Iron use efficiency (IUE) of the model marine ammonia-oxidizing archaea (AOA), Nitrosopumilus maritimus, under controlled laboratory conditions across a range of temperatures and iron concentrations

Website: https://www.bco-dmo.org/dataset/1005573
Data Type: experimental
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Project
» Collaborative Research: The impact of ocean warming on bioactive trace metal requirements and use efficiencies of marine nitrifying microorganisms (Nitrifiers_TMReqs_OceanWarming)

Contributors	Affiliation	Role
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Abstract
This dataset quantifies iron use efficiency (IUE) of the model marine ammonia-oxidizing archaea, Nitrosopumilus maritimus, under controlled laboratory conditions across a range of temperatures (23, 27, and 32 degrees Celsius) and iron concentrations (iron-replete, 1250 nM; iron-limited, 250 nM). Measurements include carbon fixation rates derived from 14C-bicarbonate incorporation assays and cellular iron quotas determined by inductively coupled plasma mass spectrometry (ICP-MS), from which IUE was calculated. Experiments were conducted in batch cultures with biological replicates for each treatment to assess the interactive effects of temperature and iron limitation on AOA physiology.

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Methods & Sampling

Trace metal clean culturing experiments were conducted using the marine ammonia-oxidizing archaeon *Nitrosopumilus maritimus* (urn:lsid:marinespecies.org:taxname:559434) grown in 2.7 L trace metal clean polycarbonate bottles containing 2 L artificial seawater medium supplemented with 1 mM ammonium. All bottles and media were acid-cleaned and treated with Chelex resin to remove trace metal contaminants, and all manipulations were performed under HEPA-filtered conditions to minimize contamination. Cultures were acclimated to experimental conditions (23, 27, and 32 °C; low Fe: 250 nM; high Fe: 1250 nM) for at least six growth cycles prior to measurements. Three biological replicates were established for each treatment.

Carbon fixation rates were determined using 14C-labeled bicarbonate incorporation. Briefly, 45 mL culture subsamples were amended with 14C-NaHCO3 and incubated for 4 hours in the dark. Incubations were

terminated by filtration onto 0.1 µm polyethersulfone filters (25 mm), and radioactivity was quantified using liquid scintillation counting.

Particulate organic carbon (POC) was measured by filtering 100–200 mL of culture onto precombusted glass fiber filters (GF75, 0.3 µm), followed by drying (~60 °C) and analysis using an elemental analyzer calibrated with organic standards.

Cellular iron quotas were determined under trace metal clean conditions. Culture samples (200–400 mL) were filtered onto acid-cleaned 0.1 µm polyethersulfone filters and rinsed with EDTA-oxalate to remove extracellular metals. Filters were stored at −20 °C prior to digestion. Samples were digested in 50% nitric acid at 90 °C for 2–3 days, dried, and re-dissolved in 0.1 M HNO3 with indium as an internal standard. Iron concentrations were measured using inductively coupled plasma mass spectrometry (ICP-MS).

Iron use efficiency (IUE) was calculated as the ratio of carbon fixation rate to cellular iron quota.

Data Processing Description

Carbon fixation rates were calculated from 14C incorporation measurements by converting scintillation counts to rates using the specific activity of added 14C-bicarbonate, with background correction applied where appropriate.

Particulate organic carbon (POC) was obtained directly from elemental analyzer measurements.

Cellular iron quotas were derived from ICP-MS measurements following calibration with external standards and correction using an internal indium standard.

Fe:C ratios were calculated by normalizing iron quotas to POC, and iron use efficiency (IUE) was calculated as the ratio of carbon fixation rate to cellular iron quota.

BCO-DMO Processing Description

This section documents curation actions performed prior to publication review with the submitter, and additional information relevant to understanding and reusing this dataset. It distinguishes changes made to the submitted (meta)data from unresolved issues and/or enhancements that improve future reuse and interoperability.

