High diversity and abundance of fish and coral in an artificial breakwater in Colombo, Sri Lanka

A. K. Smith[1*], P. De Silva[2] & H. Hui[3]

[1]*Reef Ecologic, 14 Cleveland Terrace, Townsville, QLD, Australia 4810*
[2]*Co\Sri Lanka Navy Headquarters, WRPR+QRQ, Colombo, Sri Lanka*
[3]*South China Sea Institute of Oceanology, Chinese Academy of Sciences, No.164, Xingang Road (West), Guangzhou, Guangdong, China 510301*

*Corresponding author: adam.smith@reefecologic.org

ORCID ID: https://orcid.org//0000-0002-4863-485X

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Abstract The diversity of reef fishes and the diversity and abundance of corals in artificial breakwaters were studied between June and August 2023 in Port City, Colombo in the Western Province of Sri Lanka. Four methods were used: visual census using video, photographs, stationary point count and environmental DNA (eDNA). A total of 137 fish species, 74 coral species and 175 other species were recorded using the four methods. There were similarities and differences between the methods for recording fish, corals and other species. Only three fish species: Moon wrasse (*Thalassoma lunare*); Yellowtail fusilier (*Caesio cuning*) and Diamond fish (*Monodactylus argenteus*) were recorded by all methods. The highest number of fish species was recorded by video, followed by photographs, eDNA and stationary point count in the sequence. Coral cover ranged from 9 to 50.8% and mean live coral varied from 24.4% to 34.5 ± 5.2%. The dominant coral species was *Pocillopora damicornis*. Rare observations of coral bleaching (n=1) and frequent observations of marine debris (n=20) and coral damage (n=25) were recorded. Species detection using eDNA is a biomonitoring tool that did not add significantly to the list of fish and corals, but included many microscopic groups such as bacteria, diatoms and ciliates that were not recorded using other methods, and provided new ecological insights into marine systems. This is the first use of multiple monitoring tools to identify and compare methods for the biodiversity of marine fish, coral and other species in Sri Lankan marine waters.

Keywords: Artificial breakwaters, reef fish, coral reefs

INTRODUCTION

Coral reefs around Sri Lanka have coexisted with human communities for thousands of years and are a continual source of food, economic productivity, coastal management and tourism (Fairoz *et al.*, 2023). Coral reef research is relatively new in South Asia with significant limitations in capacity and monitoring efforts over time (Souter *et al.*, 2020). Knowledge of the status of coral reefs in Sri Lanka is limited due to 30 years of civil war (Arulananthan *et al.*, 2021). Sri Lanka's coral reefs are among the most degraded reefs worldwide and have shown a gradual decline from 2000 to 2015, and a significant decline following the 2016 coral bleaching event, with an average estimated Living Coral Cover (LCC) between 2 and 20% (Souter *et al.*, 2020).

A comprehensive survey of reef fish inhabiting coastal and offshore reefs of Sri Lanka is not available. A field guide contains descriptions of 158 species of reef fish divided among 37 families (Rajasuriya, 2013). The most speciose families are Chaetodontidae (19), Labridae (18), Pomacentridae (16) and Acanthuridae (13). Fishbase (2023) tabulates 983 species of saltwater fish in the waters of Sri Lanka. The FAO "Fishery and Aquaculture Country Profiles of Sri Lanka" (FAO, 2004) indicates that there are about 975 marine and brackish water fish (610 species of coastal fish, 60 species of sharks, 90 species of oceanic pelagic fish species and 215 demersal species). In addition, Öhman, Rajasuriya, & Linden (1993) have listed over 300 species of reef-associated fish belonging to 62 families.

Sixty-five coral genera (171 species) were recorded from the reefs of Sri Lanka by Rajasuriya and White (1995). There were 36 new coral species confirmed by DNA barcoding for Northern Sri Lanka (Arulananthan *et al.*, 2021). The reefs of Sri Lanka have been increasingly exposed to deleterious natural events and anthropogenic activities in recent decades. These events have resulted in reef health decline, and the reefs of Sri Lanka have recently been classified as some of the most exploited and degraded in the region (Souter *et al.*, 2020, Fairoz *et al.*, 2023).

Artificial reefs take many forms, such as reef balls, pods, concrete pipes, wrecks, sculptures and breakwaters. A breakwater is a coastal structure (usually a rock and rubble mound structure) parallel or close to the coast. It reduces incoming wave energy, provides a sheltered beach area and shelters vessels from waves and currents. A breakwater typically comprises various stone layers and is typically armoured with large stone or concrete units (Climate Adapt, 2023). The development of commercial, residential, and industrial infrastructure has resulted in dramatic modification of near-shore habitats worldwide, with man-made structures such as breakwaters, seawalls, and jetties now making up more than half of the shoreline in many regions (Burt *et al.*, 2012). Artificial reefs naturally turn into living structures as benthic organisms begin to colonise. Artificial reefs can have positive and negative impacts on fish, fishing, tourism and the environment (Moorthy, 2021, Smith *et al.*, 2022, Lima *et al.*, 2023). Interestingly, the EIA did not predict the potential positive benefits of the recruitment of corals and fish to the future breakwater and port.

