How Satellite Derived Chlorophyll Measurements Correlate With In Situ Chlorophyll Measurements

Analysis by Simularity

August 5, 2021

Executive Summary

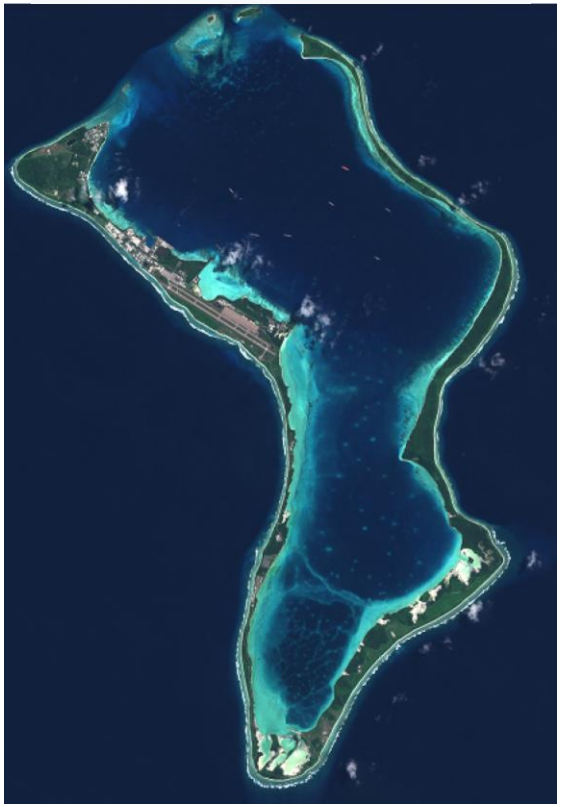
The overall health of reefs globally is declining from anthropogenic causes, primarily poor water quality, over-fishing, and the effects of climate change (ocean acidification and higher sea temperatures that result in coral bleaching). Monitoring the health of our reefs is critical to determining when and where appropriate mitigation steps should be taken to help rehabilitate damaged reefs. Maritime measurements of Chlorophyll-a in sensitive coral reef zones are used as indicator of water quality, and subsequently, coral health.

Collecting In Situ data on coral reef health is expensive, time consuming, and difficult to scale to large areas. In many cases it's not even possible to have physical access to certain areas of interest. It's more economical, scalable, and more timely to use remote sensing calculations based on multispectral satellite imagery instead of taking "on the ground" measurements.

This report focuses on comparing results of the Chlorophyll-a concentrations from the C2RCC algorithm based on multispectral Sentinel 2 satellite imagery with actual "ground truth" measurements of Chlorophyll-a published in the study "Marine Water Quality At Diego Garcia: A Preliminary Study Of Pollution Levels In Coastal And Lagoon Waters"[1] by Painting, et. al., with the island of Diego Garcia as the target area of interest.

We found that the Chlorophyll-a concentration values derived from the C2RCC algorithm based on multispectral Sentinel 2 satellite imagery can be used to predict the actual Chlorophyll-a measurements to an accuracy within one mg/m^3.

Location of Diego Garcia



Imagery credit: European Space Agency – produced from ESA remote sensing data

Diego Garcia Island - Background

Location of Diego Garcia

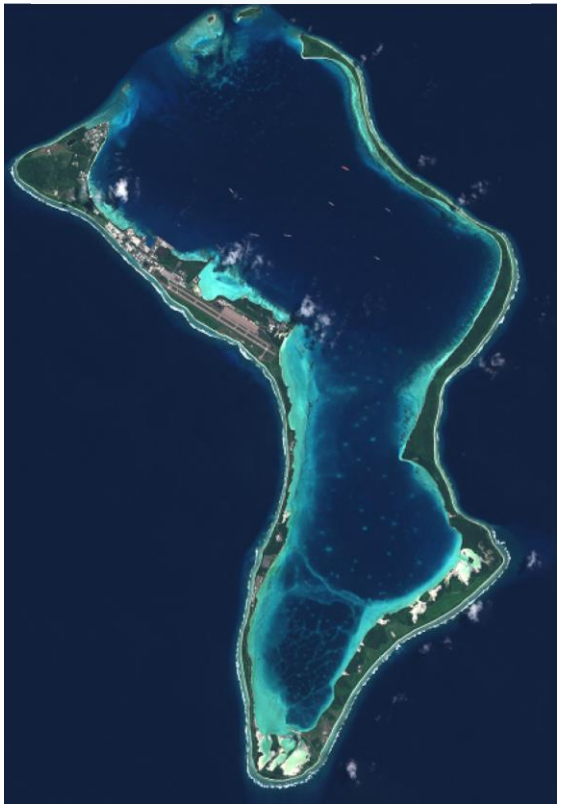
Diego Garcia, located in the Chagos Archipelago at 7°18′48″S 72°24′40″E, is an island of the British Indian Ocean Territory. UK represents the territory internationally. It is one of two US bomber bases in the Asia Pacific region. Construction for the naval base started in 1971.

