# Empirical orthogonal functions (EOFs) and benthic communities at Wailupe and Black Point on Oahu, Hawai'i

**Website**: https://www.bco-dmo.org/dataset/860764
**Data Type**: Other Field Results
**Version**: 1
**Version Date**: 2021-09-15

**Project**
» RUI: Collaborative Research: Defining the biogeochemical context and ecological impacts of submarine groundwater discharge on coral reefs (Moorea SGD)


| Contributors | Affiliation | Role |
|---|---|---|
| Nelson, Craig E. | University of Hawai'i at Mānoa | Principal Investigator |
| Donahue, Megan | University of Hawai'i at Mānoa | Co-Principal Investigator |
| La Valle, Florybeth F. | University of Hawai'i at Mānoa | Contact |
| Rauch, Shannon | Woods Hole Oceanographic Institution (WHOI BCO-DMO) | BCO-DMO Data Manager |


**Abstract**
Empirical orthogonal functions (EOFs) and benthic communities at Wailupe and Black Point on Oahu, Hawai'i. Full methods describing this dataset are found in La Valle et al. 2020 (doi:10.1002/lno.11596)

## Table of Contents



## Coverage

**Spatial Extent**: **N**:21.2760667 **E**:-157.76035 **S**:21.2576667 **W**:-157.791117
**Temporal Extent**: 2016-06-27 - 2017-07-12

### Methods & Sampling

Full methods are found in La Valle et al. 2020.

**Site descriptions and SGD characterizations:** The study sites are located along the southern shoreline of O'ahu, Hawai'i, in Maunalua Bay (21.2743°N, 157.7492°W). The two study sites, Black Point (21.2586°N, 157.7899°W) and Wailupe (21.2756°N, 157.7624°W), are on the western side of the bay and are macroalgae-dominated, with 50% and 15% fleshy macroalgal benthic cover at Wailupe and Black Point, respectively, from the shoreline to the reef crest. There is a close to conservative relationship between SGD-derived inorganic nutrients (nitrate, phosphate, and silicate) and salinity at Black Point and Wailupe (linear regressions statistics described in Table 1 of La Valle et al. 2019). SGD fluxes and nutrient delivery were described in detail in Holleman (2011), Nelson et al. (2015), Richardson et al. (2017a-b), Lubarsky et al. (2018) and summarized in La Valle et al. (2019).

Salinity time series (see instruments section) were used for EOF and community composition data analyses were related to the EOF loading scores.

**Sampling and analytical procedures:**
Benthic algal surveys were done at the grid intersection points ($n$ = 97 for Wailupe and $n$ = 115 for Black Point). The survey consisted of 25 cm by 25 cm quadrats, where species-specific percent algal cover, species-specific invertebrate percent cover and counts, and substrate type were measured. All taxa were identified to lowest taxonomic level.

Empirical orthogonal functions (EOFs) were applied to the spatially indexed salinity time series at both sites. The continuous time series were inputted in the EOFs. EOFs were used to reduce dimensionality of the spatially explicit time series and to reveal the spatial structure of the time series data. EOFs are the spatiotemporal manifestation of principal components analysis (PCA) (Wikle et al. 2018). The output for EOFs includes a spatial map of loadings and an associated normalized principal-component time series for the salinity dataset obtained using a singular value decomposition of a space-wide matrix. The singular value decomposition was done using the function svd in the base library in RStudio (version 1.0.44, R Core Team 2016).

**Instruments:**
Salinity time series were not included in this dataset because they are redundant for analyses (as EOF1 and EOF2 are included in the datasets) but are available from Florybeth La Valle (flavalle@ucsd.edu).

Twenty-three autonomous salinity sensors (Odyssey Temperature and Conductivity loggers, 3 to 60 mS cm-1) were deployed in a sparse grid across each site. The sensors were attached a few centimeters off of the benthos at Black Point for 30 days (29 May - 29 June 2015) and for 27 days at Wailupe (4 April - 21 May 2015) and took readings every 10 minutes. Two water samples were taken every week, synchronously with salinity sensor measurements, for the duration of the deployments at both sites and were analyzed using a Portasal Salinometer 8410A (accuracy 0.001) for quality control purposes and to check for sensor measurement drift.

