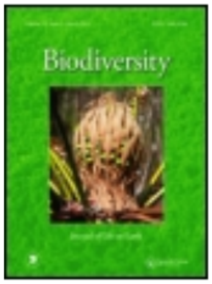
CEK - THREE DIMENSION

by D. Irawan D. Irawan

Submission date: 05-Apr-2023 09:59AM (UTC+0800)
Submission ID: 2056173296
File name: the_dimensi_1.pdf (11.6M)
Word count: 5657
Character count: 29101



Biodiversity

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tbid20

Three-dimensional (3D) modelling to determine the weight of massive corals in Gili Labak Island, Sumenep, Madura, East Java, Indonesia

D. Irawan, A. T. Mukti, S. Andriyono & F. F. Muhsoni

To cite this article: D. Irawan, A. T. Mukti, S. Andriyono & F. F. Muhsoni (2023): Three-dimensional (3D) modelling to determine the weight of massive corals in Gili Labak Island, Sumenep, Madura, East Java, Indonesia, Biodiversity, DOI: 10.1080/14888386.2023.2184425

To link to this article: https://doi.org/10.1080/14888386.2023.2184425

Published online: 23 Mar 2023.

BIODIVERSITY
https://doi.org/10.1080/14888386.2023.2184425

Three-dimensional (3D) modelling to determine the weight of massive corals in Gili Labak Island, Sumenep, Madura, East Java, Indonesia

D. Irawan[a], A. T. Mukti[b], S. Andriyono[c] and F. F. Muhsoni[d]

[a]Master Program of Fisheries Sciences, Department of Aquaculture, Faculty of Fisheries and Marine, Universitas Airlangga, Surabaya, Indonesia; [b]Department of Aquaculture, Faculty of Fisheries and Marine, Universitas Airlangga, Surabaya, Indonesia; [c]Department of Marine, Faculty of Fisheries and Marine, Universitas Airlangga, Surabaya, Indonesia; [d]Study Program of Water Resource Management, Faculty of Agriculture, Universitas Trunojoyo Madura, Bangkalan, Indonesia

ABSTRACT

This study aimed to non-destructively measure the weight of massive (live) corals through three-dimensional (3D) modelling. The 3D models were constructed using the volumes and weight of massive (dead) corals. The study was conducted through photographs, 3D analysis, and weighing 32 massive (dead) coral samples. Volume and weight were modelled using linear and non-linear regressions, and their accuracy was tested using root mean square error (RMSE) and mean absolute percentage error (MAPE). This study showed that the weight of massive (live) corals could be measured using a 3D model of the massive (dead) coral's volume and the weight mainly through regression, polynomial, and geometric equations. The power/geometric equation is a more suitable approach for determining the actual value of coral weight. Linear regression obtained an average weight of 6.13 kg per plot. Three-dimensional modelling can be widely applied to measure the massive corals in the deep sea.

ARTICLE HISTORY
Received 11 January 2023
Revised 19 February 2023
Accepted 20 February 2023

KEYWORDS
Corals; Gili Labak Island; three-dimensional modelling; volume; weight

Introduction

The preservation of coral reef ecosystems is critical because many people in the twenty-first century will rely on these resources for food production, coastal protection, and the survival of their ecosystems (Kleypas et al. 2021). Coral reefs are among the most diverse and threatened ecosystems (Hoegh-Guldberg, Pendleton, and Kaup 2019). Therefore, monitoring their responses to various threats and disturbances is critical for management and conservation. Understanding the best methods for measuring changes in corals, ecosystems, and their functions is a challenge. An emerging method for exploring colony-scale growth patterns employs underwater photogrammetry to create digital models of coral colonies (Lange, Perry, and Cooper 2020). Acoustic methods are currently widely used to detect the presence of underwater objects. These systems work exceptionally well.

Developing methodologies that allow the incorporation of three-dimensional (3D) metrics into coral reef monitoring is critical. One of the most commonly used metrics for assessing reef health is the proportion of live coral cover on reefs (Leujak and Ormond 2007). It is used as a proxy for calculating coral reef biomass and builds on the capabilities of most techniques used to evaluate linear or horizontal planar estimates. However, two-dimensional (2D) techniques alone are insufficient to estimate coral reef cover (Bamford and Forrester 2003), whereas 3D coral reef techniques provide valuable information on health (Dickens et al. 2011). The 3D surface and volume provide more accurate coral abundance statistics and allow for more accurate mapping of coral reef changes.

Manta tow, line intercept transect (LIT), point intercept transect (PIT), belt transect (BT), and quadratic transect (QT) are standard methods for researching coral reefs, depending on the purpose. The 3D modelling method is an advancement and modification of the underwater photo transect (UPT) method, which uses 3D photographs to identify coral species. Using 3D surface area and volume can provide more accurate metrics of coral abundance information and allows for more accurate capture of changes in coral reefs. This modelling is the most effective method for assessing coral reef damage and estimating carbon stocks. Comparison, photogrammetry, and 3D models offer a quick, simple, low-cost, and non-invasive method (Lange, Perry, and Cooper 2020). This study proposes a cost-effective and non-invasive method for accurate geometrical measurements of corals. Because it is impossible to obtain

CONTACT A. T. Mukti akhmad-t-m@fpk.unair.ac.id Department of Aquaculture, Faculty of Fisheries and Marine, Universitas Airlangga, Kampus C Unair, Jl. Mulyorejo, Surabaya, East Java 60115, Indonesia

photographs of all coral surfaces and know the estimated weight of corals using a 3D approach, accuracy is highly dependent on the complexity of the coral reef. This study aimed to non-destructively measure the weight of massive (live) corals through 3D modelling.

Materials and methods

Research location

This study was conducted at a depth of 8–12 m on Gili Labak Island, Talango Sub-District, Sumenep Regency, Madura, East Java, Indonesia. A map of the study location is shown in Figure 1.

Sampling

A 3D model was created using 30 colonies of massive dead corals that were weighed and photographed for analysis in the Agisoft Metashape Professional (AMP) software. The volume and weight results were used to find linear and regression non-linear equations. Next, 30 coral samples were used for an accuracy test, and volume was measured in a pond using an Olympus TG-6 camera on a transect of 30 cm × 30 cm and in the field using a 50 cm × 50 cm frame for live coral (Figueira et al. 2015).

