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Global quantitative synthesis of ecosystem functioning across climatic zones and ecosystem types

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1 **Title:** Global quantitative synthesis of ecosystem functioning across climatic zones and
2 ecosystem types

3

4 **Running header:** Multivariate ecosystem functioning

5

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8

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23

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24

25

26

27 **Biosketch**

28 The authors are part of the EMERGE (Eawag Meta-Ecosystem Research group) initiative.

29 We are interested in bridging community and ecosystem-level processes through the lens

30 of spatial ecology. Collectively, our current research aims at understanding the main

31 spatial constraints on biodiversity and how those effects scale-up to influence ecosystem

32 functioning in the landscape. (More on each author – **IG**:

33 <https://isabellegounand.wordpress.com>, **CL**: <https://chelseajeanelittle.com>, **EH**:

34 <https://metecolab.org>, **FA**: <https://www.altermattlab.ch>)

35

36

37

38 **Abstract**

39 **Aim:** Providing a quantitative overview of ecosystem functioning in a three-dimensional
40 space defined by ecosystem stocks, fluxes, and rates, across major ecosystem types and
41 climatic zones.

42 **Location:** Global

43 **Time Period:** 1966–2019

44 **Major taxa studied:** ecosystem-level measurements (all organism types)

45 **Methods:** We conducted a global quantitative synthesis of a wide range of ecosystem
46 variables related to carbon stocks and fluxes. We gathered a total of 4,479 values from
47 1,223 individual sites (unique geographical coordinates) reported in the literature (604
48 studies), covering ecosystem variables including biomass and detritus stocks, gross
49 primary production, ecosystem respiration, detritus decomposition and carbon uptake
50 rates, across eight major aquatic and terrestrial ecosystem types and five broad climatic
51 zones (arctic, boreal, temperate, arid, and tropical). We analysed the relationships among
52 variables emerging from the comparisons of stocks, fluxes, and rates across ecosystem
53 types and climates.

54 **Results:** Within our three-dimensional functioning space, average ecosystems align along
55 a gradient from fast rates-low fluxes and stocks (freshwater and pelagic marine
56 ecosystems) to low rates-high fluxes and stocks (forests), a gradient which we
57 hypothesize results mainly from variation in primary producer characteristics. Moreover,
58 fluxes and rates decrease from warm to colder climates, consistent with the metabolic
59 theory of ecology. However, the strength of climatic effects differs among variables and
60 ecosystem types, resulting, for instance, in opposing effects on net ecosystem production
61 between terrestrial and freshwater ecosystems (positive *versus* negative effects).

62 **Main conclusions:** This large-scale synthesis provides a first quantified cross-ecosystem
63 and cross-climate comparison of multivariate ecosystem functioning. This gives a basis
64 for a mechanistic understanding of the interdependency of different aspects of ecosystem
65 functioning and their sensitivity to global change. To anticipate responses to change at
66 the ecosystem level, further work should investigate potential feedbacks between
67 ecosystem variables at finer scales, which involves site-level quantifications of
68 multivariate functioning and theoretical developments.

69

Multivariate ecosystem functioning

70

71 **Keywords**

72 carbon cycle, climate, ecosystem functioning, multifunctionality, metabolic theory of

73 ecology, global change, meta-ecosystem, primary production, productivity,

74 decomposition.

75

76 **1 | INTRODUCTION**

77 Ecosystems provide multiple services, such as food, carbon storage, or detritus recycling,
78 that benefit humans (Alsterberg et al., 2017; Byrnes et al., 2014; Hector & Bagchi, 2007).
79 These services result from the functioning of ecosystems, which is often described in
80 studies either by individual ecosystem functions (e.g., production, stability; de
81 Mazancourt et al., 2013) or by proxies which integrate different functions mathematically
82 but not mechanistically (e.g., indices of multifunctionality; Soliveres et al., 2016). While
83 both approaches possess strengths to address specific questions (e.g., relationship with
84 biodiversity, ecosystem state assessment), it is also important to consider the dynamic
85 processes underlying ecosystem functioning, because ecosystem functions are not
86 independent from one another. This becomes increasingly important in the context of
87 global change, because perturbations affecting some functions of an ecosystem, for
88 instance trophic cascades affecting primary production, might then cascade to others,
89 such as on carbon storage (Atwood et al., 2015). To better forecast ecosystem response to
90 such change, we need a mechanistic understanding of how the multiple aspects of
91 ecosystem functioning constrain one another. With this study, we aim to advance in this
92 direction by providing a quantitative synthesis of multiple measures of ecosystem
93 functioning in a mechanistic framework allowing comparisons across major ecosystem
94 types.

95 We propose to consider the loop of matter transformation as the central process driving
96 functioning at the ecosystem level, a process fundamental enough to be common to all
97 ecosystem types, thus allowing cross-system comparisons, and linking mechanistically
98 different essential ecosystem functions (see conceptual framework in Fig. 1). Biological
99 communities build biomass from inorganic material, respire and produce detritus that is
100 then decomposed and mineralized into new inorganic material. This material processing
101 loop generates fluxes connecting the different ecosystem compartments (such as with
102 primary production, detritus production, or decomposition), occurring at different speeds,
103 hereafter called rates (e.g., uptake or decomposition rates). In our framework, we
104 distinguish rates –defined as mass-specific fluxes– from fluxes themselves, because rates
105 provide discriminating information on environmental and physiological constraints
106 driving processes among ecosystem types (e.g., organism efficiency), which is entangled

107 with community dynamics and organism abundance in fluxes. Overall, the balance of
108 ecosystem fluxes results in specific distributions of matter among living and non-living
109 ecosystem compartments – the stocks (i.e., biomass, detritus, nutrients). Stocks, fluxes,
110 and rates –the three dimensions of our ecosystem functioning space– relate commonly
111 used descriptors of ecosystem functioning associated with ecosystem services (e.g.,
112 biomass production, recycling of detritus, carbon storage). Their interdependency implies
113 potential feedbacks; for instance perturbations may increase the levels of dissolved
114 organic carbon in lakes, which can boost phytoplankton production, and eventually lead
115 to lake eutrophication (Brothers et al., 2014). This illustrates the need of adopting a
116 comprehensive approach, integrating the whole loop of matter transformation when
117 studying ecosystem functioning.

118 However, we still lack a general and quantitative synthesis linking stocks, fluxes and
119 rates and comparing them across ecosystem types and climates. Knowledge on ecosystem
120 functioning is concentrated in studies examining either individual aspects of ecosystem
121 functioning in isolation (e.g., BEF approaches (Loreau et al., 2001) or cross-system
122 comparisons of single functions (Tiegs et al 2019)), or whole functioning in specific
123 ecosystems (e.g., ecosystem ecology approach with fluxes and stocks budgets, for
124 instance in Eyre & McKee (2002)). A comparative synthesis of ecosystem functioning
125 would reveal potential covariations among ecosystem fluxes, stocks, and rates across
126 ecosystem types, from which a holistic understanding of ecosystem functioning could
127 emerge. Moreover, ecosystem functioning varies according to climatic constraints. For
128 example, ecosystem processes, such as respiration or decomposition, slow down under
129 colder climates (Tiegs et al., 2019; Yvon-Durocher et al., 2012). The metabolic theory of
130 ecology scales up the well-known relationship between body size and biological rates,
131 and its dependency on temperature, to ecosystem processes (Brown, Gillooly, Allen,
132 Savage, & West, 2004; Schramski et al., 2015). This provides predictions for changes in
133 ecosystem fluxes and rates across temperature gradients (Schramski et al., 2015).
134 Integrating this knowledge in a multivariate view of ecosystem functioning across
135 ecosystem types and climates would allow to characterize ecosystems based on functional
136 differences. This step is crucial to anticipate changes in ecosystem functions in response
137 to global changes, and to upscale to global nutrient and carbon cycles.

