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Evidence of high N_2 fixation rates in the temperate northeast Atlantic

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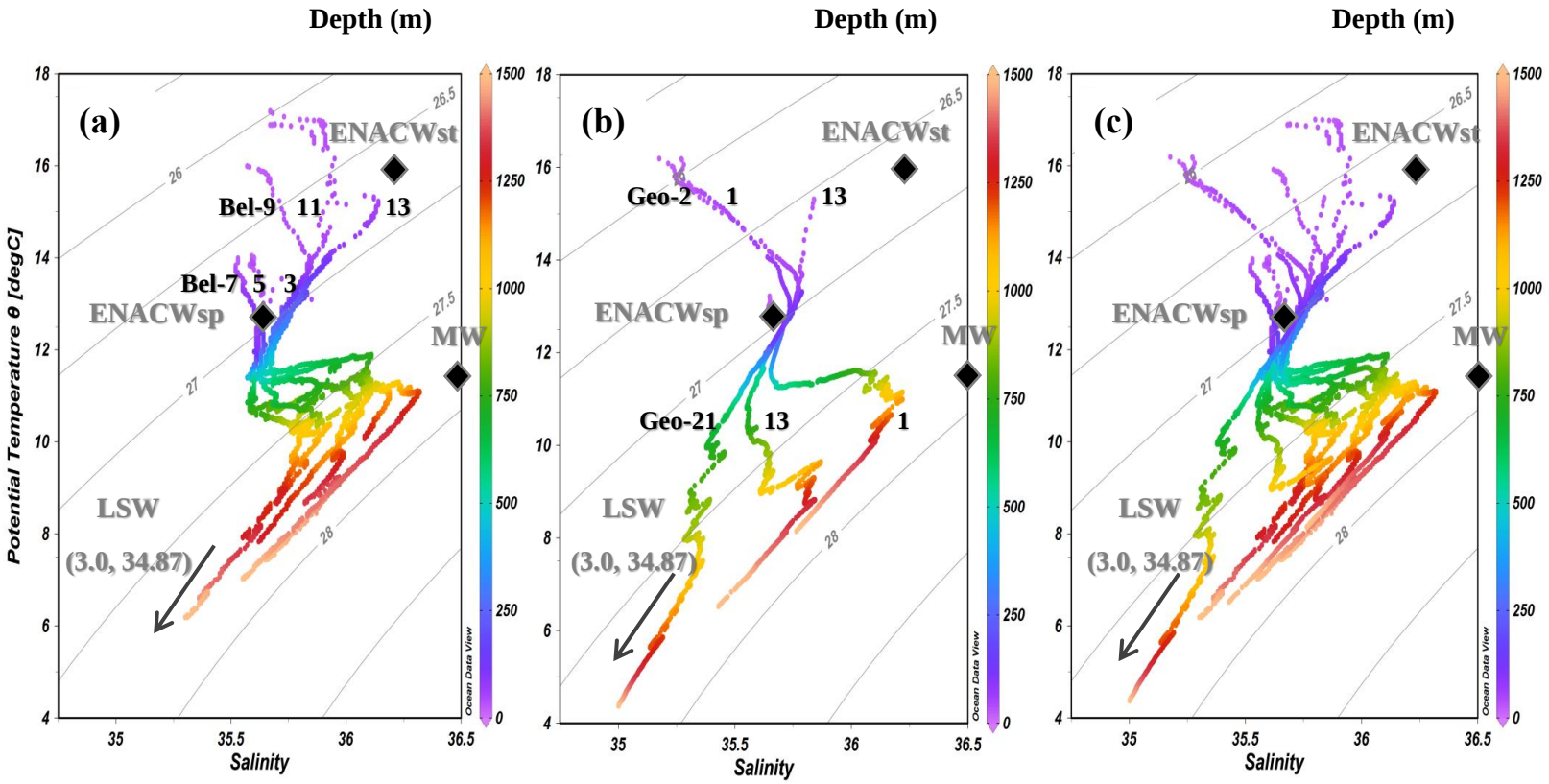


Supplementary Figure S1. θ-S diagrams obtained using CTD profiles down to 1500 m depth during **(a)** the Belgica BG2014/14 cruise (stations Bel-3, 5, 7, 11 and 13), **(b)** the GEOVIDE cruise (stations Geo-1, 2, 13 and 21) and **(c)** both expeditions combined. Diamonds indicate the characteristics of the major water masses encountered as reported in Fiúza (1984) and García-Ibáñez et al. (2015): Eastern North Atlantic Central Waters (ENACW) of subpolar (ENACWsp) and subtropical (ENACWst) origin, Mediterranean Water (MW) and Labrador Sea Water (LSW). (Schlitzer, R., Ocean Data View).