Three-dimensional measurement of massive corals

AMP software was also used to analyse the results of coral photographs. First, the image quality of underwater photographs was estimated using the image's sharpness, exposure, focus, resolution, and depth of field. The camera and build dense cloud (BDC) were then synced with the software and scaled with a scale. Third, a dense point cloud was created using depth information from each camera and a densification algorithm. Fourth, 3D nets were built. Creating texture is optional, but performing 3D measurement and analysis is not required. Planar projections by orthographic views were used to isolate a 'cleaned' coral colony model from other reconstructed elements such as reef foundations, and AMP editing oriented all models. Exported models were used for quantitative analysis and volume calculations (Kabiri, Rezai, and Moradi 2020; de Oliveira et al. 2021).

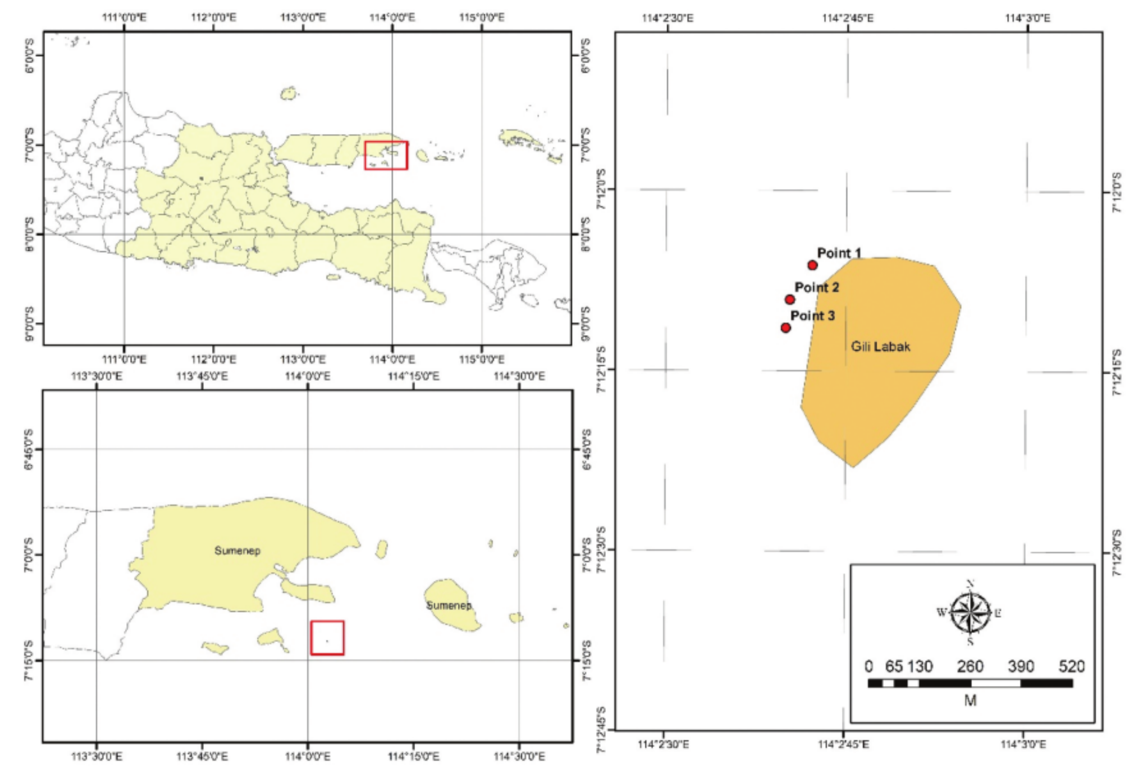


Figure 1. Map of the study location at Gili Labak Island, Talango Sub-District, Sumenep Regency, Madura, East Java, Indonesia.

Before taking the 3D photograph in the pond, the coral was weighed. These data were collected to create a model using linear and non-linear regression. Following that, 32 massive corals from the second sample were weighed for root mean square error (RMSE) and mean absolute percentage error (MAPE) tests. The 32 massive coral colonies were weighed to obtain the modelling test data. Then, the data were used to estimate the weight of massive live corals on Gili Labak Island. Data processing through 3D was carried out repeatedly.

Underwater camera

Coral colonies were photographed from every angle possible, including above and below. The camera was positioned at each object angle (Burns et al. 2015). The 3D volume was measured by collecting photographs of 32 coral colonies at a depth of 8 m. A schematic of the camera position is used to generate 3D images, as illustrated by Ahmad, Jinah, and Saad (2020).

Massive corals were photographed in the pond using a 30 cm × 30 cm transect, while corals were photographed in the field using a 50 cm × 50 cm transect (Ahmad, Jinah, and Saad 2020). Continuous underwater photography from oblique planes and angles captured the entire colony surface, with 70–80% overlap (Bythell and Pan 2001; Burns et al. 2019). All photographs were uploaded to the AMP software, and the camera was calibrated using metadata-derived focus information. Furthermore, the photographs were aligned using an algorithm capable of detecting invariant features that overlap between consecutive photographs. A geometric projection matrix was created using invariant features and position, and the camera orientation for each photograph was determined according to Westoby et al. (2012). Extrinsic parameters calculated during the photo-alignment process were combined with intrinsic and focal parameters obtained from the metadata to create the 3D geometry from the 2D images (Stal et al. 2012). Bookmarks were used as a reference for all ground control points (GCPs), and the location of each marker in all photographs containing the GCP was reviewed and corrected. Values of x, y, and z for each GCP were entered into the software to optimize alignment and ensure the resulting model's accurate interior and exterior orientation.

The pattern of relationships between independent and dependent variables influencing the 3D weight and volume of coral reefs was determined using regression analysis (Scott, Hosmer, and Lemeshow 1991). This analysis was used to determine the conversion from volume to weight of corals in the field. Conversion from volume to weight of corals was obtained to the best value of non-linear regression. Regression analysis was divided into linear and non-linear regressions based on the relationship pattern. When the variables have a power/geometric relationship, the model is called a non-linear regression. When a non-linear regression model in parameters is differentiable, the result is always a function in parameters, as stated. The non-linear regression in parameters was calculated according to Scott, Hosmer, and Lemeshow (1991). Statistical analysis was performed on three regression and non-linear regression equation models – linear, polynomial, and power/geometric – based on 3D volume and weight photographs of massive (dead) corals.

