

High coral cover at “tourist reefs” of the Sultanate of Oman

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Abstract

Despite having been relatively well studied over the past several decades, there have been few reports on the status of the Sultanate of Oman’s coral reefs since 2015. Herein I took a citizen science approach whereby I captured several hundred images of the coral reef benthos at seven sites spanning two regions within the Gulf of Oman to estimate coral cover. As opposed to simply selecting sites at random to attempt to describe the condition of a “typical” reef, “tourist reefs” hypothesized by local divemasters to feature the highest live coral cover were instead targeted, with the goal of characterizing the most coral-rich habitats of the region. The mean coral cover across the seven survey sites was nearly 40%. Furthermore, reefs of the Daymaniyat Islands, which were devastated by Cyclone Gonu in 2007, exhibited amongst the highest cover, albeit with two of the sites being dominated by 2-3 species of fast-growing *Acropora* spp. and therefore of low climate resilience. These data have been submitted to the Global Coral Reef Monitoring Network and will hopefully aid both local and global researchers in assessing coral reef change over time by knowing what the “best” reefs of the Gulf of Oman looked like in mid-2024.

Key words: AI, citizen science, coral reefs, marine ecology, Oman, Persian Gulf

Introduction

In an unbiased ecological survey, a researcher normally seeks to at least partially randomize site selection to gain a better approximation of the regional mean habitat condition (Southwood & Henderson, 2000). However, human bias is common, particularly with coral reefs, in

which local researchers may feel compelled to show their (oftentimes foreign) collaborators their “best” (in terms of aesthetics &/or coral cover) reefs. For instance, Yanbu is amongst the most popular diving destinations in the Kingdom of Saudi Arabia (go to [this page](#) for representative images from Yanbu &

elsewhere along the Saudi Arabian Red Sea coastline from 2023 to 2024.), and in 2024, its mean coral cover was 15-20% (Mayfield, 2025b). However, Aeby et al. (2021) reported values >40%. One reason for this large discrepancy is the timing; the surveys of Aeby et al. (2021) and Mayfield (2025b) were undertaken in 2015 and 2023-2024, respectively, and massive loss of coral has occurred over that period due to high-temperature-induced bleaching and other environmental insults. However, Aeby et al. (2021) were likely taken by dive operators to the most famous local dive sites since the purpose of their study was to look for coral disease; it made sense to target coral-rich areas. Their overestimate of live coral cover from failing to choose sites in a randomized manner, then, is not reflective of shoddy science.

In fact, I argue that knowing what the most beautiful, coral-abundant reefs looked like at a given point in time has scientific value despite the inherent site-selection bias (Marshall et al., 2019). Firstly, given the myriad threats against them, it is important to know which reefs are performing best, from both ecological and physiological perspectives (Mayfield & Dempsey, 2025). In some cases, these might represent the most climate-resilient reefs, though it is important to note that there is no correlation between coral cover and a reef's climate resilience (Mayfield et al., 2021); in fact, reefs with near-100%

cover of weedy acroporids are amongst the *least* climate change-tolerant. Assuming both coral abundance and generic evenness are moderately high by regional standards, it is safer to say that such a reef *might* possess higher climate resilience and should be prioritized for study or perhaps even conservation. For instance, although no reef on the planet is pristine given the wide reach of climate change (Mayfield et al., 2016), more remote reefs may have higher fish biomass (Sandin et al., 2008), and reefs of the Northern Line Islands (e.g., Kingman Reef & Palmyra Atoll) have been directly targeted by scientists for this reason. In other words, the reefs were not chosen randomly to estimate, for instance, regional coral abundance; instead, reefs hypothesized to be relatively more pristine, and hence likely more beautiful, were targeted (Smith et al., 2016). Barring such remote locations, a tropical region's most beautiful reefs are likely to be those visited most frequently by SCUBA divers (Alisa et al., 2025), and for at least 20 years we have realized that tourist divers, and especially underwater photographers, are vastly untapped resources for coral reef data collection and monitoring (Marshall et al., 2012). Perhaps this justifies the inclusion or markedly beautiful reefs in coral reef survey efforts, despite not necessarily being the most "representative" of a region?



Fig. 1. A high-coral cover reef near Muscat, Oman (“Cave site”). Image (~10 m² reef area) taken by the author at ~5 m.