Supplementary Table S1. Summary of the dataset used to test the Spearman rank correlations relating the volumetric rates of N_2 fixation and primary production to environmental variables.

Station	Date	Depth [m]	Lat. [°N]	Long. [°E]	**N_2 fixation [nmol N L^{-1} d^{-1}]**	**Primary production [µmol C m^{-3} d^{-1}]**	Temperature [°C]	Salinity [psu]	NH_4^+ [µM]	NO_3^-+NO_2^- [µM]	P* [µM]	Chl *a* [µg L^{-1}]
Bel-3	24-May-2014	5	46.5	-8.0	**< DL**	**1180.8**	13.86	35.58	< DL	0.27	0.04	1.42
Bel-3	24-May-2014	10	46.5	-8.0	**< DL**	**776.1**	13.87	35.58	< DL	0.36	0.04	1.25
Bel-3	24-May-2014	25	46.5	-8.0	**< DL**	**995.9**	13.78	35.58	< DL	1.14	0.06	1.10
Bel-3	24-May-2014	50	46.5	-8.0	**< DL**	**109.7**	12.44	35.62	0.35	4.62	-0.03	0.16
Bel-5	25-May-2014	5	45.3	-8.8	**< DL**	**429.1**	13.91	35.59	0.19	0.66	0.02	0.16
Bel-5	25-May-2014	30	45.3	-8.8	**< DL**	**360.6**	13.91	35.59	0.59	0.91	0.00	0.12
Bel-5	25-May-2014	70	45.3	-8.8	**< DL**	**433.9**	13.24	35.61	0.59	4.71	-0.04	0.21
Bel-5	25-May-2014	130	45.3	-8.8	**< DL**	**9.7**	11.92	35.62	< DL	7.74	-0.14	0.00
Bel-7	26-May-2014	5	44.6	-9.3	**1.1**	**849.1**	13.94	35.51	< DL	< DL	0.05	1.19
Bel-7	26-May-2014	16	44.6	-9.3	**1.0**	**707.3**	13.94	35.52	< DL	0.24	0.05	1.14
Bel-7	26-May-2014	30	44.6	-9.3	**2.0**	**1018.3**	13.86	35.52	0.09	1.01	0.00	0.98
Bel-7	26-May-2014	80	44.6	-9.3	**1.6**	**70.2**	13.32	35.55	0.34	2.84	0.02	0.16
Geo-21	31-May-2014	10	46.5	-19.7	**8.2**	**2824.8**	14.57	35.68	0.18	1.52		0.88
Geo-21	31-May-2014	18	46.5	-19.7	**< DL**	**3443.7**	13.70	35.69	0.39	2.21		1.21
Geo-21	31-May-2014	25	46.5	-19.7	**4.9**	**3500.1**	13.47	35.68	0.50	2.82		0.73
Geo-21	31-May-2014	40	46.5	-19.7	**1.4**	**1155.1**	12.84	35.65	0.68	4.13		0.39
Geo-21	31-May-2014	60	46.5	-19.7	**2.0**	**393.8**	12.84	35.69	0.41	5.32		0.19
Geo-21	31-May-2014	91	46.5	-19.7	**2.3**	**73.8**	12.51	35.70	< DL	7.19		

Supplementary Table S1 continued.

