), the combined variable is still considered an important indicator for reef health and productivity, and has been used in other regions (Bachtiar *et al*., 2019).

Coral mortality during the 1998 El Niño

To calculate the loss in live hard coral cover due to the 1998 bleaching event, sites with hard coral cover data from before and after the 1998 event (up to 2005) were selected. For sites only monitored during or immediately following the bleaching event (1999 and 2000) the pre-98 hard coral cover levels were estimated by adding the bleached and recent dead coral cover to the living cover data (see point 3 in criteria for site selection for baseline estimates). Where sites had more than one data point either before or after the bleaching event, the earliest data (for before) or data collected the soonest after bleaching (for after) was selected. In total, data from 66 sites representing 8 countries and 8 eco-regions across the WIO was compiled.

For each site, the percentage change in hard coral cover was calculated as the *change in cover/the original (pre-98) cover × 100,* and then all percentage change values were averaged to get national and ecoregional percentage change levels. Additionally, for each period (i.e., before and after bleaching), all site-level hard coral cover data were averaged together to get mean cover levels for each geo-unit. The regional average for the WIO was calculated by averaging across national means of percentage coral cover change to account for biases related to unequal distribution of sites. The results are analysed and presented as geo-unit percentage changes, as well as the number of sites that experienced various levels of coral loss.

Results

For baseline hard coral cover levels (Fig. 2, Table S1, n=162), Tanzania, Mauritius and Kenya had the most data points with 46, 32 and 26 respectively. For eco-regions, Mascarene Islands, N Tanzania-Kenya and N Mozambique-S Tanzania had the most data with 46, 44 and 32 data points respectively (Fig. 3, Table S1). Hard coral cover at individual sites ranged from as low as 7.8 % to as high as 97.2 %.

Mayotte had the highest mean hard coral cover with 80.9 % (n=4, 95 % CI=65.8-95.9 %), followed by Comoros with 62.1 % (n=4, 95 % CI=53.2-78.8 %) and Madagascar with 55.6 % (n=5, 95 % CI=49.8-62.5 %) (Fig. 2). Four countries had hard coral cover levels between 44 and 50 % i.e., Mozambique (n=13), Mauritius (n=32), Reunion (n=14) and Tanzania (n=46). The lowest mean hard coral cover levels in the WIO (below 35 %) were at reef sites in Kenya, Seychelles (n=14) and South Africa (n=4). When aggregated at the eco-regional scale, baseline hard coral cover levels ranged from 30.2 % in Seychelles North (n=10, 95 % CI=24.1-36.5 %) to 71.5 % for Comoros (n=8, 95 % CI= 59.7-84.2 %) (Fig. 3). Mean pre-disturbance hard coral cover is estimated to be between 41.1 % and 46.9 % across the entire WIO.

Fleshy algae data were available for 102 sites, with Mauritius, Kenya and Mozambique comprising 65 % of the