**Data Processing Description**

**Data Processing:**
We ran distance-based linear models (DistLM) on the distance matrix of community data by site using EOF1 and EOF2 as fixed effects (predictors) and substrate type as a random effect was used to explore species composition to quantify variance in benthic community structure explained by EOFs. The DistLM enables us to quantify whether either or both EOF1s contribute significantly to patterns observed in the multivariate community structure while taking in account the variability in the substrate type. The function adonis in the R package vegan was used to create these models (Oksanen et al. 2017).

**Species-specific relationships with variability in SGD:**
In order to characterize how presence or absence of each benthic taxon was related to SGD, logistic regression models were run at each site using the glm function in the stats package (R Core Team) with EOF1 as the predictors. Only species that appeared in at least three benthic samples were analyzed for univariate relationships to SGD. All logistic regression p-values were controlled for false discovery rate ($\alpha = 0.05$) using the function p.adjust with the Benjamini Hochberg method in the R package stats (Benjamini and Hochberg 1995).

**BCO-DMO Processing:**
- concatenated the two separate data files into one;
- replaced "NA" with "nd" (no data);
- renamed fields to conform with BCO-DMO naming conventions;
- replaced spaces with underscores in site column;
- changed date format to YYYY-MM-DD.

[ table of contents | back to top ]

## Data Files

| File |
|---|
| **EOF_Oahu.csv** (Comma Separated Values (.csv), 40.10 KB)<br>MD5:8a9fe1d8b761a22d0e686eab3cab5b55<br><br>Primary data file for dataset ID 860764 |

[ table of contents | back to top ]

## Related Publications

Benjamini, Y., & Hochberg, Y. (1995). Controlling the False Discovery Rate: A Practical and Powerful Approach to Multiple Testing. Journal of the Royal Statistical Society: Series B (Methodological), 57(1), 289–300. doi:10.1111/j.2517-6161.1995.tb02031.x
*Methods*

Holleman, K. 2011. Comparison of submarine groundwater discharge, coastal residence times, and rates of primary productivity, Manualua Bay, O'ahu and Honokohau Harbor, Big Island, Hawaii, USA. M.S. thesis, University of Hawai'i at Mānoa.
*Methods*

La Valle, F. F., Kantar, M. B., & Nelson, C. E. (2020). Coral reef benthic community structure is associated with the spatiotemporal dynamics of submarine groundwater discharge chemistry. Limnology and Oceanography, 66(1), 188–200. doi:10.1002/lno.11596
*Results*

La Valle, F., Thomas, F., & Nelson, C. (2019). Macroalgal biomass, growth rates, and diversity are influenced by submarine groundwater discharge and local hydrodynamics in tropical reefs. Marine Ecology Progress Series, 621, 51–67. doi:10.3354/meps12992
*Methods*

Lubarsky, K. A., Silbiger, N. J., & Donahue, M. J. (2018). Effects of submarine groundwater discharge on coral accretion and bioerosion on two shallow reef flats. Limnology and Oceanography, 63(4), 1660–1676. doi:10.1002/lno.10799
*Results*

Nelson, C. E., Donahue, M. J., Dulaiova, H., Goldberg, S. J., La Valle, F. F., Lubarsky, K., … Thomas, F. I. M. (2015). Fluorescent dissolved organic matter as a multivariate biogeochemical tracer of submarine groundwater discharge in coral reef ecosystems. Marine Chemistry, 177, 232–243. doi:10.1016/j.marchem.2015.06.026
*Methods*

Oksanen, J., Blanchet, F. B., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P. R., O'Hara, R. B., Simpson, G. L., Solymos, P., Henry, M., Stevens, H., Szoecs, E., Wagner, H. 2017. vegan: community ecology package. R package version 2. 4– 3. https://CRAN.R-project.org/package=vegan
*Methods*

RStudio Team (2016) RStudio: Integrated Development for R. Version 1.0.44,. RStudio, Inc., Boston, MA. http://www.rstudio.com/
*Methods*