The native Chagossians were forcibly removed from their island, and have not been allowed to return.

On 1 April 2010, the Chagos Marine Protected Area (MPA) was declared by the UK. However, Mauritius objected, and on 18 March 2015, the Permanent Court of Arbitration ruled that the Chagos Marine Protected Area was illegal under the United Nations Convention on the Law of the Sea.

In 2019, the UK's claim of sovereignty over the remote Chagos Islands in the Indian Ocean was ruled illegal by the UN's highest court, which told Britain to hand them back as soon as possible. In 2021, the International Tribunal for the Law of the Sea (ITLOS) added its own confirmation of Mauritius' sovereignty over the Chagos Archipelago, and criticized the UK's failure to comply with the 2019 UN resolution.

The Mauritian government has offered to lease the land to the US for up to 99 years, if it is returned to their control. US claims to upholding the rules-based order don't square with its silence on Mauritian sovereignty in the Chagos.



Imagery credit: European Space Agency – produced from ESA remote sensing data

Image Date: March 30, 2019

Summary of Findings:

The satellite computed C2RCC Chlorophyll values vary from the In Situ measurements by less than one mg/m^3 .

On the left are the In Situ water sample sites from Diego Garcia Island as reported in [Marine Water Quality at Diego Garcia: A Preliminary Study of Pollution Levels in Coastal and Lagoon Waters[1]]

Imagery credit: European Space Agency – produced from ESA remote sensing data

Chlorophyll-a Values Of Diego Garcia Island

Chlorophyll-a values from the C2RCC algorithm, derived from Sentinel 2 satellite images. This image is based on the Sentinel 2 image of Diego Garcia island on March 30, 2019, the date when the water samples were taken.

The categories "Safe for coral", "Triggers Remediation", and "Not Safe For Coral" are based on the Water Quality Guidelines for the Great Barrier Reef Marine Park:

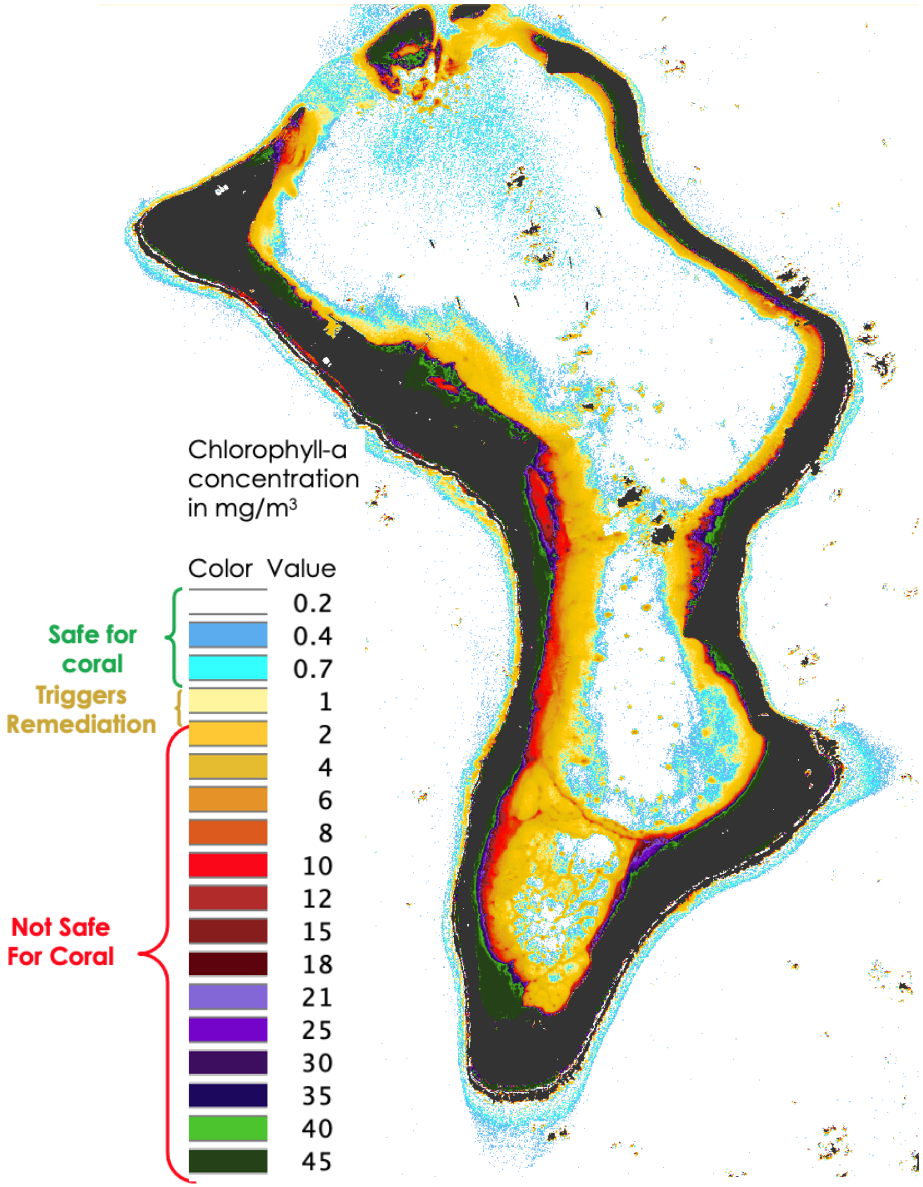
Table 2: Guideline trigger values for water clarity and chlorophyll *a*

