

*[JGR-Oceans]*

Supporting Information for

**Lagrangian studies of marine production: a multi-method assessment of productivity relationships in the California Current Ecosystem upwelling region**

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**Introduction:** The supporting data and information presented here is provided to allow the reader to get more detailed information on methods and results presented in the main manuscript.

***Chlorophyll analysis:*** Samples were filtered onto GF/F filters and subsequently placed into culture tubes containing 90% acetone and placed in a freezer. The fluorescence of the samples was read on a fluorometer (Turner 10AU) after 24 to 48 hours of extraction. The samples were subsequently acidified to degrade chlorophyll to phaeopigments (i.e. non-photosynthetic pigments). The readings prior to and after acidification are used to calculate concentrations of both chlorophyll a and phaeopigments (i.e. phaeophytin). In addition, continuous surface (c. 5m) chlorophyll a readings were taken using the ship-board flow through fluorometer.

***Gross production using variable Chl-a fluorescence:*** The FRRF measures single turnover fluorescence induction curves including a relaxation phase. Fluorescence light curve measurements (FLC) were conducted which lasted approximately 30 minutes. A 12-minute dark adaptation time was chosen with a 60 second weak light acclimation (i.e. 20 µmol photons m-2 s-1) prior to taking the variable fluorescence measurement. The instrument’s measurement chamber was temperature regulated to match the surface mixed layer. Each sample was exchanged with fresh seawater from the ship’s uncontaminated flow-through system using an automated peristaltic pump. The ship’s flow-through system ran continuously at > 4 L min-1 ensuring that the sample reflected the contemporaneous phytoplankton community.

The excitation setting was set to of 100 flashlets on a 2 µs pitch and a relaxation phase of 40 flashlets on a 60 µs pitch. The gain of the instrument was set to “auto” to adjust for the variation in biomass and fluorescence signal throughout the cruise. Excitation was provided by 3 LEDs (i.e. 450 nm, 530 nm and 625 nm). Here we only used the single 450 nm Chl *a* excitation to evaluate our data. High resolution FLCs with 19 light steps covering light intensities of 22, 49, 81, 118, 163, 216, 279, 353, 442, 547, 671, 819, 995, 1204, 1451, 1745, 2094, 2508, 3000 µmol photons m-2s-1 were conducted.

Our correlation of F0 vs. Chl *a* indicated an offset at which base fluorescence was still elevated under a zero Chl a concentration. In order to re-calculate RCII in the water column we used a baseline corrected F0 at a given Chl *a* concentration to adjust RCII to the chlorophyll concentration in the mixed layer water column.

The ratio of Reaction center to chlorophyll ηPSII (mol RCII: mol Chl *a*) was calculated based on RCII ([Oxborough et al., 2012](#_ENREF_68)) taken during nighttime and the measured Chl *a* concentration during those times