Colombo Port is mainly a sandy seabed with no sheltered water bodies, and the coastal area receives a large amount of sediment and freshwater from the nearby Kelani River (SLPA, 2006). Colombo Port City is a major development by CHEC Port City Colombo (Pvt) Ltd through China Harbour Engineering Company (CHEC) which is part of China Communications Construction Company Limited (CCCC). The construction of the 3.7 km breakwater commenced in late 2016 and was completed by the end of 2019. The final construction of the marina and buildings is scheduled for 2041 (Architect 2017).

The emerging corals on the breakwater were initially discovered by Admiral Piyal De Silva (Retd) in December 2019 while on a training dive. He has monitored the changes in corals over time and commenced studies on coral reef growth and reef restoration (Sandawala, 2023).

The choice of sampling technique to maximize the probability of detection is an important aspect of ecological surveys (Westahoff *et al.*, 2022). Rarely has citizen science and eDNA been combined to study fish and coral biodiversity (Agersnap *et al.*, 2022). The purpose of this study was to examine the reef fish and coral communities associated with sheltered breakwaters of the Port City development in Colombo, Sri Lanka.

MATERIALS AND METHODS

Prior to the proposed expansion of Colombo Port, a series of baseline field surveys of plankton, nekton, benthos, and fisheries were carried out by the National Aquatic Resources Research and Development Agency (NARA) in February and April 2005 as part of the EIA study (ADB, 2006). Five dive surveys were carried out along transects in the project site. Of the principal habitats, only sandy seabed and open waters are affected by the project. The area has four reefs, whose species are generally of low diversity and abundance. All are significantly influenced by sediments from the Kelani River, with high turbidity as well as accumulated sediments on the reef surface.

This study was carried out in Port City marina, Colombo, South-Western Sri Lanka (Figure 1).

Video survey

Coral and fish surveys were conducted between 2 and 11 June 2023. Four divers surveyed four quantitative sites by taking videos of fish and coral transects and estimated the coral coverage at six qualitative sites (Figure 1).

The method used for coral surveys at quantitative sites followed the line-point transect (LIT) (Leujak and Ormond, 2007). A 50 m long tape was laid by a diver along the breakwater at 1.5 m depth underwater. The video recording of fish around the transect was done by the first diver by swimming slowly along the transect and horizontally holding a GoPro (HERO 9). After completion of this recording, the transect and the corals were vertically filmed at a distance of 30 cm

above the transect by the next divers. Photos of corals and fish were taken by the last diver swimming freely using an underwater camera (Olympus TG6). The videos and photos taken underwater were used for identifying coral and fish species on the computer. The fish were identified using standard identification keys of Rajasuriya (2013) and FishBase (ver.06 2023).

At qualitative sites, a survey along the breakwater was done by divers for more than 50 m from the intertidal zone to 5 m depth and the average coral cover of the whole depth of the breakwater was estimated based on personal experience. Calculation of coral coverage was done by using every 10 cm as a sample point, thereby the 50 m long transect yielded 500 points. Each coral colony underneath the tape at intervals of 10 cm were recorded, and the coral cover was the number of recorded coral points divided by 500.