Richardson, C. M., Dulai, H., & Whittier, R. B. (2017). Sources and spatial variability of groundwater-delivered nutrients in Maunalua Bay, O‘ahu, Hawai‘i. Journal of Hydrology: Regional Studies, 11, 178–193. doi:10.1016/j.ejrh.2015.11.006
*Methods*

Richardson, C. M., Dulai, H., Popp, B. N., Ruttenberg, K., & Fackrell, J. K. (2017). Submarine groundwater discharge drives biogeochemistry in two Hawaiian reefs. Limnology and Oceanography, 62(S1), S348–S363. doi:10.1002/lno.10654
*Methods*

Wikle, C. K., Zammit-Mangion, A., & Cressie, N. (2019). Spatio-Temporal Statistics with R. doi:10.1201/9781351769723
*Methods*

[ table of contents | back to top ]

## Parameters

| Parameter | Description | Units |
|---|---|---|

| | | |
|---|---|---|
| site | name of the site found in Maunalua Bay, Honolulu, Hawai'i | unitless |
| index | integers representing individual codes per quadrat | unitless |
| date | date the data were collected; format: YYYY-MM-DD | unitless |
| lat | latitiude | decimal degrees North |
| lon | longitude | decimal degrees West |
| EOF1 | EOF1 calculated using methods in La Valle et al. 2020 (Journal: Limnology & Oceanography) | unitless |
| EOF2 | EOF2 calculated using methods in La Valle et al. 2020 (Journal: Limnology & Oceanography) | unitless |
| rock | exposed rock % cover within a 25 cm by 25 cm quadrat | percent cover |
| rocks_on_sand | exposed rocks and sand % cover within a 25 cm by 25 cm quadrat | percent cover |
| sand | exposed sand % cover within a 25 cm by 25 cm quadrat | percent cover |
| sand_and_rubble | exposed sand and rubble % cover within a 25 cm by 25 cm quadrat | percent cover |
| rubble | exposed rubble % cover within a 25 cm by 25 cm quadrat | percent cover |
| reef_flat | exposed reef flat (mostly composed of dead corals) % cover within a 25 cm by 25 cm quadrat | percent cover |
| Acanthophora_spicifera | Acanthophora spicifera % cover within a 25 cm by 25 cm quadrat | percent cover |
| Amansia_glomerata | Amansia glomerata % cover within a 25 cm by 25 cm quadrat | percent cover |
| Asparagopsis_taxiformis | Asparagopsis taxiformis % cover within a 25 cm by 25 cm quadrat | percent cover |
| Avrainvillea_amadelpha | Avrainvillea amadelpha % cover within a 25 cm by 25 cm quadrat | percent cover |

| | | |
|---|---|---|
| Boodlea_sp | Boodlea sp. % cover within a 25 cm by 25 cm quadrat | percent cover |
| Bryopsis_sp | Bryopsis sp. % cover within a 25 cm by 25 cm quadrat | percent cover |
| Caulerpa_spp | Caulerpa spp. % cover within a 25 cm by 25 cm quadrat | percent cover |
| Centroceras_sp | Centroceras sp. % cover within a 25 cm by 25 cm quadrat | percent cover |
| Ceramium_sp | Ceramium sp. % cover within a 25 cm by 25 cm quadrat | percent cover |
| Cladophora_sp | Cladophora sp. % cover within a 25 cm by 25 cm quadrat | percent cover |
| Codium_spp | Codium spp. % cover within a 25 cm by 25 cm quadrat | percent cover |
| Dictyota_spp | Dictyota spp. % cover within a 25 cm by 25 cm quadrat | percent cover |
| Halimeda_discoidea | Halimeda discoidea % cover within a 25 cm by 25 cm quadrat | percent cover |
| Hypnea_musciformis | Hypnea musciformis % cover within a 25 cm by 25 cm quadrat | percent cover |
| Jania_spp | Jania spp. % cover within a 25 cm by 25 cm quadrat | percent cover |
| Liagora_spp | Liagora spp. % cover within a 25 cm by 25 cm quadrat | percent cover |
| Lyngbya_majuscula | Lyngbya majuscula % cover within a 25 cm by 25 cm quadrat | percent cover |
| Pterocladiella_spp | Pterocladiella spp. % cover within a 25 cm by 25 cm quadrat | percent cover |
| Turf_algae | Turf algae % cover within a 25 cm by 25 cm quadrat | percent cover |
| Ulva_lactuca | Ulva lactuca % cover within a 25 cm by 25 cm quadrat | percent cover |
| Unknown_1 | unknown macroalgae % cover within a 25 cm by 25 cm quadrat | percent cover |
| Zoanthids | species from Order Zoantharia % cover within a 25 cm by 25 cm quadrat | percent cover |
| Anthozoa | species from Class Anthozoa % cover within a 25 cm by 25 cm quadrat | percent cover |