**Table S1.** Description of terms used in the FRRF measurements.

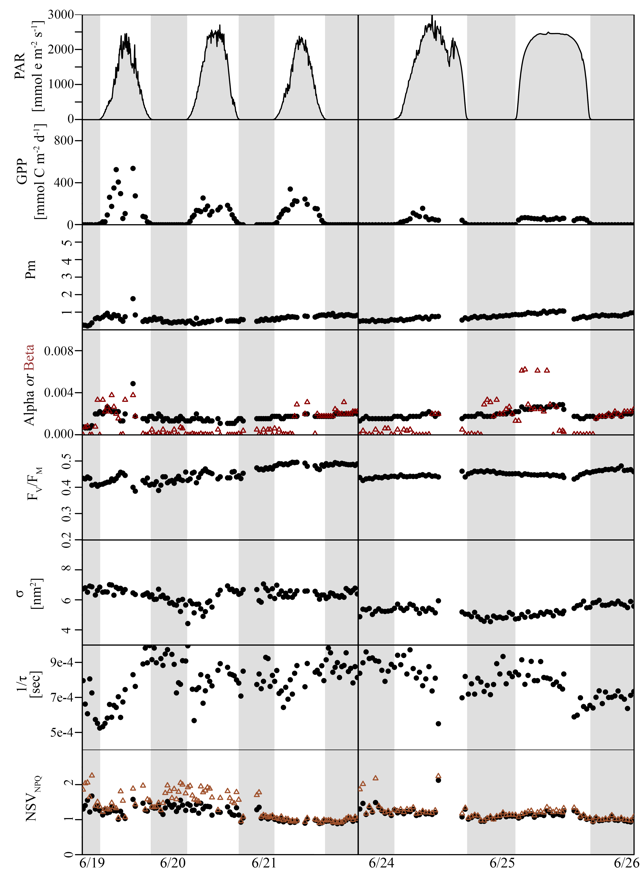
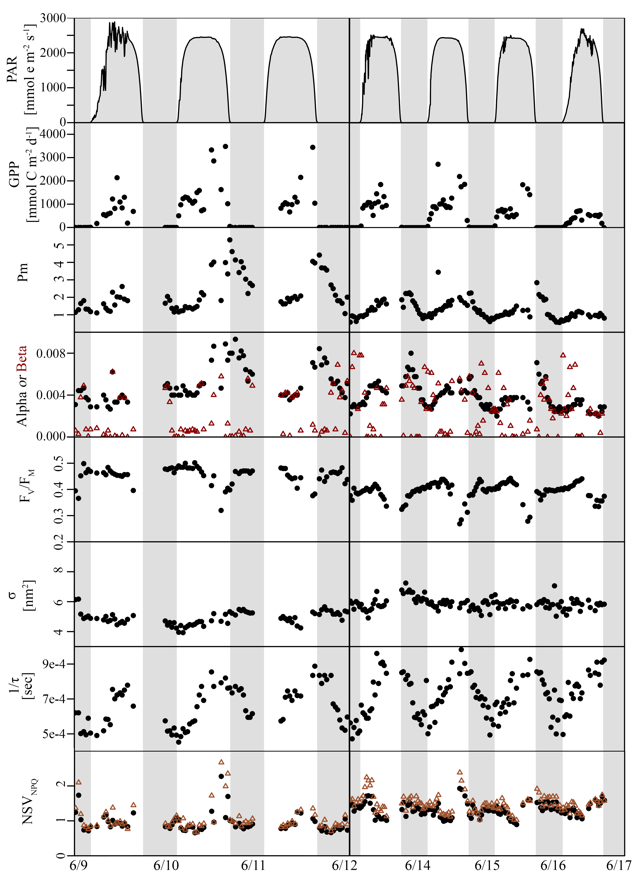
|  |  |  |
| --- | --- | --- |
| **Terms associated with the saturation phase of a single turnover (ST) FRR measurement** | | |
| **Term** | **Description** | **units** |
| C(P, J or L) | fraction of RCII in the closed state  estimated as 1 – qP, 1 – qJ or 1 – qL | dimensionless |
| E | incident photon irradiance (photon flux density) | µmol photons m-2 s-1 |
| F’ | fluorescence at zeroth flashlet of a single turnover measurement when C > 0 | unitless |
| Fo’ | Base fluorescence under ambient light | unitless |
| F­m(') | maximum fluorescence when C = 1(under ambient light) | unitless |
| F­o | fluorescence at zeroth flashlet of an ST measurement when C = 0 (under ambient light) | unitless |
| F­q' | F­m'– F­' | unitless |
| Fq'/Fm' | fluorescence parameter providing an estimate of PII under ambient light; (F­m'– F­'/ Fm') | dimensionless |
| F­v(') | F­m(')– F­o(') | unitless |
| F­v(')*/* F­m(') | fluorescence parameter providing an estimate of PII when C = 0 (under ambient light) | dimensionless |
| Ka | Instrument type-specific constant | m-1 |
| PII | PSII efficiency; Estimated as *Fq*'*/Fm*' | dimensionless |
|  | RCII to Chl *a* ratio | unitless |
| NCPNSV | normalized Stern-Volmer non-photochemical quenching coefficient, NPQNSV= (Fm’/Fv’) – 1 |  |
| Φe:c | Electron to carbon conversion, calculated as | unitless |
| oF' | fluorescence from open centers under ambient light  oF’ = (Fm x F0 )/ (Fm- F0) \* (Fq’/Fm); | unitless |
| JVPSII\_abs | PSII flux per unit volume | electrons (RCII m-3) s-1 |
| qP, qJ and qL | Fq/Fv - the fraction of RCII in the open state | dimensionless |
| σPII | absorption cross section of PSII photochemistry | m2 PSII-1 |
| σPII’ | absorption cross section of PSII photochemistry under ambient light | m2 PSII-1 |

