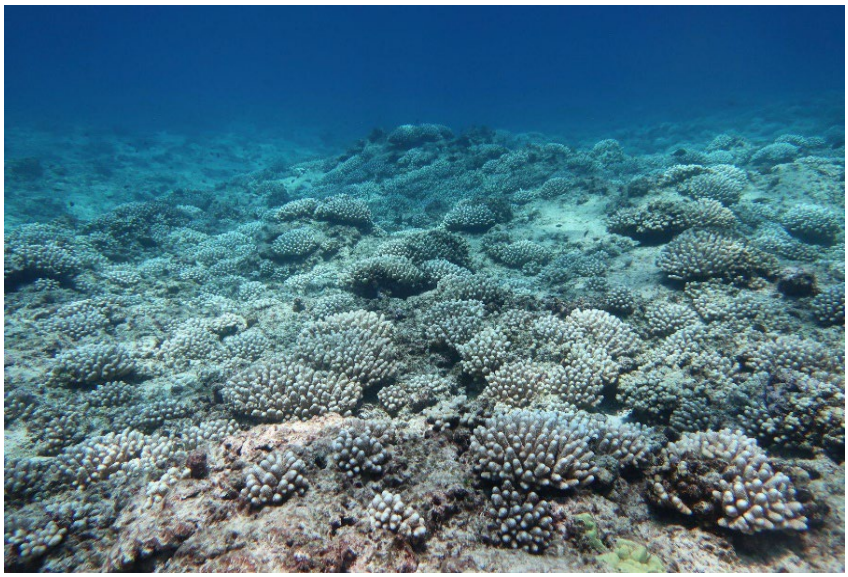
Development of a Semi-automated Coral Bleaching Classifier in CoralNet: A Summary of Standard Operating Procedures and Report of Results

Jon Ehrenberg
Morgan Winston
Thomas Oliver
Courtney Couch



U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Pacific Islands Fisheries Science Center

NOAA Technical Memorandum NMFS-PIFSC-133
https://doi.org/10.25923/d0re-9y93

November 2022

Development of a Semi-automated Coral Bleaching Classifier in CoralNet: A Summary of Standard Operating Procedures and Report of Results

Jon Ehrenberg
Morgan Winston
Thomas Oliver
Courtney Couch

Cooperative Institute for Marine and Atmospheric Research
University of Hawaii
1000 Pope Road
Honolulu, Hawaii 96822

NOAA Technical Memorandum NMFS-PIFSC-133

November 2022

U.S. Department of Commerce
Gina Raimondo, Secretary

National Oceanic and Atmospheric Administration
Richard W. Spinrad, Ph.D., NOAA Administrator

National Marine Fisheries Service
Janet Coit, Assistant Administrator for Fisheries

About this report

The Pacific Islands Fisheries Science Center of NOAA's National Marine Fisheries Service uses the NOAA Technical Memorandum NMFS-PIFSC series to disseminate scientific and technical information that has been scientifically reviewed and edited. Documents within this series reflect sound professional work and may be referenced in the formal scientific and technical literature.

Recommended citation

J Ehrenberg, M Winston, T Oliver, C Couch. 2022. Development of a Semi-automated Coral Bleaching Classifier in CoralNet: A Summary of Standard Operating Procedures and Report of Results. U.S. Dept. of Commerce, NOAA Technical Memorandum NOAA-TM-NMFS-PIFSC-133, 9 p. doi:10.25923/d0re-9y93

Copies of this report are available from

Pacific Islands Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
1845 Wasp Boulevard, Building #176
Honolulu, Hawaii 96818

Or online at

https://repository.library.noaa.gov/

Cover: Bleached *Acropora* coral colonies in French Frigate Shoals observed during the 2019 coral bleaching event (*NOAA Fisheries*).

Table of Contents

LIST OF TABLES

LIST OF FIGURES

BACKGROUND

This document provides detailed guidelines for developing a semi-automated annotation tool, hereafter referred to as a 'classifier' in CoralNet to more efficiently quantify coral bleaching from imagery. Images used to train this coral bleaching classifier were collected in 2014, 2015, 2016, and 2019 during coral reef surveys across the Hawaiian Archipelago (including the Papahānaumokuākea Marine National Monument), by the Ecosystem Sciences Division (ESD) of the NOAA Pacific Islands Fisheries Science Center (PIFSC) with funding from NOAA's Coral Reef Conservation Program (CRCP), Project ID # 31361, and its partners.

Over the past decade, there has been a notable increase in the frequency and severity of global bleaching events (Barkley et al. 2018; Hughes et al. 2018, Vargas-Ángel et al. 2019). Since 2014, the Hawaiian Archipelago has experienced three mass coral bleaching events, which resulted in high coral mortality throughout the archipelago (Bahr et al. 2017; Couch et al. 2017; Winston et al. 2022). With more frequent and severe global bleaching events on the horizon and the efficiency of collecting bleaching data using digital imagery, monitoring programs in Hawai'i need tools to efficiently extract bleaching data from images. Creating tools to quickly and accurately quantify the extent of coral bleaching is an important next step in developing strategies to appropriately respond to and monitor future mass bleaching events.