RMSE test

An accuracy test was carried out to determine the best equation for estimating the volume and weight of corals. Using RMSE, an accuracy test was employed to determine the error value of the regression equation. Then, 3D volume photographs were compared to 3D weight photographs. The RMSE equations used were the following:

$$\mathrm{RMSE} = \sqrt{\frac{i}{n}\sum_{i=1}^{n}(x_1 - y_1)^2}$$

$$\mathrm{RMSE}(\%) = \frac{RMSE}{\acute{Y}} \times 100$$

where RMSE = root mean square error, x_1 = 3D measurement result value, y_1 = 3D value prediction, and $\acute{Y}$ = average 3D measurement results (Suprayogi, Trimaijon, and Mahyudin 2014; Gurchiek et al. 2017).

MAPE test

MAPE was used to evaluate the estimation of the results and determine the accuracy of the estimated number and the realization rate. The following equation was used to calculate the value:

$$\mathrm{MAPE}(\%) = \frac{\sum_{t=1}^{n}\frac{[A_t - F_t]}{At}}{n} \times 100$$

where MAPE = mean absolute percentage error, F_t = estimated value at time t, A_t = actual value at time t, and n = total data (t = 1, 2, . . ., n).

The MAPE test model's accuracy was measured according to three criteria: very accurate (MAPE <

5%), accurate (5% < MAPE < 10%), and inaccurate (MAPE > 10%) (Nabillah and Ranggadara 2020).

Data analysis

Three-dimensional photographs were taken in a small pond with 30 colonies to find linear and non-linear regression models, using 30 colonies for accuracy tests, and 32 samples of massive coral colonies for comparison (Fukunaga and Burns 2020). A digital elevation model (DEM) is a raster grid that references the subject surface's starting point. This modelling allows for the removal of objects from the surface, resulting in a 3D model with a smooth surface. If the DEM image does not appear during analysis, the volume results will not be displayed, and the analysis cannot be continued in the AMP software. The average number of photographs analysed in 3D for each coral colony was 93 to 98. The photographs were then analysed (Lange, Perry, and Cooper 2020) using AMP software (Kabiri, Rezai, and Moradi 2020; de Oliveira et al. 2021).

Results

We developed a 3D volume model of dead coral samples collected in the field. Dead coral samples were used to avoid causing harm to the coral ecosystem at the study site. Experiments with a frame binding point of 30 cm × 30 cm yielded photographs of the dead coral samples. The number was indicated as a binding point in the corner of the frame; the binding point's purpose is to serve as a GCP for 3D photo analysis. The results of the dead coral colony analysis are presented in Figure 2.

Next we analysed, using AMP software, the 3D images captured underwater from 30 massive (dead) coral colonies in a pond, which yielded 3D modelling volumes from the coral samples, with images captured of the entire coral surface. Each coral sample contains an average of 102 photographs. Table 1 shows the results of the RMSE control point analysis on the 3D photographs of corals in the pond.

The photographs were analysed in 3D using the AMP 1.7.4 software, and the RMSE control point value was calculated. Based on this analysis, the 3D photo error in the water (small pond) is less than 1 mm. The 3D photo analysis yielded an average RMSE (of corals in small ponds with an average of 102 photographs) X error of 0.29206 mm, Y error of 0.50167 mm, Z error of 0.34566 mm, XY error of 0.59070, and total error of 0.72119 mm. The water's influence can affect the camera and distort the image. Table 2 displays the results of linear and non-linear regression analysis of weight and volume using AMP software.

Table 2 shows that the model with the best power/geometric accuracy resulted in $y = 2.451x^{0.898}$, $R^2 = 0.916$ with RMSE test of 251.20 g, %RMSE of 18.10%, and MAPE of 19.17%, while linear regression resulted in $y = 0.964x + 314.470$, $R^2 = 0.912$, RMSE of 284.50 g, %RMSE of 20.50%, and MAPE of 27.43%. Meanwhile, the polynomial resulted in $y = 0.001x^{2} + 1.235x + 49.448$ $R^2 = 0.915$ with RMSE test of 354.30 g, %RMSE of 25.5%, and MAPE of 20.0%. Based on its orthographic projections, the coral colony orientation is utilized to calculate volume. On the other hand, growth orientation is influenced by environmental factors such as habitat complexity, slope, and light plane, potentially leading to estimation bias.

Coral samples were also weighed to calculate the mass of massive corals. All coral samples from the 3D photo volume and the weight of dead corals were used to obtain a model for the estimated live coral weight. The volume from 3D photographs and the weight of corals shown in Table 3 were used to construct a model using linear and non-linear regression equation approaches.

The volume of the coral could not be directly considered in the 3D photo analysis using AMP software because the coral has a complex shape and a concave bottom with small cavities. The volume of a 3D photo model is usually invisible and illegible. As a result, a conversion is required to minimize errors when using a regression approach. The power/geometric conversion of the model from the initial data to the linear regression equation model is y = 2.451x0.898, $R^2 = 0.916$ with RMSE test of 251.20 g, %RMSE of 18.10%, and MAPE of 19.17%.

Data on corals

The results of the analysis of live coral colonies on Gili Labak Island can be seen in Figure 3. The modelling application and field data collection were tested on Gili Labak Island. Photographs were taken of a sample of 32 coral colonies by diving to depths ranging from 8 to 12 m. The iron frame used is 50 cm × 50 cm or 2500 cm^2, with a mark on each corner of the frame serving as a binding point for the photograph and making analysis easier in the AMP software. The results of the 3D analysis are shown in Table 3.

The model conversion from the initial data using the power/geometric equation model was $y = 2.451x^{0.898}$ with $R^2 = 0.916$. In Gili Labak Island, the average weight of coral volume produced is 6.13 kg per plot, and the total coral volume weight for the 32 plots is 169.92 kg, with a maximum value of 32.92 kg per plot and a minimum value of 0.04 kg per plot.