Parameter\Water Body	Enclosed coastal (Wet Tropics/Central Coast)	Open coastal	Midshelf	Offshore
Secchi (m) (minimum mean annual water clarity) [1]	1.0/1.5	10	10	17
Chl *a* (µg/L)[2]	2.0	0.45	0.45	0.4

[1] At shallower depths Secchi will be visible on the seafloor. Guideline trigger values for water clarity need to be decreased by 20% for areas with greater than 5 m tidal ranges. Seasonal adjustments for Secchi depths are presently not possible due to the lack of data.

[2] Chlorophyll values are ~40% higher in summer and ~30% lower in winter than mean annual values.

Table 2 (above) shows trigger values for water clarity and Chlorophyll-a. When these values are exceeded, further reef management action is initiated to address the issue. This table was obtained from the most current water quality guidelines of the Great Barrier Reef: [Water Quality Guidelines for the Great Barrier Reef Marine Park. Great Barrier Reef Marine Park Authority, TownSVille. REVISED EDITION 2010]



Imagery credit: European Space Agency – produced from ESA remote sensing data

Diego Garcia bathymetry and in situ sample collection sites. Sample Collection Dates: March 28-31, 2019.[1]

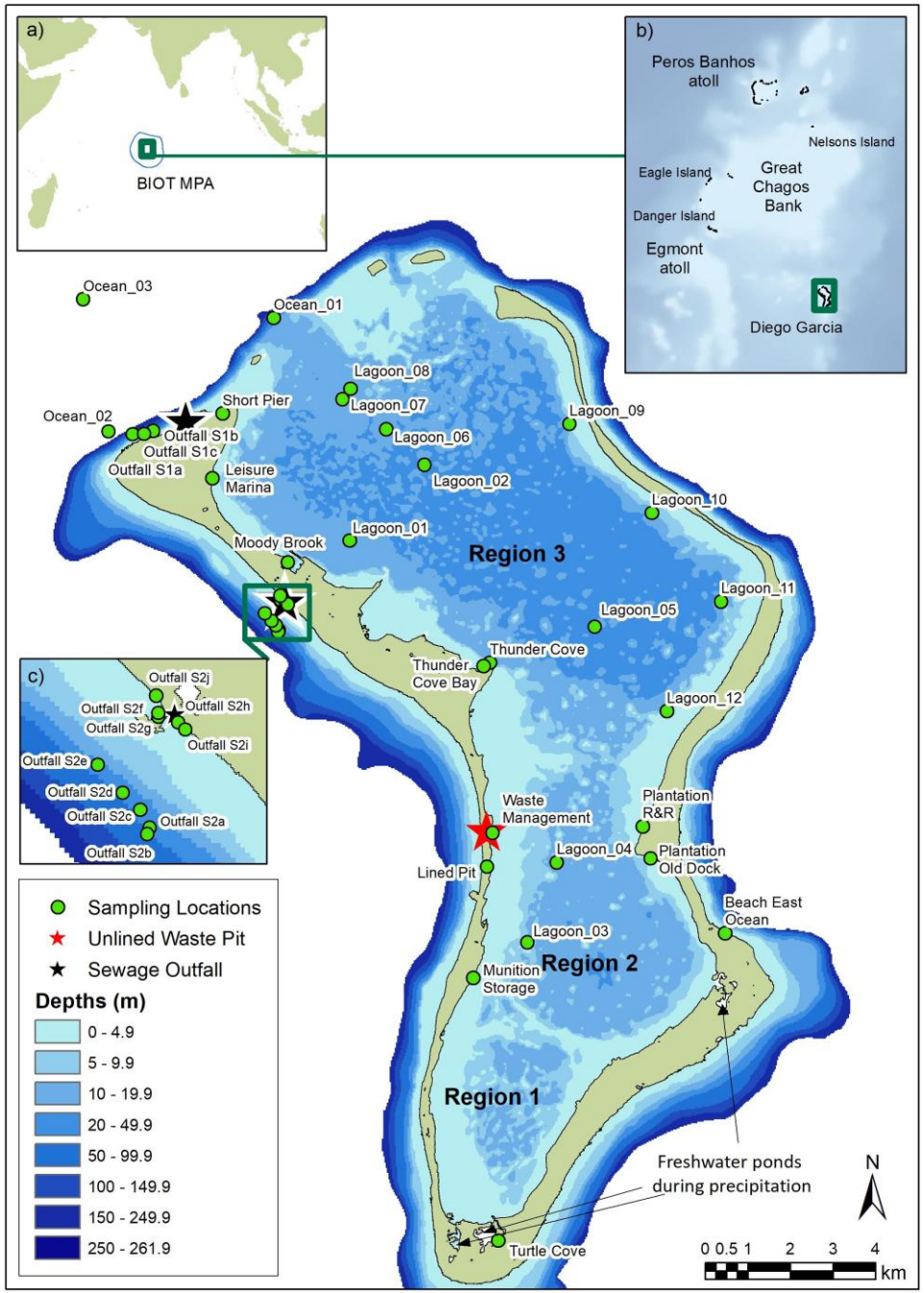
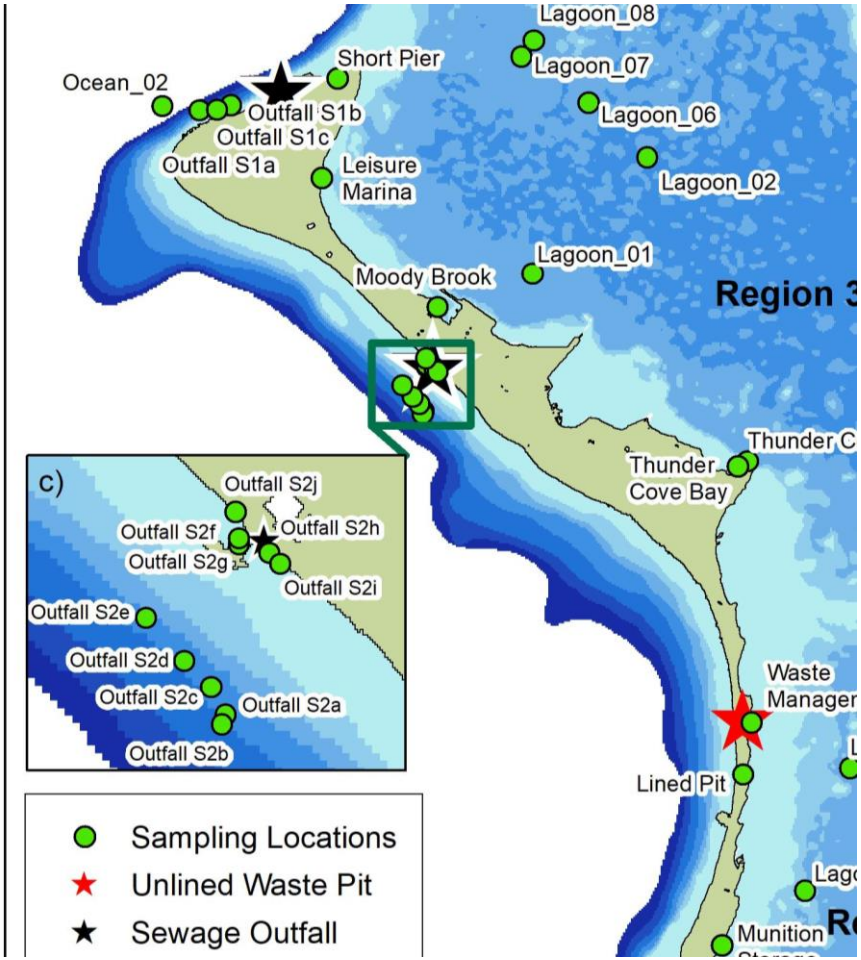