In this report, we provide a description of how to create a coral bleaching classifier in CoralNet using photoquadrat imagery. We also include a summary of accuracy of NOAA ESD's classifier at both the point and site level. The trained bleaching classifier is publically available (Global ID 24223) and can be accessed using the CoralNet Application Program Interface (API). See the API blog (https://coralnet.ucsd.edu/pages/help/api/) for details.

CREATION & TRAINING OF A BLEACHING CLASSIFIER IN CORALNET

Considerations before starting

Good image quality is essential for annotating imagery in CoralNet. Poor image quality (pixelated, discolored/overexposed, or unfocused) will make it difficult for human annotators, as well as CoralNet's classifiers to correctly label annotations. Annotators should be well trained and calibrated to ensure the classifier of each source (housing the particular collection of imagery) is trained properly. Lastly, labelsets used in each source must be clearly defined to reduce confusion for annotators.

Source initialization

Creating a new source and labelset

1. Launch CoralNet in your preferred internet browser: https://coralnet.ucsd.edu/
    - Refer to Lozada-Misa et al. (2017) for instructions for first time users and for instructions on creating a new source, creating a labelset, and uploading a label set.
    - *The ESD bleaching classifier labelset consisted of three labels: live hard coral, bleached hard coral, and unknown (Table 1); bleached coral was only labeled if the severity of bleaching at the point was severity level 2 or 3 (Table 2, (Figure 1−Figure 3) in order to avoid misidentifying lighter pigmented corals as bleached. Severity one was not included due to challenges with consistently identifying low levels of paling across annotators.*

Table 1. Labelset used for classifying bleaching ESD CoralNet bleaching source.

Label ID	Name	Short Code	Functional Group
184	Coral	*CORAL	Hard Coral
119	Bleached Hard Coral	*CORAL_BL	Hard Coral
1354	CRED-Unclassified/Unknown	*UNK	Other

Table 2. Bleaching severity levels as defined by ESD.

Level	Description
1	Slight paling. Not recorded as bleached in ESD CoralNet bleaching source.
2	Significant loss of pigmentation (either with patches of severe bleaching or total colony paling)
3	Stark white or almost complete lack of pigmentation

Level	Description
1	Slight paling. Not recorded as bleached in ESD CoralNet bleaching source.
4	Recent mortality due to bleaching. Recorded as ‘Other’ in ESD CoralNet bleaching source.

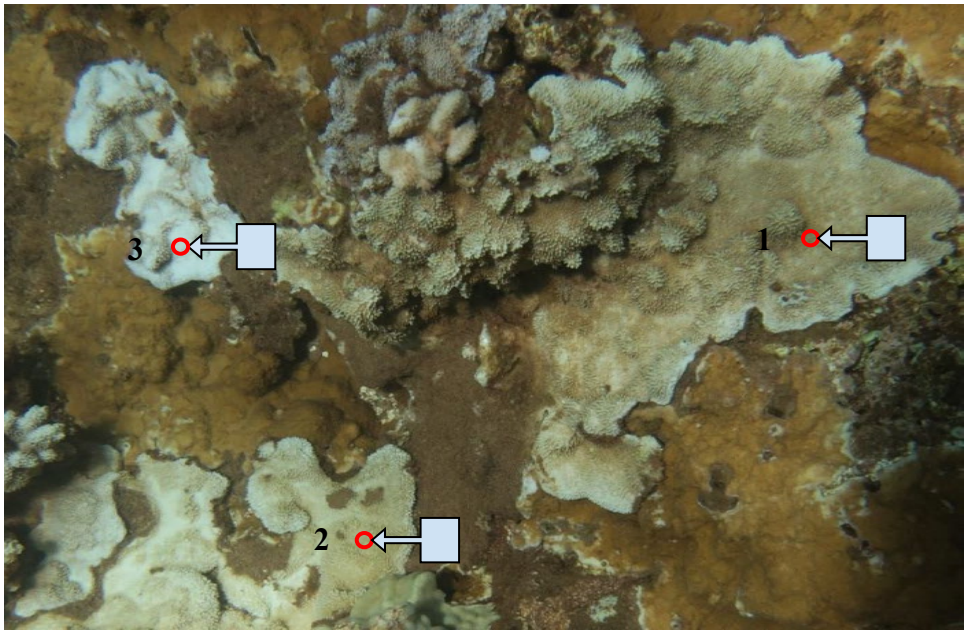


Figure 1. Example of bleaching severity levels 1 through 3 labeled per point. Following the ESD bleaching classifier labelset, bleaching severity 1 point would be labeled as unbleached live coral (*CORAL).