Station	Date	Depth [m]	Lat. [°N]	Long. [°E]	**N_2 fixation [nmol N L^{-1} d^{-1}]**	**Primary production [µmol C m^{-3} d^{-1}]**	Temperature [°C]	Salinity [psu]	NH_4^+ [µM]	NO_3^-+NO_2^- [µM]	P* [µM]	Chl *a* [µg L^{-1}]
Bel-9	27-May-2014	5	42.4	-9.7	**3.9**	**335.9**	16.04	35.55	< DL	< DL	0.05	0.16
Bel-9	27-May-2014	25	42.4	-9.7	**0.7**	**207.3**	15.96	35.56	< DL	0.38	0.04	0.18
Bel-9	27-May-2014	45	42.4	-9.7	**0.9**	**571.2**	14.33	35.83	< DL	2.07	-0.01	0.55
Bel-9	27-May-2014	120	42.4	-9.7	**< DL**	**6.9**	13.24	35.78	< DL	5.99	-0.08	0.01
Bel-11	28-May-2014	5	40.7	-11.1	**65.4**	**565.3**	16.95	35.56	< DL	< DL	0.05	0.15
Bel-11	28-May-2014	35	40.7	-11.1	**7.0**	**630.7**	15.18	35.84	< DL	< DL	0.05	0.28
Bel-11	28-May-2014	45	40.7	-11.1	**< DL**	**292.3**	15.26	35.83	< DL	0.61	0.02	0.12
Bel-11	28-May-2014	80	40.7	-11.1	**4.9**	**334.6**	14.01	35.90	< DL	4.35	-0.08	0.23
Bel-13	29-May-2014	5	38.8	-11.4	**45.0**	**599.4**	17.23	35.68	< DL	< DL	0.05	0.22
Bel-13	29-May-2014	30	38.8	-11.4	**10.5**	**323.2**	16.46	35.89	< DL	< DL	0.09	0.09
Bel-13	29-May-2014	45	38.8	-11.4	**12.6**	**692.0**	15.38	35.97	< DL	0.52	0.12	0.20
Bel-13	29-May-2014	80	38.8	-11.4	**2.4**	**92.6**	14.84	36.10	< DL	2.39	0.07	0.08
Geo-1	19-May-2014	6	40.3	-10.0	**4.8**	**621.8**	16.70	35.11	0.33	< DL		0.16
Geo-1	19-May-2014	11	40.3	-10.0	**7.1**	**696.9**	16.53	35.18	< DL	< DL		0.19
Geo-1	19-May-2014	16	40.3	-10.0	**4.8**	**667.8**	16.09	35.26	< DL	< DL		
Geo-1	19-May-2014	25	40.3	-10.0	**2.5**	**579.1**	15.33	35.36	< DL	0.42		0.33
Geo-1	19-May-2014	34	40.3	-10.0	**1.2**	**842.3**	15.14	35.46	< DL	0.76		0.35
Geo-1	19-May-2014	48	40.3	-10.0	**1.1**	**676.9**	14.35	35.62	< DL	2.44		0.46
Geo-2	20-May-2014	11	40.3	-9.5	**4.7**	**474.3**	16.82	34.99	< DL	< DL		0.21
Geo-2	20-May-2014	31	40.3	-9.5	**2.8**	**1170.5**	14.67	35.54	< DL	0.93		0.47
Geo-2	20-May-2014	39	40.3	-9.5	**2.7**	**1149.5**	13.97	35.70	0.09	1.38		0.98
Geo-2	20-May-2014	85	40.3	-9.5	**2.3**	**72.5**	13.32	35.77	< DL	4.39		0.02

Supplementary Table S1 final.

Station	Date	Depth [m]	Lat. [°N]	Long. [°E]	**N_2 fixation [nmol N L^{-1} d^{-1}]**	**Primary production [µmol C m^{-3} d^{-1}]**	Temperature [°C]	Salinity [psu]	NH_4^+ [µM]	NO_3^-+NO_2^- [µM]	P* [µM]	Chl *a* [µg L^{-1}]
Geo-13	24-May-2014	15	41.4	-13.9	**5.5**	**1670.7**	15.47	35.84	0.21	0.34		0.56
Geo-13	24-May-2014	30	41.4	-13.9	**1.0**	**403.0**	14.73	35.81	0.34	0.68		0.68
Geo-13	24-May-2014	43	41.4	-13.9	**2.4**	**910.9**	13.66	35.77	0.73	2.21		
Geo-13	24-May-2014	58	41.4	-13.9	**2.2**	**790.5**	13.36	35.76	0.68	3.47		0.45
Geo-13	24-May-2014	75	41.4	-13.9	**3.9**	**338.1**	13.14	35.76	0.07	4.54		0.17
Geo-13	24-May-2014	116	41.4	-13.9	**3.1**	**22.8**	12.91	35.75	< DL	6.27		0.01

Supplementary Table S2. Summary of the dataset used to run the principal component analysis relating the depth-integrated rates of N_2 fixation and primary production to environmental variables.