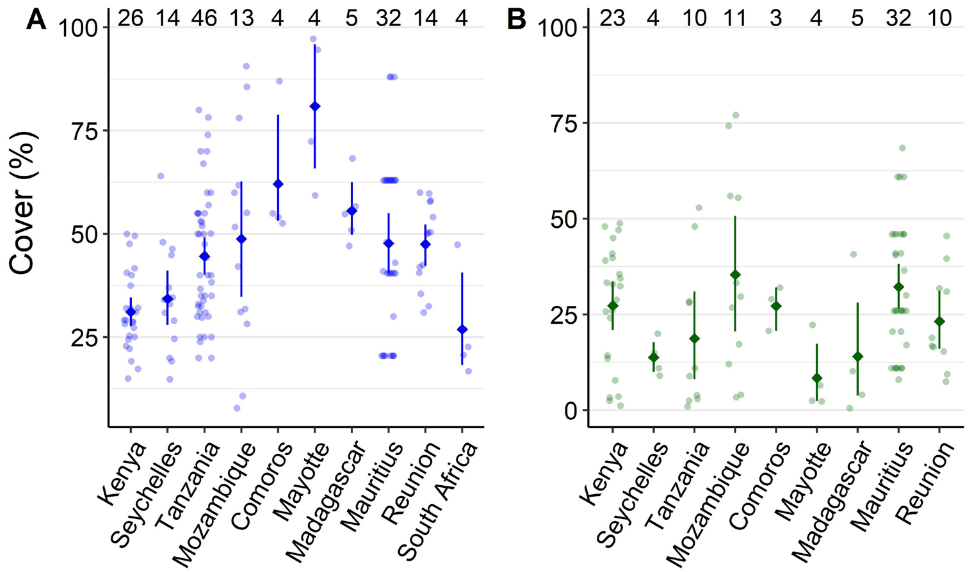

Figure 2. Baseline (pre-disturbance) (A) hard coral cover and (B) fleshy algae cover levels (%) for countries/territories in the Western Indian Ocean (WIO). Error bars represent the upper and lower limit of bootstrapped 95 % confidence intervals of the mean, diamond point represents the mean, and lighter points are individual data points (site means). The number above each bar represents the number of data points. Countries/territories arranged from North to South along x-axis.

data points (Fig. 2, Table S2; n=32, 23, 11 respectively). At the national/territory scale, mean fleshy algae cover varied from 8.4 % in Mayotte (n=4, 95 % CI=2.4-17.4 %) to 35.4 % in Mozambique (n=11, 95 % CI=20.6-50.8 %) (Fig. 2), and aggregated for eco-regions, from 0.5 % in Madagascar East (n=1) to 39.2 % in Delagoa (n=7, 95 % CI=18.4-60.2 %) (Fig. 3). For the WIO, averaging across eco-regional means, mean fleshy algae cover was 18.9 %.

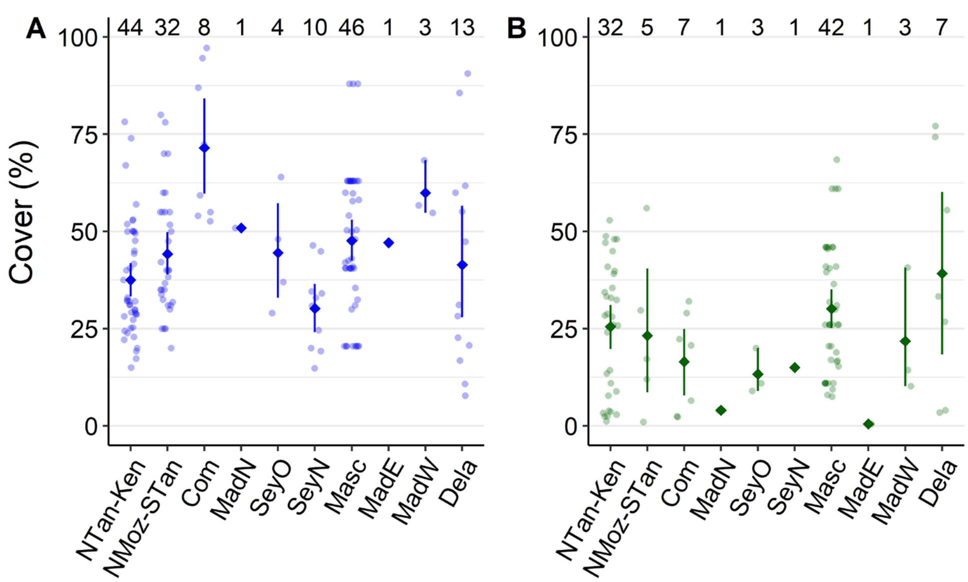

Figure 3. Baseline (pre-disturbance) (A) hard coral cover and (B) fleshy algae cover levels (%,) for 10 eco-regions using sites considered to be in a pre-disturbance state in the Western Indian Ocean (WIO). Error bars represent the upper and lower limit of bootstrapped 95 % confidence intervals of the mean, diamond point represents the mean, and lighter points are individual data points (site means). N represents the number of data points. Eco-regions arranged from North to South along x-axis. Eco-region labels: NTan-Ken – Northern Tanzania-Kenya, NMoz-STan – Northern Mozambique-Southern Tanzania, Com – Comoros, MadN – Madagascar North, SeyO – Seychelles Outer, SeyN – Seychelles North, Masc – Mascarene Islands, MadE – Madagascar East, MadW – Madagascar West, Dela – Delagoa.