CURATION ACTIONS PERFORMED ON DATA

- Loaded data from an Excel file (Sheet1) titled "Iron use efficiency (IUE) of the model marine ammonia-oxidizing archaea (AOA), Nitrosopumilus maritimus, under controlled laboratory conditions across a range of temperatures and iron concentrations.xlsx", assigning it the table name iron_use_efficiency_nitrosopumilus; used header row 1, limited rows loaded to 1000, preserved cell display formatting, and set missing value markers to empty string and "nd"
- Renamed columns to comply with BCO-DMO parameter naming conventions: "Total iron concentration (nM)" to total_iron_concentration, "Standard deviation of POC (umol C/L)" to POC_std, "Fe (nmol/L)" to Fe, "Standard deviation of Fe (nmol/L)" to Fe_std, "Fe/C (umol/mol)" to Fe_C_ratio, "Standard deviation of Fe/C (umol/mol)" to Fe_C_ratio_std, "Standard deviation of Carbon fixation (umolC L-1 d-1)" to Carbon_fixation_std, "Iron use efficiency (umol C/hr/ umol Fe)" to iron_use_efficiency, "Standard deviation of Iron use efficiency (umol C/hr/ umol Fe)" to iron_use_efficiency_std, "POC (umol C/L)" to POC, and "Carbon fixation (umolC L-1 d-1)" to Carbon_fixation
- Output as 1005573_v1_iron_use_efficiency_nitrosopumilus.csv

CURATION ACTIONS PERFORMED ON METADATA

- Used context from methods section to provide more detail for parameter descriptions
- Added WORMS URI: All scientific names in the data are valid and accepted names as of 2026-08-21

ISSUES POTENTIALLY IMPACTING REUSE

- The dataset contains only treatment-level means and standard deviations, along with replicate counts. Raw

values were not provided.

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Related Publications

Qin, W., Tagliabue, A., Hou, L., Xu, M., Bian, X., Moran, D. M., Zhao, D., Li, Q., McIlvin, M. R., Zheng, Y., Kao, S.-J., Zhang, Y., Saito, M. A., John, S. G., Fu, F.-X., & Hutchins, D. A. (2026). Ocean warming enhances iron use efficiencies of marine ammonia-oxidizing archaea. Proceedings of the National Academy of Sciences, 123(10). https://doi.org/10.1073/pnas.2531032123
Methods
,
Results

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Parameters

Parameter	Description	Units
Condition	Iron treatment condition (e.g., iron-replete or iron-limited) applied to the culture	unitless
total_iron_concentration	Total dissolved iron concentration added to the culture medium under the specified treatment	nanomole per liter (nM)
Temperature	Incubation temperature	degrees Celsius (°C)
POC	Mean particulate organic carbon concentration in the culture, measured by elemental analyzer	micromole carbon per liter (µmol C L^{-1})
POC_std	Standard deviation of particulate organic carbon across three biological replicates	micromole carbon per liter (µmol C L^{-1})
Fe	Mean cellular iron concentration in the culture, measured by ICP-MS	nanomole per liter (nM)
Fe_std	Standard deviation of cellular iron concentration across three biological replicates	nanomole per liter (nM)
Fe_C_ratio	Mean cellular iron-to-carbon ratio (Fe:C), calculated by normalizing cellular iron quota to particulate organic carbon	micromole per mole (µmol mol^{-1})
Fe_C_ratio_std	Standard deviation of Fe:C ratio calculated across three biological replicates	micromole per mole (µmol mol^{-1})

Carbon_fixation	Mean rate of carbon fixation by the culture, determined from ^{14}C-bicarbonate incorporation assays	micromole carbon per liter per day (µmol C L^{-1} d^{-1})
Carbon_fixation_std	Standard deviation of the carbon fixation rate calculated across three biological replicates	micromole carbon per liter per day (µmol C L^{-1} d^{-1})
iron_use_efficiency	Mean iron use efficiency (IUE), calculated as the carbon fixation rate normalized to the cellular iron quota, representing carbon fixed per unit of cellular iron per hour	micromole carbon per hour per micromole iron (µmol C h^{-1} µmol Fe^{-1})
iron_use_efficiency_std	Standard deviation of iron use efficiency calculated across three biological replicates	micromole carbon per hour per micromole iron (µmol C h^{-1} µmol Fe^{-1})
Replicates	Number of biological replicate cultures used to calculate the mean and standard deviation for each treatment (temperature × iron concentration combination)	count

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Instruments

Dataset-specific Instrument Name	Costech elemental analyzer (Costech Analytical Technologies Inc.)
Generic Instrument Name	Elemental Analyzer
Dataset-specific Description	Particulate organic carbon (POC) was analyzed using a Costech elemental analyzer (Costech Analytical Technologies Inc.) calibrated with methionine and acetanilide standards.
Generic Instrument Description	Instruments that quantify carbon, nitrogen and sometimes other elements by combusting the sample at very high temperature and assaying the resulting gaseous oxides. Usually used for samples including organic material.