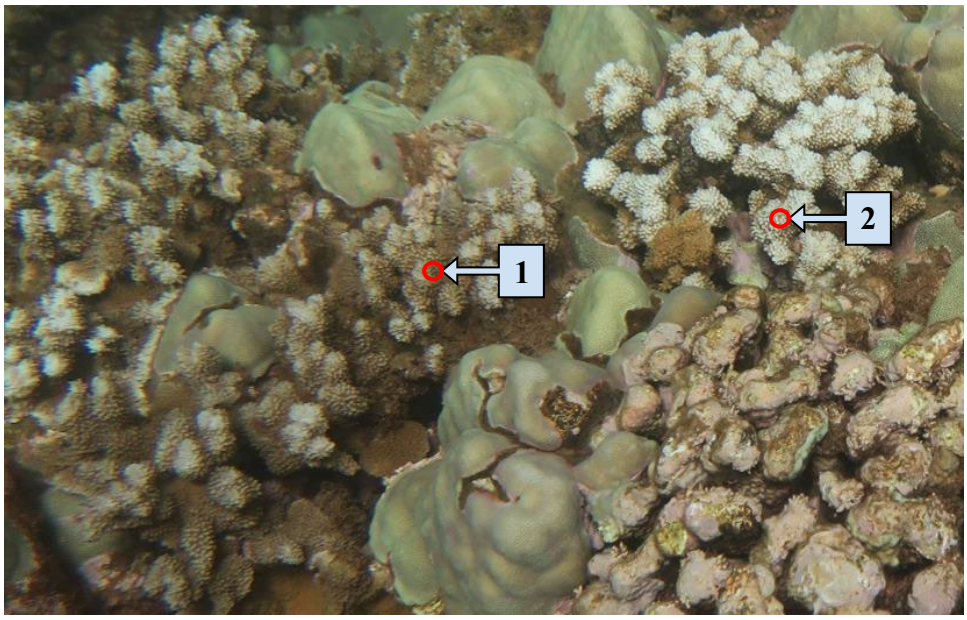


Figure 2. Example of bleaching severity levels 1 and 2 labeled per point.

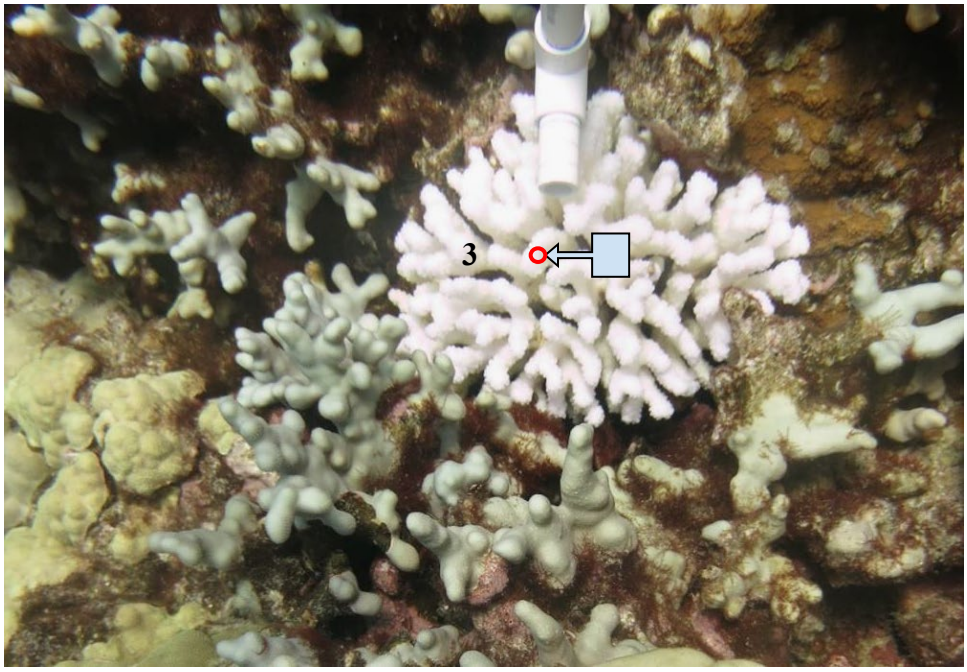


Figure 3. Example of bleaching severity 3.

Uploading imagery and generating initial annotations

1. To properly train a bleaching classifier, imagery selection should include sites with a high prevalence of bleached corals.
2. For instructions on how to upload image files and metadata, refer to the Lozada-Misa et al. (2017).
3. CoralNet will randomly assign annotations to each image.

Training with additional annotations

To more efficiently train the CoralNet bleaching classifier, additional point annotations of bleached coral can be created using R Statistical Software (RStudio Team 2021). We recommend choosing sites that have high bleaching prevalence with a range of bleaching severity levels. Note, these bleaching annotations should be used for training purposes only and should not be used to generate percent cover values.

All cited R scripts can be found in GitHub (https://github.com/morgan-winston/coralnet-bleaching-classifier-development). Additional data or information can be requested from the authors.