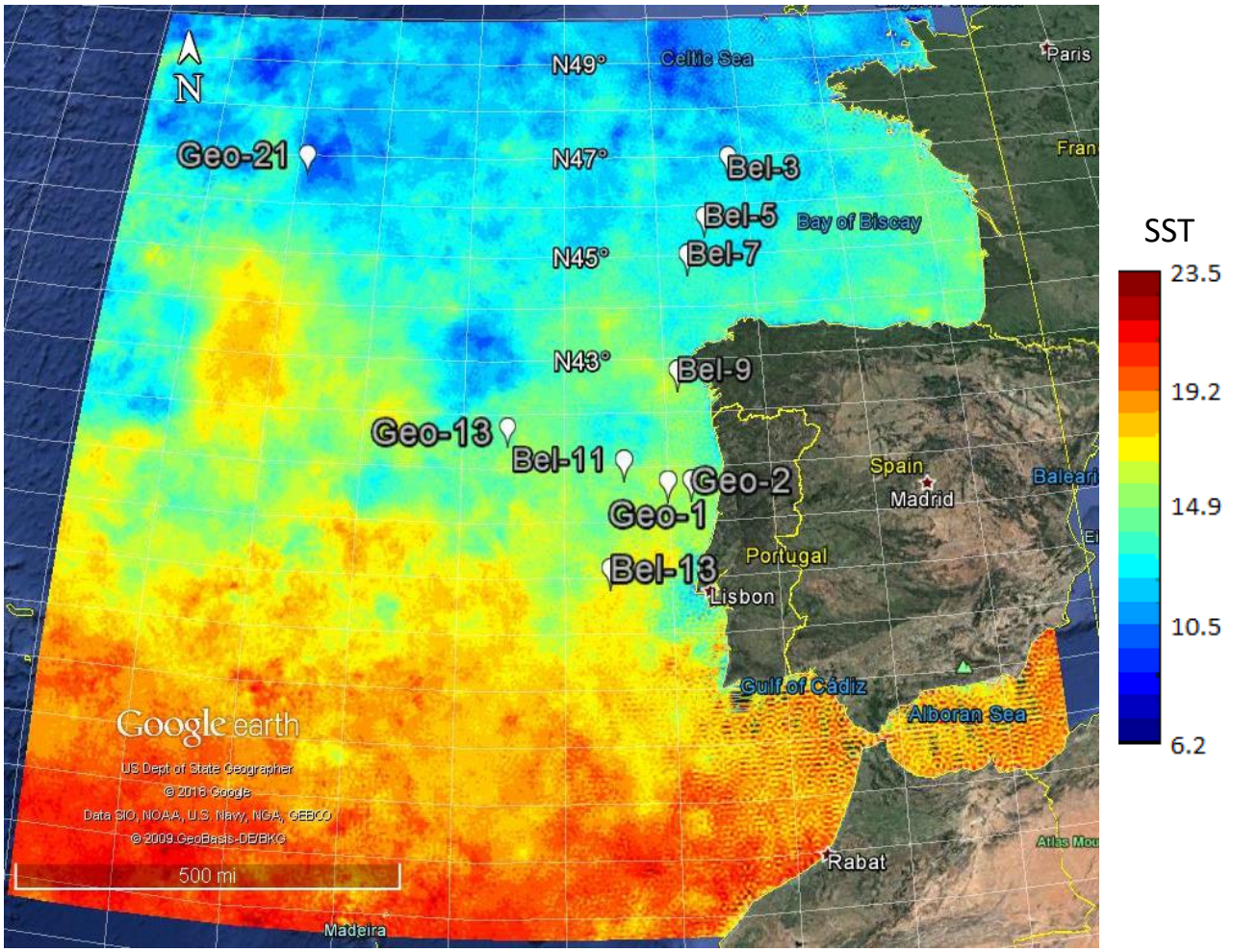
Station	MLD	Lat. [°N]	Long. [°E]	**N_2 fixation [µmol N m^{-2} d^{-1}]**	**Primary Production [mmol C m^{-2} d^{-1}]**	Euphotic layer averaged Temperature [°C]	Euphotic layer averaged Salinity [psu]	Euphotic layer integrated Chl *a* [mg m^{-2}]	Euphotic layer integrated NH_4^+ [µmol m^{-2}]	Euphotic layer integrated NO_3^-+NO_2^- [µmol m^{-2}]	Climatology P* at 20 m depth [µmol m^{-2}]	Satellite-based dust deposition [Apr. 2014] [µg m^{-2} d^{-1}]	Satellite-based dust deposition [May 2014] [µg m^{-2} d^{-1}]
Bel-3	27	46.5	-8.0	**0**	**37.9**	13.5	35.6	47.1	6.7	86.2	0.06	1263	2539
Bel-5	41	45.3	-8.8	**0**	**42.6**	13.2	35.6	17.1	54.0	509.0	0.06	1647	1914
Bel-7	33	44.6	-9.3	**128**	**52.1**	13.8	35.5	62.3	12.9	107.1	0.07	2147	1443
Geo-21	17	46.5	-19.7	**279**	**135.3**	13.3	35.7	38.1	34.2	452.5	0.04	2147	1443
Bel-9	26	42.4	-9.7	**81**	**36.6**	14.9	35.7	32.6	7.7	332.2	0.06	3650	1088
Bel-11	33	40.7	-11.1	**1533**	**36.4**	15.3	35.8	15.2	5.1	93.5	0.05	2799	618
Bel-13	25	38.8	-11.4	**1355**	**35.9**	16.0	35.9	12.1	5.1	58.3	0.06	2147	618
Geo-1	12	40.3	-10.0	**141**	**33.1**	15.7	35.3	14.2	5.3	68.4	0.03	3650	618
Geo-2	14	40.3	-9.5	**262**	**59.1**	14.7	35.5	37.8	6.0	219.4	0.01	4758	820
Geo-13	29	41.4	-13.9	**384**	**78.9**	13.9	35.8	42.4	34.0	274.2	0.07	1647	820