Dataset-specific Instrument Name	Wallac 1400 liquid scintillation counter (PerkinElmer)
Generic Instrument Name	Liquid Scintillation Counter
Dataset-specific Description	Liquid scintillation counting was performed using a Wallac 1400 liquid scintillation counter (PerkinElmer) to quantify 14C incorporation for carbon fixation rate measurements.
Generic Instrument Description	Liquid scintillation counting is an analytical technique which is defined by the incorporation of the radiolabeled analyte into uniform distribution with a liquid chemical medium capable of converting the kinetic energy of nuclear emissions into light energy. Although the liquid scintillation counter is a sophisticated laboratory counting system used to quantify the activity of particulate emitting (ß and a) radioactive samples, it can also detect the auger electrons emitted from 51Cr and 125I samples. Liquid scintillation counters are instruments assaying alpha and beta radiation by quantitative detection of visible light produced by the passage of rays or particles through a suitable scintillant incorporated into the sample.

Dataset-specific Instrument Name	Thermo Scientific Element2 inductively coupled plasma mass spectrometer (ICP-MS)
Generic Instrument Name	Thermo Fisher Scientific ELEMENT 2 inductively coupled plasma mass spectrometer
Dataset-specific Description	Cellular iron concentrations were measured using a Thermo Scientific Element2 inductively coupled plasma mass spectrometer (ICP-MS) at the University of Southern California. Instrument calibration was performed using external iron standards (10 ppb and 90 ppb), and indium was used as an internal standard to correct for signal drift and matrix effects.
Generic Instrument Description	The Thermo Scientific Element 2 ICP-MS is a double-focussing magnetic-sector-field Inductively Coupled Plasma Mass Spectrometer equipped with a discrete dynode detector system, linear over nine orders of magnitude - from ppq to ppm concentrations. Other features include: Sensitivity (Concentric Nebuliser) greater than 1 x 10^9 counts per second (cps)/ppm In; Dark noise less than 0.2 cps; Mass resolution 300, 4,000, 10,000 (10 percent valley, equivalent to 5 percent height), 600, 8,000, 2,000 (FWHM); Signal stability better than 1 percent RSD over 10 minutes or 2 percent RSD over 1 hour; Mass stability: 25 ppm / 8 hours; Magnetic scan speed: m/z 7 to 240 to 7 in less than 150 ms, Electronic scan speed: 1 ms/jump, independent of mass range.

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Project Information

Collaborative Research: The impact of ocean warming on bioactive trace metal requirements and use efficiencies of marine nitrifying microorganisms (Nitrifiers_TMReqs_OceanWarming)

Coverage: Eastern North Pacific: HNLC and subtropical gyre; SPOT time-series station; HOT time-series station.

NSF Award Abstract:

This project seeks to provide a deeper understanding of how major biogeochemical cycles that support all living marine resources will respond to climate warming in a changing ocean environment. It will train one postdoctoral researcher and three graduate students, and provides research training opportunities for undergraduate students in microbial physiology and ecology, bioinformatics, trace metal biogeochemistry, and

oceanography. Project personnel also conduct K-12 education and outreach activities. All data is freely available through the Biological and Chemical Oceanographic Data Management Office (BCO-DMO).

This project investigates how climate warming will interact with the unique trace metal requirements of marine nitrifying microorganisms (nitrifiers) to affect ammonia and nitrite oxidation pathways in the rapidly changing ocean. Four investigators with diverse expertise in microbial global change physiology, nitrogen and trace metal biogeochemistry, and mechanistic transcriptomics and proteomics combine their efforts, using well-controlled pure culture-based laboratory studies along with field incubation experiments with natural communities to systematically investigate 1) thermal effects on iron (Fe) and copper (Cu) requirements and use efficiencies in isolated cultures and natural populations of marine ammonia-oxidizing archaea and bacteria (AOA, AOB) and nitrite-oxidizing bacteria (NOB), 2) the underlying molecular and biochemical mechanisms that facilitate such thermally-driven adaptive responses, and 3) system-level feedbacks between global change, trace metal biogeochemistry, and marine nitrifiers and their associated microbial communities in diverse marine environments. Together, these studies enhance our understanding of the marine nitrogen cycle and trace metal biogeochemistry, and ultimately contribute to a more detailed understanding of the impact of rapid ocean warming on critical major nutrient and micronutrient cycles.

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-2336533
NSF Division of Ocean Sciences (NSF OCE)	OCE-2336534
NSF Division of Ocean Sciences (NSF OCE)	OCE-2610907

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