Creating new annotations

4. Locate original imagery used in steps 1−4 and download the benthic photoquadrats for designated high bleaching sites.
    - *For NOAA users, processing imagery can be done through the T drive or any network drive; however, this will make R Studio run much slower and could cause the session to crash; therefore, we recommend pulling imagery onto your local hard drive.*
5. Organize photos in a working folder (e.g. based on the site name). If a site has more than 30 photos, they should be split into groups of ≤ 30 to avoid R Studio from aborting the session.
    - *For NOAA users, ensure folder names contain site number (i.e. LAN-B1824)*
6. Cross reference photo names from the folder that the imagery is stored in to photo names in the CoralNet source that you plan to upload new annotations to.
    - Note: If image names do not match correctly, the annotations will not be properly assigned to the correct image in CoralNet.
7. Download the point annotation script: "Point_Annotator_Raster_v1.3.R". Place the folder of photos in the same working directory as where the script is saved, and name the folder of photos "Images." Add another folder to the working directory called "Annotations" to store the annotations CSV file you will generate using this script.
8. Open the point annotation script in R Studio. Ensure that the packages used in this script are installed. Once this has been done, run the entire script at once (also known as sourcing the file)—this can be accomplished by pressing Ctrl+Shift+S on your keyboard.
9. The plot viewer window of R Studio should start by displaying the first image in your 'Images' folder, with the text 'Welcome to Point Annotator" (Figure 4). Next, it will prompt you to resize the plot viewer to remove all white edges. You can resize the plot viewer by clicking and dragging the outside borders of the window.

    - *Failing to resize the window and remove the white edges will result in your points being misaddressed in CoralNet, and therefore will generate poor training results.*

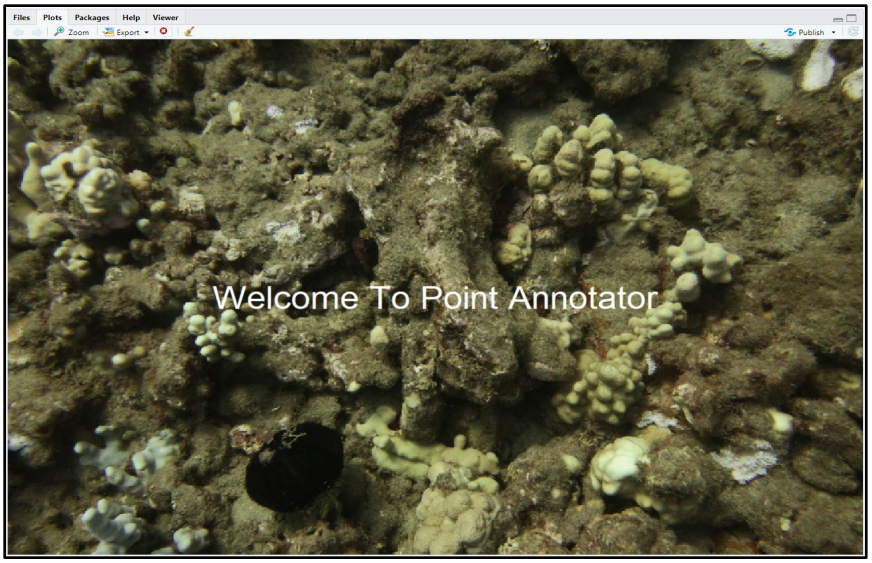


Figure 4. Initial image with text that will display in the R Studio plot viewer after sourcing the Point_Annotator_Raster_v1.3.R script.

10. Once the plot viewer is the correct size, follow the prompt by clicking the console and hitting return on your keyboard.
11. You will be prompted through the console to click on a point in the image and assign a number to that point, with 1: UNK, 2: CORAL, and 3: CORAL_BL (this can be altered in the code to reflect your personal labelset by editing `LABELSET=c("[insert labels here])"`).
12. After entering a number to represent that point, press enter and the point will show up in the plot viewer and the point location will be displayed in the console.
13. Continue marking and identifying points, until you have reached your target number of annotations for each category for that image (Figure 5, Figure 6).