138 In this study, we provide a quantified multivariate view of ecosystem functioning across
139 major ecosystem types and climatic zones (i.e., at the biome scale; see Fig. 1b). We focus
140 on carbon, unified for stocks and fluxes across time and area, as a common currency to
141 make the material loop comparable across systems. We assemble extensive empirical
142 data from the literature on ecosystem carbon stocks (i.e., biomass, organic carbon,
143 detritus), fluxes (i.e., gross primary production, ecosystem respiration), and rates (i.e.,
144 uptake and decomposition rates). We then examine the variation and covariation of these
145 ecosystem variables across ecosystem types and climatic zones. Our analysis
146 characterizes broad types of functioning as well as patterns of functioning variation with
147 climatic constraints, that we discuss in the light of the metabolic theory of ecology.

148

149 **2 | METHODS**

150 **2.1 | Study design**

151 We collected empirical data of carbon stocks (biomass, detritus, and organic carbon),
152 fluxes (gross primary production (GPP), ecosystem respiration (ER), and net ecosystem
153 production (NEP)), and rates (community carbon uptake rate, i.e., mass-specific GPP =
154 GPP/ autotroph biomass, and decomposition rate as described by the k constant) from the
155 literature (Fig. 1a), for eight major ecosystem types, both terrestrial (forest, grassland and
156 shrubland –thereafter called “grassland” for simplicity–, agroecosystem, and desert) and
157 aquatic (stream, lake, ocean pelagic, ocean benthic), and for five climatic zones (arctic,
158 boreal, temperate, tropical, and arid). We lumped climatic zones of ocean pelagic and
159 benthic systems into “Cold” and “Warm” to account for lower climatic imprint on marine
160 systems (see Fig. 1b for the combinations considered and Table S1.1 of Appendix S1 in
161 Supporting Information for definitions). Note that, as rates are fluxes normalized by
162 stocks, uptake and decomposition rates represent respectively the mass of carbon taken
163 up per biomass unit, and the proportion of detritus decomposed in a given time (T^{-1}
164 dimension). Notably, uptake rate conveys information informs about producers’
165 biological efficiency and physiological constraints, while GPP also includes information
166 on their abundance. We aimed at covering a wide range of ecosystem x climate x variable
167 combinations, and retrieved at least ten independent values for each of these

168 combinations (see Appendix S1 for extended methods and a decision tree on study
169 selection for data collection, and Appendix S2 in Supporting Information for a detailed
170 presentation of the dataset). Overall, we compiled a dataset of 4,479 data points from
171 1,223 individual sites (unique geographical coordinates) distributed across the globe (Fig.
172 2), extracted from 604 published studies. The list of data sources is provided in Appendix
173 1.

174

175 **2.2 | Conversions**

176 To make the dataset consistent, we homogenized the units of stocks, fluxes and rates into
177 gC m^{-2} , $\text{gC m}^{-2} \text{ year}^{-1}$, and year^{-1} , respectively (noted as “ $\text{g g}^{-1} \text{ year}^{-1}$ ” for uptake rates, for
178 clarity). Data originally not provided in carbon units (21%) were converted with
179 commonly accepted conversion factors, using preferentially the most specific one
180 depending on the level of information available (see Table S1.2 for factors). Flux and rate
181 data provided on timescales shorter than a year (19%) were scaled up to a year assuming
182 standardized numbers of growing days per climatic zone (Garonna et al., 2014). We also
183 had to convert volume to areal units for some data on aquatic systems. We integrated
184 metrics over the relevant depth of water column, which could be average depth (e.g.,
185 shallow stream) or depth relevant to pelagic production (e.g., Secchi depth for gross
186 primary production in pelagic systems). We standardized soil and sediment organic
187 carbon data by integrating values over the first 30 centimetres depth. Complete details on
188 these unit conversions are provided in extended methods (see Appendix S1).

189

190 **2.3 | Data analysis**

191 Our goal was to analyse the variation and covariation of the focal ecosystem variables
192 across ecosystem types, E, and climatic zones, C. To reach this goal we used three
193 complementary steps: (1) we used linear models to quantify the relative contribution of E
194 and C in explaining the variance, and to test mean differences within each ecosystem
195 variable; (2) then, we examined covariation between ecosystem variables with Pearson’s
196 correlation tests, using a bootstrapping procedure so that we could include the variance
197 even though data for the different ecosystem variables were measured in different sites;
198 (3) finally we used Pearson’s correlation to test the relationships between ecosystem

199 variables and latitude for each ecosystem type, to further analyse climatic modulation of
200 ecosystem functioning. Together, these three approaches provide a holistic view on
201 ecosystem functioning in the three-dimensional space of stocks, fluxes, and rates.

202

203 **2.3.1 | Differences among climatic zones (C) and ecosystem types (E)**

204 As a first step, we ran a two-way ANOVA on each ecosystem variable to evaluate the
205 extent to which they were explained by climatic zones (C), ecosystem type (E) and their
206 interaction (C:E). We applied the linear model $y \sim C + E + C:E$ to log-transformed data.
207 The few zero values of biomass, detritus and GPP (seven in total) were removed from
208 this analysis to allow for log-transformation. NEP data were not log-transformed due to
209 negative values. We also carried out these two-way ANOVAs on pooled categories of
210 variables, for stocks (biomass, detritus, and organic carbon), gross fluxes (i.e., GPP, ER),
211 and rates (uptake and decomposition rates). We scaled each variable between 0 and 1
212 before grouping to avoid giving different weights to variables among E x C combinations
213 due to different numbers of data points. Because the residuals were not homogenously
214 distributed, we repeated the model design using more conservative non-parametric
215 Kruskal-Wallis tests on ranks, followed by post-hoc multiple comparisons based on rank
216 sums to identify the groups that were significantly different; parametric and non-
217 parametric tests give the same results on effect significance, so we report ANOVAs
218 results here to visualize the variance partitioning, and non-parametric tests are reported in
219 the supporting information (see full statistical results in Appendix S3 in Supporting
220 Information, Tables S3.1 to S3.7). Finally, since C was found to be an important driver of
221 fluxes and decomposition rate in the above analysis, and C:E interactions were
222 significant, we investigated further climate sensitivity of these variables by comparing the
223 variance explained by C within each ecosystem type. For that, we ran a series of one-way
224 ANOVAs on GPP, ER and decomposition rates of each individual ecosystem type with C
225 as the explanatory variable. Desert and Agroecosystem were excluded from this last
226 analysis since we only had data from one climatic zone.

227

228 **2.3.2 | Covariation among ecosystem variables**

229 As a second step, we examined the correlations among ecosystem variables across
230 ecosystems and climates. Since data were measured at different sites for each ecosystem
231 variable, we did not have measurements of all the variables per site. We therefore
232 adopted a bootstrapping procedure (sampling with replacement) to integrate the
233 variability present in our data. For each pair of ecosystem variables, we randomly
234 sampled one value of each variable in the subsets of data corresponding to each
235 Ecosystem type x Climatic zone combination (E x C), and tested the correlation between
236 variables with Pearson's test. We repeated the sampling and test 10,000 times. All values
237 were log-transformed; therefore, we excluded the few zero values mentioned above. We
238 display the distributions of the 10,000 Pearson correlation coefficients, and provide the
239 mean of these distributions and the percentage of significant correlations to assess the
240 direction and strength of the relationships between ecosystem variable pairs. Correlations
241 on subsets of data in which pairs of variables were available per site confirm that the
242 bootstrapping approach is conservative (Appendix S2.4, Figs S2.10 and S2.11, Table
243 S3.13). Finally, we synthesize the average trends in ecosystem functioning by displaying
244 the median values of each E x C combination in the 3-D space defined by stocks
245 (biomass, organic carbon, and detritus), gross fluxes (GPP and ER) and rates (uptake and
246 decomposition). We scaled the values of each ecosystem variable between 0 and 1 before
247 pooling them in broader categories (i.e., stocks, fluxes and rates) to avoid biases due to
248 different numbers of data point per E x C x V combination (V for ecosystem variable).

249

250 **2.3.3 | Latitudinal trends**

251 As a third and final step, we analysed the correlations between ecosystem variables and
252 latitude for each ecosystem type covered on multiple climatic zones (agroecosystem and
253 desert were excluded) using Pearson's two-sided correlation tests (Table S3.8) This
254 analysis was carried out on the 87% of the data for which we could obtain geographical
255 coordinates. The rest of the data originates from sites with unspecified coordinates, or
256 were estimated at scales too broad (e.g., GPP of boreal forest in Canada) for coordinates
257 to be meaningful.

