Literature review of Ocean Acidification (OA) effects on phytoplankton (P-ExpEv project)

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Project
» Impacts of Evolution on the Response of Phytoplankton Populations to Rising CO2 (P-ExpEv)

Program
» Science, Engineering and Education for Sustainability NSF-Wide Investment (SEES): Ocean Acidification (formerly CRI-OA) (SEES-OA)

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Abstract
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Dataset Description

Literature review of Ocean Acidification (OA) effects on phytoplankton, focusing on growth rate effects.

Details of literature review are contained in Dutkiewicz et al. 2015 (10.1038/NCLIMATE2722). Any use or re-analysis of this data should cite this paper.

Methods & Sampling

Compilation of Acidification Experiments
(modified from supplemental material associated with Dutkiewicz et al., submitted 2015)

In order to develop a baseline understanding of the responses of phytoplankton groups to ocean acidification, we conducted a comprehensive literature search of laboratory studies (current as of December 2014). We focused on growth rate effects, but additional data were recorded as well. A search of the Web of Science was conducted using the search phrase "(coccolith* OR diatom* OR prochloroc* OR synechoc* OR trichodes* OR crocosphae* OR diazotroph*) AND (CO_2 OR "carbon dioxide" OR "ocean acidification") AND ("growth rate")". Each abstract was read and any paper that mentioned a comparison between ambient and elevated CO_2 conditions was downloaded. Additional papers were selected based on reference lists from the above papers and personal communications with researchers. We further curated these papers by excluding any that i) did not actually compare growth rates at different CO_2 concentrations, ii) did not specify the CO_2 levels examined,

iii) used CO_2 concentrations outside the range 250 – 1100 ppmv, iv) attempted to separately manipulate CO_2 concentration and pH using organic buffers, v) manipulated CO_2/pH in such a way as to radically change alkalinity, and/or vi) presented data in such a way that it was impossible to calculate a ratio of elevated:ambient growth rates. One additional paper was removed because it had been retracted. We also did not consider comparisons of growth rates for organisms in mixed communities or for freshwater species.

Table 1 (PDF) shows the papers that were used for the meta-analysis, and Table 2 (PDF)shows the papers that were rejected along with the reasons for rejection. Values were collected from tabulated data in papers where possible; otherwise values were estimated visually from figures. No attempt was made to extract information about replication level, variance, or significance level of data; only experimental means were collected. Many papers examined the response to CO_2 enrichment under a variety of environmental conditions (e.g., different light or nutrient levels). Each environment was considered as a unique experiment, and no attempt was made to examine covariance or synergy between any other parameter and response to CO_2.

All data points in the dataset represent ratios of the value in a high CO_2 experiment to the value in an ambient CO_2 environment.

Data Processing Description

BCO-DMO Processing Notes:
- Replaced spaces with underscores in the reference, organism, and class columns.
- Removed commas and parentheses from the reference column.
- Replaced commas with semi-colons throughout the dataset.
- Replaced blanks 'nd', meaning 'no data'.
- Modified parameter names to conform with BCO-DMO naming conventions.
- Created new column, 'measurement_type', and sorted data accordingly.

Version history:
Version 2 (current): published 2015-07-07 (spreadsheet submitted by J.J. Morris on 0215-07-03; significant changes made in the organization of data, including the creation of separate columns for different CO_2 conditions). Version 2 is available from the "Get Data" button on this page.

Version 1: published 2015-03-26 (spreadsheet submitted by J.J. Morris on 19 March 2015). Version 1 is attached as a Supplemental File (OA_Lit_Review_03262015.csv)

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Data Files

File
OA_Lit_Review.csv (Comma Separated Values (.csv), 228.60 KB) MD5:6f4fe8b519c9b8cf2cf6dad3b11e2ce9 Primary data file for dataset ID 554221

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Supplemental Files

File	
OA_Lit_Review_03262015.csv Version 1 of dataset "OA Lit Review" (datset ID 554221; PI Morris)	(Comma Separated Values (.csv), 109.86 KB) MD5:0cf2b33d5e91fb3b697504cd0ae827b9
Table_1_Morris.pdf Citations of the papers that were used for the meta-analysis. Supplemental File for dataset "OA Lit Review" (dataset ID 554221; PI: Morris).	(Portable Document Format (.pdf), 325.32 KB) MD5:59a70d3a6dade0b40922e1f1d34fb28f
Table_2_Morris.pdf List of papers that were rejected along with the reasons for rejection. Supplemental File for dataset "OA Lit Review" (dataset ID 554221; PI: Morris).	(Portable Document Format (.pdf), 226.37 KB) MD5:c06fe89d9305bf8027ea2821c10ae050