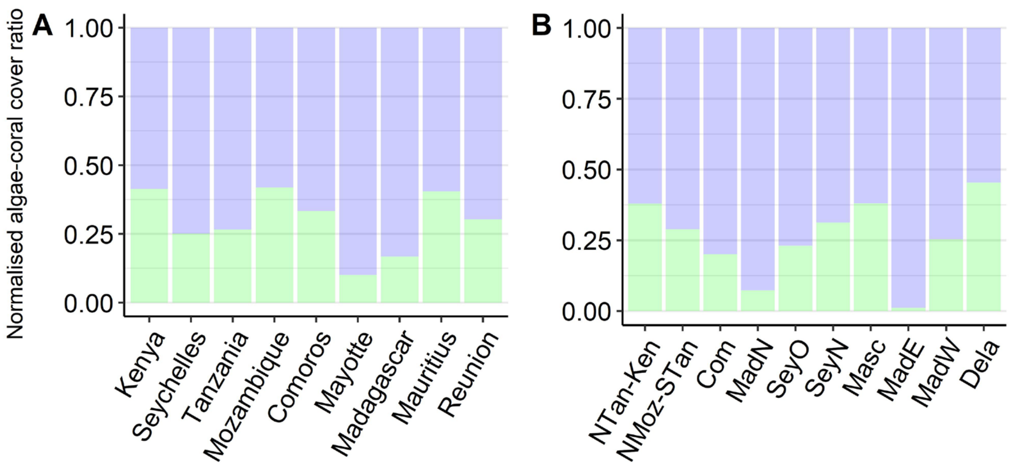

Figure 4. Algae-coral-ratio normalised to the sum of fleshy algae (green) and hard coral (blue) cover for nine countries/territories (A) and 10 eco-regions (B) in the Western Indian Ocean. Calculated using sites considered to be in a pre-disturbance state and with both algae and hard coral data. Countries/territories and eco-regions arranged from North to South along x-axis. Eco-region labels: NTan-Ken – Northern Tanzania-Kenya, NMoz-STan – Northern Mozambique-Southern Tanzania, Com – Comoros, MadN – Madagascar North, SeyO – Seychelles Outer, SeyN – Seychelles North, Masc – Mascarene Islands, MadE – Madagascar East, MadW – Madagascar West, Dela – Delagoa.

When considering the ratio of fleshy algae to hard coral cover, reefs across all geo-units were dominated by hard coral, though algae cover was above 50 % at some sites (Fig. 4, Table S2). Algae-coral ratio ranged from 0.101 (95 % CI=0.024-0.211) in Mayotte (algae cover approximately one tenth that of hard coral), to a highest value of 0.419 (95 % CI=0.252-0.596) in Mozambique, indicating mean algae cover and mean hard coral cover across 11 sites were close to equivalent. For eco-regions, the mean ratio varied between 0.011 for Madagascar East to 0.454 (95 % CI=0.208-0.702) for Delagoa. The mean WIO ratio was 0.258.

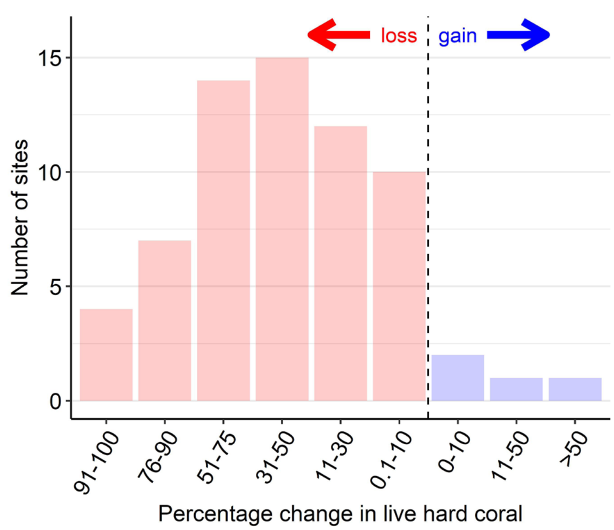

Figure 5. The magnitude of change in live hard coral (%) at sites across the Western Indian Ocean during the mass coral bleaching in 1998. Left of dashed vertical line (red bars) are sites which reported a loss in hard coral cover, and to the right (blue bars) are sites which reported an increase. Total of 66 sites from eight WIO countries/territories.