Coral reefs of the Sultanate of Oman, especially those within the Persian Gulf (Musandam) and the Gulf of Oman, have been the subject of study for decades; pioneering coral reef researchers like the late Charles Sheppard (Sheppard & Salm, 1988), as well as Rodney Salm (1993), Steve Coles (1997a-b), and others, have spent considerable time characterizing Oman’s reefs. However, with the exception of several publications that either highlighted specific phenomena (e.g., Oladi et al., 2019; Claereboudt & Bruss, 2025) or reported results derived exclusively from the Musandam area (e.g., Bento et al., 2017; Aeby et al., 2020), reefs

within the Gulf of Oman south of Musandam have not been described in any detail since Burt et al. (2016), who summarized results from studies conducted several years prior. Herein I took a citizen science approach whereby I sought to gain insight on the coral abundance on reefs noted by local divemasters to be the most aesthetically appealing to (& thereby popular with) tourists (Fig. 1). These were hypothesized to possess higher live coral cover than a typical reef in the area though lower cover than the more popular reefs of the Musandam area, which have been better characterized due to their proximity to the United Arab Emirates (Foster et al., 2013).

Materials and methods

Coral reef imagery acquisition.

Between May 20 and May 25, four reefs in the Muscat (“capitol”) area and three in the Daymaniyat Islands (Tab. 1) were surveyed with a citizen science+AI approach described by Mayfield (2025a-b) after querying 2-3 local divemasters each at Gulf Divers Oman (website down as of 2025-10-13) and [ExtraDivers Oman](#) as to where their guests preferred to dive and specifically which reefs they themselves and tourists considered to be the most beautiful. Interestingly, these divemasters, as well as local scientists, regional scientists, and divemasters working elsewhere in Oman said to avoid visiting the reefs of the Daymaniyat Islands since they were presumably devastated by Cyclone Gonu in 2007 and were thought to have never recovered; instead, tourists now go there to see juvenile turtles. Daymaniyat sites 1 and 3 (Tab. 1) were sheltered bays on the leeward side of the main island. Site 2 was instead on its exposed side and was visited to serve as a surface interval between “turtle snorkels” to give tourists more diversity in topside scenery; it was not predicted to be a reef worth exploring given the expectation of storm damage.

At each of the four and three sites of Muscat and the Daymaniyat Islands, respectively, I used an Olympus TG7

underwater camera (Japan) to take ~50 m² reefscape photos (Fig. 2) between ~1 and 12 m; at greater depths, light levels are too low to capture colors accurately without strobes, thereby making it difficult for both scientists and the AI to distinguish key benthic taxa like corals and algae. This method has been described previously (Mayfield, 2025a-b), though involved a random swimming approach in which images of the benthos were taken every few seconds, white-balancing when changing depth by >1-2 m to ensure that colors were accurate. In poorly- (or non-) white-balanced images, it can be difficult to differentiate key benthic taxa. Of the 670 images taken that included visible reef benthos, 9 were either poorly white-balanced or of too low resolution to be used to characterize the benthos. For the remainder, 30 points were randomly overlaid by CoralNet, and each was manually scored for the first 106 images for initial AI training (Tab. 2). Images were analyzed in random order to ensure that certain sites were not used exclusively for AI training, with others analyzed only by the trained AI. Upon determining that the minimum acceptable accuracy of 85% (Mayfield, 2025a-b) was not realized (Tab. 2), an additional 154 images were scored manually (n=260 manually scored images). Afterwards, the AI automatically annotated all 30 features in each of the

Tab. 1. Site information. Lowercase superscripts in the right-most column reflect Tukey's *post-hoc* differences ($p < 0.05$). Site names have been overlaid with hyperlinks leading to the web pages hosting the edited versions of the images. These and all other error terms represent standard deviation. For a collection of the most beautiful images, go to the "[Best of Oman](#)" [collection](#).

Site name	Region	# photos	Date	Latitude	Longitude	Mean image depth (m)	Coral cover (%) [*]
Novice Bay	Muscat-Khayran	135	May 20	23.52125°N	58.75010°E	10	38.5±22.5 ^b
Cave Site	Muscat-Khayran	170	May 20	23.52869°N	58.74031°E	7.5	51.4±21.0 ^a
Jissah Point	Muscat-Jissah	61	May 21	23.55740°N	58.66159°E	7.5	33.3±21.0 ^{bc}
Cat Island	Muscat-Jissah	81	May 21	23.58587°N	58.60933°E	7.5	24.9±19.8 ^c
Daymaniyat-site 1	Daymaniyat	79	May 25	23.85726°N	58.10143°E	2	41.7±20.8 ^b
Daymaniyat-site 2	Daymaniyat	106	May 25	23.85730°N	58.08516°E	3	38.1±22.1 ^b
Daymaniyat-site 3	Daymaniyat	28	May 25	23.85435°N	58.08445°E	2	33.0±4.0 ^{bc}

*See Fig. 5.

Tab. 2. Summary of coral cover data from assessment 661 “tourist diver” photos. CoralNet was used to estimate coral cover from images taken between ~1 and ~12 m (CoralNet accession#[6625](#)) after manually training at various stages.