**Table S2.** Bio/physico/chemical properties of the mixed layer during each day of a cycle as well as mean and standard error of the mean for each cycle. Prior to the termination of a cycle the water column properties were measured, these are indicated as “final”. Temperature (Temp; [°C]), mixed layer depth (MLD; [m]), Phosphorus (PO43-; [µM]), Silicate (Si; [µM]), Nitrite (NO2-; [µM]), Nitrate (NO3-; [µM]), Ammonia (NH4+; [µM]) and chlorophyll concentration; [Chl a ,µg L-1]), POC and PON [ug L-1], POC:PON [mol:mol].

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Cycle | Temp | MLD | PO4 | dSi | NO2 | NO3 | NH4 | Chl *a* | POC | PON | C:N |
|  | [°C] | [m] | [µM] | [µM] | [µM] | [µM] | [µM] | [µg L-1] | [µg L-1] | [µg L-1] | mol:mol |
| P1604 | | | | | | | | | | | |
| Cycle 1-1 | 17.44 | 13.04 | 0.23 | 1.58 | 0.00 | 0.05 | 0.02 | 0.07 | 41 | 6.99 | 6.84 |
|  | | | | | | | | | | | |
| Cycle 2-1 | 15.31 | 68.08 | 0.33 | 2.01 | 0.01 | 0.13 | 0.00 | 0.14 | 35.44 | 5.44 | 7.59 |
| Cycle 2-2 | 15.31 | 70.96 | 0.34 | 2.02 | 0.00 | 0.14 | 0.00 | 0.12 | 34.86 | 5.74 | 7.09 |
| Cycle 2-3 | 15.42 | 73.72 |  | 1.75 | 0.00 | 0.01 | 0.00 | 0.13 | 34.75 | 5.54 | 7.31 |
| Cycle 2-4 | 15.53 | 67.34 | 0.27 | 2.10 | 0.00 | 0.00 | 0.01 | 0.11 | 34.63 | 5.34 | 7.56 |
| *Mean* | ***15.39*** | ***70.03*** | ***0.31*** | ***1.97*** | ***0.00*** | ***0.07*** | ***0.00*** | ***0.13*** | ***34.92*** | ***5.52*** | ***7.38*** |
| *SEM* | ***0.05*** | ***1.46*** | ***0.02*** | ***0.08*** | ***0.00*** | ***0.04*** | ***0.00*** | ***0.01*** | ***0.179*** | ***0.08*** | ***0.11*** |
|  | | | | | | | | | | | |
| Cycle 3-1 | 13.69 | 17.57 | 0.61 | 6.01 | 0.15 | 4.44 | 0.16 | 0.89 | 124.6 | 27.93 | 5.20 |
| Cycle 3-2 | 13.91 | 18.02 | 0.60 | 6.03 | 0.15 | 3.59 | 0.11 | 1.06 | 65.76 | 16.67 | 4.60 |
| Cycle 3-3 | 13.95 | 15.89 | 0.58 | 6.71 | 0.13 | 3.49 | 0.08 | 0.99 | 177.9 | 40.91 | 5.07 |
| Cycle 3-4 | 14.29 | 12.91 | 0.50 | 6.00 | 0.12 | 2.54 | 0.05 | 0.93 | 94.7 | 20.18 | 5,47 |