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Related Publications

Dutkiewicz, S., Morris, J. J., Follows, M. J., Scott, J., Levitan, O., Dyhrman, S. T., & Berman-Frank, I. (2015). Impact of ocean acidification on the structure of future phytoplankton communities. Nature Climate Change, 5(11), 1002–1006. https://doi.org/10.1038/nclimate2722 https://doi.org/10.1038/NCLIMATE2722
Results

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Parameters

Parameter	Description	Units
reference	Source for the row's data.	text
organism	Species/strain analyzed.	text
class	Functional group of organism: Coccolithophore, diatom, other large, diazotroph, Prochlorococcus, or other small.	text
CO2_low	CO2 concentration of "Low CO2" value examined.	refer to "CO2_units"
CO2_high	CO2 concentration of "High CO2" value examined.	refer to "CO2_units"
CO2_units	Units in which CO2 concentration was expressed: ppm, parts per million; pH, pH as a proxy for CO2; M, moles CO2 per L of solution.	text
temp	Temperature of the observation in C.	degrees Celsius
light	Light level in micromoles photons m-2 s-1.	micromoles photons per square meter per second (m-2 s-1)

notes	Other important variables OR reason that the paper was excluded from consideration.	text
measurement_type	Whether the given data points are from a high CO2 treatment (High_CO2), a low CO2 treatment (Low_CO2), or are the ratio of high:low CO2 (Ratio_high_to_low_CO2) for the indicated parameter.	text
growth_rate	Calculated from exponential growth rates.	cell # or proxy thereof and d^-1 unless otherwise stated
yield	Maximum cell concentration.	cells (or filaments)
cell_vol	Cell volume, absolute measurement.	cubic micrometers (um^3) per cell
cell_vol_FC	Cell volume, approximation from flow cytometer light scattering.	Flow cytometer estimate
cell_diam	Cell diameter.	micrometers (um)
cells_per_fil_len	Cells/filament length.	micrometers (um)
surf_area	Surface area.	square micrometers per cell (um^2 cell^-1)
surf_area_to_vol	Surface area:volume ratio.	Ratio
POC	Amount of organic carbon per cell.	micromoles per cell (umol cell^-1) or per chlorophyll (chl^-1) where cell densities not given
PON	Amount of nitrogen per cell.	micromoles per cell (umol cell^-1)
POP	Amount of phosphorus per cell.	micromoles per cell (umol cell^-1)
PIC	Amount of inorganic carbon per cell.	micromoles per cell (umol cell^-1) or per chlorophyll (chl^-1) where cell densities not given
PIC_to_POC	Ratio of inorganic to organic carbon.	ratio
C_to_N	Carbon:nitrogen ratio.	M/M

C_to_P	Carbon:phosphorus ratio.	M/M
N_to_P	Nitrogen:phosphorus ratio.	M/M
chla_pg_per_cell	Concentration of chl A per cell.	picograms per cell (pg cell^-1)
chla_ug_per_umolC	Concentration of chl A per mole of carbon.	micrograms per micromoles Carbon (ug umolC^-1)
chla	Cell-normalized fluorescence; Amount of chlorophyll estimated from in vivo chlorophyll fluorescence.	cell-normalized fluorescence
acc_pig_pg_per_cell	Accessory pigments; concentration of pigments such as carotenoids per cell.	picograms per cell (pg cell^-1)
acc_pig_ug_per_umolC	Concentrations of pigments such as carotenoids per mole of carbon.	micrograms per micromoles Carbon (ug umolC^-1)
tot_carb	Total carbohydrates per cell.	picograms per cell (pg cell^-1)
tot_protein	Total proteins per cell.	picograms per cell (pg cell^-1)
RUBISCO_activity	RUBISCO activity; from cell extracts, normalized to total protein.	mAb340 mgprotein^-1
RUBISCO_exp	RUBISCO expression: transcripts per cell.	arbitrary units
alpha_init_slope	Alpha: initial slope of the PE curve measured from O2 evolution.	initial slope
alpha	Alpha: initial slope of the PE curve measured based on CO2 fixation.	micromoles C per milligram chlorophyll per hour per microeinstein (umolC mgchl^-1 h^-1 uein^-1)
Pmax_for_PE_curve	Pmax: inferred asymptote of the PE curve measured from O2 evolution.	millimoles O2 per milligram chlorophyll per hour (mmolO2 mgchl^-1 h^-1)
Pbmax	Pbmax: inferred asymptote of the PE curve measured from CO2 fixation.	micromoles C per milligram chlorophyll per hour (umolC mgChl^-1 h^-1)
Ek	Ek: light saturation constant for the PE curve.	microEinsteins (uEin)