Metric	Value	Notes/Details
#images taken for informal “tourist diver” analysis	670	
#images used in tourist diver CoralNet analysis	661	Nine images failed quality control.
#images accessible for analysis and/or download	660	One image was deleted by accident.
#images used for initial CoralNet AI training	106	
CoralNet-calculated classification accuracy (%)	83%	See “ Classifier Overview ” for details.
#images for <i>post-hoc</i> CoralNet accuracy verification	154	
Manually-calculated classification accuracy (%)	85±13%	
Total #images scored manually for CoralNet training	260	Scored 7,800 features manually.
Total #images classified automatically by CoralNet	401	
Total #features scored by CoralNet across 401 images	12,030	
Total #features scored by human and CoralNet	19,800	
Mean percent benthos (benthic groups/30 x 100)	89±14%	
Mean percent bleaching (hard corals only)	0.02%	

remaining 401 images. All images can be accessed [here](#).

The labelset used to annotate the images is shown in Fig. 2 and included hard corals (HC), soft corals (SC), various types of algae, and several abiotic categories (e.g., sand). Of the 21 labels listed in Fig. 2, 3 correspond to organisms that were *not* seen: fluorescing hard corals (F_HC), bleached soft corals (SOFT_BL), and non-coral invertebrates that had bleached (B_OTH-SINV; e.g., bleached anemones). Since a portion of most images included the water column, as well as fish swimming within it, both “water” and “fish” were amongst the remaining 18

potential labels. However, these non-benthic features were removed when calculating the percent live coral cover. In other words, hard coral cover was assessed relative to the benthic portion of the image only, which averaged 89% (i.e., 11% of the area in each image was either water or fish; see Fig. 4 for a breakdown of all annotations.). Note that neither coral diversity nor coral cover by genus or species was considered. This is because there are not yet enough images of Persian Gulf corals of high enough quality to train the CoralNet (or other) AI to differentiate them, especially the acroporids. It is hoped that increasingly more scientists will take,

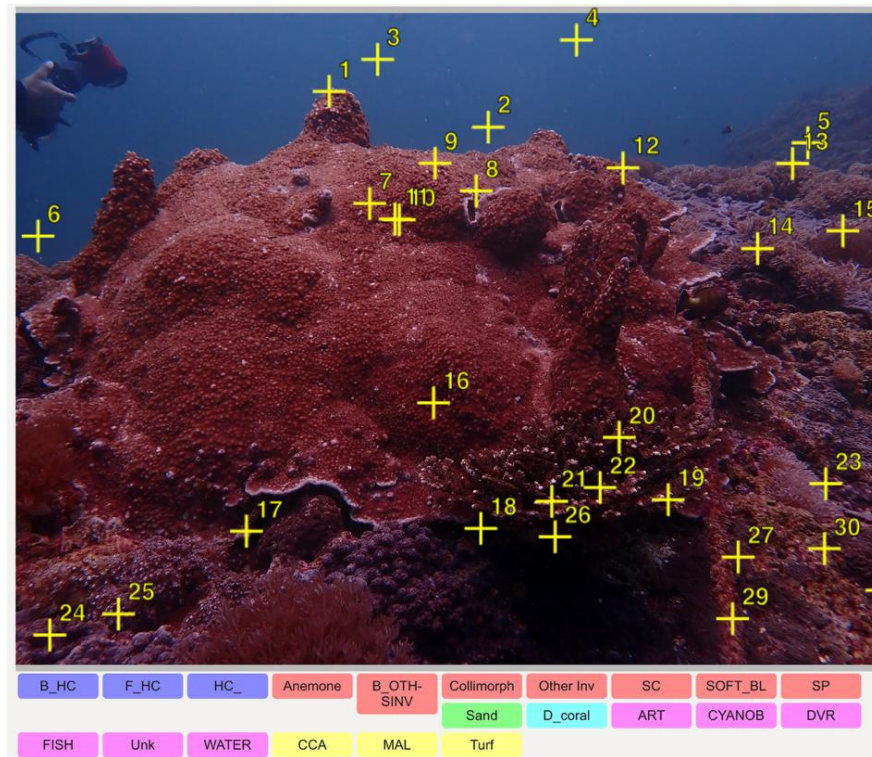


Fig. 2. A representative image of a reef area undergoing annotation in CoralNet. In this image from Cave Site, 54% of the benthos was occupied by hard corals, similar to the overall mean coral cover of this site of 51% (Tab. 1).

and then share, their coral reef images in the future (assuming this is permitted by their respective governments, funding agencies, &/or institutions).