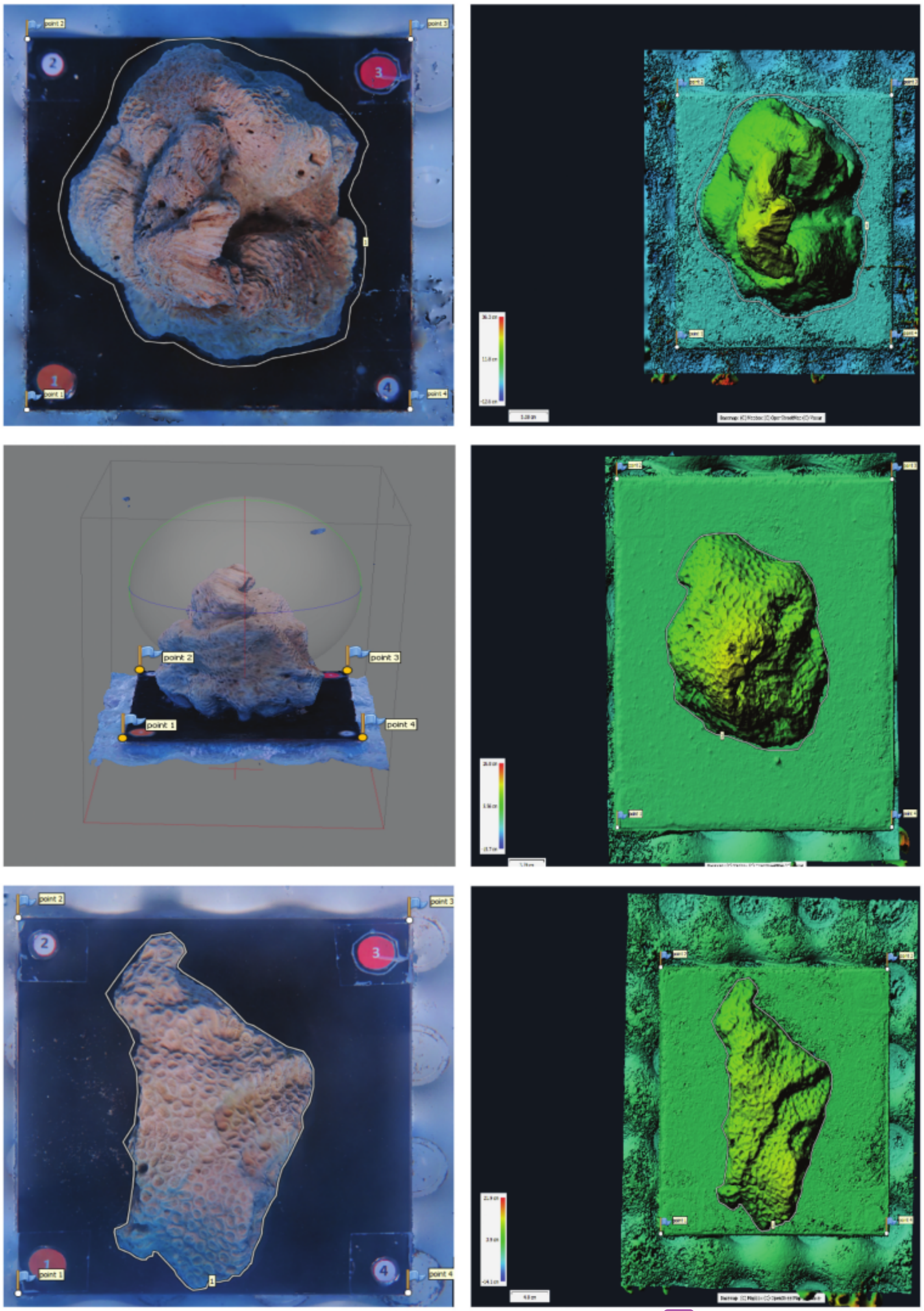


Figure 2. Results from the analysis, using Agisoft Metashape Professional (AMP) software, of the digital elevation model (DEM) and three-dimensional photographs of massive (dead) corals.

Table 1. Root mean square error (RMSE) control points on the results of three-dimensional (3D) photographs analysis in a small pond.

Coral no.	No. of photos	Root mean square error (RMSE)				
		X error (mm)	Y error (mm)	Z error (mm)	XY error (mm)	Total (mm)
1	97	0.55387	1.13955	0.77888	1.26703	1.48728
2	100	0.27418	0.18195	0.04357	0.32906	0.33193
3	96	0.86821	0.86821	2.64072	1.18693	2.89520
4	94	0.44546	0.40574	0.48895	0.60255	0.77597
5	102	0.16377	0.31121	0.01835	0.35167	0.35215
6	95	0.23989	0.26469	0.32463	0.35722	0.48270
7	89	0.01553	0.23047	0.15672	0.23099	0.27913
8	96	0.31492	0.28618	0.41279	0.42553	0.59285
9	110	0.26506	0.24065	0.15519	0.35801	0.39020
10	82	0.19772	0.57799	0.20527	0.60183	0.63587
11	89	0.06381	0.21831	0.12998	0.22744	0.26196
12	115	0.26025	0.42471	0.20647	0.49811	0.53921
13	114	0.26427	0.30750	0.20589	0.40546	0.45474
14	114	0.10470	0.33880	0.18488	0.35461	0.39992
15	95	0.15410	0.33145	0.23749	0.36552	0.43590
16	100	0.10025	0.36274	0.18387	0.37634	0.41886
17	102	0.05425	0.34436	0.16343	0.34861	0.38502
18	104	0.11650	0.13726	0.14757	0.18004	0.23279
19	93	0.30765	0.43068	0.06607	0.52928	0.53339
20	100	0.26892	0.42773	0.26986	0.50525	0.57280
21	110	0.08382	0.15316	0.26245	0.17459	0.31522
22	113	0.08055	0.18929	0.28779	0.20571	0.35375
23	114	0.16094	0.20679	0.04977	0.26204	0.26673
24	111	2.18783	5.24739	0.98116	5.68522	5.76926
25	110	0.14644	0.34430	0.68882	0.37415	0.52542
26	119	0.51075	0.23892	0.66404	0.56387	0.87115
27	94	0.10643	0.17073	0.18373	0.20119	0.27246
28	108	0.08465	0.21065	0.01163	0.22703	0.22733
29	101	0.07523	0.20130	0.13604	0.21490	0.25434
30	103	0.17461	0.25764	0.08381	0.31109	0.32218
Average	102	0.29206	0.50167	0.34566	0.59070	0.72119

Table 2. The volume of corals from three-dimensional (3D) photographs analysis by weight.