| *Mean* | ***13.96*** | ***16.10*** | ***0.57*** | ***6.19*** | ***0.14*** | ***3.52*** | ***0.10*** | ***0.97*** | ***115.7*** | ***26.42*** | ***5.08*** |
| *SEM* | ***0.12*** | ***1.16*** | ***0.02*** | ***0.17*** | ***0.01*** | ***0.39*** | ***0.02*** | ***0.04*** | ***47.89*** | ***10.74*** | ***0.36*** |
|  | | | | | | | | | | | |
| Cycle 4-1 | 14.53 | 14.86 | 0.41 | 4.32 | 0.05 | 0.63 | 0.61 | 4.07 | 455.59 | 85.94 | 6.18 |
| Cycle 4-2 | 14.78 | 11.86 | 0.36 | 5.61 | 0.06 | 0.68 | 0.34 | 4.22 | 508.3 | 98.78 | 6.00 |
| Cycle 4-3 | 14.78 | 13.33 | 0.45 | 6.16 | 0.08 | 0.97 | 0.53 | 2.66 | 393.4 | 78.63 | 5.83 |
| Cycle 4-4 | 14.50 | 12.90 | 0.49 | 7.03 | 0.10 | 1.51 | 0.49 | 4.09 | 466.0 | 92.24 | 5.89 |
| *Mean* | ***14.65*** | ***13.24*** | ***0.43*** | ***5.78*** | ***0.07*** | ***0.95*** | ***0.49*** | ***3.76*** | ***455.8*** | ***88.9*** | ***5.98*** |
| *SEM* | ***0.08*** | ***0.62*** | ***0.03*** | ***0.57*** | ***0.01*** | ***0.20*** | ***0.06*** | ***0.37*** | ***23.7*** | ***4.3*** | ***0.07*** |
| P1706 | | | | | | | | | | | |
| Cycle 1-1 | 13.60 | 19.90 | 0.89 | 11.00 | 0.27 | 10.41 | 0.35 | 7.34 | 361.9 | 72.23 | 5.84 |
| Cycle 1-2 | 13.20 | 20.70 | 0.45 | 5.72 | 0.21 | 5.31 | 0.23 | 13.49 | 582.3 | 116.4 | 5.83 |
| Cycle 1-3 | 13.20 | 22.80 | 0.51 | 5.84 | 0.24 | 5.72 | 0.51 | 8.02 | 431.8 | 90.00 | 5.59 |
| Cycle 1-final | 12.80 | 22.80 | 0.55 | 5.16 | 0.28 | 6.62 | 0.85 | 9.62 | 464.3 | 85.94 | 6.30 |
| *Mean* | ***13.20*** | ***21.55*** | ***0.60*** | ***6.93*** | ***0.25*** | ***7.02*** | ***0.49*** | ***9.62*** | ***460.0*** | ***91.13*** | ***5.89*** |
| *SEM* | ***0.16*** | ***0.74*** | ***0.10*** | ***1.36*** | ***0.02*** | ***1.16*** | ***0.13*** | ***1.38*** | ***46.00*** | ***9.22*** | ***0.14*** |
|  | | | | | | | | | | | |
| Cycle2-1 | 13.10 | 25.40 | 0.59 | 1.28 | 0.32 | 6.72 | 0.53 | 4.75 | 476.8 | 85.68 | 6.49 |
| Cycle2-2 | 13.10 | 27.50 | 0.78 | 3.49 | 0.35 | 8.18 | 0.72 | 3.43 | 308.9 | 56.98 | 6.32 |