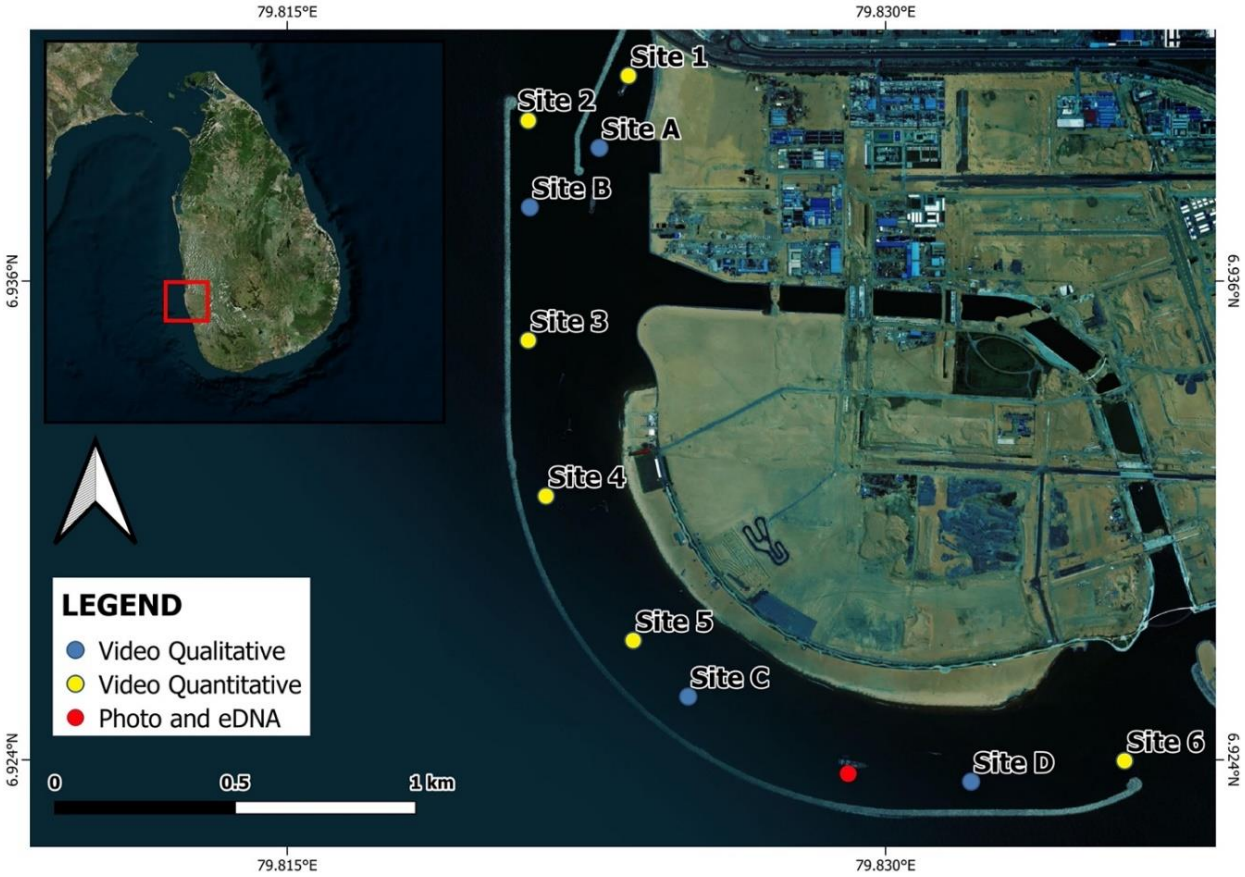

Fig 1. Location of site for underwater video and photo surveys and eDNA collection at Port City Colombo

iNaturalist survey

Fish, corals and other invertebrates were photographed over three days between 12 and 16 August 2023. The sampling sites for iNaturalist photos are indicated in Figure 1. Observations were added to iNaturalist and identified by the citizen science community.

Observations for the iNaturalist methodology were undertaken following training of Sri Lankan and US Military personnel in marine citizen science methodology associated with the 2023 Indo-Pacific Environment Security Forum (Smith *et al.*, In Press).

Stationary Point Count survey

Stationary Point Counts involved multiple pairs of snorkelers recording benthic habitat and fish species and abundance within a predefined

cylindrical area (2 m radius) along the breakwater. The snorkelers remained stationary while recording benthos into four categories (rock, coral, oyster, other) and counting all the fish from the bottom to the top of the water column in an imaginary cylinder for a set amount of 10 minutes.

eDNA survey

A single eDNA sample was collected on 16 August 2023 using the Wilderlab methodology of active syringe sampling and filtering 1000 ml of seawater through a 1.2-micron size filter. A total sample volume of 1000 ml was sampled as 20 x 50 ml sub-samples, each taken from 5 cm below the water surface. Post-filtration, syringe filters were preserved with 350 µl of DNA/RNA Shield (Zymo Research Cat. No. R1200-125). Once fixed, eDNA samples were labelled and stored in cool dark conditions before processing in the laboratory and were effectively sealed to prevent any form of cross-contamination through the design of the filtration and packaging system.

Laboratory procedures

Sample extraction, library preparation, sequencing and bioinformatics broadly followed the method outlined in David *et al.* (2021), except that DNAs were extracted using the Genolution GD141 cartridge on the Nextractor NX-48S system (Genolution), and pooled libraries were run on the Illumina iSeq 100 platform at Wilderlab NZ Limited in Wellington.

RESULTS

Video survey

Through an investigation on the inner side of the breakwater in Port City, it was found that abundant corals grow on the inner side of the breakwater. The distribution of corals was mainly concentrated on the hard substrate between the low tide line and the bottom of the breakwater, and there was no coral growth on the muddy substrate on the inside of the breakwater. The highest coral density appears from the low tide line to a depth of 1 m. The density of coral decreased with increasing water depth.

The average coral coverage rate of four quantitative sites was 37.4%. The highest coverage rate occurred at Site 4, which was 50.8%, while the lowest coverage rate occurred at Site 2, which was 26.6%.

The coral covers of qualitative sites were lower than that of quantitative sites, which may be due to less coral abundance in deeper areas. The coral covers of six qualitative sites ranged from 9.0% to 30.0%, and the average coral cover was 15.67% (Figure 2).

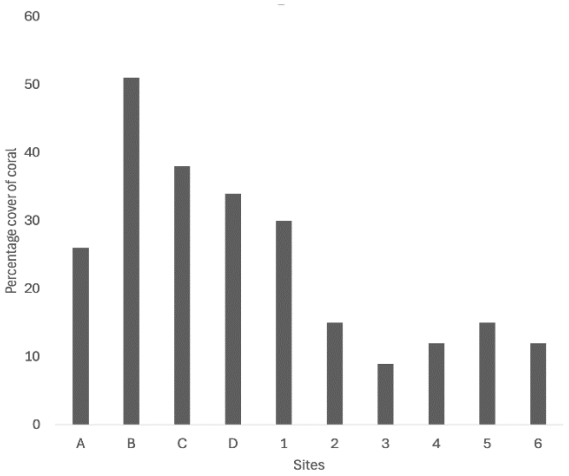

Fig 2. Coral cover at 10 sites at Port City (see Figure 1 for locations)