Analysis	Massive coral reefs	Test data
Linear	$y = 0.964x + 314.470$ $R^2 = 0.912$	RMSE = 284.50 g %RMSE = 20.50% MAPE = 27.43%
Polynomial	$y = 0.001x^2 + 1.235x + 49.448$ $R^2 = 0.915$	RMSE = 354.30 g %RMSE = 25.50% MAPE = 20.00%
Power/ geometric	$y = 2.451x^{0.898}$ $R^2 = 0.916$	RMSE = 251.20 g %RMSE = 18.10% MAPE = 19.17%

RMSE = root mean square error, MAPE = mean absolute percentage error.

Discussion

The diversification of new methods in coral reef research is increasing. In this study, a new method was used to assist examiners who do not have direct experience in identifying coral in the sea, allowing novices to process data and identify coral on land without direct identification in the field. One advantage of the 3D method used in this study is the ability to obtain more controlled and verifiable data, and data on the volume of coral reefs that could not be obtained using previous methods. The work of Reichert et al. (2016) on scleractinian corals shows that the 3D method yields measurements of coral surface area and volume that are highly precise and easy to reproduce.

This study uses DEM results from AMP software to determine the volume of massive coral colonies and then models massive coral weight in Gili Labak Island, Sumenep, Madura. Three-dimensional modelling is the most effective data presentation method for describing coral reef damage. Acoustic methods are commonly used at present to detect the presence of underwater objects. This system is beneficial for exploring the underwater environment (Kornder et al. 2021).

The emerging method of developing digital models of coral colonies using underwater photogrammetry provides a new and non-invasive way to examine colony-scale growth patterns and fill gaps in existing knowledge (Lange, Perry, and Cooper 2020). The main difficulty in coral reef ecology is estimating the

Table 3. The volume of three-dimensional (3D) photographs produced by Agisoft Metashape Professional (AMP) software and weight of coral conversion using a power/geometric model.

No.	Volume from the 3D photo analysis (cm^3)	Coral weight estimated using power/geometric model (g)	Genus of coral
1	2951	3191.71	*Favia*
2	3173	3406.42	*Favites*
3	6045	6075.19	*Pavona*
4	39,727	32,924.42	*Favia*
5	26,236	22,687.22	*Leptoseris*
6	5402	5491.86	*Favia*
7	5125	5238.42	*Coscinaraea*
8	8601	8337.39	*Leptoria*
9	1825	2073.42	*Favia*
10	2564	2813.35	*Caulastrea*
11	2093	2344.78	*Caulastrea*
12	3937	4134.27	*Pavona*
13	13,706	12,666.88	*Montastrea*
14	1703	1948.57	*Montastrea*
15	23,181	20,301.18	*Favites*
16	4388	4556.98	*Favia*
17	2223	2475.09	*Psammocora*
18	2983	3222.76	*Goniastrea*
19	4112	4298.86	*Favia*
20	384	511.77	*Montastrea*
21	10,421	9904.99	*Psammocora*
22	4016	4208.66	*Psammocora*
23	7715	7562.26	*Coscinaraea*
24	21	37.69	*Leptoseris*
25	7036	6962.07	*Psammocora*
26	14,529	13,347.55	*Psammocora*
27	226	318.00	*Euphyllia*
28	969	1174.64	*Psammocora*
29	471	614.73	*Montastrea*
30	255	354.40	*Porites*
31	253	351.90	*Porites*
32	2509	2759.12	*Favia*

abundance and composition of communities living in such complex ecosystems (Kornder et al. 2021). This study used technological advances to identify volumes in massive coral colonies using a 3D model. The advancement of photogrammetric technology has created a viable and practical method for exploring coral reefs (House et al. 2018). The structural parameters of reef surfaces and organisms have been shown to have relatively high accuracy when using photogrammetry in combination with underwater photogrammetry (Veal et al. 2010; Bryson et al. 2017).

Testing accuracy and precision are critical in any research, including underwater photogrammetry of corals. The accuracy and precision of the geometry obtained from the massive coral's 3D model were tested in this study. The results indicate that 3D measurement is an accurate quantitative study of the physiology and various sizes of coral colonies, and it can be done in situ. This technique could also be used to measure morphometrics of branching species, such as branch spacing, density, branch length, and branch angle. The 3D method precisely measures architectural complexity, topography, rugosity, volume, and other critical structural properties in ecosystems (Burns et al. 2015). This method reconstructs the 3D structure of corals and habitat-forming organisms at high resolution and accuracy by using a series of overlapping images taken from multiple perspectives (Bryson et al. 2017). Reichert et al. (2016) stated that the 3D method yields highly precise and reproducible measurements of the surface area and volume of corals.

This study also included RMSE test results, which had a value of 18.10% and a MAPE of 19.17%, whereas Hatcher et al. (2020) produced a relative RMSE of 0.013%. The present study produced a higher value of RMSE compared to Figueira et al. (2015), who obtained results of 10% from bottle coral measurements. The number of cameras used impacts the precision of results. In this study, only one camera was used; therefore, the RMSE value was higher and the results less precise than those of previous studies completed by Hatcher et al. (2020) and Figueira et al. (2015), who used five cameras to capture their underwater objects.

Photogrammetry was initially developed and applied in terrestrial settings, but it has since become a valuable tool for creating 3D models of bathymetry and underwater habitats. Because complete recordings of all surfaces are not possible, complex corals cannot be observed adequately with this model. This is a noninvasive method for obtaining precise geometric