258

259 **2.4 | Software**

260 We analysed the data and plotted the figures with the open source software R version
261 3.3.3, using the R-packages *maps* (Becker & Wilks, 2018), *vioplot* (Adler, 2018),
262 *minpack.lm* (Elzhov, Mullen, Spiess, & Bolker, 2016), *plot3D* (Soetaert, 2017) and
263 *dunn.test* (Dinno, 2017). See Appendix S1 for more details. Final artwork was realized
264 with Illustrator CC 22.0.1.

265

266 **3 | RESULTS**

267 **3.1 | Variance explained by ecosystem types (E) and climatic zones (C)**

268 All stocks, gross fluxes (GPP and ER), and rates vary significantly among ecosystem
269 types (E) and climatic zones (C), (see Fig. 3) according to both parametric and non-
270 parametric tests (see Tables S3.1-S3.5). Main and interactive effects (C, E versus C:E) for
271 each ecosystem variable are all highly significant (Table S3.1). The ANOVAs on pooled
272 categories (stocks, fluxes and rates) show that E, C and E:C explained about 58% of the
273 total variance (Table S3.2). When considering individual ecosystem variables, the 2-way
274 ANOVAs show that more variance is explained for organic carbon (91%) and biomass
275 (78%) and less for NEP (39%), GPP (57%), and detritus (55%) (Fig. 4a). On average
276 across the different ecosystem variables, C, E, and C:E represent 18%, 71% and 11% of
277 the variance explained, respectively. While ecosystem type (E) corresponds to most of
278 the explained variance, notably for stocks (91%), climatic zones also modulate ecosystem
279 variables, especially fluxes and decomposition rates (C effect represents 42% and 27% of
280 the explained variance, respectively, compared to 5% in stocks). This climatic
281 modulation, however, is highly variable among ecosystem types for some variables, for
282 instance for GPP, which depends strongly on climatic zones for forests (where climate
283 explains 66% of the variance) but not for streams (where climate is not significant). By
284 contrast, the climatic effect on ecosystem respiration (ER) is relatively homogenous
285 across ecosystems (see Fig. 4c, Tables S3.6 and S3.7). Lastly, interactive effects between
286 ecosystem types and climatic zones appear to be especially important for NEP and
287 detritus (27% and 22% of explained variance, respectively; see Fig. 4a and Table S3.1),
288 indicating that the direction of climatic effects varies across ecosystem types.

289

290 3.2 | Stocks, fluxes, and rates' variation across ecosystem types

291 Stocks, fluxes, and rates vary widely but consistently among ecosystem types. Moreover,
292 ecosystem types cluster at distinct positions in the space defined by ecosystem variable
293 pairs, and this clustering drives most of the correlations observed between variables
294 (Figs. 5 and S4.1). On a log-log scale, stocks, fluxes and rates correlate positively within
295 each category. For instance, ecosystem types displaying high biomass also have high
296 organic carbon stocks (Fig. 5a), and those displaying high GPP also show high ER (Fig.
297 5b). While such relationship between GPP and ER is expected in systems where
298 productivity is driven by autotrophic organisms like in terrestrial ecosystems (Chen et al.,
299 2015; see Fig. S2.10, and discussion in Appendix S2.4), it could be assumed to be
300 disconnected in heterotrophic ecosystems where production is mainly driven by the
301 detritivore biotic loop (e.g., in freshwater ecosystems). Surprisingly, we observe it across
302 all ecosystem types regardless of their average auto- or heterotrophic status. On the
303 whole, correlations we observe within stock, flux, and rate categories emerge mainly
304 from differences among ecosystems types: globally, terrestrial ecosystems have high
305 stocks and fluxes and low rates while aquatic ecosystems have low stocks and fluxes and
306 high uptake and decomposition rates. Looking more into detail, stocks and fluxes
307 decrease from forests to agroecosystems, grasslands, deserts and benthic marine systems,
308 to finally be the lowest in streams, lakes, and pelagic marine systems (Figs. 5a, 5b), while
309 rates are higher in streams and pelagic marine ecosystems than in the rest of ecosystem
310 types (see Fig. 5c; see significantly different groups in Table S3.4). Stocks generally
311 correlate positively with fluxes, such as biomass with GPP, but negatively with rates,
312 such as biomass with uptake rate (Fig. 5 panels d and e, and Fig. S4.1), the later relation
313 being also strongly conserved within ecosystems (Fig. S2.10). Thus, in systems
314 sustaining more standing biomass, more biomass is produced in total but at a lower rate.
315 The negative stock-rate relationships, however, does not hold for detritus and
316 decomposition rates (Fig. 5f; but see the relatively opposed directions of these variables
317 in a PCA on median ecosystems in Fig. S4.2).

318 Overall, positioning median ecosystems in the three-dimensional space of stocks, fluxes
319 and rates results in a gradient of functioning types (Fig. 6): forest ecosystems have the
320 largest stocks and fluxes but low rates. Grasslands also have relatively slow biological

321 processes, but with lower stocks and fluxes than forests. Agroecosystems position close
322 to grasslands but with noticeably higher rates. This is followed by deserts and benthic
323 marine systems with intermediate stocks and fluxes. Finally, freshwater and pelagic
324 marine ecosystems cluster in the region of lower stocks and fluxes but higher rates. In
325 addition, fluxes and rates in freshwater and terrestrial ecosystems display a marked
326 climatic-induced secondary gradient ranging from low values in arctic/boreal zones to
327 higher values in temperate and arid zones, and highest values in tropical zones (see
328 shapes in Fig. 6).

329

330 **3.3 | Climatic modulation**

331 A climatic imprint is most visible on fluxes and decomposition rates (Figs. 4a, 4b, Tables
332 S3.1 and S3.2). In comparison, stocks vary less, and less consistently, with climate (Figs
333 4b, S4.3). For instance, while we note a significant decrease in biomass with latitude in
334 forests, an opposing trend can be found in marine pelagic ecosystems (Fig. S4.3, Table
335 S3.8). By contrast, GPP, ER and rates systematically decrease with latitude (Figs 7,
336 S4.4), although the relationship is not significant in all ecosystem types: for instance,
337 GPP does not correlate with latitude in streams (Fig. 7a). This absence of a climatic effect
338 was also apparent when using discrete climatic zones (see Fig. 4c and Table S3.6).
339 Moreover, different responses of GPP and ER to latitude within ecosystem types might
340 result in opposite response of Net Ecosystem Production (NEP) to latitude, for instance in
341 grasslands versus streams: NEP decreases significantly with latitude in grasslands, while
342 it increases in streams (Fig. 7d), a pattern confirmed with discrete climatic zones when
343 comparing mean NEP of these systems in arctic and tropical zones (Table S3.9).

344

345 **4 | DISCUSSION**

346 By integrating quantifications of ecosystem functioning in the 3-D space of stocks, fluxes
347 and rates, this synthesis provides a global overview of ecosystem functioning, its
348 characteristics and variability within and among ecosystem types. Compared to previous
349 work, our comparative and multivariate approach reveals a gradient of functioning.

350 Analogous to r-K ecological strategies at the species level, ecosystems have different
351 typologies, either with fast biological processes and low storage (e.g., freshwater and
352 pelagic systems), or slower processes but with large storage and production capacity
353 (e.g., forests). Climate regulates the speed of this processing, modulating the position of
354 ecosystems in the functioning space.

355 **4.1 | Ecosystem functioning types in a multi-dimensional space**

356 Functioning types – how material is stored and processed within ecosystems – align on a
357 gradient from terrestrial ecosystems with high storage capacities, high fluxes, but slow
358 biological rates, to aquatic ecosystems with low stocks and fluxes but fast biological
359 rates. Forests *versus* streams and pelagic marine systems occupy the respective extremes
360 of this gradient.