A total of 73 coral species in 26 genera were observed in this survey. The dominant coral species was *Pocillopora damicornis*, about 74% of coral colonies were *P. damicornis*, and *P. verrucosa* was the second dominant species. Bleached corals were found during the survey, and the coral bleaching rate was about 7.97% at that time. Most bleached corals were *P. damicornis*, and *P. verrucosa*, a few Porites, Acropora and Montipora corals were faded or bleached. One hundred and fourteen (114) fish species in 63 genera were recorded by divers, including Maori Wrasse (*Cheilinus undulatus*), Spotted eagle ray (*Aetobatus narinari*), and Yellowmargin triggerfish (*Pseudobalistes flavimarginatus*). A list of fish and coral species is in Appendices 1 and 2.

iNaturalist survey

A total of 155 observations of 83 species by 5 observers and 33 identifiers were included in the project ‘Coral Reef Restoration Sri Lanka”. Fishes comprised 62 species and 75% of observations. Seventeen of the top twenty observations were ray-

finned fishes and Brown Algae, coral and moon snails were the other observations. The top three species observed were the Indian Redfin Butterflyfish (*Chaetodon trifasciatus*), Indo-Pacific Sergeant Major (*Abudefduf vaigiensis*) and Moon Wrasse (*Thalassoma lunare*) (Figure 3). As of 12 November 2023, 50.2% of observations were research grade and verified by at least two other people. The project is publicly available at https://inaturalist.ala.org.au/projects/coral-reef-restoration-sri-lanka.

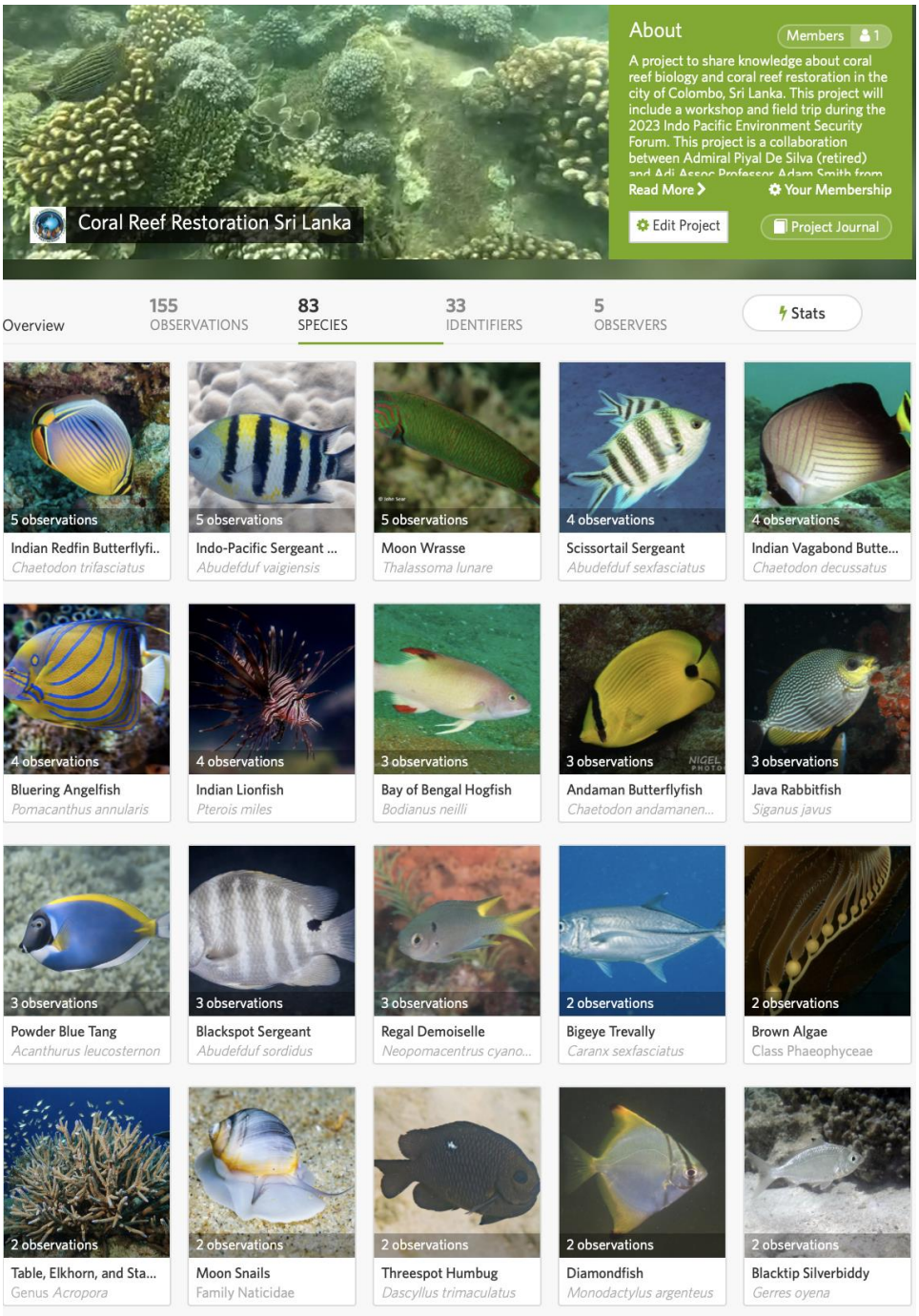

Fig 3. A summary of the top twenty observations of species and groups from photos using the iNaturalist methodology for a project Coral reef restoration Sri Lanka.