Meta-analysis. Of the 303 coral reef benthic surveys performed in Oman between 2008 and 2025 (as of 2025-10-14) that have been submitted to Wildlife Conservation Society's [Mermaid](#) database, 116 are associated with benthic data, and none are open-access (nor can data summaries even be plotted). However, data from 232 fish surveys can be accessed,

of which a subset of 180 correspond to fish biomass surveys. Of the 277 surveys of Omani coral reefs (n=132 sites) carried out between 2003 and 2025 and submitted to the Global Coral Reef Monitoring Network ([GCRMN](#)) database, all are closed-access except for the one associated with this manuscript. Of the 145 transects for Oman deposited in the [ReefCheck](#) database (available by email request to rcinfo@reefcheck.org), 132 were from the Musandam region, and only 1 of the remaining 13 was in the vicinity of my

survey sites (a transect assessed at Novice Bay in 2017 at 6 m; mean coral cover=14%). Given the overall lack of access to coral cover data from prior Gulf of Oman reef surveys, it was necessary to extract coral cover percentages and other key ecological data from the manuscripts shown in Tab. 3.

Results and discussions

AI accuracy. Initial training of the CoralNet AI with >100 manually annotated images resulted in an accuracy of only 83%, below the threshold advocated by Mayfield (2025a-b) based on recommendations from the CoralNet development team (Beijbom et al., 2015). After manually annotating another 154 images, accuracy rose to 85% (7,800 features scored manually). To see how accuracy improved over the course of training at a higher level of detail, go to the CoralNet page hosting the images (referenced in Tab. 2). Although the mean AI accuracy of 85%, which was calculated based on *post-hoc* validation of images scored by both myself and the AI, is inferior to my own (assumed to be 100%, though of course likely to be lower since no *in situ* classifications were conducted), the remaining 401 images were annotated by the AI in several minutes. In contrast, it took me several weeks to manually annotate the first 260 images. Those without significant time constraints may

still opt for CPCe or more traditional, manual image annotation tools. However, it is likely that, as more individuals gravitate towards CoralNet and other AIs (e.g., ReefCloud) for annotation of benthic images, the accuracy will continue to improve, perhaps even reaching levels that are now the exclusive domain of highly trained coral reef scientists.

Temperature. Although formal temperature data were not acquired, an Oceanic OCi dive computer (USA) was used on each dive to estimate temperatures. Unfortunately, the data from the computer were lost due to an issue with the software. Instead, NOAA sea surface temperature (SST) data from the “virtual” Oman station have been plotted (Fig. 3) for 2023-2025 ([NOAA Coral Reef Watch](#)). On May 20-21, the mean estimated SST around Muscat was approximately 30.5°C (35°C air temperature). There was an extreme thermocline at the four Muscat area sites in which the temperature was ~20-21°C 1-3 m above the benthos at depths of 5-12 m. This is evidently a normal phenomenon there, with a 30 vs. 20°C difference also documented by Al-Azri et al. (2010) at 5-15 m. Upwelling can also lead to large, rapid temperature changes in the region (Coles, 1997b), and cold-water upwelling in other coral-rich regions has been known to thwart bleaching, especially when it occurs during the summer months (Mayfield et al., 2012). If this temperature

Tab. 3. Manuscripts featured in a meta-analysis of temporal variation in coral cover on reefs of the Daymaniyat Islands and Muscat, Oman. Error terms represent standard deviation. NR=not reported.

REGION (Site)	Year	Coral cover (%)	Depth	Reference(s)
MUSCAT (capital area)				
Muscat	1986	72±16	1-5 m	Sheppard & Salm (1988)
Bandar Jissah	1993	20±14*	NR	Coles et al. (2015)
Bandar Jissah	2008	8±3	5-6 m	Burt et al. (2011)
Bandar Jissah	2012	7±20	NR	Coles et al. (2015)
Bandar Jissah	2024	29±6	1-10 m	Herein
Bandar Khayran	1992	67±25	1-13 m	Salm (1993)
Bandar Khayran	2017	14 ^{&}	6 m	ReefCheck
Bandar Khayran	2024	45±9	1-10 m	Herein
DAYMANIYAT ISLANDS				
Daymaniyat	1992	73±19	3-13 m	Salm (1993)
Daymaniyat	2006	61±4	NR	Taylor (2009, 2010)
Daymaniyat	2008	22±3	NR	Taylor (2009, 2010)
Daymaniyat	2008	14±12	5-6 m	Burt et al. (2011)
Daymaniyat	2024	38±4	1-5 m	Herein
GULF OF OMAN (both regions)				
Both regions	1986	72±16	1-5 m	Sheppard & Salm (1988)
Both regions	1992	67±25	1-13 m	Salm (1993)
Both regions	1993	20±14	NR	Coles et al. (2015)
Both regions	2006	61±4	NR	Taylor (2009, 2010)
Both regions	2008	11±3	6-8 m	Taylor (2009), Burt et al. (2011), Bauman et al. (2013)
Both regions	2012	7±20	NR	Coles et al. (2015)
Both regions	2017	14	6 m	ReefCheck
Both regions	2024	37±8	1-10 m	Herein