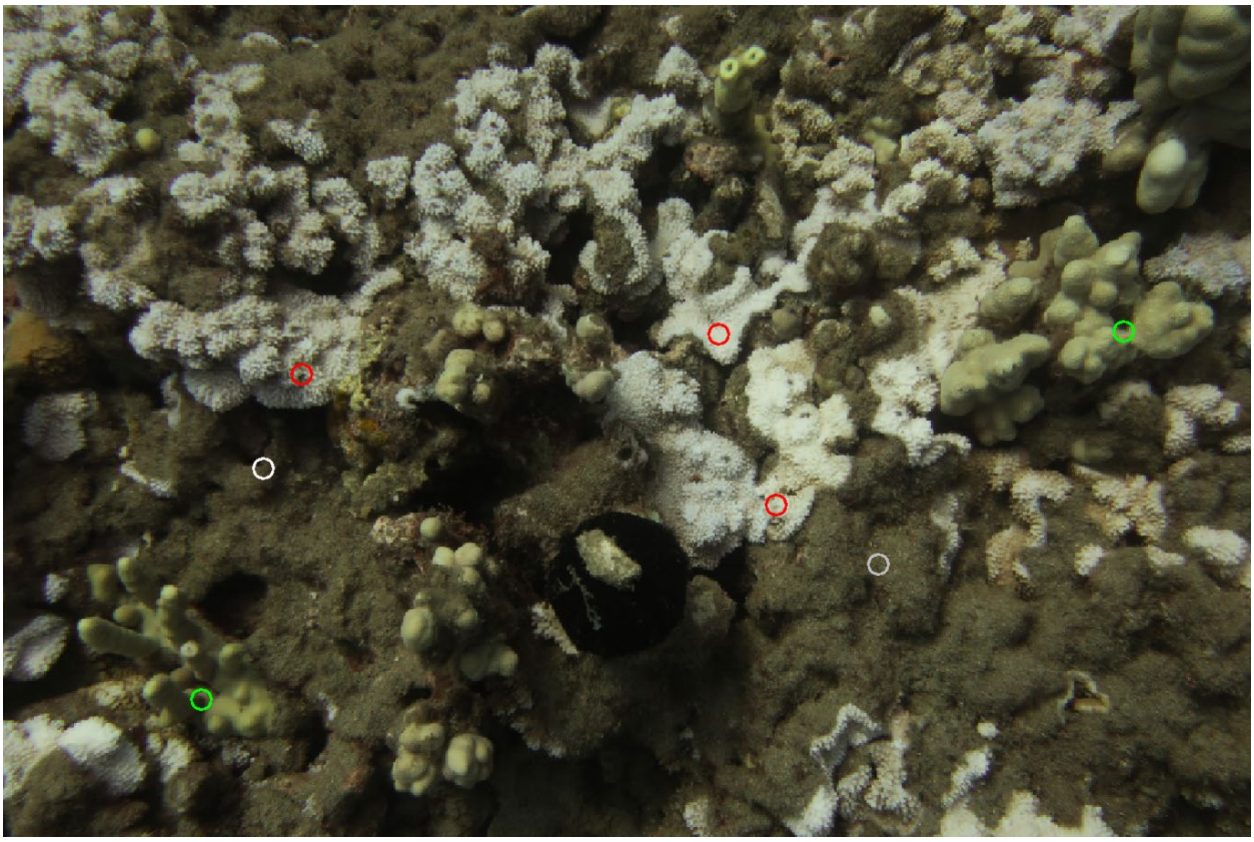


Figure 5. R Studio plot viewer window showing six targeted annotations generated on the image shown.

```
[1] "Waiiit for it... Click on your point:"
Input Label or Skip? [1]:*UNK [2]:*CORAL [3]:*CORAL_BL [-999]:End All Annotation [0]:Skip to Next Image: 3
                  Name  Row Column Row_plot     Label
1 MAI-B2482_2019_02.JPG 2192   3396     1456 *CORAL_BL
[1] "Waiiit for it... Click on your point:"
Input Label or Skip? [1]:*UNK [2]:*CORAL [3]:*CORAL_BL [-999]:End All Annotation [0]:Skip to Next Image: 2
                  Name  Row Column Row_plot  Label
1 MAI-B2482_2019_02.JPG 3042    882      606 *CORAL
[1] "Waiiit for it... Click on your point:"
Input Label or Skip? [1]:*UNK [2]:*CORAL [3]:*CORAL_BL [-999]:End All Annotation [0]:Skip to Next Image: 3
                  Name  Row Column Row_plot     Label
1 MAI-B2482_2019_02.JPG 1623   1321     2025 *CORAL_BL
[1] "Waiiit for it... Click on your point:"
Input Label or Skip? [1]:*UNK [2]:*CORAL [3]:*CORAL_BL [-999]:End All Annotation [0]:Skip to Next Image: 1
                  Name  Row Column Row_plot Label
1 MAI-B2482_2019_02.JPG 2452   3840     1196  *UNK
[1] "Waiiit for it... Click on your point:"
Input Label or Skip? [1]:*UNK [2]:*CORAL [3]:*CORAL_BL [-999]:End All Annotation [0]:Skip to Next Image: 2
                  Name  Row Column Row_plot  Label
1 MAI-B2482_2019_02.JPG 1436   4915     2212 *CORAL
[1] "Waiiit for it... Click on your point:"
Input Label or Skip? [1]:*UNK [2]:*CORAL [3]:*CORAL_BL [-999]:End All Annotation [0]:Skip to Next Image: 3
                  Name  Row Column Row_plot     Label
1 MAI-B2482_2019_02.JPG 1448   3142     2200 *CORAL_BL
```

Figure 6. Screenshot of the R Studio console as six targeted annotations are generated on a single image.