361 We interpret these functioning differences observed at the ecosystem level as originating
362 from fundamental differences in the type of organisms dominating resource use and
363 primary production. Notably terrestrial *versus* aquatic physical conditions have selected
364 contrasting producer types, especially in terms of individual size (Kenrick & Crane,
365 1997). Terrestrial systems are dominated by large primary producers (trees and grasses),
366 harbouring complex structures to uptake nutrients in soils and access to light (roots and
367 stems). In pelagic waters of freshwater and marine systems, carbon enters through
368 microscopic producers (phytoplankton), whose small sizes are optimized for osmotic
369 nutrient uptake mode (larger surface to volume ratios of small organisms) and sinking
370 avoidance. These differences in producers primarily impact carbon uptake and
371 decomposition rates. We observe higher uptake rates in systems having smaller producers
372 than in those having large ones (e.g., forests versus stream in Table S3.4), in line with the
373 metabolic theory of ecology (MTE) and previous data compilations (Brown et al., 2004;
374 Cebrian, 1999; Schramski et al., 2015): smaller organisms grow faster (Gounand et al.,
375 2016). Along with increasing size, which imposes energetic constraints on production
376 rates, primary producers' stoichiometry shows increasing C:N ratios (Elser et al., 2000;
377 Sitters, Atkinson, Guelzow, Kelly, & Sullivan, 2015), leading to decreasing
378 decomposability from aquatic to lignin-rich terrestrial systems (Cebrian & Lartigue,
379 2004; Shurin, Gruner, & Hillebrand, 2006; Tiegs et al., 2019). Since aquatic conditions

380 also favour decomposition, decomposition rates decrease from aquatic to terrestrial
381 systems and indirectly correlate positively with carbon uptake rates (Fig. 5c; e.g.,
382 between forest and pelagic marine ecosystems Table S3.4); both ecological processes go
383 faster in streams and pelagic marine systems, and slower in forests, with benthic and
384 grassland systems processing material at intermediate speed.

385 Contrary to rates, stocks are higher in terrestrial than in aquatic systems. This necessarily
386 results from among-ecosystem differences in input-to-output ratios for the different
387 stocks. Indeed, forests accumulate more biomass and detritus than streams and pelagic
388 systems, due to higher production to loss ratios, which could have several origins.
389 Terrestrial systems experience less herbivory and slower decomposition due to a higher
390 proportion of structural tissues and dry conditions (Cebrian, 1999; Cebrian & Lartigue,
391 2004). By contrast, biomass and detritus in aquatic communities experience higher output
392 fluxes of consumption, mortality, respiration, and export by currents or sinking (McCoy
393 & Gillooly, 2008). In benthic sediments, however, carbon could accumulate in large
394 stocks when detritus production rates and sinking input exceed local mineralisation
395 (Duarte & Cebrián, 1996; Fourqurean et al., 2012).

396 Ecosystems harbouring higher stocks also have higher fluxes (GPP and ER), resulting,
397 for instance, in biomass correlating positively with GPP (Fig. 5d), as previously found for
398 different community types (Hatton et al., 2015); the regression slope lower than 1 on log-
399 log scale indicates, however, that mass-specific uptake rates decrease with biomass across
400 ecosystems (Fig. 5e). This second relationship also holds with a surprising consistency
401 within ecosystem types (Fig. S2.10), but explanations of change in uptake rates based on
402 individual size variation fail because community biomass rarely correlates with mean
403 individual body mass (Hatton et al., 2015). In similar ecosystems, slower uptake rates
404 with increasing biomass is better explained by variation in competition: if biomass raises
405 with abundance of primary producers, then shading would reduce community uptake rate
406 in high biomass ecosystems. Across broad types of producers, however, differences in
407 size in itself could drive negative biomass-uptake rate relationships because size integrate
408 not only differences in uptake efficiency but also in structural and stoichiometric
409 differences. This likely explains much of the difference in stocks, fluxes and rates at the
410 ecosystem scale (Allen, Gillooly, & Brown, 2005; Schramski et al., 2015). For instance,

411 trees build structural biomass involving complex molecules such as lignin and cellulose
412 to optimize access to light and therefore production capacity, compared to algae, but this
413 also lowers uptake and decomposition rates (Cebrian, 1999). In aquatic systems, uptake
414 rate is fast but production capacity (GPP) is limited by access to light (Krause-Jensen &
415 Sand-Jensen, 1998), notably in deep or turbid waters (84% of freshwater and 63% of
416 benthic marine ecosystems in our data are net heterotrophic: more carbon is respired than
417 locally produced). This interpretation is congruent with observations of strong positive
418 correlations between carbon residence time and producer individual body mass across
419 broad types of autotrophic ecosystems (Schramski et al., 2015).

420 Overall, despite considerable variability in our dataset (see presentation in Appendix S2),
421 functioning types emerge that we hypothesize are driven by both the dominant primary
422 producer categories (e.g., tree, grass, algae), which would determine stocks' general
423 magnitude and potential activity rates, and by environmental constraints modulating the
424 realized activity (e.g., water turbidity, water availability, temperature).

425

426 **4.2 | Variation of ecosystem functioning with climatic constraints**

427 The high variance observed in ecosystem variables at the broad organisational scale
428 considered here must arise from variation in species' functional traits or food web
429 structure (Cornwell et al., 2008; Datry et al., 2018), or different availability in nutrients,
430 which we do not examine explicitly, and also in response to climatic constraints. In
431 particular, rates and fluxes of production and respiration (GPP and ER) consistently
432 decrease from warmer to colder climates (see Figs. 7, S4.4 and Tables S3.3 and S3.8) as
433 predicted by the MTE (Brown et al., 2004; Clarke, 2006; Gillooly, Brown, West, Savage,
434 & Charnov, 2001), and in line with the quite universal temperature-dependency of
435 biological rates observed across many taxa and systems (Gillooly et al., 2001; Yvon-
436 Durocher et al., 2012). Slowing down of biochemical reactions with decreasing
437 temperature results in a relatively conserved decrease of biological rates along latitudes
438 within ecosystems (see decomposition and uptake rates in Figs. 7 and S4.4). While the
439 flux decrease with latitude is well quantified in some ecosystems, for instance thanks to
440 the FLUXNET program (Yu et al., 2013), our results also show that the strength of the

441 response to latitude might also vary among processes and ecosystems, such as with
442 production (GPP) and respiration (ER). As a result, net ecosystem production can
443 respond to latitude in opposite directions among ecosystem types. In grasslands, NEP
444 decreases with latitude (Fig. 7d) meaning that ER decreases less rapidly than GPP (Yu et
445 al., 2013), maybe due to differences in soil and air temperatures. Conversely, NEP
446 increases with latitude in streams (Fig. 7d, Table S3.8), and between temperate and arctic
447 lakes (Table S3.9). In fact, by slowing down detritivore activity (ER), cold temperatures
448 make freshwater less heterotrophic, as found by Demars et al. (2011) in Icelandic streams
449 of different temperatures, even in the absence of any significant GPP decline.

450 Stocks also vary among climates (see Tables S3.1–S3.3) but not in a systematic way
451 across ecosystem types (Figs. S4.3, S4.6, Table S3.8). Environmental constraints which
452 do not follow a latitudinal gradient, such as water availability in terrestrial systems, also
453 affect the balance between input and output fluxes regulating stocks (Anderson-Teixeira,
454 Delong, Fox, Brese, & Litvak, 2011; Yang, Yuan, Zhang, Tang, & Chen, 2011). For
455 instance, drought limits more GPP than respiration, as observed in Europe during the
456 exceptionally warm summer of 2003 (Ciais et al., 2005), and is associated with specific
457 output fluxes such as erosion, depleting stocks in arid zones (Ravi, Breshears, Huxman,
458 & D’Odorico, 2010). This illustrates how different constraints affecting fluxes in
459 different ways might induce shifts in ecosystem functioning.