| Cycle2-3 | 13.30 | 31.40 | 0.75 | 3.51 | 0.36 | 7.79 | 0.65 | 3.27 | 306.0 | 56.62 | 6.31 |
| Cycle2-4 | 13.40 | 33.60 | 0.78 | 3.92 | 0.35 | 7.71 | 0.72 | 2.39 | 264.9 | 46.84 | 6.60 |
| Cycle2-final | 13.50 | 33.10 | 0.83 | 4.48 | 0.35 | 7.68 | 1.40 | 1.68 | 199.17 | 37.77 | 6.15 |
| *Mean* | ***13.33*** | ***31.40*** | ***0.79*** | ***3.85*** | ***0.35*** | ***7.84*** | ***0.87*** | ***2.69*** | ***311.16*** | ***56.77*** | ***6.37*** |
| *SEM* | ***0.08*** | ***1.24*** | ***0.01*** | ***0.21*** | ***0.00*** | ***0.10*** | ***0.16*** | ***0.36*** | ***45.91*** | ***8.05*** | ***0.08*** |
|  | | | | | | | | | | | |
| Cycle3-1 | 15.00 | 18.90 | 0.53 | 2.76 | 0.22 | 4.19 | 0.15 | 1.79 | 215.39 | 38.35 | 6.55 |
| Cycle3-2 | 15.20 | 21.20 | 0.39 | 3.05 | 0.10 | 1.61 | 0.21 | 0.60 | 104.46 | 17.54 | 6.94 |
| Cycle3-3 | 15.50 | 36.80 | 0.34 | 3.03 | 0.06 | 1.00 | 0.16 | 0.44 | 57.34 | 9.95 | 6.72 |
| Cycle3-final | 15.40 | 46.00 | 0.34 | 2.62 | 0.07 | 0.92 | 0.45 | 0.34 | 70.08 | 12.55 | 6.51 |
| *Mean* | ***15.28*** | ***30.73*** | ***0.40*** | ***2.87*** | ***0.11*** | ***1.93*** | ***0.24*** | ***0.79*** | ***111.82*** | ***19.6*** | ***6.68*** |
| *SEM* | ***0.11*** | ***6.46*** | ***0.04*** | ***0.11*** | ***0.04*** | ***0.77*** | ***0.07*** | ***0.34*** | ***35.9*** | ***6.44*** | ***0.10*** |
|  | | | | | | | | | | | |
| Cycle4-1 | 15.30 | 21.40 | 0.55 | 0.29 | 0.21 | 2.41 | 1.39 | 0.30 | 94.13 | 17.24 | 6.37 |
| Cycle4-2 | 15.70 | 19.00 | 0.61 | 0.70 | 0.22 | 3.13 | 1.63 | 0.23 | 87.18 | 14.98 | 6.78 |
| Cycle4-final | 16.30 | 15.10 | 0.62 | 0.88 | 0.20 | 3.12 | 2.16 | 0.20 | 87.63 | 17.41 | 5.87 |
| *Mean* | ***15.77*** | ***18.50*** | ***0.59*** | ***0.62*** | ***0.21*** | ***2.89*** | ***1.73*** | ***0.24*** | ***89.64*** | ***16.54*** | ***6.34*** |
| *SEM* | ***0.29*** | ***1.84*** | ***0.02*** | ***0.17*** | ***0.01*** | ***0.24*** | ***0.23*** | ***0.03*** | ***2.24*** | ***0.78*** | ***0.26*** |