Supplementary Table S3. Spearman correlation matrix opposing depth-integrated rates of N_2 fixation and primary production (PP), from BG2014/14 and GEOVIDE cruises together, to euphotic layer averaged or integrated environmental variables. The correlation factor (r) and its significance given by the p-value (p) at $p < 0.001$, $p < 0.01$ and $p < 0.05$ presented with ***, ** and *, respectively, and the number of observations (n) are shown for each combination tested. Also, dFe correlations were made only for GEOVIDE sampling stations. These results were obtained from SigmaPlot (Systat Software, San Jose, CA).

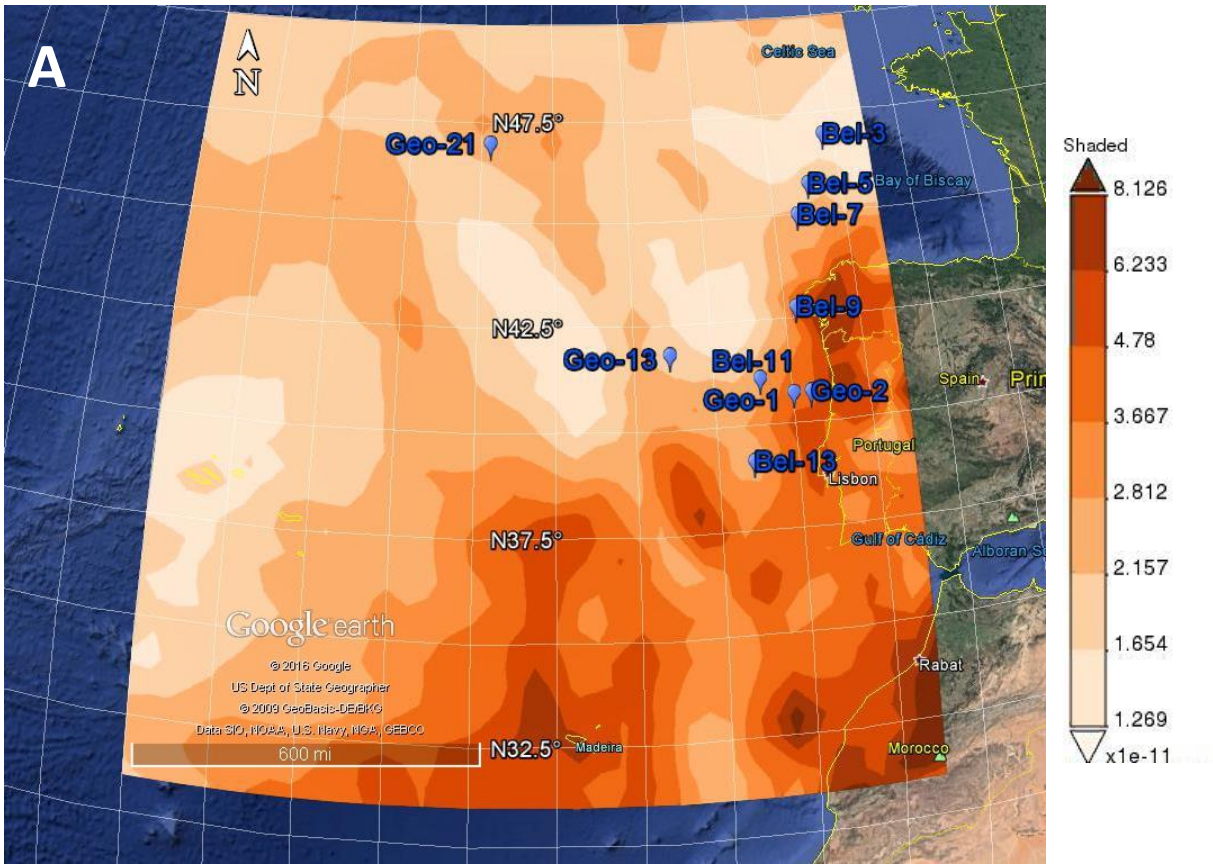
		Average salinity	Integrated $[NH_4^+]$ [µmol m^{-2}]	Integrated $[NO_3^- + NO_2^-]$ [µmol m^{-2}]	Average in situ P* [µM]	Surface climatology P* [µM]	Integrated dFe [nmol m^{-2}]	Satellite-based dust deposition April 2014 [µg m^{-2} s^{-1}]	Satellite-based dust deposition May 2014 [µg m^{-2} s^{-1}]	**PP [mmol C m^{-2} d^{-1}]**	**N_2 fixation [µmol N m^{-2} d^{-1}]**
Average temperature [°C]	**r**	**0.188**	**-0.869*** **	**-0.721***	**0.0788**	**-0.0732**	**0.8**	**0.587**	**-0.901*** **	**-0.721***	**0.553**
	p	*0.583*	*0.0000002*	*0.0157*	*0.811*	*0.811*	*0.333*	*0.0665*	*0.0000002*	*0.0157*	*0.0892*
	n	10	10	10	10	10	4	10	10	10	10
Average salinity			**-0.109**	**0.152**	**0.00606**	**0.366**	**-0.6**	**-0.29**	**-0.265**	**-0.0182**	**0.62***