460

461 **4.3 | Perspectives: ecosystem functioning facing changes**

462 Integrating ecosystem stocks, fluxes, and rates in a single framework allows us to
463 characterize a gradient of broad functioning types. Environmental constraints, such as
464 climate, move the cursors of ecosystem within the functioning space, but the fine
465 directions and possible magnitude of these movements are still to investigate. To develop
466 fine predictions of process changes at the ecosystem level, we need more complete
467 quantification of ecosystem functioning at the site level. The main limitation of our study
468 is that not all variables are available for each site. Our bootstrapping procedure does not
469 include constraints linking ecosystem variables within specific sites. Observing
470 relationships despite this limitation demonstrates the strength of feedbacks between

471 variables at the cross-ecosystem level. A more mechanistic understanding of these
472 feedbacks would require examining systematically the persistence of these relationships
473 within ecosystem types, which we were able to do for GPP-ER and Biomass-uptake rates
474 variable pairs (Fig. S2.10). Quantification of multivariate functioning at the site level
475 would further allow us to define reference states in the functioning space, and to analyse
476 deviations from these states with changes in environmental constraints or in community
477 composition. This would be a necessary step for early detection and prediction of
478 ecosystem functioning changes (Petchey et al., 2015). To go further, simple models using
479 this general framework matter transformation should allow to compare the responses to
480 perturbations of different ecosystem types and to identify testable mechanisms for
481 potential variations. In that respect, incorporating the decomposition process would
482 constitute an interesting mechanistic expansion of the trophic-level-focused ‘Madingley’
483 model (General Ecosystem Model; Harfoot et al., (2014)) to investigate indirect
484 feedbacks of perturbations on the structure of ecosystems. Moreover, the absence of
485 negative relationships between decomposition and detritus in our data (Fig. 5f) might be
486 the imprint of cross-ecosystem linkages playing a significant role in ecosystem
487 functioning: the signal is blurred by the high variability of detritus stocks and
488 decomposition in freshwater ecosystems, likely because detritus in these systems often
489 comes from terrestrial inputs (Collins, Kohler, Thomas, Fetzer, & Flecker, 2016;
490 Gounand, Little, Harvey, & Altermatt, 2018). Thus, anticipating changes in ecosystem
491 functioning and in the global carbon cycle could necessitate consideration of ecological
492 processes at both local and meta-ecosystem scales (Gounand, Harvey, Little, & Altermatt,
493 2018; Gounand, Little, et al., 2018). Overall, the patterns emerging from such global data
494 synthesis could help evaluating mechanistic ecosystem models (e.g., Madingley) to
495 generate hypotheses on dominant processes and factors driving ecosystem functioning.

496

497 **5 | Conclusion**

498 Acknowledging the multi-faceted nature of ecosystem functioning and the feedbacks
499 linking these facets is crucial to develop a mechanistic understanding of ecosystems’
500 response to change. Our quantified comparison of ecosystem functioning among broad

Multivariate ecosystem functioning

501 ecosystem types and climatic zones integrates previous knowledge into a coherent
502 framework based on material flow, and sets the basis for a mechanistic investigation of
503 ecosystem multifunctionality.

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670 **Data accessibility**

671 The dataset is available in xlsx file format from a Zenodo public repository, doi:
672 10.5281/zenodo.3644247. R scripts to reproduce the figures and statistical results are
673 available.

674

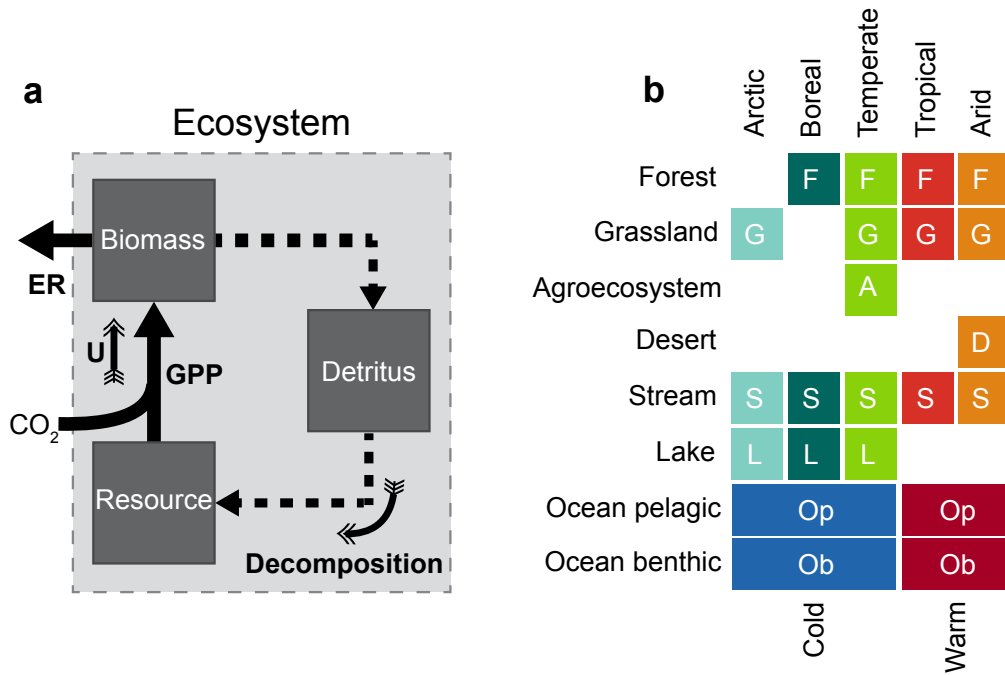
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676 **Supporting information**

677 Additional Supporting Information may be found online in the supporting information tab
678 for this article.

679

680 **Figures**

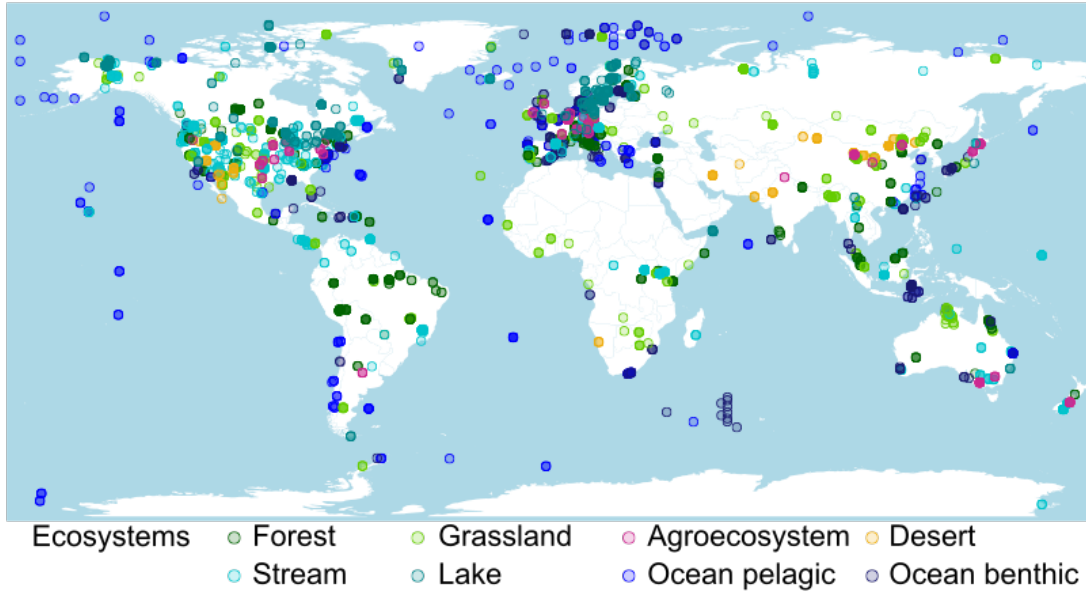


681

682 **Figure 1 | Study design.**

683 **a)** Ecosystem functioning variables considered in the study for each Ecosystem type x
 684 Climatic zone combination shown in panel **b**. We compiled values of stocks (squares in
 685 **a**), fluxes (solid large arrows), and rates (arrows with feathers) from the literature. The
 686 dotted arrows denote production of detritus and decomposition flux, for which we did not
 687 gathered estimates. For decomposition, we compiled rates (arrow with feathers) –the
 688 proportion of detritus processed per unit of time– because they were more available than
 689 fluxes. GPP, ER, and U stand for Gross Primary Production, Ecosystem Respiration, and
 690 Uptake rate, respectively. Note that GPP is a flux, that is an amount of matter produced
 691 per unit of time and area, while U is a rate (i.e., mass-specific GPP), expressed in mass of
 692 carbon uptake per unit of biomass and time. In addition, we also gathered values of Net
 693 Ecosystem production (not shown in **a**) for all combinations displayed in panel **b**.