*Calculated by regressing their categorical scores of 1, 2, 3, 4, and 5 against the average of the binned percentages corresponding to each: 0-5% (mean=2.5%), 6-30% (18%), 31-50% (40.5%), 51-75% (63%), and 76-100% (88%), respectively. [&]No replication

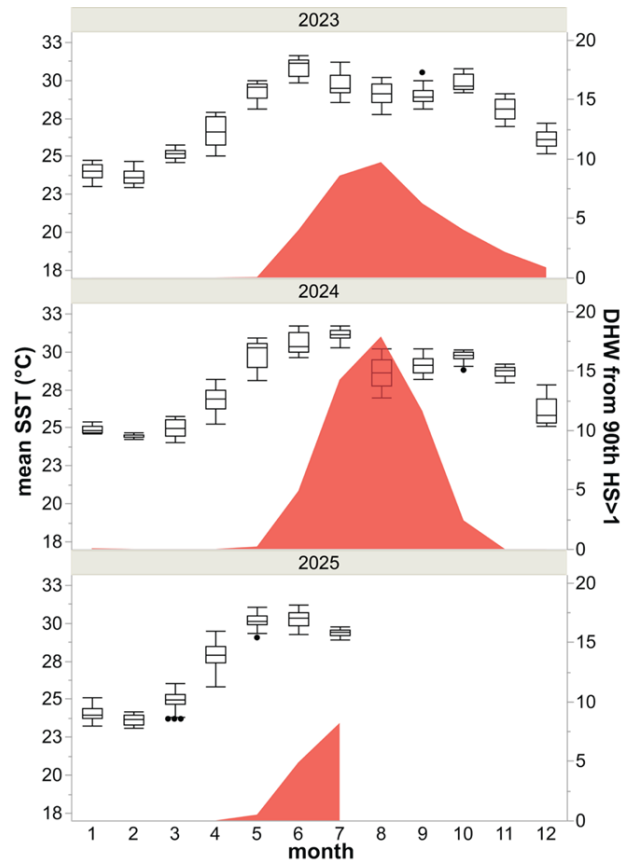


Fig. 3. Monthly sea surface temperature (SST) data from NOAA's Oman virtual station (left-y-axis; box plots) and degree-heating weeks (DHWs; right y-axis; red area plot) in 2023, 2024 (the survey year: survey dives on May 20-25), and 2025. HS=hot spot.

differential is maintained during the warmest months (July-September), it could actually offset the slightly negative impact of upwelling on coral growth documented farther south (Spreter et al., 2022). Given the absence of *in situ* data, it is premature to speculate too broadly on the role of thermoclines and upwelling on these coral reefs, though this is certainly a fruitful topic for future research given their

roles in establishing refugia (Mayfield et al., 2011).

Image analysis. Even had there been no thermocline at the Muscat sites, only 2-3 DHWs had been logged at the time of surveying (Fig. 3); no bleaching was anticipated, nor were many bleached corals observed (~0.02% of tissue surface area). Fig. 4 instead shows the most dominant features captured in the 661 images. Water and fish comprised ~11% of