Stationary Point Count

The Stationary Point Count method was used to estimate the abundance of benthic habitat and fish at the site. The highest proportion of benthic habitat was rock at 62.7% followed by hard coral at 32.5%, oysters at 2.2% and others at 2.6% (Figure 4). Stationary point counts of fish species over a ten-minute period ranged from 6 to 24 with a mean of 11.9 +1.7. Stationary point counts of fish abundance ranged from 80 to 400 with a mean of 207.5 + 59. Minor observations of coral bleaching (n=1) and frequent observations of marine debris (n=20) and coral damage (n=25) were recorded.

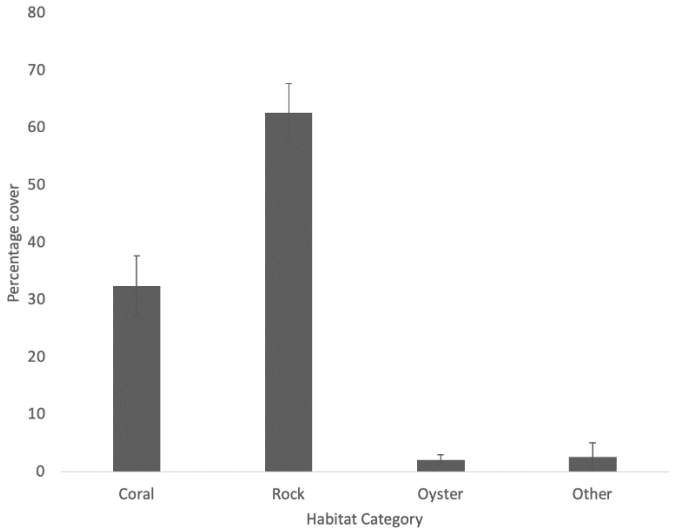

Fig 4. Average percentage cover (+SE) of benthic habitat at City Port Breakwater from Stationary Point Counts (n=12).

eDNA survey

A total of 177 categories including 22 species, 57 genera and 98 family/class/phylum/order and no rank were recorded from the water sample (Sample number 35202) (Table 1, Figure 5). The analysis is publicly available at https://s3.ap-southeast-2.amazonaws.com/wilderlab.openwaters/reports/ecad5458b34b7d 0c.html.

Table 1. Classification of fish species and other groups from eDNA analysis at Port City Colombo.

Clade	Family	Genus	Species
Percomorphaceae	Acanthuridae	Caranx	*Thalassoma lunare*
Eupercaria	Pomacentridae	Sigans	*Thalassoma bifasciatum*
	Monodactylidae	Abudefduf	*Siganus canaliculatus*
	Labridae	Chaetodon	*Siganus sutor*
		Pomacentrus	*Monodactylus argenteus*
		Drepane	*Entomacrodus vermiculatus*
		Stolephorus	*Caesio cuning*