694



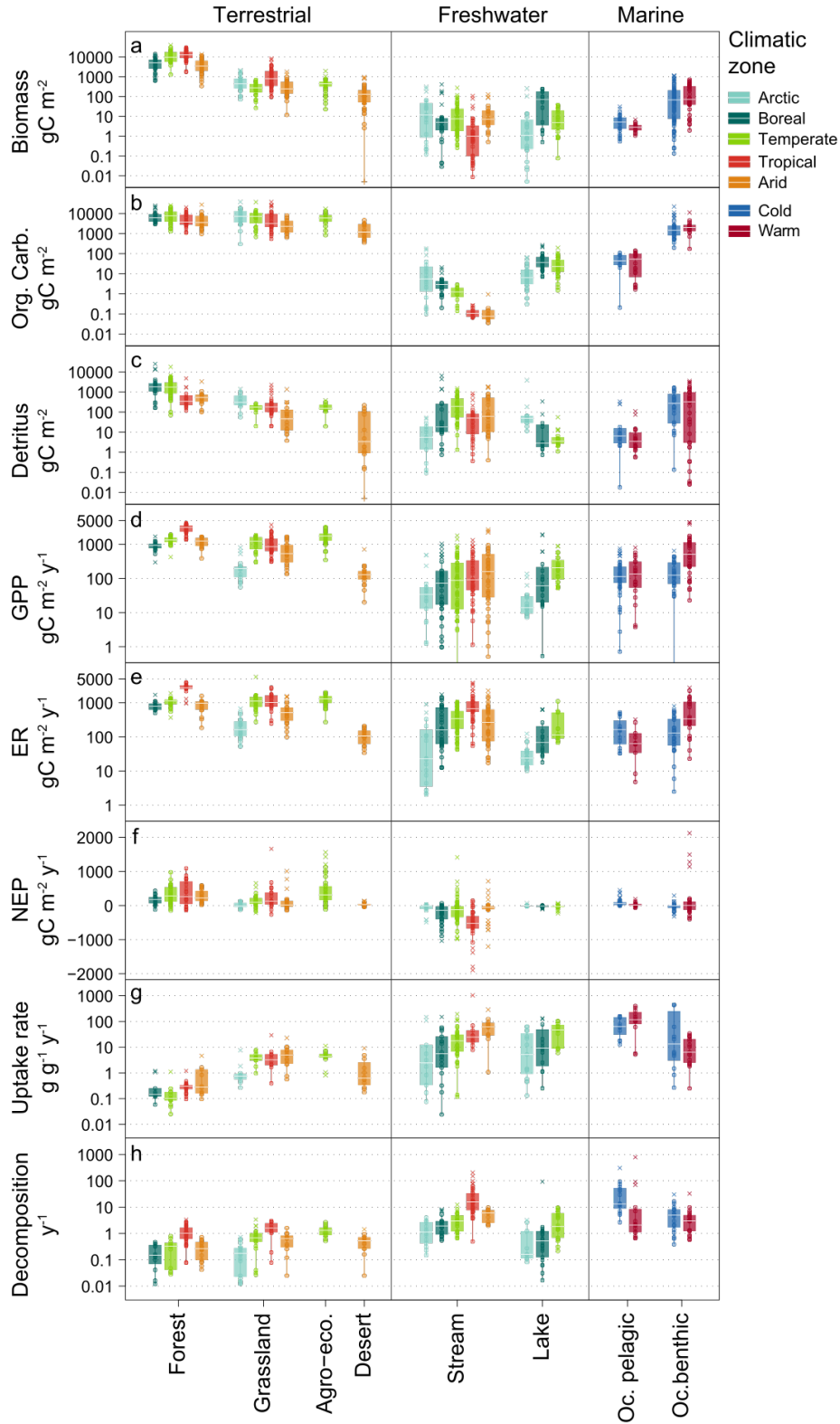
695

696 **Figure 2 | Geographical distribution of the data.**

697 Each dot shows the geographic location of sites from which we obtained data. Colours
698 denote the different ecosystem types. Note that for about 13% of the data either the
699 coordinates are not provided or the geographical scale given is too large or too coarse to
700 be meaningfully reflected in the map (e.g., geographical scale in original study given as
701 “boreal forests of Canada”), thus these data points are not displayed here. The map is
702 made with Natural Earth. Free vector and raster map data @ naturalearthdata.com.

703

Multivariate ecosystem functioning



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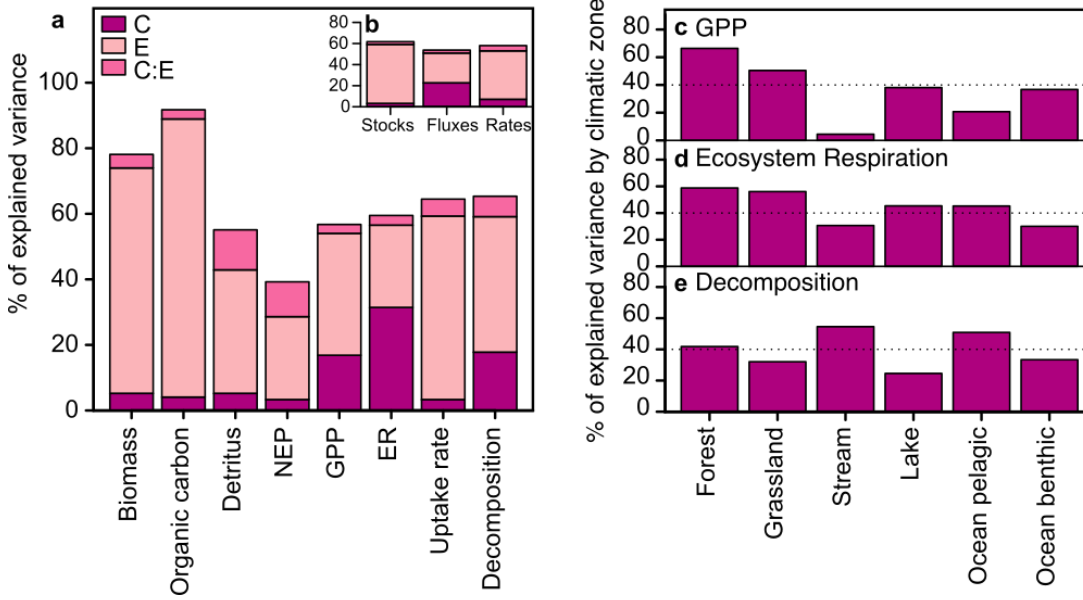
706

Figure 3 | Carbon stocks, fluxes, and rate across ecosystems and climates.

707 Panels show different ecosystem functioning variables (top to bottom) across different
708 ecosystem types (left to right) and for different climatic zones (colours). Ecosystem
709 variables considered are **a** biomass, **b** organic carbon, **c** detritus stocks, **d** gross primary
710 production (GPP), **e** ecosystem respiration (ER), **f** net ecosystem production (NEP), **g**
711 uptake rate (i.e., mass-specific GPP), and **h** decomposition rate. Points give values, with
712 “x” denoting outliers. Zero values are replaced by 0.005 to be displayed despite log scales
713 and are given as “+” in the figure panels **a**, **c** and **h**). Boxplots give median (white line),
714 25% and 75% percentiles (box), extended by 1.5* inter-quartile range (whiskers). Scales
715 were adapted to maximise clarity. For that purpose, 3 very low values of NEP in tropical
716 streams and 5 null values of GPP in temperate streams and an aphotic benthic site are not
717 displayed here (but see figure 7). Tables S3.11 and S3.12 of Appendix S3 in Supporting
718 Information report the numbers of values of each Variable x Ecosystem type x Climatic
719 zone combination, and the groups given by non-parametric post-hoc test of multiple mean
720 comparisons within each variable, following a significant Kruskal-Wallis test (see
721 methods).