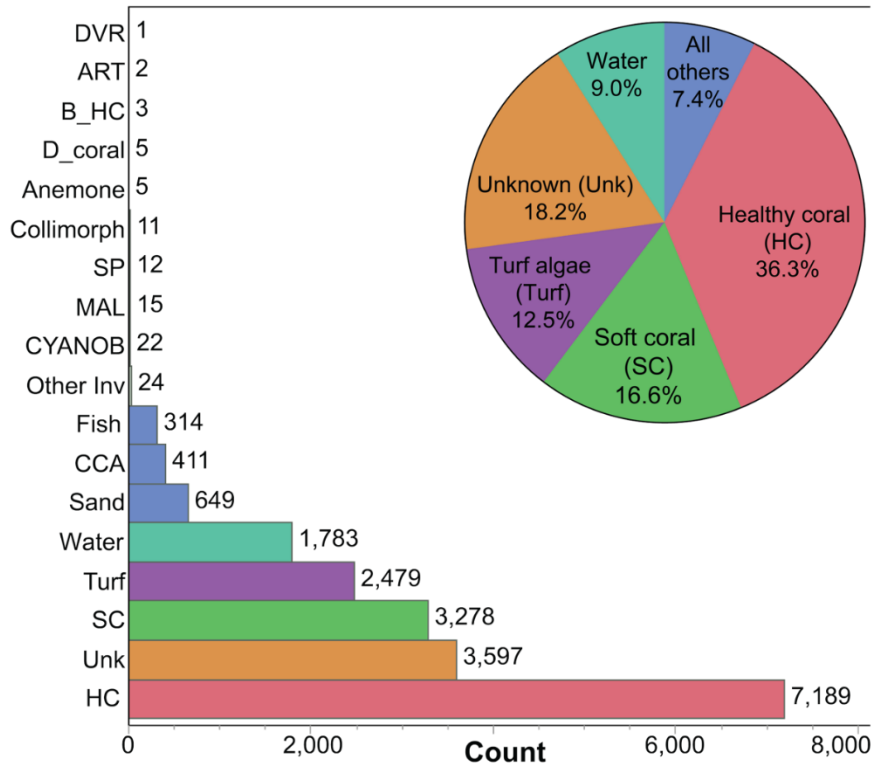


Fig. 4. Histogram showing breakdown of all 19,800 annotations (661 photos x 30 points randomly placed by CoralNet on each). Unlike other studies conducted using the same method in summer of 2024 (e.g., Mayfield, 2025a-b), very little coral bleaching was observed in Oman in May 2024 (<1% of all coral tissue surface area). See the online supplemental data file for full names of the benthic taxa, as well as the abiotic features (e.g., artificial structures [ART]). The colors in the pie graph inset correspond to those in the histogram.

the mean image area, meaning that 89% of each image featured benthos and was therefore usable in calculations of live coral cover. Hard corals comprised 36% of each image; when considering that 11% was excluded from calculations of cover, this results in a mean coral cover per image of 40-41%. This value is slightly higher than the true mean coral cover values

discussed below because more photos were taken on reefs with higher coral cover.

Coral cover. The mean coral cover across the seven sites (Fig. 5) was 37.3 ± 8.3 and ranged from only ~25% at Cat Island (capitol region) to >50% at nearby Cave Site (Fig. 2). Consequently, there was a statistically significant effect of site in a one-way ANOVA ($df=6$, $F=16.5$, $p<0.001$),

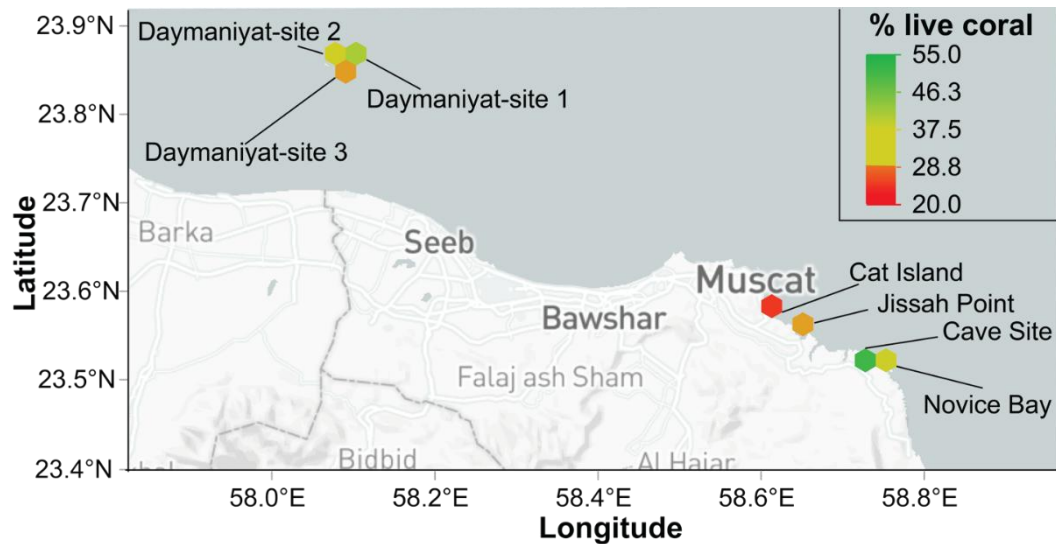


Fig. 5. Map of study sites overlaid with coral cover data. The mean live coral cover percentages (%) across the 661 photos and seven sites were $39.8 \pm 22.9\%$ and $37.3 \pm 8.3\%$, respectively; these values differ because different numbers of photos were taken at each site (Tab. 1), with the latter value being more representative of the regional spatial variation within the Gulf of Oman (Fig. 6).

and *post-hoc*, inter-site differences are shown in Fig. 6. When pooling data across the four and three Muscat and Daymaniyat sites, respectively, mean coral cover values of $37.0 \pm 11.1\%$ and $37.6 \pm 4.3\%$, respectively, were documented when using site as the replicate, and these coral abundances were statistically similar ($p > 0.05$).