Ec	Ec: irradiance necessary to yield sufficient energy for growth via photosynthesis.	compensation light; microEinsteins (uEin)
beta	Beta: initial slope of photosynthesis vs. DIC curve.	micromoles O2 per milligram chlorophyll per hour per micromole DIC (umolO2 mgchl^-1 h^-1 umolDIC^-1)
Km	Km: light saturation constant for the photosynthesis vs. DIC curve.	CO2 affinity; milliMolar DIC (mM DIC)
Pmax_for_DIC_curve	Pmax for DIC curve: inferred asymptote of the photosynthesis vs. DIC curve.	micromoles O2 per milligram chlorophyll per hour (umolO2 mgchl^-1 h^-1)
Phi_max	Phi-max: moles of CO2 fixed per mole of photons.	moles C per moles quanta (molC molquanta^-1)
abar	Abar*. Chlorophyll absorption coefficient.	Chl abs coefficient; m^2 mgChl^-1
rETRmax	rETRmax: maximum rate of photosynthetic electron transfer.	umol m^-2 s^-1
C_fix_nmol_per_cell_hr	C fixation: rate of CO2 fixed per cell.	nmol cell^-1 h^-1
C_fix_nmol_per_mgChl_hr	C fixation: rate of CO2 fixed per mg Chl A.	nmolC mgChl^-1 h^-1
C_spec_CO2_fix	Carbon specific CO2 fixation: rate of CO2 fixed per mole of carbon.	h^-1
net_photosyn_uM	Net photosynthesis: moles O2 produced per mg chl A.	uMO2 mgchla^-1 h^-1
net_drk_resp_umol	Net dark respiration: moles O2 consumed per mg chl A.	umolO2 mg chla^-1 h^-1
net_photosyn_pmol	Net photosynthesis: moles O2 produced per cell.	pmolO2 cell^-1 d^-1
net_drk_resp_pmol	Net dark respiration: moles O2 consumed per cell.	pmolO2 cell^-1 d^-1
N_cost_photosyn	N cost of photosynthesis: Amount of nitrogen assimilated per mole of CO2 fixed.	mmolN molCfixed^-1 d^-1
PIC_prod	PIC Production: rate of PIC production per cell.	pmol cell^-1 d^-1

POC_prod	POC production: rate of POC production per cell.	pmol cell^-1 d^-1
PIC_to_POC_prod	PIC/POC Productivity ratio.	Ratio
PON_prod_uptake	PON prod/uptake: rate of nitrogen uptake per cell.	pmolN cell^-1 d^-1
NO3_uptake	NO3 uptake: rate of nitrate uptake per cell.	femtomoles per cell per hour (fmol cell^-1 h^-1)
NH4_uptake	NH4 uptake: rate of ammonium uptake per cell.	femtomoles per cell per hour (fmol cell^-1 h^-1)
P_prod_uptake	P prod/uptake: rate of phosphorus assimilation per cell.	picomoles P per cell per day (pmolP cell^-1 d^-1)
Si_prod_uptake	Si prod/uptake: rate of silicate uptake per cell.	picomoles per cell per day (pmol cell^-1 d^-1)
CO2_to_HCO3_uptake	Ratio of CO2 uptake to HCO3 uptake.	Ratio
CO2_leakage	CO2 leakage: rate of CO2 loss to gross uptake of DIC.	efflux:gross uptake
abb_cocco	% aberrant coccoliths: Proportion of cells showing microscopic evidence of malformed coccoliths.	%
detach_cocco	# detached coccoliths/coccospheres: abundance of coccoliths without coccolithophores.	count
Fv_to_Fm	Fv/Fm: Variable fluorescence (a measure of photosynthetic efficiency/health).	Ratio of arbitrary fluorescence units
N_fix_nmol	N fixation: rate of fixation of N2 gas per mole of carbon.	nanomoles N per micromoles C per hour (nmolN umolC^-1 h^-1)
N_fix_fmol	N fixation: rate of fixation of N2 gas per cell.	femtomoles N per cell per hour (fmolN cell^-1 h^-1)
N_fix_umol	N fixation: rate of fixation of N2 gas per mg Chl a.	micromoles N per milligram chlorophyll per hour (umolN mgChl^-1 h^-1)
Nspec_N_fix	N specific N fixation: rate of N fixation per mole of cellular nitrogen.	h^-1
DOC_umol_per_chl	DOC: dissolved organic carbon per mg chl A.	umol chl^-1

