

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

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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 Hawaii at Manoa	Principal Investigator
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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)

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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.

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Data Files

File
EOF_Oahu.csv (Comma Separated Values (.csv), 40.10 KB) MD5:8a9fe1d8b761a22d0e686eab3cab5b55
Primary data file for dataset ID 860764

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](https://doi.org/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, Manuaia 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](https://doi.org/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](https://doi.org/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](https://doi.org/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](https://doi.org/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 Maunaloa Bay, O'ahu, Hawai'i. *Journal of Hydrology: Regional Studies*, 11, 178–193.

doi:[10.1016/j.ejrh.2015.11.006](https://doi.org/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](https://doi.org/10.1002/lno.10654)

Methods

Wikle, C. K., Zammit-Mangion, A., & Cressie, N. (2019). *Spatio-Temporal Statistics with R*.

doi:[10.1201/9781351769723](https://doi.org/10.1201/9781351769723)

Methods

Parameters

Parameter	Description	Units
site	name of the site found in Maunaloa 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	latitude	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_amadelpa	Avrainvillea amadelpa % 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
Pterocliadiella_spp	Pterocliadiella 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	Montipora 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

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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.

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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.

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Funding

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

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