			0.733	*0.656*	*0.973*	*0.275*	*0.417*	*0.404*	*0.446*	*0.946*	*0.048*
			10	10	10	10	4	10	10	10	10
Integrated $[NH_4^+]$ [µmol m^{-2}]				**0.857*** **	**-0.0304**	**0.26**	**-0.8**	**-0.471**	**0.737***	**0.729***	**-0.482**
				0.0000002	*0.919*	*0.446*	*0.333*	*0.16*	*0.0131*	*0.0131*	*0.148*
				10	10	10	4	10	10	10	10
Integrated $[NO_3^- + NO_2^-]$ [µmol m^{-2}]					**-0.0182**	**0.116**	**-0.8**	**-0.228**	**0.512**	**0.758****	**-0.195**
					0.946	*0.733*	*0.333*	*0.512*	*0.116*	*0.0087*	*0.559*
					10	10	4	10	10	10	10
Average in situ P* [µM]						**-0.274**	**-0.4**	**0.161**	**-0.253**	**0.479**	**0.511**
						0.425	*0.75*	*0.631*	*0.468*	*0.148*	*0.116*
						10	4	10	10	10	10
Surface climatology P* [µM]							**-0.8**	**-0.491**	**0.205**	**0.0732**	**-0.0856**
							0.333	*0.137*	*0.559*	*0.811*	*0.785*
							4	10	10	10	10
Integrated dFe [nmol m^{-2}]								**0.8**	**-0.632**	**-0.8**	**-0.6**
								0.333	*0.333*	*0.333*	*0.417*
								4	4	4	4
Satellite-based dust deposition April 2014 [µg m^{-2} s^{-1}]									**-0.588**	**-0.265**	**0.257**
									0.0665	*0.446*	*0.446*
									10	10	10
Satellite-based dust deposition May 2014 [µg m^{-2} s^{-1}]										**0.512**	**-0.774****
										0.116	*0.00686*
										10	10
PP [mmol C m^{-2} d^{-1}]											**-0.0365**
											0.892
											10