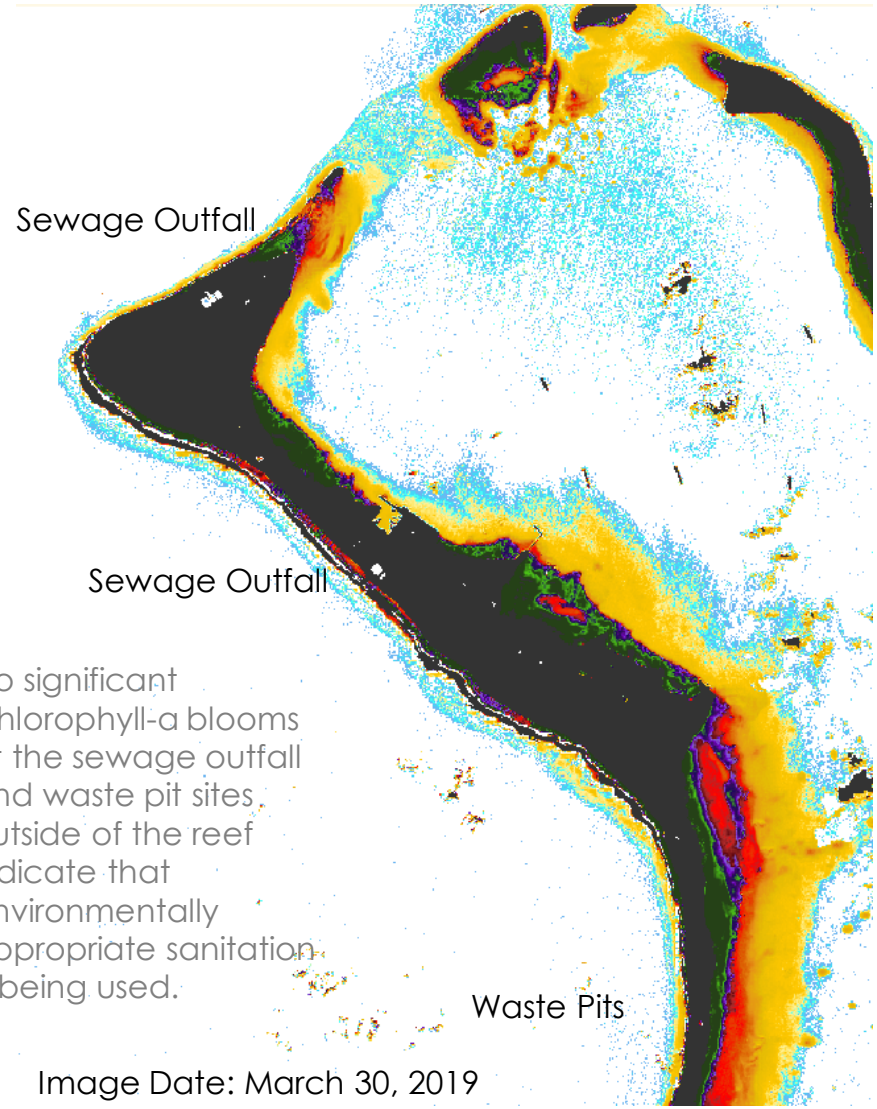
Image Credit: Marine Water Quality at Diego Garcia: A Preliminary Study of Pollution Levels in Coastal and Lagoon Waters [1]

C2rcc Results At Sewage and Waste Locations, March 30, 2019



Sample Collection Dates: March 28-31, 2019

Image Credit: Marine Water Quality at Diego Garcia: A Preliminary Study of Pollution Levels in Coastal and Lagoon Waters [1]