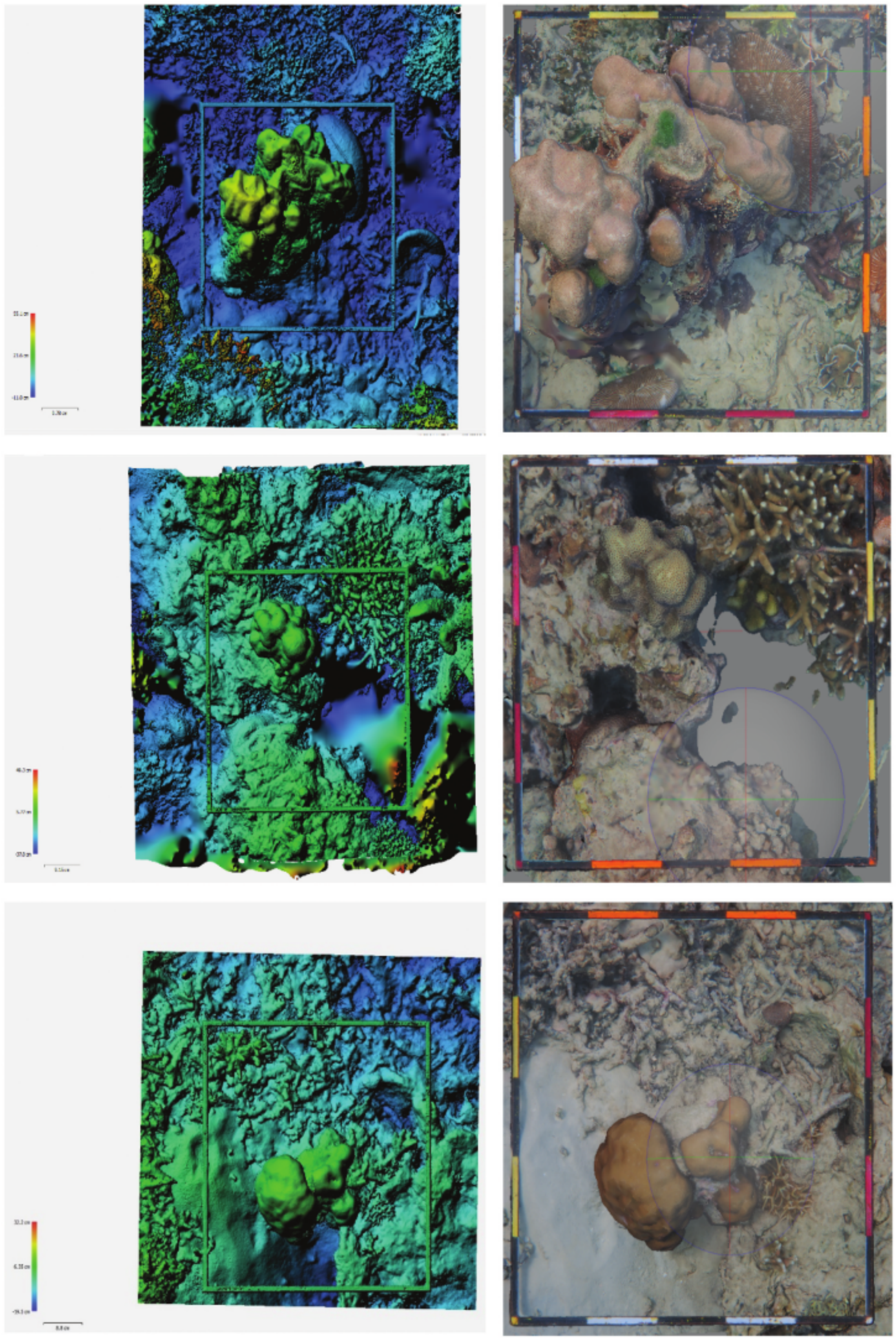


Figure 3. Results from the analysis of the digital elevation model (DEM) and three-dimensional photographs of corals in Gili Labak Island, Sumenep, Madura.

measurements of corals and other irregular underwater objects (Bythell and Pan 2001). The 3D method has many advantages but also several weaknesses, including longer analysis time and a requirement for more sophisticated software, high-spec computer devices, and special skills in underwater data collection through diving.

Conclusion

The massive corals in the deep sea can be identified and measured using non-disruptive 3D modelling. This study contributes to a growing body of knowledge revealing pathways that can be used to determine the carbon sequestered in coral reefs. This method is a non-invasive, cost-effective, and time-saving approach for obtaining accurate coral geometric measurements. Due to the difficulty in obtaining complete photographs of all surfaces, accuracy is highly dependent on the complexity of the coral reef and the number of cameras available for image capture.

Acknowledgements

The authors thank the Directorate of Research, Technology, and Community Services (DRTPM), Directorate General of Higher Education, Research, and Technology, Ministry of Education, Culture, Research, and Technology, Republic of Indonesia. The authors also thank the editor, reviewers, and proofreaders for the comments, corrections, and suggestions to improve this article.

Author contributions

DI conceptualized the study, collected the materials, performed the experiment, measured parameters, analysed the data, and prepared the manuscript draft; ATM conceptualized the study, designed it, analysed the data, and edited and corrected the final manuscript; SA proofread the manuscript draft and corrected the English grammar; FFM designed and corrected the manuscript draft. All authors read and approved the final manuscript.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This study was supported by the Directorate of Research, Technology, and Community Services (DRTPM), Directorate General of Higher Education, Research, and Technology, Ministry of Education, Culture, Research, and Technology, the Republic of Indonesia through the Grants of Penelitian Tesis Mahasiswa (PTM) with Decree Number: 1004/UN3/2022 and Contract Number: 085/E5/PG.02.00.PT/2022.

Notes on contributors

D. Irawan is a student at Master Program of Fisheries Science, Department of Aquaculture, Faculty of Fisheries and Marine, Universitas Airlangga.

A. T. Mukti is a lecturer at Department of Aquaculture, Faculty of Fisheries and Marine, Universitas Airlangga.

S. Andriyono is a lecturer at Department of Marine, Faculty of Fisheries and Marine, Universitas Airlangga.

F. F. Muhsoni is a lecturrer at Study Program of Water Resource Management, Faculty of Agriculture, Universitas Trunojoyo Madura.

ORCID

A. T. Mukti http://orcid.org/0000-0002-1649-5090
S. Andriyono http://orcid.org/0000-0002-2566-1636
F. F. Muhsoni http://orcid.org/0000-0003-3265-1636

References

Ahmad, Z. B., M. I. H. B. M. Jinah, and S. B. Saad. 2020. “Comparison of 3D Coral Photogrammetry and Coral Video Transect for Coral Lifeform Analysis Using Low-Cost Underwater Action Camera.” *ASEAN Journal on Science and Technology for Development* 37 (1): 15–20. doi:10.29037/AJSTD.602.

Bamford, D. R., and P. L. Forrester. 2003. “Managing Planned and Emergent Change within an Operations Management Environment.” *International Journal of Operations and Production Management* 23 (5): 546–564. doi:10.1108/01443570310471857.

Bryson, M., R. Ferrari, W. Figueira, O. Pizarro, J. Madin, S. Williams, and M. Byrne. 2017. “Characterization of Measurement Errors Using Structure-From-Motion and Photogrammetry to Measure Marine Habitat Structural Complexity.” *Ecology and Evolution* 7 (15): 5669–5681. doi:10.1002/ece3.3127.