On average hard coral cover loss in 1998 was 38.6 % (n=66). Thirty-eight percent (38 %) of sites experienced greater than 50 % loss in coral cover, with 16 % of sites experiencing more than 75 % loss and 6 % experiencing more than 90 % loss e.g., the reef flat at Surprise Reef in Mayotte and North St. Pierre in Seychelles (Fig. 5). Overall, 94 % of sites experienced some degradation from the event. Reef sites in Seychelles (n=8), Mayotte (n=6) and Kenya (n=14) experienced the greatest losses in cover, losing on average 70 %, 58 % and 51 % living coral respectively (Table S4, Supplementary Information).

Discussion

Reefs in the WIO have unequivocally been altered over the past 30 to 40 years (Ateweberhan *et al*., 2011; McClanahan *et al*., 2014). Increasing pollution, fishing, and temperatures, coupled with inadequate protection have set coral reefs on a path of diminishing returns to society (Cinner *et al*., 2009; Halpern *et al*., 2015; Samoilys *et al*., 2017). The data presented in this paper provides insights into what reef state was likely to have been for different parts of the WIO before various threats began causing widespread degradation.

Reef condition prior to the 1998 El Nino was non-uniform within and across eco-regions, with coral cover varying from below 10 % to above 95 %. Coral dominance was common, with fleshy algae cover less than half that of coral cover in all but 3 eco-regions, with particularly low algae levels in Mayotte, Seychelles, and Madagascar. Reefs in Mayotte had the highest coral cover and the lowest algae cover, though this was from just four sites. When combined with four more sites from Comoros (Eco-region=Comoros), hard coral cover levels for all eight sites were above 50 %. Hard coral cover was highest in the Northern Mozambique channel, reflecting the vibrancy and diversity of this region as the 2nd most biodiverse coral region in the world (Obura, 2012). Baseline estimates use a selection of sites which are assumed to be representative of general reef condition around 1970. Sites were rigorously selected to mainly use data prior to 1998 when reef degradation was less widespread in the WIO, and only sites known or assumed to have had minimal degradation since 1970 were included. This selection of the 'best' sites is an example of space-for-time substitution similar to using pristine or uninhabited reefs as references, and has been used when long-term data is lacking (Sandin *et al*., 2008; Blois *et al*., 2013).

There are large differences in the amount of data reported from different parts of the WIO. The most data points were from sites in Kenya (n=120) and the least from South Africa (n=17). Tanzania (n=46), Mauritius (n=32) and Kenya (n=26) had the highest number of sites for which data met the selection criteria to calculate hard coral cover baseline levels. More hard coral cover data was found in published records compared to algae data, an indication of differences in data collection effort between the two taxonomic groups. Confidence in the results (baseline means) varies based on the amount of data and its spread, but encouragingly the Coefficient of Variation (CV) is less than 1 for all hard coral cover and algae-coral ratio estimates, except for the algae-coral ratio for Mayotte (CV =1.168). Delagoa, Seychelles North, Mascarene Islands, N Mozambique-S Tanzania and N Tanzania-Kenya, have the most robust results, due to a sufficient and/or well-represented sample size (in terms of distribution of sites; CV ranging from 0.36-0.66 and n= 10-46). However, ranges could not be established for three of Madagascar's eco-regions due to low or no sample sites. Various methods were tried to establish a range of values to account for the natural variation between sites, and the confidence intervals (95 %) calculated from bootstrapping provide more precise estimates of baseline levels, particularly for geo-units with higher sampling e.g., Kenya. The assertion is that principal coral habitats on the majority of reefs in a geo-unit would have once fallen within this range assuming low to no levels of degradation.

Some caveats exist with the process described in this paper. Although a thorough search for literature containing suitable data was conducted, invariably these efforts were not exhaustive. There are other datasets which exist but remain unpublished, hidden or have only been presented as aggregations in the literature, minimising their suitability for these and other purposes. Baseline averages are not disaggregated by reef zone, as zonal information was not available for some sites, resulting in too few data points for some geo-units. This is consistent with the protocols of other recent regional analyses (Obura *et al*., 2017; Gudka *et al*., 2018; Obura *et al*., 2021). An element of subjectivity with the method comes from determining the sites reflecting pre-disturbance conditions for each geo-unit, and consequently the exclusion of sites that had already degraded prior to 1998. This was mainly based on expert judgement of threatening processes and health of reef sites, and interpretation of the data or site descriptions in the source literature. For example, data from 1970 and 1992 for Diani on the south-coast of Kenya were not included as the sites were damaged by overfishing and high urchin populations in the decades preceding the reference year 1998 (Khamala, 1971; McClanahan and Muthiga, 1988), which is clear from the low hard coral cover of between 1 and 7 %. Data from very specific habitats which are not representative of the regional reef system were also excluded e.g., data collected in 1987 for offshore reefs in Lamu, Kenya by Samoilys (1988). This selection protocol was consistently followed, resulting in some low hard coral cover sites being included as these conditions were deemed to be normal for the site (or area) and not due to prior degradation or disturbance (e.g., Mike's Cupboard in Inhambane, Mozambique). Data were included as much as possible to increase the sample size.