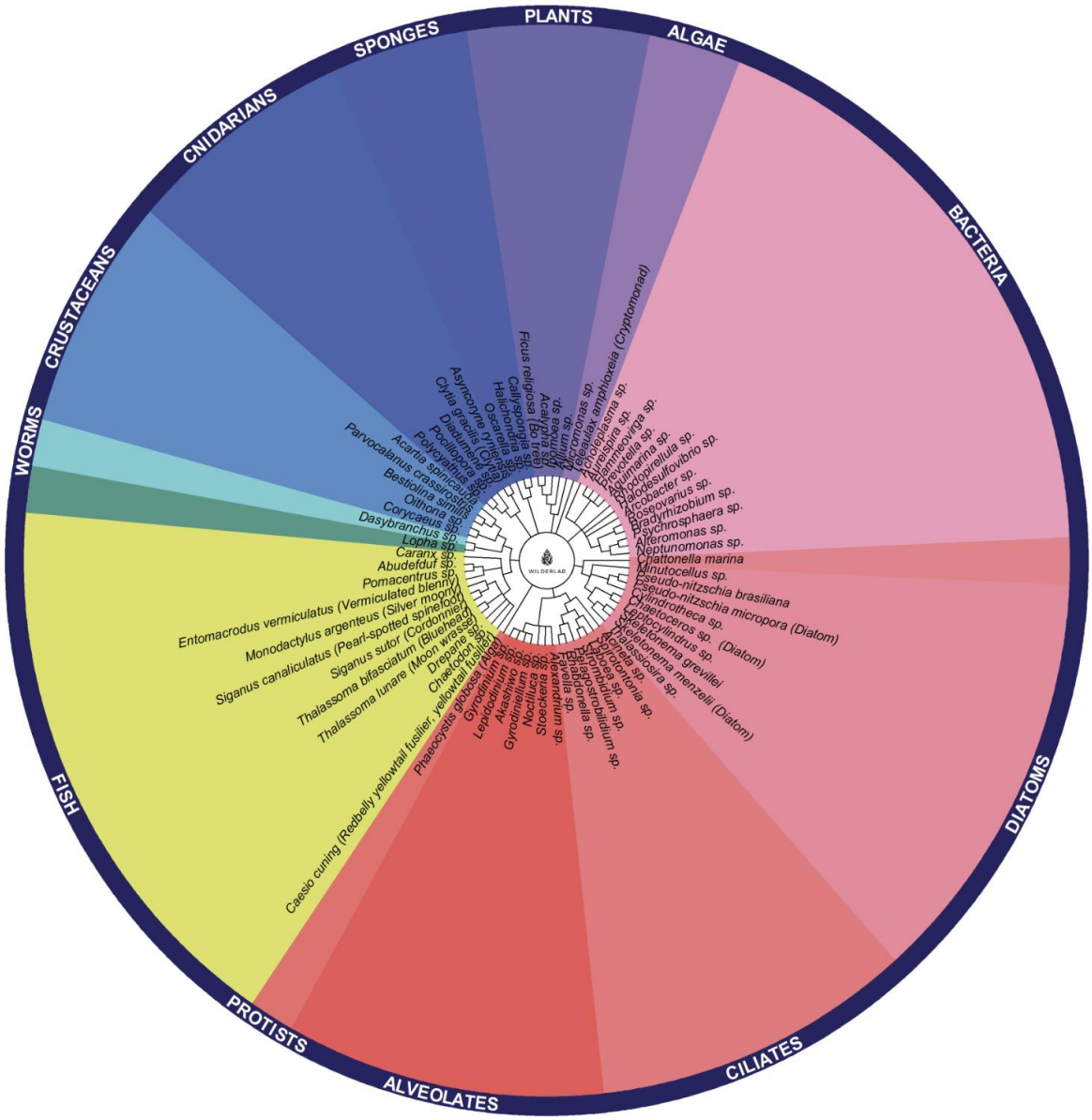

Fig 5. eDNA wheel of life of groups and species recorded from Port City Colombo.

A list of the scientific names and common names of the fish recorded for video, photo and eDNA is in Appendix 1 and summarised in Table 2. Only three species of fish were recorded using all three methods: Moon wrasse (*Thalassoma lunare*), Yellowtail fusilier (*Caesio cuning*) and Diamond fish (*Monodactylus argenteus*). There was strong consistency between the species recorded by the video and photo methods (70%).

Table 2. Comparison of biodiversity of fish, coral and other taxa using three methods and the relative effort, cost and time to collect data.

	Video	Photos	SPC	eDNA
Fish species/genera	114	62	6-24	14
Additional unique fish species		18	0	2
Coral species\genera	73	8	NA	1
Additional unique coral species		1	0	0
Other species	NA	13	NA	162
Sampling effort (hours)	15	3	1.5	0.5
Effort (cost) USD	9,000	1,000	1,000	250
Time (data availability)	2 months	0-1 day	0-1 day	3 weeks

DISCUSSION

Citizen science has seen increased use in recent years within the biological sciences (Kelly *et al.*, 2020; Wehn *et al.*, 2021, Gotama *et al.*, 2023) due to increased technology and global applications such as iNaturalist.

Baseline information on biodiversity

The total number of fish species from the three methods was 137 at Port City Colombo. This is much higher and more than double when compared with similar studies of fish in the Port of Trincomalee where 58 species were recorded at Elephant Island, 55 species at Coral Cove, 49 species at Tokyo cement sites and 12 species at the IOC site.

The total number of coral species from the three methods was 74 at Port City Colombo. This is lower than that of Arulananthan *et al.* (2021) who recorded 113 species of scleractinian corals, representing 16 families and 39 genera, as well as seven soft coral genera from Jaffna Peninsula, Northern Sri Lanka. However, the coral reefs in the vicinity of Port City Colombo are regionally significant as coral reef development in the south-western sector of the coastline is poor due to heavy rainfall during the monsoon and the resulting impact from sedimentation and turbidity. In addition, most nearshore reefs in Sri Lanka have been severely damaged due to human activities such as coral mining in the sea, destructive fishing and uncontrolled harvesting (Rajasuriya and White, 1995).

Baseline information on habitat and corals

The percentage of hard coral at one site during August was 32.5% at Port City Colombo. This is higher than the average coral cover of 24.36% from surveys of 10 sites in June 2023 (Figure 2). However, there is a strong similarity between coral cover from site D which is adjacent to the photo quadrat site.

Fairoz *et al.* (2023) compared seven coral reefs, four from the northeast end of Sri Lanka and three from the southern end and the per cent live coral cover ranged from 16.5% at Paraviwella reef to 69.8% at Pigeon Island and the mean across all sample sites (mean ± SD) was 43.8 ± 17.2%.

Comparison between survey methods

The video survey method recorded the highest number of species of both fish and corals and this is likely to be due to great survey effort over several years compared to one day for iNaturalist and eDNA sampling. The photo survey method recorded a higher number of fish species and some corals, molluscs and algae including 18 species that were not recorded by video and also some mistaken identifications. eDNA methodology included twelve categories including several microscopic groups such as bacteria, diatoms and ciliates which were not recorded using other methodologies.

We estimated the cost/benefit of the four methods based on financial costs for field work and time to analyse and report data. The fastest methods were iNaturalist and Stationary Point Count with results within one day. The cheapest method was eDNA followed by iNaturalist and Stationary Point count. The total estimated cost for field work and data entry for all four methods was approximately 11,250 USD.

Advantages and limitations

There were several advantages to this project including the support from the Sri Lankan and US Military for training in marine citizen science associated with the 2023 Indo-Pacific Environment Security Forum.