Burns, J. H. R., D. Delparte, R. D. Gates, and M. Takabayashi. 2015. “Utilizing Underwater Three-Dimensional Modeling to Enhance Ecological and Biological Studies of Coral Reefs.” *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives* 40 (5W5): 61–66. doi:10.5194/isprsarchives-XL-5-W5-61-2015.

Burns, J. H. R., A. Fukunaga, K. H. Pascoe, A. Runyan, B. K. Craig, J. Talbot, A. Pugh, and R. K. Kosaki. 2019. “3D Habitat Complexity of Coral Reefs in the Northwestern Hawaiian Islands is Driven by Coral Assemblage Structure.” *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences* 42 (2/W10): 61–67. doi:10.5194/isprs-archives-XLII-2-W10-61-2019.

Bythell, J. C., and P. Pan. 2001. “Three-Dimensional Morphometric Measurements of Reef Corals Using Underwater Photogrammetry Techniques.” *Coral Reefs* 20: 193–199. doi:10.1007/s003380100157.

de Oliveira, L. M. C., A. Lim, L. A. Conti, and A. J. Wheeler. 2021. “3D Classification of Cold-Water Coral Reefs:

A Comparison of Classification Techniques for 3D Reconstructions of Cold-Water Coral Reefs and Seabed." *Frontiers in Marine Science* 8: 640713. doi:10.3389/fmars.2021.640713.

Dickens, L. C., Christopher H. R. Goatley, J. K. Tanner, D. R. Bellwood, and Richard K. F. Unsworth. 2011. "Quantifying Relative Diver Effects in Underwater Visual Censuses." *PLoS ONE* 6 (4): 6–8. doi:10.1371/journal.pone.0018965.

Figueira, W., R. Ferrari, E. Weatherby, A. Porter, S. Hawes, and M. Byrne. 2015. "Accuracy and Precision of Habitat Structural Complexity Metrics Derived from Underwater Photogrammetry." *Remote Sensing* 7 (12): 16883–16900. doi:10.3390/rs71215859.

Fukunaga, A., and J. H. R. Burns. 2020. "Metrics of Coral Reef Structural Complexity Extracted from 3D Mesh Models and Digital Elevation Models." *Remote Sensing* 12 (17): 1–18. doi:10.3390/RS12172676.

Gurchiek, R. D., R. S. McGinnis, A. R. Needle, J. M. McBride, and H. van Werkhoven. 2017. "The Use of A Single Inertial Sensor to Estimate 3-Dimensional Ground Reaction Force during Accelerative Running Tasks." *Journal of Biomechanics* 61: 263–268. doi:10.1016/j.jbiomech.2017.07.035.

Hatcher, G. A., J. A. Warrick, A. C. Ritchie, E. T. Dailey, D. G. Zawada, C. Kranenburg, and K. K. Yates. 2020. "Accurate Bathymetric Maps from Underwater Digital Imagery without Ground Control." *Frontiers in Marine Science* 7: 1–20. doi:10.3389/fmars.2020.00525.

Hoegh-Guldberg, O., L. Pendleton, and A. Kaup. 2019. "People and the Changing Nature of Coral Reefs." *Regional Studies in Marine Science* 30: 100699. doi:10.1016/j.rsma.2019.100699.

House, J. E., V. Brambilla, L. M. Bidaut, A. P. Christie, O. Pizarro, J. S. Madin, and M. Dornelas. 2018. "Moving to 3D: Relationships between Coral Planar Area, Surface Area and Volume." *PeerJ* 6: e4280. doi:10.7717/peerj.4280.

Kabiri, K., H. Rezai, and M. Moradi. 2020. "A Drone-Based Method for Mapping the Coral Reefs in the Shallow Coastal Waters – Case Study: Kish Island, Persian Gulf." *Earth Science Informatics* 13 (4): 1265–1274. doi:10.1007/s12145-020-00507-z.

Kleypas, J., D. Allemand, K. Anthony, A. C. Baker, M. W. Beck, L. Z. Hale, N. Hilmi, et al. 2021. "Designing A Blueprint for Coral Reef Survival." *Biological Conservation* 257: 109107. doi:10.1016/j.biocon.2021.109107.

Kornder, N. A., J. Cappelletto, B. Mueller, M. J. L. Zalm, S. J. Martinez, M. J. A. Vermeij, J. Huisman, and J. M. de Goeij. 2021. "Implications of 2D versus 3D Surveys to Measure the Abundance and Composition of Benthic Coral Reef Communities." *Coral Reefs* 40: 1137–1153. doi:10.1007/s00338.

Lange, I. D., C. T. Perry, and N. Cooper. 2020. "A Quick, Easy, and Non-Invasive Method to Quantify Coral Growth Rates Using Photogrammetry and 3D Model Comparisons." *Methods in Ecology and Evolution* 11 (6): 714–726. doi:10.1111/2041-210X.13388.

Leujak, W., and R. F. G. Ormond. 2007. "Comparative Accuracy and Efficiency of Six Coral Community Survey Methods." *Journal of Experimental Marine Biology and Ecology* 351 (1–2): 168–187. doi:10.1016/j.jembe.2007.06.028.

Nabillah, I., and I. Ranggadara. 2020. "Mean Absolute Percentage Error for Evaluation of Prediction Result of Marine Commodity." *JOINS (Journal of Information System)* 5 (2): 250–255. doi:10.33633/joins.v5i2.3900.

Reichert, J., J. Schellenberg, P. Schubert, and T. Wilke. 2016. "3D Scanning as a Highly Precise, Reproducible, and Minimally Invasive Method for Surface Area and Volume Measurements of Scleractinian Corals." *Limnology and Oceanography: Methods* 14 (8): 518–526. doi:10.1002/lom3.10109.

Scott, A. J., D. W. Hosmer, and S. Lemeshow. 1991. "Applied Logistic Regression." *Biometrics* 47 (4): 1632. doi:10.2307/2532419.

Stal, C., J. Bourgeois, P. De Maeyer, G. De Mulder, A. De Wulf, R. Goossens, M. Hendrickx, T. Nuttens, and B. Stichelbaut. 2012. "Test Case on the Quality Analysis of Structure from Motion in Airborne Applications." Proceedings of the 32nd EARSeL Symposium: 'Advances in Geosciences', Mykonos, Greece, May 11.