Supplementary Table S4. Spearman correlation matrix opposing volumetric rates of N_2 fixation and primary production (PP) to depth-specific environmental variables for the combined Belgica 2014/14 and GEOVIDE cruises. The correlation factor (r) and its significance given by the p-value (*p)* at $p < 0.001$, $p < 0.01$ and $p < 0.05$ presented with ***, ** and *, respectively, and the number of observations (n) are shown for each combination tested. Note that when nutrient concentrations were < DL we used the DL value to run the correlation test. Also, P* correlations were only made for the Belgica 2014/14 studied sites and dFe correlations only for GEOVIDE sampling stations. These results were obtained from SigmaPlot (Systat Software, San Jose, CA).

		Salinity	$[NH_4^+]$ [µM]	$[NO_3^- + NO_2^-]$ [µM]	In situ P* [µM]	DFe [nM] (Tonnard et al., 2018)	Chl *a* [µg L^{-1}]	**PP [µmol C m^{-3} d^{-1}]**	**N_2 fixation [nmol N L^{-1} d^{-1}]**
Temperature	**r**	**-0.191**	**-0.418****	**-0.854*****	**0.628****	**0.291**	**0.00461**	**0.158**	**0.54*****
[°C]	*p*	*0.202*	*0.00398*	*0.0000002*	*0.00104*	*0.267*	*0.976*	*0.292*	*0.00012*
	n	46	46	46	24	16	43	46	46
Salinity			**0.0922**	**0.39****	**0.0288**	**0.0883**	**-0.195**	**-0.214**	**0.106**
			0.54	*0.00765*	*0.892*	*0.738*	*0.208*	*0.152*	*0.482*
			46	46	24	16	43	46	46
$[NH_4^+]$				**0.344***	**-0.441***	**-0.462**	**0.128**	**0.255**	**-0.154**
[µM]				*0.0194*	*0.031*	*0.0695*	*0.411*	*0.0869*	*0.307*
				46	24	16	43	46	46
$[NO_3^- + NO_2^-]$					**-0.716*****	**-0.253**	**-0.216**	**-0.314***	**-0.362***
[µM]					*0.0000325*	*0.336*	*0.162*	*0.0338*	*0.0136*
					24	16	43	46	46
In situ P*						**undefined**	**0.149**	**0.369**	**0.557****
[µM]						*undefined*	*0.481*	*0.0746*	*0.00481*
						0	24	24	24
DFe							**-0.57**	**-0.416**	**0.175**
[nM]							*0.0322*	*0.104*	*0.505*
(Tonnard et al., 2018)							14	16	16
Chl *a*								**0.85*****	**-0.0874**
[µg L^{-1}]								*0.0000002*	*0.575*
								43	43
PP									**0.143**
[µmol C m^{-3} d^{-1}]									*0.342*
									46