DOC_umol_per_L	DOC: dissolved organic carbon per liter of culture media.	umol L^-1
DON_umol_per_chl	DON: dissolved organic nitrogen per mg chl A.	umol chl^-1
DMSP_prod	DMSP production: rate of production of dimethylsulfoniopropionate normalized to cell volume.	uM h^-1 cell volume^-1
DMSP	DMSP: amount of DMSP per cell.	fmol cell^-1
membr_perm	Membrane permeability: a measure of viability based on uptake of a fluorescent dye.	viability; arbitrary fluorescence units
Fe_to_C	Fe:C: iron to carbon ratio.	umol mol^-1
Mo_to_C	Mo:C: molybdenum to carbon ratio.	umol mol^-1
Fe_use_eff	Fe use Efficiency: amount of CO2 fixed per mole of Fe assimilated.	molC molFe^-1 d^-1
Mo_use_eff	Mo use efficiency: amount of CO2 fixed per mold of Mo assimilated.	molC molMo^-1 d^-1
UV_inhib	UV inhibition: growth rate inhibition by ultraviolet light, %.	%
TEP_exudates	TEP exudates: moles of carbon in the form of transparent extracellular polymers per mL of culture media.	fmolC um^-3
domoic_acid_quota	Domoic acid quota: amount of domoic acid per cell.	picomoles per cell (pmol cell^-1)
domoic_acid_prod	Domoic acid production: rate of domoic acid production per cell.	picomoles per cell per day (pmol cell^-1 d^-1)
Si	Si: moles of silicon per cell.	picomoles per cell (pmol cell^-1)
Si_to_C	Si:C ratio: silicon to carbon ratio.	M/M

HCO3_uptake	HCO3 uptake: rate of bicarbonate attack per mg chlA.	micromoles per milligram chlorophyll per hour (umol mgchl^-1 h^-1)
CO2_uptake	CO2 uptake: rate of CO2 uptake per mg chlA.	micromoles per milligram chlorophyll per hour (umol mgchl^-1 h^-1)
K1_2_CO2_uptake	K1/2 CO2: half-saturation constant for CO2 uptake.	umol L^-1
K1_2_HCO3_uptake	K1/2 HCO3: half-saturation constant for HCO3 uptake.	umol L^-1
ecarbonic_anydr_act	eCarbonic Anhydrase activity: units of extracellular carbonic anhydrase active per mg chl A.	U ugchla^-1
icarbonic_anhydr_act	iCarbonic anhydrase activity: units of intracellular carbonic anhydrase activity per mg chl A.	U ugchla^-1
DIC_uptake	DIC uptake: rate of uptake of dissolved inorganic carbon per liter of culture media.	umol L^-1 d^-1
DIC_leakage	DIC leakage: rate of dissolved inorganic carbon leaker per liter of culture media.	umol L^-1 d^-1
saxitoxin	Saxitoxin: moles per cell.	fmol cell^-1

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Project Information

Impacts of Evolution on the Response of Phytoplankton Populations to Rising CO2 (P-ExpEv)

Coverage: Experiment housed in laboratories at Michigan State University

Note: This project is also affiliated with the NSF BEACON Center for the Study of Evolution in Action.

Project Description from NSF Award:
Human activities are driving up atmospheric carbon dioxide concentrations at an unprecedented rate, perturbing the ocean's carbonate buffering system, lowering oceanic pH, and changing the concentration and composition of dissolved inorganic carbon. Recent studies have shown that this ocean acidification has many short-term effects on phytoplankton, including changes in carbon fixation among others. These physiological changes could have profound effects on phytoplankton metabolism and community structure, with concomitant effects on Earth's carbon cycle and, hence, global climate. However, extrapolation of present understanding to the field are complicated by the possibility that natural populations might evolve in response to their changing environments, leading to different outcomes than those predicted from short-term studies. Indeed, evolution experiments demonstrate that microbes are often able to rapidly adapt to changes in the environment, and that beneficial mutations are capable of sweeping large populations on time scales relevant to predictions of environmental dynamics in the coming decades. This project addresses two major areas of uncertainty for phytoplankton populations with the following questions:

1) What adaptive mutations to elevated CO2 are easily accessible to extant species, how often do they arise, and how large are their effects on fitness?
2) How will physical and ecological interactions affect the expansion of those mutations into standing populations?