Suprayogi, I., Trimaijon, and Mahyudin. 2014. "Model Prediksi Liku Kalibrasi Menggunakan Pendekatan Jaringan Saraf Tiruan (ZST) (Studi Kasus: Sub DAS Siak Hulu)." *Jurnal Online Mahasiswa Fakultas Teknik Universitas Riau* 1 (1): 1–18.

Veal, C. J., M. Carmi, M. Fine, and O. Hoegh-Guldberg. 2010. "Increasing the Accuracy of Surface Area Estimation Using Single Wax Dipping of Coral Fragments." *Coral Reefs* 29 (4): 893–897. doi:10.1007/s00338-010-0647-9.

Westoby, M. J., J. Brasington, N. F. Glasser, M. J. Hambrey, and J. M. Reynolds. 2012. "Geomorphology Structure-from-Motion Photogrammetry: A Low-Cost, Effective Tool for Geoscience Applications." *Geomorphology* 179: 300–314. doi:10.1016/j.geomorph.2012.08.021.

CEK - THREE DIMENSION

ORIGINALITY REPORT

16%	14%	13%	2%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	www.dspace.uce.edu.ec:8080 Internet Source	1%
2	hl-128-171-57-22.library.manoa.hawaii.edu Internet Source	1%
3	archimer.ifremer.fr Internet Source	1%
4	link.springer.com Internet Source	1%
5	M. Nurliyana, S. Jumria, B. Lukman, M.Y. Ina-Salwany et al. "An outbreak of lymphocystis disease virus infection in cultured juvenile John's snapper (Lutjanus johnii) in Malaysia", Aquaculture, 2023 Publication	1%
6	jast-journal.springeropen.com Internet Source	1%
7	peerj.com Internet Source	1%
8	www.frontiersin.org Internet Source	

		1%
9	I A Santoso, D G Pratomo, Khomsin. "Identification of a wharf wall condition using an Oblique Side Scan Sonar approach", IOP Conference Series: Earth and Environmental Science, 2021 Publication	1%
10	seaninstitute.org Internet Source	1%
11	academic.oup.com Internet Source	<1%
12	www.dubnews.com Internet Source	<1%
13	Satutya Wicaksono, Alexander Patera Nugraha, Jola Rahmahani, Fedik Abdul Rantam et al. "Adipose Mesenchymal Stem Cell Metabolites Oral Gel Enhance Pro-Angiogenic Factors Expression, Angiogenesis, and Clinical Outcome of Oral Ulcer Rat Model", European Journal of Dentistry, 2023 Publication	<1%
14	ul.qucosa.de Internet Source	<1%
15	www.matec-conferences.org Internet Source	<1%

16 ikee.lib.auth.gr
Internet Source
<1 %

17 iopscience.iop.org
Internet Source
<1 %

18 www.researchgate.net
Internet Source
<1 %

19 J. H. R. Burns, D. Delparte, R. D. Gates, M. Takabayashi. "UTILIZING UNDERWATER THREE-DIMENSIONAL MODELING TO ENHANCE ECOLOGICAL AND BIOLOGICAL STUDIES OF CORAL REEFS", ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2015
Publication
<1 %

20 science.utm.my
Internet Source
<1 %

21 theses.gla.ac.uk
Internet Source
<1 %

22 www.mdpi.com
Internet Source
<1 %

23 Mitch Bryson, Renata Ferrari, Will Figueira, Oscar Pizarro, Josh Madin, Stefan Williams, Maria Byrne. "Characterization of measurement errors using structure-from-motion and photogrammetry to measure
<1 %

marine habitat structural complexity", Ecology and Evolution, 2017
Publication

24	Yu Hou, Xing-wei Cai, Zhi-fang Liang, Dan-dan Duan, Xiao-ping Diao, Ji-liang Zhang. "An integrative investigation of developmental toxicities induced by triphenyltin in a larval coral reef fish, Amphiprion ocellaris", Science of The Total Environment, 2023 Publication	<1 %
25	ijebmr.com Internet Source	<1 %
26	www.sagepub.com Internet Source	<1 %
27	e-journal.unair.ac.id Internet Source	<1 %
28	edoc.unibas.ch Internet Source	<1 %
29	irep.iium.edu.my Internet Source	<1 %
30	ore.exeter.ac.uk Internet Source	<1 %
31	www.collectionscanada.ca Internet Source	<1 %
32	Adi Lavy, Gal Eyal, Benjamin Neal, Ray Keren, Yossi Loya, Micha Ilan. "A quick, easy and	<1 %

non - intrusive method for underwater volume and surface area evaluation of benthic organisms by 3D computer modelling", Methods in Ecology and Evolution, 2015
Publication

33	bib.irb.hr Internet Source	<1 %
34	mdpi-res.com Internet Source	<1 %
35	pure.rug.nl Internet Source	<1 %
36	A A Abdillah, J Triastuti. "Effect of Culture Combination on Growth and Carrageenan Content of Kappaphycus alvarezii Green and Red Variety", IOP Conference Series: Earth and Environmental Science, 2021 Publication	<1 %
37	A.T. Mukti, Y.G.P. Sari, G.S.R. Agusdinata, W.H. Satyantini, A.S. Mubarak, E.M. Luqman, Widjiati. "The effects of laserpuncture on gonadal maturity and sperm quality of male striped catfish (Pangasianodon hypophthalmus)", Theriogenology, 2020 Publication	<1 %
38	Yuki Okamoto, Hidetoshi Ikeno, Yasuhiro Hirano, Toko Tanikawa, Keitaro Yamase,	<1 %

	Chikage Todo, Masako Dannoura, Mizue Ohashi. "3D reconstruction using Structure-from-Motion: a new technique for morphological measurement of tree root systems", Plant and Soil, 2022 Publication	
39	cmgds.marine.usgs.gov Internet Source	<1%
40	ejournal.forda-mof.org Internet Source	<1%
41	www.sysrevpharm.org Internet Source	<1%
42	www.tandfonline.com Internet Source	<1%
43	Jenny E House, Luc M Bidaut, Alec P Christie, Oscar Pizarro, Maria Dornelas. "Moving to 3D: relationships between coral planar area, surface area and volume", PeerJ, 2016 Publication	<1%
44	www.rjptonline.org Internet Source	<1%

Exclude quotes	On	Exclude matches	Off
Exclude bibliography	On		