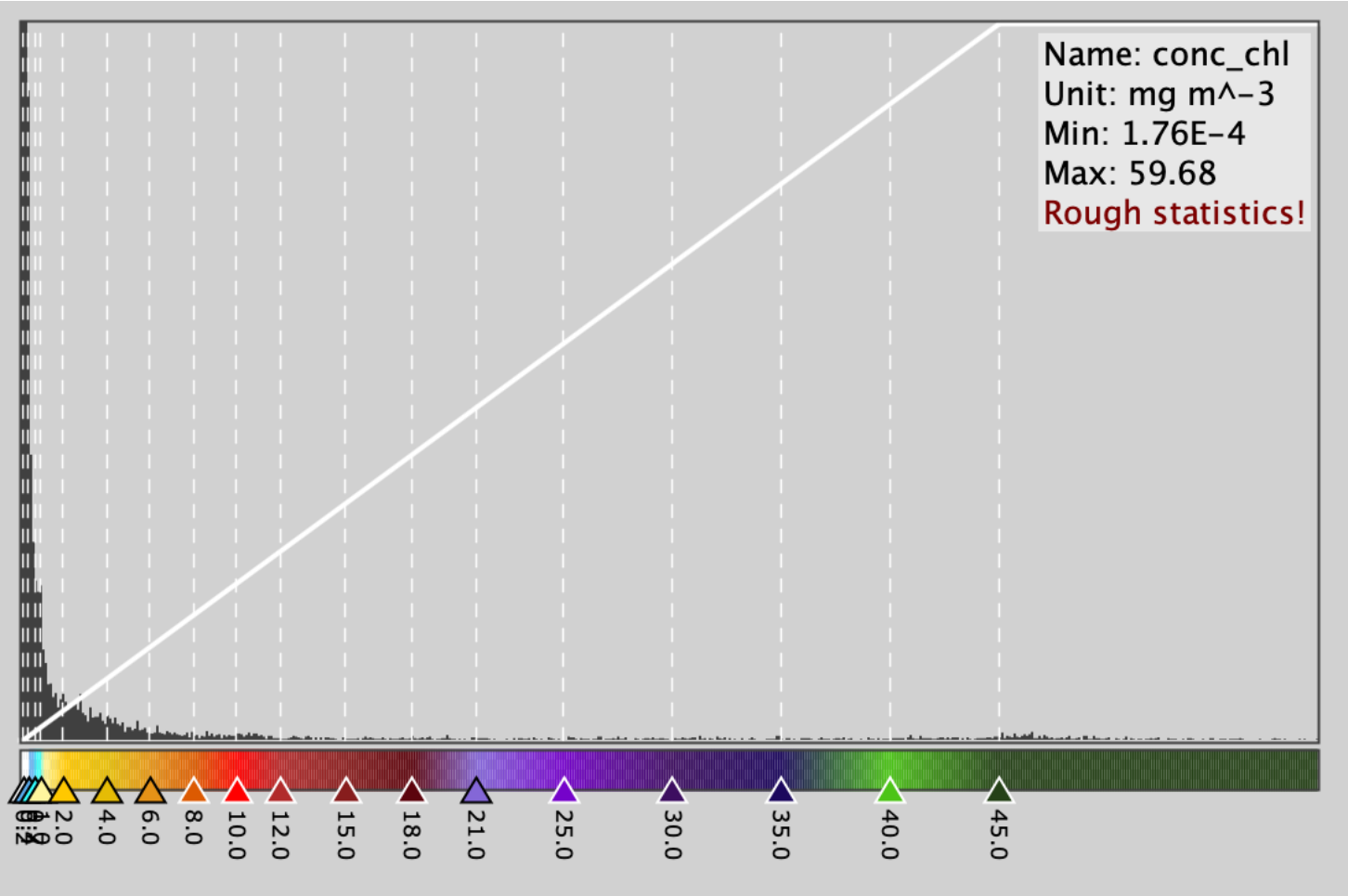


No significant Chlorophyll-a blooms at the sewage outfall and waste pit sites outside of the reef indicate that environmentally appropriate sanitation is being used.

Image Date: March 30, 2019

Imagery credit: European Space Agency – produced from ESA remote sensing data

Histogram Of Chlorophyll-a Values In The Image



In Situ Chlorophyll Values At The Collection Sites, from "Marine Water Quality at Diego Garcia: A Preliminary Study of Pollution Levels in Coastal and Lagoon Waters"[1]

The C2RCC values were derived from a March 30, 2019 image of Diego Garcia, within 2 days of the in situ data collection.

Station Name	Date	Lat	Long	Sample depth (m)	E. coli (CFU per 100 ml)	Surface Probe				Conductivity, Temperature and Depth (CTD) instrument package					
						pH	Sal	DO (mg l^{-1})	T (° C)	Time (DG)	T (° C)	Sal	Chl (~$\mu g\ l^{-1}$)	DO (mg l^{-1})	Turb (NTU)
Beach East Ocean	31/03/2019	−7.3698	72.4829	0	3										
Lagoon_01	28/03/2019	−7.2868	72.4036	1	1					09:30	30.4	33.97	N/A	N/A	0.56
Lagoon_02	30/03/2019	−7.2707	72.4194	1	0					08:55	30.4	34.12	0.33	5.9	0.35
Lagoon_03	28/03/2019	−7.3718	72.4412	1	0					10:44	30.8	33.81	N/A	N/A	−1.30
Lagoon_04	28/03/2019	−7.3548	72.4473	1	0					10:21	30.8	33.86	N/A	N/A	0.65
Lagoon_05	28/03/2019	−7.3049	72.4554	1	1					10:00	30.2	34.05	N/A	N/A	0.55
Lagoon_06	30/03/2019	−7.2632	72.4113	1						08:30	30.2	34.12	0.40	6.0	0.34
Lagoon_07	30/03/2019	−7.2567	72.4020	1						08:15	30.2	34.10	0.38	5.7	0.37
Lagoon_08	28/03/2019	−7.2546	72.4038	1	0					09:00	30.5	34.05	N/A	N/A	0.52
Lagoon_09	30/03/2019	−7.2621	72.4500	1	0					09:15	30.9	34.16	0.29	4.3	0.74
Lagoon_10	30/03/2019	−7.2808	72.4674	1	0					09:40	30.9	34.11	0.36	6.1	0.46
Lagoon_11	30/03/2019	−7.2996	72.4820	1						10:03	31.0	34.08	0.32	6.0	0.44
Lagoon_12	30/03/2019	−7.3228	72.4706	1	1					10:25	31.0	34.08	0.60	6.2	0.70
Landfill Leachate	01/04/2019	−7.3558	72.4326	0		9.2	< LOD	7.8	35.0						
Leisure Marina	27/03/2019	−7.2735	72.3745	0	1				32.0						