| | | |
|---|---|---|
| Echinometra_mathaei | Echinometra mathaei % cover within a 25 cm by 25 cm quadrat | percent cover |
| Isognomon_californicum | Isognomon californicum % cover within a 25 cm by 25 cm quadrat | percent cover |
| Sponge | species from the Phylum Porifera % cover within a 25 cm by 25 cm quadrat | percent cover |
| Pocillopora_spp | Pocillopora spp. % cover within a 25 cm by 25 cm quadrat | percent cover |
| Nerita_picea | Nerita picea % cover within a 25 cm by 25 cm quadrat | percent cover |
| coral_rubble | exposed coral rubble % cover within a 25 cm by 25 cm quadrat | percent cover |
| silt_mud | exposed silt and mud % cover within a 25 cm by 25 cm quadrat | percent cover |
| pebbles | exposed pebbles % cover within a 25 cm by 25 cm quadrat | percent cover |
| Gracilaria_salicornia | Gracilaria salicornia % cover within a 25 cm by 25 cm quadrat | percent cover |
| Hypnea_sp | Hypnea musciformis % cover within a 25 cm by 25 cm quadrat | percent cover |
| Gratalupia_sp | Gratalupia sp. % cover within a 25 cm by 25 cm quadrat | percent cover |
| Dictyota_sp | Dictyota spp. % cover within a 25 cm by 25 cm quadrat | percent cover |
| Galaxaura_spp | Galaxaura spp. % cover within a 25 cm by 25 cm quadrat | percent cover |
| Chaetomorpha_sp | Chaetomorpha sp. % cover within a 25 cm by 25 cm quadrat | percent cover |
| Lyngbya_sp | Lyngbya sp. % cover within a 25 cm by 25 cm quadrat | percent cover |
| Coelothrix_irregularis | Coelothrix irregularis % cover within a 25 cm by 25 cm quadrat | percent cover |
| Spyridia_sp | Spyridia sp. % cover within a 25 cm by 25 cm quadrat | percent cover |
| Dictyosphaeria_versluvsyii | Dictyosphaeria versluvsyii % cover within a 25 cm by 25 cm quadrat | percent cover |

| | | |
|---|---|---|
| CCA | crustose coralline algae % cover within a 25 cm by 25 cm quadrat | percent cover |
| Gelidium_spp | Gelidium spp. % cover within a 25 cm by 25 cm quadrat | percent cover |
| Simploca_sp | Simploca sp. % cover within a 25 cm by 25 cm quadrat | percent cover |
| Laurencia_spp | Laurencia spp. % cover within a 25 cm by 25 cm quadrat | percent cover |
| Unknown_2 | unknown macroalgae % cover within a 25 cm by 25 cm quadrat | percent cover |
| Uknown_green_3 | unknown green macroalgae % cover within a 25 cm by 25 cm quadrat | percent cover |
| Pocillopora_spo | Pocillopora spp. % cover within a 25 cm by 25 cm quadrat | percent cover |
| Montipora_sp | Monitpora sp. % cover within a 25 cm by 25 cm quadrat | percent cover |
| Zooanthids | species from Order Zoantharia % cover within a 25 cm by 25 cm quadrat | percent cover |

[ table of contents | back to top ]