Limitations to this project include the lack of funding for the design and implementation of a scientific study. Therefore, this project was opportunistic and is a technical report of field work primarily conducted by military and citizen scientists with support from scientific experts to identify species.

The conceptual and methodological framework for aquatic eDNA detection and interpretation were developed primarily in freshwater environments and have not been well established for estuaries and marine environments which are dynamic by nature, turbid, and hydrologically complex (Nagarajan *et al.*, 2022). Several species of fish that were rare, cryptic or mobile that were difficult to photograph such as blennies and gobies were only identified with eDNA methodology. No field work was undertaken using extractive sampling such as traps, nets or lines which may have collected additional species of fish. No field work was undertaken during the night which may have included additional nocturnal species. Coral species are difficult to identify by visual aids alone due to diverse morphology. No genetic analysis was undertaken to check visual identifications. Only one eDNA sample was collected with no replications. Generally, three to six replicates are recommended for increasing the reliability of eDNA samples.

Future benefits and research

The Port City Colombo is planning on creating awareness about marine tourism and the significant coral and marine life along the Port City breakwater will provide opportunities for research and marine tourism.

The benefits of citizen science to the scientific community are numerous with the most commonly reported by scientists being to infill regions of data scarcity and expand monitoring or investigations beyond what research or authority budgets usually allow. Citizen science provides a specific, actionable, win-win opportunity to strengthen leadership, stewardship, collective regional capabilities and knowledge sharing between scientists, Defense and communities. It is particularly important for conservation and knowledge sharing during major events such as global coral bleaching (Hussein, 2024).

We recommend that future annual "Bioblitz" or "Reef Blitz" monitoring involving students, scientists, citizen scientists, fishers, tourism, Defense and community groups using tools such as iNaturalist and eDNA shouldbe conducted at multiple sites at Port City Colombo and throughout Sri Lanks to increase understanding of biodiversity and increase community care for the marine environment.

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REFERENCES

ADB 2006. Sri Lanka: Proposed Colombo Port South Harbor Development Project. Summary Environmental Impact Assessment. Project Number: 39431. July 2006. https://www.adb.org/sites/default/files/project-documents//39431-sri-seia.pdf. Accessed 17 November 2023.

Agersnap, S., E.E. Sigsgaard, M.R. Jensen, M. Avila, C. Henrik, M. Peter, R. Krøs, S, Knudsen, W. Steen, M. Wisz, & P. Thomsen, 2022. A National Scale "BioBlitz" Using Citizen Science and eDNA Metabarcoding for Monitoring Coastal Marine Fish Frontiers in Marine Science 9 https://doi.org/10.3389/fmars.2022.824100

Anon 2023. Sri Lankan, Chinese experts hold symposium on coral reef ecology?https://english.news.cn/20230607/db58f4c567514768ba08f0138291b3c8/c.html. Accessed 22 August 2023.

Architect 2017. Port City of Colombo. https://www.architectmagazine.com/project-gallery/port-city-of-colombo_o Accessed 17 November 2023

Arulananthan, A. V. Herath, S. Kuganathan, A. Upasanta & A. Harishchandra, 2021. The Status of the Coral Reefs of the Jaffna Peninsula (Northern Sri Lanka), with 36 Coral Species New to Sri Lanka Confirmed by DNA Bar-Coding. *Oceans*, *2*, 509-529. https://doi.org/10.3390/oceans2030029

Athukorala, A., W. Kumara, K. Dissanayake, K. Guruge, R. Pethiyagoda, & P. B. T. P. Kumara, 2017. Marine environmental indicators in the aspects of biodiversity at the port of Trincomalee. Conference: Proceedings of the International Research Symposium on Sustainable Coastal and Ocean Environment. Sri Lanka NEXT, BMICH, Colombo.

Burt, J., D. Feary, G. Cavalcante, A. Bauman & P. Usseglio. 2012. Urban breakwaters as reef fish habitat in the Persian Gulf. Marine pollution bulletin. 72. 10.1016/j.marpolbul.2012.10.019.

Climate Adapt 2023. Groynes, breakwaters and artificial reefs. https://climate-adapt.eea.europa.eu/en/metadata/adaptation-options/groynes-breakwaters-and-artificial-reefs. Accessed 18 August 2023.

Fairoz, M.F.M., K.T. Green, K.N.M. Sajith, W.A.S. Chamika, A.M.K.N. Kularathna, S. Macherla, D.S. Naliboff, A. Cobián-Güemes, L. Wegley-Kelly & F. Rohwer, 2023 Microbiome of Sri Lankan Coral Reefs: An Indian Ocean Island Subjected to a Gradient of Natural and Anthropogenic Impacts. Oceans, 4, 185-199. https://doi.org/10.3390/oceans402 0013

FISHBASE 2023. List of Marine Fishes reported from Sri Lanka. https://www.fishbase.se/country/CountryChecklist.php?c_code=144&vhabitat=saltwater&csub_code= Accessed 18 August 2023.

Gotama, R., S. Stean, L. Sparks, R. Prasetijo, & P. Sebastian, 2023. Citizen science approach for monitoring fish and megafauna assemblages in a remote Marine Protected Area, Regional Studies in Marine Science, 64, https://doi.org/10.1016/j.rsma.2023.103058.