Recent benthic cover values published in regional reports (Table 2), allow for some interesting comparisons to suggest how reef state may have changed over the last two to three decades. At a regional scale, average pre-disturbance hard coral cover is estimated to be between 41 and 47 %. Prior to the 2016 bleaching event, hard coral cover averaged across over 130 sites (though only representing 6 WIO countries) was estimated to be around 41 %, which dropped to 33 % post-bleaching (Gudka *et al*., 2018). Obura *et al*. (2017) reported mean WIO coral cover at around 30 % between 2010-2015. Though these values are not directly comparable due to differences in methods and data, it tentatively indicates that today's coral cover is lower than what it once was, though with high variation across and within geo-units. Tanzanian reefs have apparently changed the least, with recent levels being similar to baseline levels calculated here, of 30-45 % for hard coral cover and 12-20 % for fleshy algae cover (Table 2). South African reefs show a gradual decline in living hard coral consistent with the regional reports, but inconsistent with some site-based studies (Porter and Schleyer, 2017). Baseline levels are very close to values prior to the 2016 bleaching event for both Seychelles' eco-regions, supporting the notion that reefs had recovered to near pre-98 levels (Robinson *et al*., 2019). For Reunion, both algae and coral levels ranged between 40-50 % in 2014/15, indicating that hard coral cover had remained quite stable since baselines (though more recent bleaching and extreme-tides have caused significant coral mortality (Nicet *et al*., 2017)), but algae may be on an upward trajectory. Mauritius had a coral cover of ~50 % with corresponding algae levels of ~20 % in 2015 (Obura *et al*., 2017), though the data in this study is from an extensive rapid assessment of the entire Mauritius Island, making direct comparisons imprecise. For Madagascar, average hard coral and algae cover was reported as 30 % and ~45 % in 2015 respectively (in Obura *et al*., 2017), and 45 % and 14 % in 2017, respectively (from 14 sites, W and North Madagascar) (Gudka *et al*., 2018), indicating an inter-site disparity in current reef health relative to baseline levels. In Kenya, reef benthic state may not have departed drastically from historic conditions, with average hard coral cover ranging from 18-31 %, and algae at around 30 % between 2013-2017. The condition of reefs in Grande Comore and Mohéli (Comoros) in 2010 and 2016 was highly variable, with live coral cover ranging between 6 % and 60 % (Cowburn *et al*., 2018). The comparisons tentatively indicate that there may have been substantial recovery at several sites across the region after the 1998 bleaching event, though compositional and functional changes in benthic communities are not revealed through the aggregated indicators used in these studies. In order to ascertain clear trends on reef health, it is imperative that data collection standards are improved to collect data at higher taxonomic resolution consistently (e.g. coral genera or species level), and reporting includes non-aggregated indicators.

The impact of the first global bleaching event in 1998 was considerable on WIO reefs, with reefs in

Table 2. Hard coral and fleshy algae cover i) baseline values calculated in this study (95% confidence intervals from bootstrapping), ii) values prior to (Pre-2016) and after (Post-2016) the 2016 bleaching event from regional reports (a-Obura *et al*., 2017, b- Gudka *et al*., 2018). All post-2016 records are from Gudka *et al*. (2018).