Leisure Marina	29/03/2019	−7.2735	72.3745	0		8.1	33.90	7.2	30.9						
Moody Brook	26/03/2019	−7.2913	72.3905	0	0				32.0						
Munition Storage	31/03/2019	−7.3793	72.4296	0	0	8.3	33.80	10.8	32.9						
Ocean_01	28/03/2019	−7.2396	72.3875	1	0					08:30	29.6	34.16	N/A	N/A	0.27
Ocean_02	29/03/2019	−7.2636	72.3526	1	0					10:50	29.6	34.12	N/A	N/A	N/A
Ocean_03	29/03/2019	−7.2356	72.3472	1	0					11:20	29.5	34.20	N/A	N/A	0.29
Outfall S1a	29/03/2019	−7.2642	72.3577	1	0					10:10	29.9	34.21	N/A	N/A	0.10
Outfall S1b	29/03/2019	−7.2634	72.3621	1	0					10:21	29.6	34.18	N/A	N/A	0.68
Outfall S1c	29/03/2019	−7.2641	72.3601	1	0					10:34	29.5	34.21	N/A	N/A	0.46
Outfall S2a	29/03/2019	−7.3056	72.3885	1	0					08:35	29.8	34.21	N/A	N/A	0.35
Outfall S2b	29/03/2019	−7.3060	72.3884	1	0					08:50	29.8	34.19	N/A	N/A	0.40
Outfall S2c	29/03/2019	−7.3046	72.3880	1	0					09:00	N/A	N/A	N/A	N/A	N/A
Outfall S2d	29/03/2019	−7.3037	72.3870	1	0					09:16	29.8	34.21	N/A	N/A	0.35
Outfall S2e	29/03/2019	−7.3021	72.3856	1	0					09:40	29.8	34.20	N/A	N/A	0.37
Outfall S2f	31/03/2019	−7.2995	72.3890	0	0	8.3	34.10	8.9	32.2						
Outfall S2g	31/03/2019	−7.2993	72.3890	0	0	8.3	34.10	8.1	32.6						
Outfall S2h	31/03/2019	−7.2998	72.3901	0	0	8.2	34.10	8.9	32.0						
Outfall S2i	31/03/2019	−7.3002	72.3905	0	0	8.2	34.10	7.8	32.0						
Outfall S2j	31/03/2019	−7.2983	72.3889	0	0	8.2	34.10	8.0	32.0						
Plantation Old Dock	31/03/2019	−7.3540	72.4671	0	3				32.0						
Plantation R&R	26/03/2019	−7.3472	72.4655	0	1				34.0						
Short Pier	27/03/2019	−7.2598	72.3767	0		8.4	33.30	11.1	31.2						
Thunder Cove	26/03/2019	−7.3126	72.4332	0					32.0						
Thunder Cove	31/03/2019	−7.3132	72.4319	0	1	8.2	33.90	7.9	33.6						
Turtle Cove	31/03/2019	−7.4349	72.4349	0	0										
Waste Management	27/03/2019	−7.3486	72.4338	0	0				33.0						
Waste Management	01/04/2019	−7.3482	72.4341	0											
Waste Management	01/04/2019	−7.3484	72.4340	0											
Waste Management	01/04/2019	−7.3486	72.4339	0		8.1	33.80	7.7	31.7						
Waste Management	01/04/2019	−7.3487	72.4338	0											