722

723



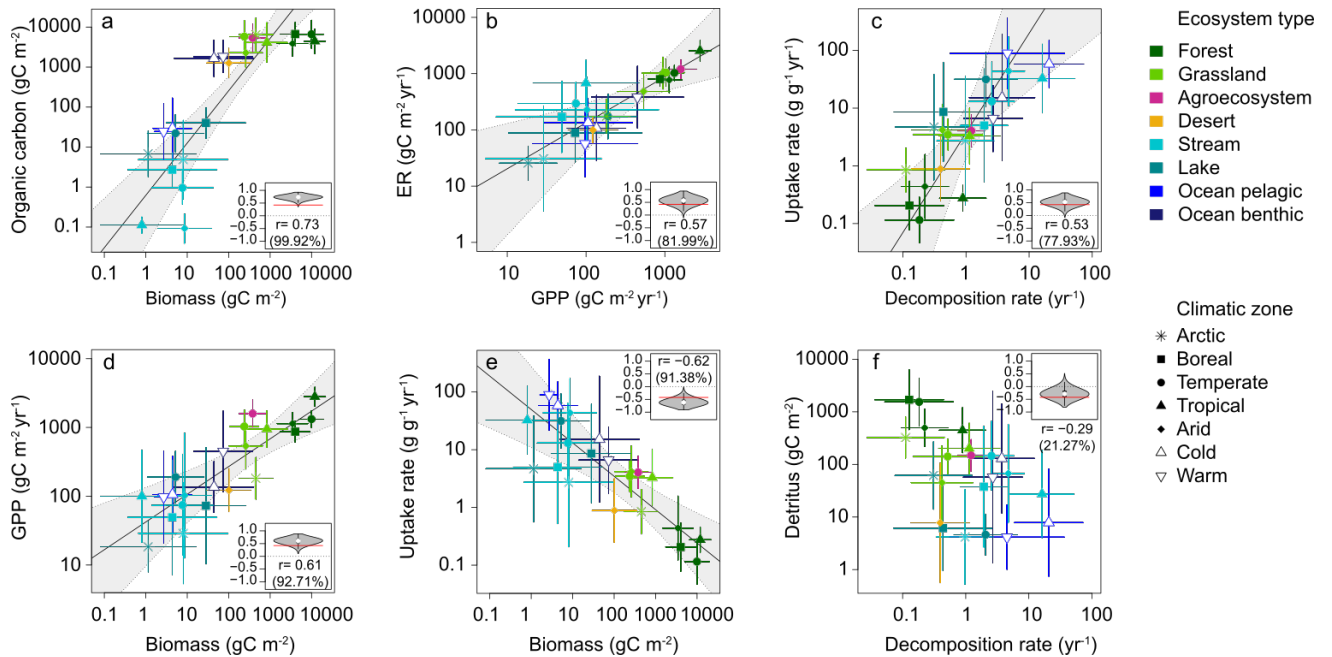
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725 **Figure 4 | Variance of ecosystem variables explained by climatic zone and ecosystem**
 726 **type.**

727 **a** Proportion of variance explained in a series of two-way ANOVAs performed on log-
 728 transformed values of each individual ecosystem variable, with climatic zone (C) and
 729 ecosystem type (E) as explanatory variables; model: $y \sim C + E + C:E$. NEP, GPP, and ER
 730 stand for Net Ecosystem Production, Gross Primary Production and Ecosystem
 731 Respiration, respectively. One null value of biomass and of detritus in a desert and 5 of
 732 GPP were removed to allow log-transformation. In **b**, stocks (Biomass, Organic carbon,
 733 detritus), fluxes (GPP and ER) and rates (uptake and decomposition) are pooled into
 734 broader categories after the individual ecosystem variables are individually scaled. Panels
 735 **c**, **d**, and **e** show the variance explained by climatic zone in a series of one-way ANOVAs
 736 performed individually on GPP, ER, and decomposition rate for each ecosystem type (18
 737 models). Agroecosystem and desert ecosystems are removed because they are represented
 738 in only one climatic zone (temperate and arid, respectively). See full statistical results in
 739 Tables S3.1, S3.2 and S3.6.

740

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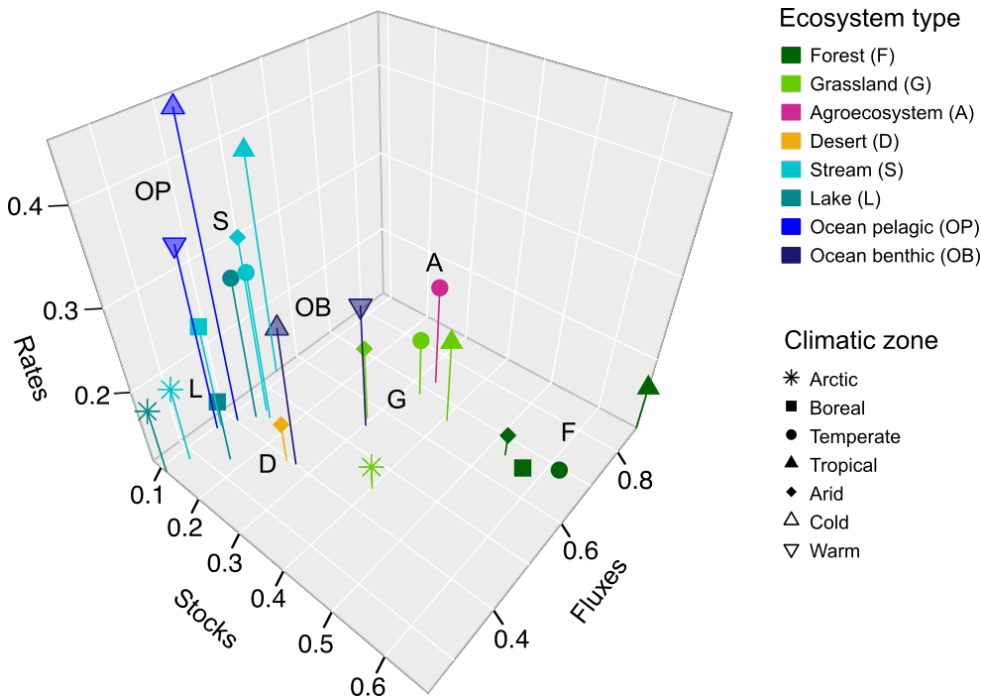
742

743 **Figure 5 | Relationships between ecosystem variables from bootstrap procedure.**

744 Points and bars give mean and standard deviation values, respectively, for the given
 745 ecosystem variables in each ecosystem type (colours) – climatic zone (shapes)
 746 combination. GPP and ER stand for gross primary production and ecosystem respiration,
 747 respectively. Black lines and grey areas give the mean linear regressions and the 95%
 748 confidence interval, respectively, of regressions realized in 10,000 iterations of
 749 bootstrapped values for each ecosystem x climatic zone combination (see methods and
 750 Appendix S1). The violin plots within panels show the distributions of Pearson's
 751 correlation coefficients for these 10,000 series of bootstrapped values; the numbers give
 752 the mean value of this distribution and the percentage of significant correlations into
 753 brackets. The red lines show the limit value above and below which the correlation is
 754 significant, for positive and negative coefficients respectively. Mean and quantile
 755 regressions are not displayed when less than 75% of the correlations are significant (**d**).
 756 The equations for the mean regressions in log-log space are: **(a)** $y = 1.31 * x - 0.48$, **(b)** $y =$
 757 $0.82 * x + 1.13$, **(c)** $y = 1.72 * x + 1.31$, **(d)** $y = 0.4 * x + 3.75$, **(e)** $y = -0.58 * x + 3.91$. See
 758 relations from bootstrap procedure between other pairs of ecosystem variables in Fig.
 759 S4.1, and correlations for subsets of empirical data for which pairs of variables are
 760 available per site in Table S3.13, Figs S2.10 and S2.11, and Appendix S2.4 for
 761 discussion.