14. To move to the next image, click again on the photo and then enter the numeral 0.

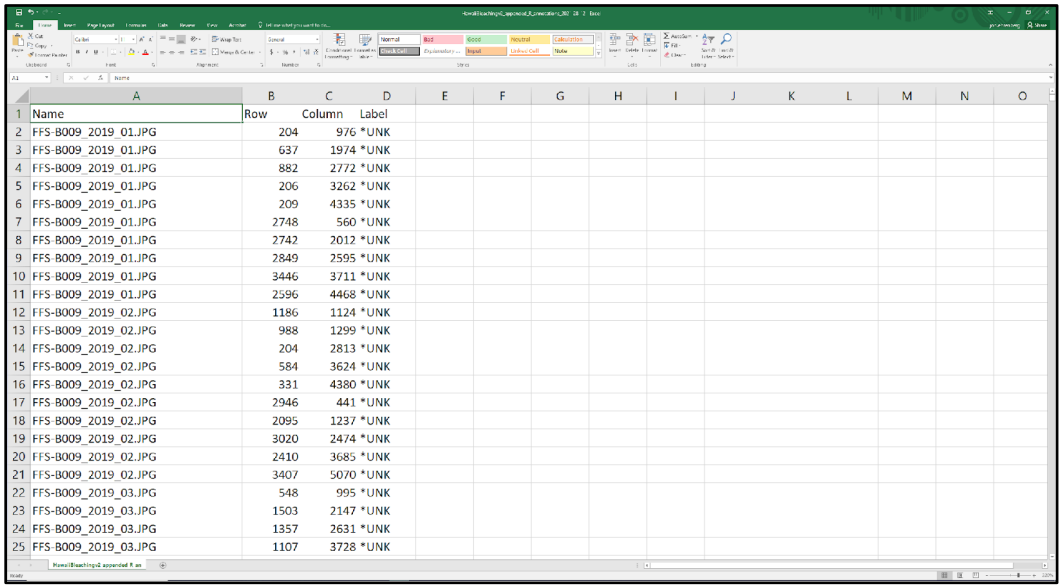
- The number of targeted annotations can either be a set number or vary based on the presence of bleaching in each photo.
- *In the NOAA ESD Coral Bleaching Classifier source, the number of targeted annotations per image were dependent on bleaching prevalence.*

15. The R script displays how many images remain and it will let you know once you have reached the end of the image stack.
16. You can complete your annotation session either by the following: (1) processing all images in the stack, or (2) by entering the numeral -999 when prompted. Either will result in a CSV file with all the annotations for the entire image stack you have annotated being written and placed the 'Annotations' folder you created.
17. All of the annotations for the site should be reviewed before moving on to the next step
    - Open the CSV file in excel and look for N/A or 0, these rows should be deleted and the CSV file should be saved.

Uploading new annotations to CoralNet

18. Download the current annotations from the CoralNet source to which you would like to add the targeted annotations. Append the new annotations to the bottom of the CSV file.
    - See Lozada-Misa et al. (2017) for instructions on how to download annotations.
    - Downloading the original annotations can be done by image, by site, or by source.
    - Note: Appending new annotations to the original annotations for the entire source can be risky and time consuming, depending on how many targeted annotations you created. If only one site requires added generated annotations, downloading the site annotations from CoralNet and appending the new annotations is the best option.
19. Appending the generated annotations is simple and easily done through Microsoft Excel
    - Open the original CoralNet annotations CSV file, and paste the new annotations directly below (Figure 7).

- There is no need to specifically place the new annotations directly under the old ones for each site, CoralNet will do this automatically based on the image name linked to each annotation.



	A	B	C	D
1	Name	Row	Column	Label
2	FFS-B009_2019_01.JPG	204	976	*UNK
3	FFS-B009_2019_01.JPG	637	1974	*UNK
4	FFS-B009_2019_01.JPG	882	2772	*UNK
5	FFS-B009_2019_01.JPG	206	3262	*UNK
6	FFS-B009_2019_01.JPG	209	4335	*UNK
7	FFS-B009_2019_01.JPG	2748	560	*UNK
8	FFS-B009_2019_01.JPG	2742	2012	*UNK
9	FFS-B009_2019_01.JPG	2849	2595	*UNK
10	FFS-B009_2019_01.JPG	3446	3711	*UNK
11	FFS-B009_2019_01.JPG	2596	4468	*UNK
12	FFS-B009_2019_02.JPG	1186	1124	*UNK
13	FFS-B009_2019_02.JPG	988	1299	*UNK
14	FFS-B009_2019_02.JPG	204	2813	*UNK
15	FFS-B009_2019_02.JPG	584	3624	*UNK
16	FFS-B009_2019_02.JPG	331	4380	*UNK
17	FFS-B009_2019_02.JPG	2946	441	*UNK
18	FFS-B009_2019_02.JPG	2095	1237	*UNK
19	FFS-B009_2019_02.JPG	3020	2474	*UNK
20	FFS-B009_2019_02.JPG	2410	3685	*UNK
21	FFS-B009_2019_02.JPG	3407	5070	*UNK
22	FFS-B009_2019_03.JPG	548	995	*UNK
23	FFS-B009_2019_03.JPG	1503	2147	*UNK
24	FFS-B009_2019_03.JPG	1357	2631	*UNK
25	FFS-B009_2019_03.JPG	1107	3728	*UNK

Figure 7. Example of the annotation CSV file for an ESD site.