T = temperature, Sal = salinity, DO = dissolved oxygen, Chl = chlorophyll, Turb = turbidity. Shading indicates stations where vertical profiles were obtained.

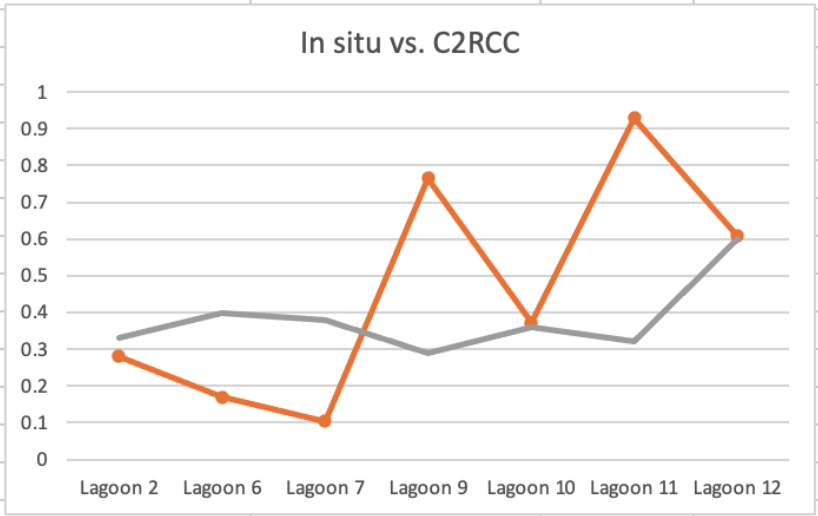
Data Credit: Marine Water Quality at Diego Garcia: A Preliminary Study of Pollution Levels in Coastal and Lagoon Waters [1]