This study will address these questions by coupling experimental evolution with computational modeling of ocean biogeochemical cycles. First, cultured unicellular phytoplankton, representative of major functional groups (e.g. cyanobacteria, diatoms, coccolithophores), will be evolved under simulated year 2100 CO2 concentrations. From these experiments, estimates will be made of a) the rate of beneficial mutations, b) the magnitude of fitness gains conferred by these mutations, and c) secondary phenotypes (i.e., trade-offs) associated with these mutations, assayed using both physiological and genetic approaches. Second, an existing numerical model of the global ocean system will be modified to a) simulate the effects of changing atmospheric CO2 concentrations on ocean chemistry, and b) allow the introduction of CO2-specific adaptive mutants into the extant populations of virtual phytoplankton. The model will be used to explore the ecological and biogeochemical impacts of beneficial mutations in realistic environmental situations (e.g. resource availability, predation, etc.). Initially, the model will be applied to idealized sensitivity studies; then, as experimental results become available, the implications of the specific beneficial mutations observed in our experiments will be explored.

This interdisciplinary study will provide novel, transformative understanding of the extent to which evolutionary processes influence phytoplankton diversity, physiological ecology, and carbon cycling in the near-future ocean. One of many important outcomes will be the development and testing of nearly-neutral genetic markers useful for competition studies in major phytoplankton functional groups, which has applications well beyond the current proposal.

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Program Information

Science, Engineering and Education for Sustainability NSF-Wide Investment (SEES): Ocean Acidification (formerly CRI-OA) (SEES-OA)

Website: https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=503477

Coverage: global

NSF Climate Research Investment (CRI) activities that were initiated in 2010 are now included under Science, Engineering and Education for Sustainability NSF-Wide Investment (SEES). SEES is a portfolio of activities that highlights NSF's unique role in helping society address the challenge(s) of achieving sustainability. Detailed information about the SEES program is available from NSF (https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=504707).

In recognition of the need for basic research concerning the nature, extent and impact of ocean acidification on oceanic environments in the past, present and future, the goal of the SEES: OA program is to understand (a) the chemistry and physical chemistry of ocean acidification; (b) how ocean acidification interacts with processes at the organismal level; and (c) how the earth system history informs our understanding of the effects of ocean acidification on the present day and future ocean.

Solicitations issued under this program:
NSF 10-530, FY 2010-FY2011
NSF 12-500, FY 2012
NSF 12-600, FY 2013
NSF 13-586, FY 2014
NSF 13-586 was the final solicitation that will be released for this program.

PI Meetings:
1st U.S. Ocean Acidification PI Meeting(March 22-24, 2011, Woods Hole, MA)
2nd U.S. Ocean Acidification PI Meeting(Sept. 18-20, 2013, Washington, DC)
3rd U.S. Ocean Acidification PI Meeting (June 9-11, 2015, Woods Hole, MA – Tentative)

NSF media releases for the Ocean Acidification Program:

Press Release 10-186 NSF Awards Grants to Study Effects of Ocean Acidification

Discovery Blue Mussels "Hang On" Along Rocky Shores: For How Long?

Discovery nsf.gov - National Science Foundation (NSF) Discoveries - Trouble in Paradise: Ocean Acidification This Way Comes - US National Science Foundation (NSF)

Press Release 12-179 nsf.gov - National Science Foundation (NSF) News - Ocean Acidification: Finding New Answers Through National Science Foundation Research Grants - US National Science Foundation (NSF)

Press Release 13-102 World Oceans Month Brings Mixed News for Oysters

Press Release 13-108 nsf.gov - National Science Foundation (NSF) News - Natural Underwater Springs Show How Coral Reefs Respond to Ocean Acidification - US National Science Foundation (NSF)

Press Release 13-148 Ocean acidification: Making new discoveries through National Science Foundation research grants

Press Release 13-148 - Video nsf.gov - News - Video - NSF Ocean Sciences Division Director David Conover answers questions about ocean acidification. - US National Science Foundation (NSF)

Press Release 14-010 nsf.gov - National Science Foundation (NSF) News - Palau's coral reefs surprisingly resistant to ocean acidification - US National Science Foundation (NSF)

Press Release 14-116 nsf.gov - National Science Foundation (NSF) News - Ocean Acidification: NSF awards $11.4 million in new grants to study effects on marine ecosystems - US National Science Foundation (NSF)

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Funding

Funding Source	Award
NSF Division of Ocean Sciences (NSF OCE)	OCE-1316101

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