20. Once the new annotations have been appended, save the new CSV file appropriately.
21. See Lozada-Misa et al. (2017) for instructions on uploading annotations to a source.
22. The new uploaded annotations should be reviewed in CoralNet and confirm they are accurate.
23. Contact CoralNet directly to initiate the classifier to retrain using the new targeted annotations that you have added to the source.
    - This may not be possible for some, so creating an entirely new source is the next best option.
24. Allow approximately 24−48 hours for the classifier to finish retraining.
    - After allowing classifier to train, click on the “Backend” button in the top row of buttons in the source’s main page.
    - A table measuring the performance of the classifier, also known as a confusion matrix, will display the estimated accuracy of the classifier for each label.

CREATION & TRAINING OF A BLEACHING CLASSIFIER IN CORAL NET

To create a trained bleaching classifier using CoralNet, the ESD first created a new source (*CREP-HAWAII BLEACHING v2*: Global ID 23472) (steps 1−4) containing imagery collected across 178 sites in the Hawaiian Archipelago during the 2019 mass coral bleaching event (Table 3). A total of 5207 images were used, with approximately 30 images for each site; however, image numbers ranged from 5 to 72 images per site. The imagery was manually annotated using the simple labelset in Table 1. Once the initial round manual of annotations were completed, a subset of sites with the highest prevalence of coral bleaching were selected and targeted annotations were added manually using steps 5−40. *CREP-HAWAII BLEACHING v2* served as an experimental test source to confirm that annotations created using steps 5-40 could be uploaded to CoralNet and be used to train a new source.

Table 3. Number of sites by island and year used to train the ESD CoralNet bleaching classifier.

Island	2014	2015	2016	2019	Total
Hawai‘i Island	0	4	0	2	**6**
Maui	0	1	0	50	**51**
O‘ahu	0	1	0	63	**64**
Lāna‘i	0	0	0	11	**11**
Moloka‘i	0	1	0	0	**1**
Kure	0	0	1	15	**16**
Lisianski	1	0	0	11	**12**
French Frigate Shoals	0	0	1	6	**7**
Pearl and Hermes	0	2	0	8	**10**
Total	**1**	**9**	**2**	**166**	**178**

To test the machine accuracy of the bleaching classifier, 80% of the sites were designated as training sites and uploaded to a new source using the default feature extractor EfficentNet (*NOAA ESD Coral Bleaching Classifier*: Classifier ID 24223), while the remaining 20% served as test sites for the new source. Sites were randomly sorted using V3_Bleaching_Site_Sorting.R. There were a total of 143 training sites selected for *NOAA ESD Coral Bleaching Classifier*; 129 sites had only random annotations and 14 sites had targeted and random annotations. The resulting 48,622 training annotations were uploaded to *NOAA ESD Coral Bleaching Classifier* and the classifier accuracy was obtained from the confusion matrix.

A total of 35 sites were randomly selected as test sites (sites with only random annotations). Test site imagery was uploaded without annotation labels to *NOAA ESD Coral Bleaching Classifier*. Machine suggestions were downloaded and compared to the original human annotations. From this comparison, machine accuracy was calculated as the proportion of machine points that matched with the human annotations (Table 4).

Table 4. Point-level accuracy of machine suggested annotations across all test sites compared to original human annotations.

Label	# Correct	%	# Incorrect	%	Total
CORAL	886	85.69	148	14.31	1034
CORAL_BL	191	70.48	80	29.52	271
UNK	8460	98.89	95	1.11	8555
Total	9537	96.72	323	3.28	9860

Of the total 1034 original 'CORAL' point annotations, the classifier correctly identified 85.69% of them. The remaining 14.31% of the original CORAL annotations were misidentified as either bleached coral or unknown (Table 4). 70.48% of the bleached corals were correctly identified, while 29.52% were assigned incorrect labels (Table 4). The highest accuracy was in the correct identification of the unknown annotations, at 98.89% (Table 4). While the classifier correctly assigned labels to points at a relatively high percentage, incorrect labels were also assigned to a relatively high number of points for bleached corals (80 or 29.52%). At the site level, there was a strong correlation between machine generated annotations and human annotations (Figure 8, Linear Regression: $p = < 0.00001$, $R^2 = 0.86$, RSME = 4.6%). There was a slight bias towards human annotations at higher bleaching prevalence greater than 20%, but this may be partially influenced by the sparsity of points at high bleaching prevalence.