Meta-analysis. Although not surveyed herein, virtually all prior works reported higher coral cover in Musandam than elsewhere in Oman (Burt et al., 2016). Reefs of Musandam possessed coral cover approaching 60% in 2011 (Bento et al., 2016), but upon averaging all values in the meta-analysis of Burt et al. (2016), which

included data collected between 2010 and 2015 (values of 22, 25, 30, 32, & 65% appeared for various sites throughout the article.), with those of ReefCheck (mean coral cover across 14 transects spanning 2-4 sites surveyed in 2016 = $58 \pm 19\%$), the local mean coral cover in 2016 was probably closer to 40%. This is still an impressive abundance of coral by international standards (Mayfield & Dempsey, 2025), and although the value has surely continued to drop since then due to repeated marine heat waves, it was nevertheless slightly higher than the mean value of the seven reefs of presumed highest coral abundance in the Gulf of Oman surveyed herein (though the

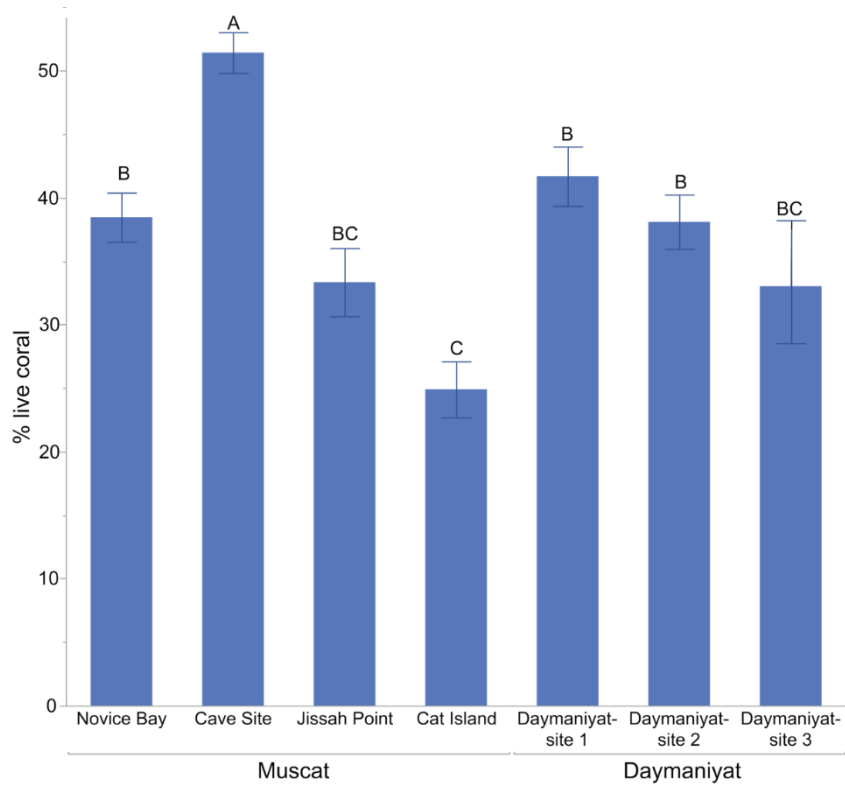


Fig. 6. Mean live coral cover (%) across the seven survey sites. Error terms represent standard deviation, and capital letters above bars represent Tukey's *post-hoc* differences ($\alpha=0.05$).

difference was not statistically significant; $p>0.05$). In other words, an average Musandam reef in 2016 was characterized by similar coral cover as some of the highest cover reefs of the Gulf of Oman surveyed in 2024. Of course, these seven sites were chosen subjectively by divemasters (for Muscat area sites) based on their own and their guests' aesthetic preferences. At Daymaniyat, sites 1 and 3 were instead selected because of their high turtle densities, and site 2 was effectively discovered by accident. In some parts of the world, such as particular islands in

Indonesia and the Philippines, divers are as inclined, if not more so, to go to areas with few corals because they tend to feature unusual organisms that make excellent photographic subjects (i.e., "muck diving"). Although no popular muck dive sites are regularly visited in the Muscat area or in the Daymaniyat Islands, it is certainly possible that these seven subjectively chosen reefs do not represent the most scleractinian-rich areas in the Gulf of Oman, and divers or scientists who encounter superior ones should contact GCRMN, local researchers, or myself