**Table S3**. Production estimates for each day of a cycle. Net primary production using 14C (NPP14C), Net Primary production using the dilution experiment (NPPG/G), New Production using the 15N incubation method, Net community production using a weighted k (NCPPRIOR). Net community production using an instantaneous k (NCPRT), average respiration during the night using the NCPRT analysis (NCPRESP), Gross primary production using the NCPRT analysis (GPPO2/Ar), Gross primary production using the FRRF data. All data are given in (mmol C m-2 d-1). ND indicates no measurement was performed, X indicates that data were not usable.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **NPP14C** | **NPPG/G** | | | **NP15N** | **NCPPrior** | **NCPRT** | **NCPResp** | **GPPO2/Ar** | **GPPFRRF** |
| *P1604* | | | | | | | | | | |
| P1604-cycle 2 | | | | | | | | | | |
| 2-1 | 22.34 | 44.42 | | | 15.95 | 5.79 | 9.74 | 55.08 | 70 | ND |
| 2-2 | 16.72 | 24.31 | | | 8.25 | 5.74 | 7.18 | 63.06 | 47 | ND |
| 2-3 | 13.97 | 36.32 | | | 7.68 | 5.00 | 1.14 | 53.61 | 33 | ND |
| P1604-cycle 3 | | | | | | | | | | |
| 3-1 | 36.10 | 49.41 | | | 14.39 | -10.75 | -2.28 | X | 22 | ND |
| 3-2 | 44.52 | 60.29 | | | 14.45 | 0.39 | 0.11 | X | X | ND |
| 3-3 | 64.42 | 76.25 | | | 39.72 | 8.61 | 1.78 | 130 | 149 | ND |
| P1604-cycle 4 | | | | | | | | | | |
| 4-1 | 149.79 | ND | | | 28.76 | 43.46 | 12.32 | 288 | 228 | ND |
| 4-2 | 103.02 | ND | | | 17.02 | 35.49 | 20.41 | 632 | 608 | ND |
| 4-3 | 113.09 | ND | | |  |  |  |  |  | ND |
| P1705 | | | | | | | | | | |
| P1705-cyle 1 | | | | | | | | | | |
| 1-1 | 219.62 | | 252.20 | 122.35 | | 58.62 | 76.99 | 1381 | 1212 | 455 |
| 1-2 | 718.00 | | 731.89 | 159.32 | | 56.90 | 77.84 | 1128 | 813 | 945 |
| 1-3 | 596.95 | | 588.11 | 188.79 | | 61.18 | 78.70 | 1327 | 1220 | 830 |
| P1705-cyle 2 | | | | | | | | | | |
| 2-1 | 247.43 | | 349.58 | 189.6 | | 7.98 | 15.62 | 852 | 385 | 487 |
| 2-2 | 284.09 | | 337.47 |  | | -14.26 | -21.07 | 494 | 390 | 691 |
| 2-3 | 311.33 | | 219.51 | 57.59 | | -9.01 | -12.90 | 479 | 540 | 529 |
| 2-4 | 182.21 | | 170.41 | 57.59 | | -33.65 | -38.72 | 394 | 287 | 242 |
| P1705-cyle 3 | | | | | | | | | | |
| 3-1 | 92.33 | | 177.07 | 83.80 | | -3.11 | -4.16 | 39 | X | 113 |
| 3-2 | ND. | | 55.42 | 20.32 | | -17.37 | -20.90 | 47 | X | 69 |
| 3-3 | 48.45 | | 30.02 | 6.72 | | -13.17 | -14.12 | 92 | X | 87 |
| 3-4 |  | |  | 6.377 | | -13.67 | -2.74 | 97 | X |  |
| P1705-cyle 4 | | | | | | | | | | |
| 4-1 | 13.1 | | 15.60 | 5.17 | | -2.35 | -0.42 | 85 | X | 29 |
| 4-2 | 18.57 | | 28.40 | 5.49 | | 1.62 | 0.57 | 45 | X | 32 |
| 4-2 |  | |  | 5.52 | | 0.17 | 0.07 | 45 | X |  |

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**Figure S1.** Chronology of photophysiological parameters during the CCE Process cruise P1706. Panels A, B, C, D show the diel cycles of light intensity. Panels E, F, G, H show the diel cycle of estimated GPP. Panels I, J, K, L depict maximum photosynthetic rates [ electrons RCII-1 s-1]. Panels M, N, O, P show the changes of the slope of photosynthetic activity under low light intensities (alpha) and the slope of the light inhibition term (beta). Panels Q, R, S, T show the photosynthetic quantum yield. Panels U, V, X, Y show the absorption cross sectional area of the photosystem. Panels Z, AA, AB, AC show the rate of electron transport through the photosystem in the dark-adapted stage. Panels AD, AE, AF, AG show the rate of non-photochemical quenching (NPQNSV) at the light intensity of the light saturation point (EK) (black dots) and 2x EK brown dots.



**Figure S2.** Chlorophyll concentration during CCE Process cruise P1604 and P1706. Values show how the chlorophyll progresses throughout the Lagrangian cycles. Values are also given in Table S2. Data are