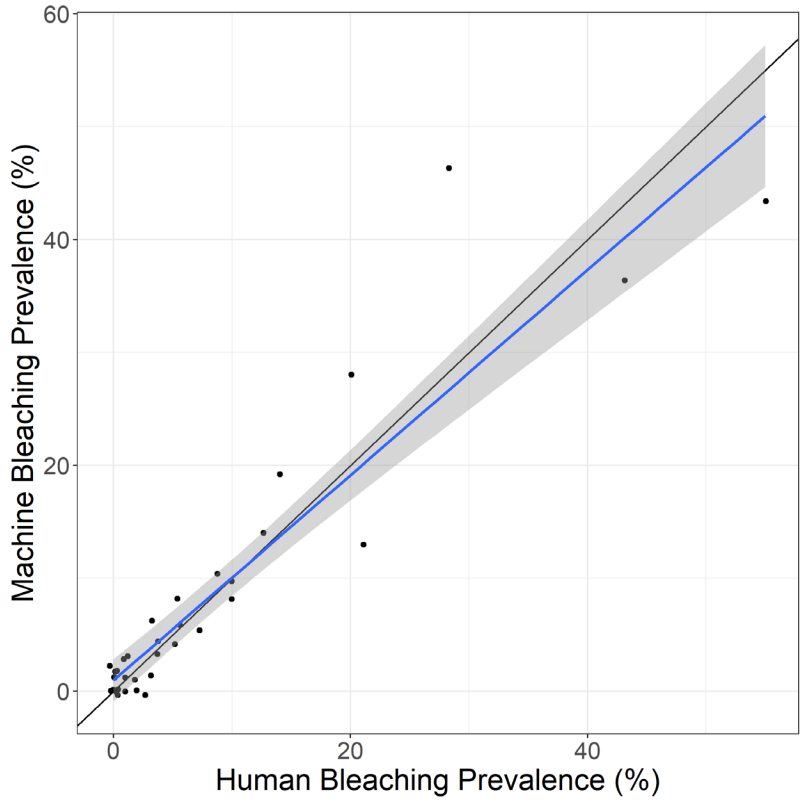


Figure 8. Site-level machine reported bleaching plotted against human reported bleaching from the NOAA ESD Coral Bleaching Classifier.

These results demonstrate that overall, the ESD bleaching classifier performed quite well and presents an efficient strategy for the fast annotation of benthic photoquadrat imagery. We would specifically recommend using the classifier used in a "human-in-the-loop" process taking advantage of CoralNet's alleviation feature to allow the classifier to work on point with high estimated certainty and allow humans to double-check the lower certainty point. This approach is standard with CoralNet, and existing CoralNet documentation can guide users in its implementation.

The classifier will continue to train as more imagery is added to the source, and the ESD will welcome additional imagery from other organizations who are interested in extracting bleaching percent cover data from their benthic imagery. A potential next phase of this project could be to test how well this classifier performs outside of the Hawaiian Archipelago by uploading imagery from other Pacific Regions.

REFERENCES

Bahr KD, Rodgers KS, Jokiel PL. 2017. Impact of three bleaching events on the reef resiliency of Kāneʻohe Bay, Hawaiʻi. *Front. Mar. Sci.* 4:398 doi: 10.3389/fmars.2017.00398

Barkley HC, Cohen AL, Mollica NR, Brainard RE, Rivera HE, DeCarlo TM, Lohmann GP, Drenkard EJ, Alpert AE, Young CW, Vargas-Ángel B, Lino KC, Oliver TA, Pietro KR, Luu VH. 2018. Repeat bleaching of a central Pacific coral reef over the past six decades (1960–2016). *Commun Biol* 1:177. doi: 10.1038/s42003-018-0183-7

Couch CS, Burns JHR, Liu G, Steward K, Gutlay TN, Kenyon J, Eakin CM, Kosaki RK. 2017. Mass coral bleaching due to unprecedented marine heatwave in Papahānaumokuākea Marine National Monument (Northwestern Hawaiian Islands). *PLOS ONE* 12(9): e0185121. doi: 10.1371/journal.pone.0185121

Hughes TP, Anderson KD, Connolly SR, Heron SF, Kerry JT, Lough JM, et al. 2018. Spatial and temporal patterns of mass bleaching of corals in the Anthropocene. *Science* 359: 80–83. pmid:29302011

Lozada-Misa P, Schumacher B, Vargas-Ángel B. 2017. Analysis of benthic survey images via CoralNet : a summary of standard operating procedures and guidelines. *PIFSC Admin Rep.* H-17-02 doi:http://doi.org/10.7289/V5/AR-PIFSC-H-17-02

RStudio Team. 2021. RStudio: Integrated Development Environment for R. RStudio, PBC, Boston, MA. http://www.rstudio.com/.

Vargas-Ángel B, Huntington B, Brainard RE, Venegas R, Oliver TA, Barkley HC, Cohen AL. 2019. El Niño-associated catastrophic coral mortality at Jarvis Island, central Equatorial Pacific. *Coral Reefs* 38: 731–741. doi: 10.1007/s00338-019-01838-0

Winston M, Oliver T, Couch C, Donovan MK, Asner GP, Conklin E, et al. 2022. Coral taxonomy and local stressors drive bleaching prevalence across the Hawaiian Archipelago in 2019. *PLOS ONE* 17(9): e0269068. doi: 10.1371/journal.pone.0269068