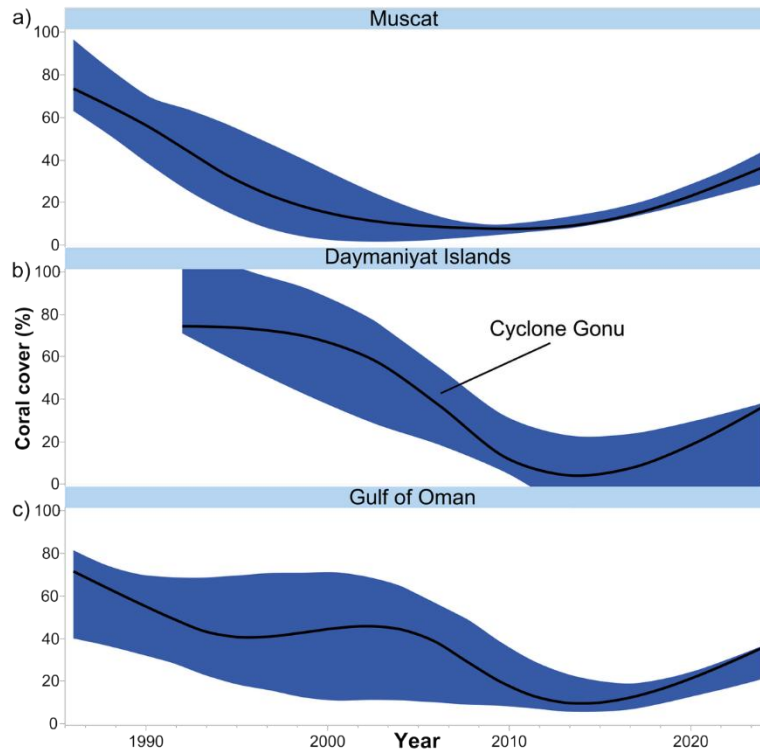


Fig. 7. Temporal changes in coral cover in the Gulf of Oman. The region-wide mean coral cover was $35 \pm 25\%$ across all survey times, though has halved from $>70\%$ in 1986 to $37 \pm 8\%$ in 2024. Cyclone Gonu (2007) was particularly devastating in the Daymaniyat Islands (b). The Muscat (a) and Daymaniyat Islands data were pooled in (c). Shading about all splines reflects 95% confidence and encompasses negative values in (b)(not shown). The final values for 2024 are not identical to the data presented in Figs. 5-6 because a lambda of 0.01 was used (a lambda of 0 would fit the data perfectly while lambda=2,000 would approximate a straight line.).

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They may also directly upload their images to CoralNet, which can now distinguish Gulf of Oman corals from other benthic taxa at an accuracy of 85%, a value that will continue to rise as more users manually validate images for AI training.

Coral reef recovery from cyclone damage.

Despite repeated recommendations from tourists, dive companies, and scientists to avoid the Daymaniyat Islands unless I specifically wished to see turtles, recovery from Cyclone Gonu has been impressive (Fig. 7b). Coral cover in the Daymaniyat Islands



Fig. 8. An *Acropora* sp.-dominated reef in the shallows (2-4 m) around the Daymaniyat Islands (Daymaniyat site 1).

dropped just after this intense storm from around 40% to under 10% before slowly recovering to values just under 40% in my 2024 surveys. Although promising, it is worth noting that the majority of the corals of Daymaniyat sites 1 and 3, both sheltered embayments on the leeward side of the islands, were fast-growing *Acropora* spp. (Fig. 8); diversity was low (<5 species), and the dominant corals are amongst the most thermo-sensitive (Loya et al., 2001). As such, these sites are likely of low climate resilience. Daymaniyat site 2, in contrast, featured a rich assemblage of poritids, pocilloporids, and pavonids (for additional images, access the link provided in Tab. 1.), the vast majority of which being older than 20 years and hence having

survived Cyclone Gonu. Given that the embayment faced east (windward), even the non-massive corals (e.g., *Pocillopora* spp.) were in their most corymbose, robust growth forms and so most corals were adapted to a relatively higher wave energy environment. This might explain why only this site featured corals that pre-dated the cyclone.

Conclusions and future perspectives. Although both the capitol and Daymaniyat regions have experienced decreases in live coral cover since the 1980s, both have been trending in an upward direction since around 2015 (Fig. 7). Two of the three Daymaniyat sites are dominated by weedy acroporids with low thermotolerance, yet the remaining

Daymaniyat site (2) features numerous massive poritids and pavonids that are known to be more resilient (Barshis et al., 2010; Yu et al., 2020). Furthermore, the Muscat area sites feature corals residing within an extreme thermocline that can be 10°C lower than the top layer of the water column. If this temperature differential is maintained during the warmest months in perpetuity, these sites may represent coral reef “refugia” where climate change impacts may be muted (Bachman et al., 2022). Unfortunately, thermocline depths are predicted to increase in the future as a result of climate change-driven (& other) processes (Wyatt et al., 2023), meaning only deeper corals may benefit from these cooler waters (Diaz et al., 2023).

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