Supplementary Figure S2. High resolution trihourly averaged sea surface temperature (SST) on May 29th 2014 (sampling date of station Bel-13, 10 days following the sampling of station Geo-1), derived from the European Sea (sea surface subskin temperature) of Copernicus Marine Environment Monitoring Service (CMEMS, European Commission). White markers indicate the location of the stations sampled during our study (image provided by Google Earth Pro).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© 2009 GeoBasis-DE/BKG
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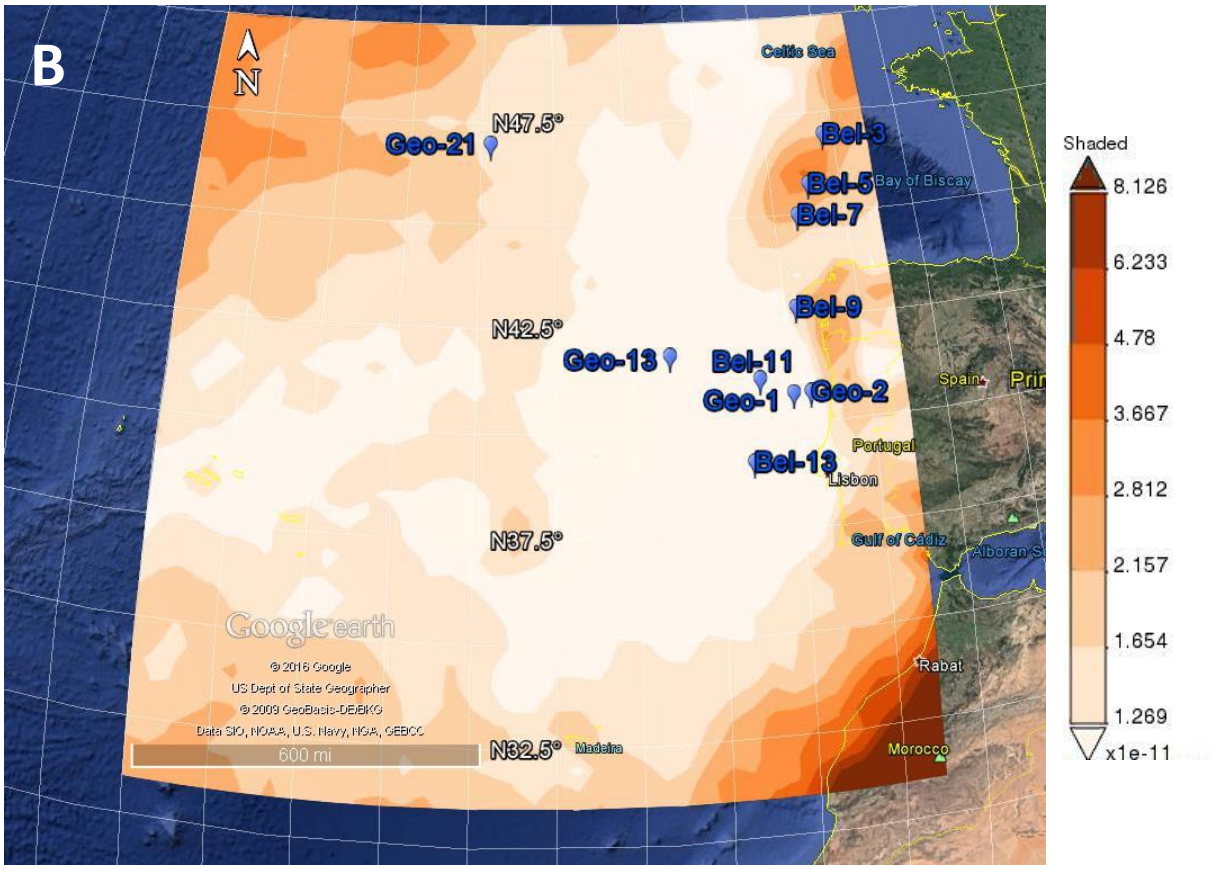
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© 2016 Google
US Dept of State Geographer
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Morocco
Shaded
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Supplementary Figure S3. April (A) and May (B) 2014 monthly averaged dry + wet dust deposition (kg m^{-2} s^{-1}) derived from Giovanni online satellite data system (NASA Goddard Earth Sciences Data and Information Services Center). Blue markers indicate the location of the stations sampled during our study (image provided by Google Earth Pro).

Supplementary Table S5. Principal component matrix illustrating the components (or axis) loadings, in other words the correlation of each variable to a determined axis as obtained with the XLSTAT 2017 software (Addinsoft, Paris, France, 2017). The percentage of variability of the system explained by each of the two axes is indicated, for a total explained variance of 68%.

	Axis 1	**Axis 2**
% Variability explained:	48%	20%
Variables		
Euphotic layer integrated primary production	**-0.812**	0.088
Euphotic layer averaged temperature	**0.942**	0.130
Euphotic layer integrated Chl *a*	**-0.768**	-0.085
Euphotic layer integrated [NH_4^+]	**-0.936**	-0.007
Euphotic layer integrated [$NO_3^- + NO_2^-$]	**-0.783**	0.154
Climatology surface P* (20 m)	-0.305	**0.584**
Euphotic layer averaged salinity	0.125	**0.943**
Satellite dry + wet dust deposition (April 2014)	0.583	-0.423
Euphotic layer integrated N_2 fixation	**0.506**	**0.602**