## Instruments

| | |
|---|---|
| **Dataset-specific Instrument Name** | Odyssey Temperature and Conductivity loggers |
| **Generic Instrument Name** | Salinity Sensor |
| **Generic Instrument Description** | Category of instrument that simultaneously measures electrical conductivity and temperature in the water column to provide temperature and salinity data. |

| | |
|---|---|
| **Dataset-specific Instrument Name** | Portasal Salinometer 8410A |
| **Generic Instrument Name** | Salinometer |
| **Generic Instrument Description** | A salinometer is a device designed to measure the salinity, or dissolved salt content, of a solution. |

[ table of contents | back to top ]

## Project Information

**RUI: Collaborative Research: Defining the biogeochemical context and ecological impacts of submarine groundwater discharge on coral reefs (Moorea SGD)**

**Coverage**: Mo'orea, French Polynesia

*NSF Award Abstract:*
Submarine groundwater discharge (SGD) is the flow of water from land through the coastal seafloor into the nearby ocean. Approximately 13,000 cubic kilometers of groundwater is discharged into coastal environments every year, yet the effects of this fresh and often nutrient rich SGD are still poorly understood for coral reefs. This SGD input is driven by changes in precipitation, human land use, sea-level rise, tidal amplitude, and groundwater usage, many of which are rapidly changing with climate and human impacts. This project improves our understanding of SGD effects on coral reefs to better predict how both natural and human-induced changes will affect coastal ecosystem functioning in the future. Working in one of the most comprehensively studied coral reef ecosystems in the Pacific (Mo'orea, French Polynesia, home of the Mo'orea Coral Reef Ecosystem LTER); this project tests the influence of SGD on individual, community, and ecosystem-scale coral reef processes. Using mensurative studies, caging experiments, and a synthetic model, the investigators: 1) characterize SGD gradients and relate it to high resolution coral reef cover data, 2) determine how individual to ecosystem processes are influenced by SGD, and 3) develop a synthetic model to show how changes in SGD fluxes will alter reef ecosystem functioning. As SGD is a common feature on nearshore coral reefs worldwide, the results of this study have global implications for understanding the performance of coral reefs, which are essential economic, cultural, and scientific resources. This project is structured to provide training across multiple career levels, linking 13 undergraduate students, 2 graduate students, 2 senior personnel, 1 postdoctoral researcher, 1 female beginning lead investigator, and 2 senior co-investigators, with a focus on encouraging participation from underrepresented groups (e.g., through the Alaska Native and Native Hawaiian, Asian American and Native American Pacific Islander, and Hispanic-Serving Institutions of California State University Northridge, the University of Hawai'i at Mānoa, and California State University Long Beach). The investigators work with local K-12 students and teachers in Mo'orea and collaborate with an artist-in-residence to communicate science to the broader public through interactive and immersive art experiences in Mo'orea, Miami, and Los Angeles.

SGD is a natural and understudied feature of many nearshore coral reef ecosystems, which can contribute substantial changes to marine biogeochemistry, with impacts for coastal organisms such as reef-building corals, macroalgae, and bioeroders. SGD may play a key role in coral reef ecosystem functioning because it alters key physicochemical parameters (e.g., temperature, salinity, and nutrient and carbonate chemistry) that substantially affect both biotic and abiotic processes on coral reefs. This project (i) characterizes the spatial extent and biogeochemical signal of SGD in Mo'orea, French Polynesia, (ii) identifies how SGD influences microbial processes, benthic organism growth rates and physiology, species interactions between corals, macroalgae, and herbivores, and net ecosystem calcification and production rates, and (iii) quantitatively assesses how changes in SGD fluxes will alter reef biogeochemistry and ecosystem functioning through an integrative modelling effort. Specifically, the hydrogeological, biogeochemical, and ecological data collected in this study are synthesized in a Bayesian structural equation model. This project characterizes and quantifies how SGD directly and indirectly affects ecosystem functioning via changes in biogeochemistry and altered individual to ecosystem responses, thereby providing a better capacity to track and predict alterations in reef ecosystem function.

This award reflects NSF's statutory mission and has been deemed worthy of support through evaluation using the Foundation's intellectual merit and broader impacts review criteria.

[ table of contents | back to top ]

## Funding


| Funding Source | Award |
|---|---|
| NSF Division of Ocean Sciences (NSF OCE) | OCE-1923877 |


[ table of contents | back to top ]