Hylkema, H., A.O.R. Debrot, A.R. Cammenga, P.M. van der Laan, M. Pistor, A.J. Murk & R. Osinga, 2022.The effect of artificial reef design on the attraction of herbivorous fish and coral recruitment, survival and growth, Ecological Engineering, Volume 188, https://doi.org/10.1016/j.ecoleng.2022.106882.

Hussein, S. 2024. Divers turn conservationists as corals bleach worldwide. Atchinson GLOBE. https://www.atchisonglobenow.com/news/national/divers-turn-conservationists-as-corals-bleach-worldwide/article_7024b73e-ea28-5f66-841b-d3c10fbf4bf1.html Accessed 29 June 2024.

Kelly, R., A. G. T. Fleming, J. Pecl, von Gönner & A. Bonn, 2020. Citizen science and marine conservation: a global review. Philos. Trans. R. Soc. B Biol. Sci. 375:20190461. https://doi: 10.1098/rstb.2019.0461

Leujak, W. & R.F.G. Ormond, 2007. Comparative Accuracy and Efficiency of Six Coral Community Survey Methods. Journal of Experimental Marine Biology and Ecology, 351, 168-187. http://dx.doi.org/10.1016/j.jembe. 2007. 06.028

Lima, J.S., I.R., Zalmon & M. Love, 2019. Overview and trends of ecological and socioeconomic research on artificial reefs. Mar. Environ. Res. 145, 81–96.

Nagarajan, R.P., M. Bedwell & A.E. Holmes, T. Sanches, S. Acuna, M. Baerwald, M.A. Barnes, R.E. Connon, K. Deiner, K. D. Gille. C.S. Goldberg, M.E. Hunter, C.L. Jerde, G. Luikart, R.S. Meyer, A. Watts, & A. Schreier, 2022. Environmental DNA Methods for Ecological Monitoring and Biodiversity Assessment in Estuaries. Estuaries and Coasts 45, 2254–2273 (2022). https://doi.org/10.1 007/s12237-022-01080-y

Öhman, M.C., A. Rajasuriya & E. Ólafsson, 1997. Reef fish assemblages in north-western Sri Lanka: distribution patterns and influences of fishing practises. *Environmental Biology of*

Fishes 49, 45–61. https://doi.org/10.1023/A:1007309230416

Moorthy, S. 2021. Why Sri Lanka's artificial reef plan for fish breeding is 'toxic' in India. Ocean Research Foundation. https://www.orfonline.org/expert-speak/why-sri-lankas-artificial-reef-plan-for-fish-breeding-is-toxic-in-india/. Accessed 18 August 2023.

Port City Colombo 2023. Marine life at Port City https://www.portcitycolombo.lk/press/2023/06/19/marine-life-at-port-city.html Accessed 23 August 2023.

Rajasuriya, A. 2013. Field Guide to Reef fishes of Sri Lanka. Volume 1. Colombo: IUCN Sri Lanka Office. xxix+ 104 pages

Rajasuriya, A. & A. T. White, 1995. Coral Reefs of Sri Lanka: Review of Their Extent, Condition, and Management Status, Coastal Management, 23:1, 77-90, DOI: 10.1080/08920759509362257

Sandawala, S. 2023. Colombo's new coral reef found on port city premises. Climate Fact Checks. 6 July 2023.

Smith, A., A.J. Songcuan, N. Cook, R. Brown, K. Cook & R. Richardson, 2022. Engineering, Ecological and Social Monitoring of the Largest Underwater Sculpture in the World at John Brewer Reef, Australia. *J. Mar. Sci. Eng. 10*, 1617. https://doi.org/10.3390/jmse10111617

Smith, A., P. De Silva & C. Sholes, (In Press). Collaborative citizen science can help military and civilian objectives. *Journal of Indo-Pacific Affairs*.

Souter, D., S. Planes, J. Wicquart, M. Logan, D. Obura & F. Staub, (eds) 2021. Status of coral reefs of the world: 2020 report. Global Coral Reef Monitoring Network (GCRMN) and International Coral Reef Initiative (ICRI). DOI: 10.59387/WOTJ9184

Wang, S., Z. Yan, B. Hänfling, X. Zheng, P. Wang, J. Fan & J. Li, 2021. Methodology of fish eDNA and its applications in ecology and environment, Science of The Total Environment, 755(2). https://doi.org/10.1016/j.scitotenv.2020.142622.

Weerakoon, D.K. & S. Wijesundara Eds 2012. Provisional Checklist of Marine fish of Sri Lanka. In: The National Red List 2012 of Sri Lanka; Conservation Status of the Fauna and Flora.., Ministry of Environment, Colombo, Sri Lanka. 411-430 pp. Available from: https://www.researchgate.net/publication/336902450_Provisional_Checklist_of_Marine_fish_of_Sri_Lanka_In_The_National_Red_List_2012_of_Sri_Lanka_Conservation_Status_of_the_Fauna_and_Flora_Weerakoon_DK_S_Wijesundara_Eds_Ministry_of_Environment_Colombo_S [accessed Aug 18 2023].

Wehn, U., M. Gharesifard, L. Ceccaroni, H. Joyce, R. Ajates & S. Woods, et al. 2021. Impact assessment of citizen science: state of the art and guiding principles for a consolidated approach. Sustain. Sci. 16, 1683–1699. doi: 10.1007/s11625-021-00959-2