Geo-unit	Variable	Baseline (95% CI)	Pre-2016	Post-2016
Comoros	Hard coral	62.1 (53.2-78.8)	55 (2007)[b]; 64 (Fore), 40 (back)[a]	55
	Fleshy algae	27.2 (20.7-32.0)		<5
Kenya	Hard coral	31.1 (27.6-34.7)	31[b]; 18-25[a]	25-27
	Fleshy algae	27.3 (20.9-33.5)	30[b]; <20[a]; 34[a]	~30
Madagascar	Hard coral	55.6 (50.1-32.5)	30[a]; ~50[b]	~45
	Fleshy algae	14 (3.8-28.1)	~45[a]; 9[b]	14
Mauritius	Hard coral	47.7 (40.5-54.8)	50 (2002)[a]; 20 (2010) [a]; ~50 (2015)[a]	35
	Fleshy algae	32.2 (26.4-38.2)	~20 (2015)[a]	
Mozambique	Hard coral	48.8 (35-62.8)	~22[a]	
	Fleshy algae	35.4 (20.6-50.8)		
Reunion	Hard coral	47.5 (42.1-52.4)	40-50[a]	
	Fleshy algae	23.2 (16.1-31.2)	40-50[a]	
Seychelles Inner (N)	Hard coral	30.2 (24-36.5)	33[b]; 42[a]	13
	Fleshy algae	15		
Seychelles Outer	Hard coral	44.5 (33-57.2)	44[a]	37
	Fleshy algae	13.3 (9.0-20.0)		
South Africa	Hard coral	26.9 (18.3-40.7)	~18[a]	16.9-20
	Fleshy algae			
Tanzania	Hard coral	44.6 (40.1-49.3)	44[b]; 30-45[a]	40
	Fleshy algae	18.7 (8.1-31.0)	12; ~15-16	15-20

Seychelles, Mayotte and Kenya the most impacted. On average across the WIO, sites lost close to 40 % living coral. This value does not represent an actual mean regional loss in hard coral cover as there is unequal representation of sites across space. However, it does corroborate the severe impact of this event reported elsewhere (Wilkinson, 2000; Ateweberhan *et al.*, 2011; Obura *et al.*, 2017), though the coral loss values vary because of differences in methodologies. Obura *et al.* (2017) estimated the decline to be approximately 25 % based on a relatively small pre-1998 data sample, Ateweberhan *et al.* (2011) estimated a loss of ~45 %, and Wilkinson (2000) stated that some sites lost between 50-80 % live coral resulting in an overall hard coral loss of 16 % in the WIO.

The baseline levels and the wider data compiled for these two key ecological components offers numerous uses for management and research. Baseline levels provide a useful benchmark for current states and combined with time-series data can identify the trajectory of reefs towards or away from possible phase-shifts. Marine Park managers can commission repeat surveys at sites to enable comparisons over decadal timescales enabling evaluations of the effectiveness of past and current interventions. Baseline information can be used to set realistic objectives for new interventions based on historical ecological limits (carrying capacity of community) to ensure they are achievable (McQuatters-Gollop *et al.*, 2019). As demonstrated by the WIO coral reef RLE (Obura *et al.*, 2021), the data can be incorporated into frameworks or other analyses that provide policy or management relevant results.

As reef condition continuously changes, there is heightened need for more, and better-quality data to be made available for management and research. Scaled national investment in long-term, high-resolution monitoring is recommended through regional entities like the Global Coral Reef Monitoring Network (GCRMN) nodes and Nairobi Convention Coral Reef Task Force. Project donors are also encouraged to enforce strict data publishing measures that follow the FAIR principles (Findable, Accessible, Interoperable, and Reusable) (Wilkinson *et al.*, 2016), but researchers are also requested to voluntarily avail data particularly for data-deficient regions as well as other key taxonomic groups such as fish and urchins. Coupled, this will enable historical baseline conditions to be calculated at a higher precision across more ecoregions in the WIO, and using other variables, as well as to trace trends in reef health over time, particularly after acute disturbance events. It is the belief of these authors that the prospects of conservation are greater with open data practices than without them.

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Supplementary material

Provided in separate PDF file

Table S1. Baseline (pre-disturbance) hard coral cover levels (%) for 10 countries/territories (top) and 11 eco-regions (bottom) in the Western Indian Ocean (WIO).

Table S2. Baseline (pre-disturbance) fleshy algae cover levels (%) with comparative (same sites) hard coral cover levels (%) and algae-coral-ratios for 9 countries/territories (top) and 11 eco-regions (bottom) in the Western Indian Ocean.

Table S3. List of all publications where data was extracted from.

Table S4. Change in hard coral cover (%) during 1998 bleaching.

Figure S1. Types of publication from which the data was extracted (n=58).