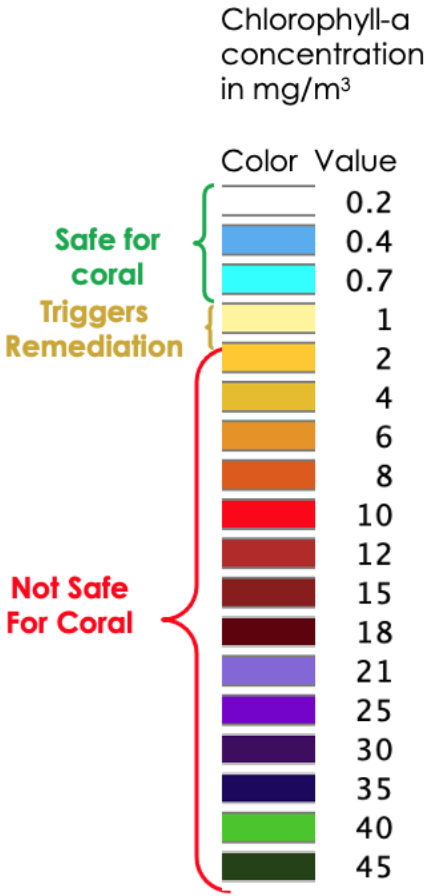
Comparison Of In Situ Values To C2RCC Derived Values

The C2RCC Chlorophyll values derived from the Sentinel 2 satellite image vary from the In Situ measurements by **less than one mg/m³** .

The maximum Chlorophyll-a value from the image was 59.68 mg/m³.

Collection Site	In Situ Chlorophyll Concentration	C2RCC Chl-a Value	difference
Lagoon 2	0.33	0.28112	-0.04888
Lagoon 6	0.4	0.1702	-0.2298
Lagoon 7	0.38	0.10344	-0.27656
Lagoon 9	0.29	0.76548	0.47548
Lagoon 10	0.36	0.37203	0.01203
Lagoon 11	0.32	0.92888	0.60888
Lagoon 12	0.6	0.6084	0.0084





Based on "Water Quality Guidelines for the Great Barrier Reef Marine Park. Great Barrier Reef Marine Park Authority, TownSVille. REVISED EDITION 2010"

In Situ Data Credit: Marine Water Quality at Diego Garcia: A Preliminary Study of Pollution Levels in Coastal and Lagoon Waters [1]

C2RCC Data Credit: European Space Agency – produced from ESA remote sensing data, SNAP Toolbox

Reference 1. “Marine Water Quality At Diego Garcia: A Preliminary Study Of Pollution Levels In Coastal And Lagoon Waters"

The in situ data and sample location images in this report are based on this research:

Marine Water Quality at Diego Garcia: A Preliminary Study of Pollution Levels in Coastal and Lagoon Waters

Painting Suzanne J., Nelson Paul, Smith Andy J., Graves Carolyn A., Powell Andy, Bersuder Philippe, Bullen Samuel, Archer-Rand Simeon

Frontiers in Marine Science VOLUME=8 YEAR=2021 PAGES=798
https://www.frontiersin.org/article/10.3389/fmars.2021.671319

ABSTRACT=Diego Garcia is the largest atoll within the Chagos Archipelago in the Indian Ocean. Since the 1960s it has been a military base, populated only by military and support personnel. Infrastructure includes sewage treatment works, a waste disposal facility and an airbase. Lagoon use includes boating and large vessel anchorage. Current pollution levels by inorganic nutrients and other contaminants are unknown. A field study was undertaken in March 2019 to obtain baseline information on key environmental parameters and pollutants for assessing the state of marine water quality. Outside the atoll, three stations were sampled where human impacts were likely to be lowest (two off the north coast, considered as ‘near-pristine’; one on the east coast); one station was sampled in the lagoon mouth; 10 stations were sampled downstream from two sewage outflows. Inside the lagoon, 10 stations were sampled at near-shore sites likely to be directly impacted by activities such as boating and waste management; six stations were sampled in the central or eastern lagoon. In situ sensors were used to estimate temperature, salinity, chlorophyll (as fluorescence) and dissolved oxygen. Discrete water samples were analyzed for nutrients, chemical contaminants, heavy metals and fecal indicator bacteria. Sea surface temperatures were highest (29.5–35 °C) inside the lagoon; salinities were generally higher (> 34.1) outside the lagoon (vs 33.8–34.1 inside). Surface nutrient concentrations at near-pristine stations were undetectable for nitrate and phosphate and averaged 1.39 μM for dissolved inorganic nitrogen (DIN) and 1.73 μM for silicate. Concentrations were higher at most other stations (maximum 5.7 μM DIN, 0.38 μM phosphate, and 9.93 μM silicate), with ammonium contributing most to DIN. In the lagoon, chlorophyll concentrations were relatively low (0.3 – 0.6 μg chl l^{–1}) near the surface and higher (max 0.9 μg chl l^{–1}) at depth. Results suggested low levels of pollution overall. However, levels of nutrients, oxygen deficiency, chemical contaminants (e.g., solvents and DEET) and heavy metals (cadmium, nickel, zinc and copper) at some sites inside the lagoon are a concern due to slow flushing rates and will be used to inform future monitoring and assessment of environmental health at Diego Garcia.