762

763



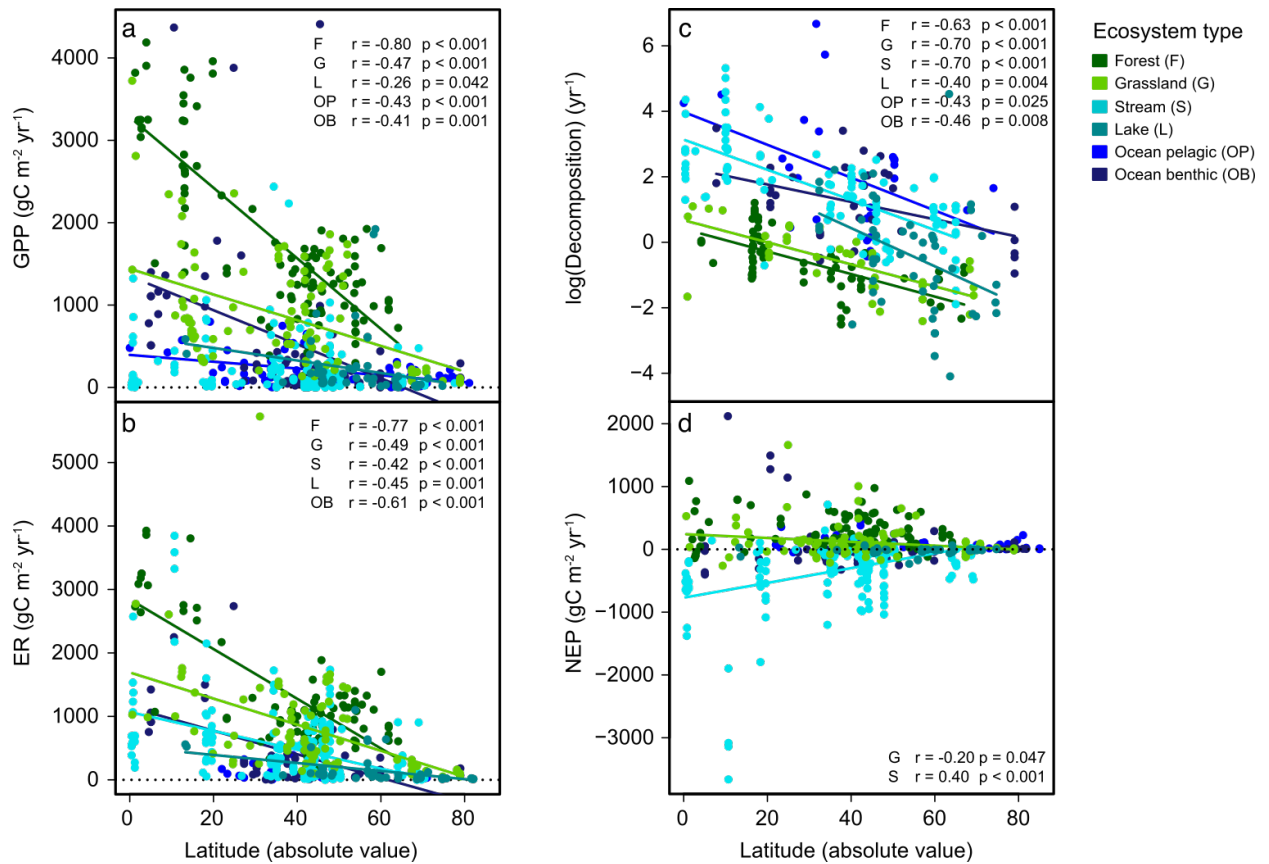
764

765 **Figure 6 | Relative positions of median ecosystems in the ecosystem functioning**
 766 **space.**

767 Ecosystem types (colours, labels) in each climatic zone (shapes) according to the medians
 768 of stocks (biomass, organic carbon, detritus), fluxes (gross primary production,
 769 ecosystem respiration), and rates (mass-specific uptake and decomposition rates). Values
 770 are scaled between 0 and 1 within each ecosystem variable before pooling them into
 771 broader categories (i.e., stocks, fluxes, and rates) to avoid biases resulting from different
 772 numbers of data points among ecosystem x climate x variable combinations. Note that in
 773 each category, variables are pooled and not summed because it would be only meaningful
 774 for stocks. Then each variable has the same weight within each category of stocks, fluxes
 775 or rates. For purpose of clarity, scaled median values are double square root-transformed.

776

777



778

779 **Figure 7 | Latitudinal trends in decomposition rates and Net Ecosystem Production.**

780 Regression lines for significant correlations between latitude and **a** gross primary
 781 production (GPP), **b** ecosystem respiration (ER), **c** decomposition rates (log-transformed
 782 values) or **d** net ecosystem production (NEP) and latitude, based on two-sided Pearson's
 783 two-sided correlation tests. Solid circles show the data points. Colours denote ecosystem
 784 types. Pearson correlation coefficients and p-values are provided for the significant
 785 relationships (see colour legend for abbreviations of ecosystem types, and full details on
 786 statistical tests in Table S3.8). Significant correlations of stocks, uptake rates, and
 787 GPP/ER ratios with latitude are available in Figs. S4.3, S4.4 and S4.5, respectively.

788

789 **List of Supplementary items in the Supporting information**

790 (See new section after page 134, at the end of this file)

791

792 **Appendix S1** Extended methods

793 **Table S1.1** Definitions of ecosystem and climate categories

794 **Table S1.2** Factors used for conversions into grams of carbon

795 **Figure S1.1** Decision tree of the data collection process

796 **Figure S1.2** Data treatment

797

798 **Appendix S2** Data set presentation

799 **Figure S2.1** Geographical distribution of data for each ecosystem variable

800 **Figure S2.2** Data distribution among studies, sites, and ecosystem variables

801 **Figure S2.3** Partitioning of biomass data

802 **Figure S2.4** Comparing data with or without aboveground-only biomass estimates

803 **Figure S2.5** Comparing freshwater data with or without partial biomass estimates

804 **Figure S2.6** Methods used to estimate GPP in our data set

805 **Figure S2.7** Boxplots comparing data with or without correction of estimates from ¹⁴C method

806 **Figure S2.8** Functioning type gradient including correction for ¹⁴C method

807 **Figure S2.9** GPP/ER ratios

808 **Figure S2.10** Correlations among pairwise ecosystem variables (I – fluxes & rate)

809 **Figure S2.11** Correlations among pairwise ecosystem variables (II – among stocks)

810

811 **Appendix S3** Statistical results

812 **Table S3.1** Two-way ANOVAs on ecosystem variables

813 **Table S3.2** Two-way ANOVAs on broad categories of ecosystem variables

814 **Table S3.3** Non-parametric tests for climatic effect on ecosystem variables

815 **Table S3.4** Non-parametric tests for ecosystem type effects on ecosystem variables

816 **Table S3.5** Non-parametric tests of mean differences among E x C combinations

817 **Table S3.6** One-way ANOVAs on fluxes and rates of each ecosystem type

818 **Table S3.7** Non-parametric tests on fluxes and rates of each ecosystem type

819 **Table S3.8** Correlations between ecosystem variables and

820 **Table S3.9** Non-parametric tests for climatic effect on NEP of each ecosystem type

821 **Table S3.10** Non-parametric tests for climatic effect within forests

Multivariate ecosystem functioning

822	Table S3.11 Mean values, coefficients of variation and number of data points
823	Table S3.12 Non-parametric tests of mean differences among E x C combinations
824	Table S3.13 Empirical relationships between pairs of ecosystem variables
825	
826	Appendix S4 Supplementary figures
827	Figure S4.1 Relationships between ecosystem variables
828	Figure S4.2 Principal Component Analysis (PCA) on median ecosystems
829	Figure S4.3 Latitudinal trends in ecosystem stocks
830	Figure S4.4 Latitudinal trends in mass-specific uptake rates
831	Figure S4.5 Latitudinal trends in GPP/ER ratios
832	Figure S4.6 Functioning shift of forests among climatic zones
833	
834	
835	
836	

837 **Appendix 1 – Data sources**

838

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Global quantitative synthesis of ecosystem functioning across climatic zones and ecosystem types

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Appendix S1 – Extended methods

This appendix provides details on the methods used in this study.

Data collection

Our systematic search covered four broad categories of terrestrial ecosystems (forest, grassland and shrubland, agroecosystem, and desert) and four of aquatic ecosystems (stream, lake, pelagic ocean, and benthic ocean). We considered all ecosystems (if available) in five major global climatic zones (arctic/alpine, boreal, temperate, tropical, and arid). Table S1.1 provides the definitions of ecosystem categories and climatic zones. For marine ecosystems, we grouped arctic, boreal, and temperate *versus* arid and tropical climates into Cold and Warm, respectively, to account for a lesser influence of climate on oceanic systems due to the buffering effect of large water volumes. For each relevant ecosystem x climatic zone combination, we collected data of carbon stocks (biomass, organic carbon, detritus), fluxes (gross primary production (GPP), ecosystem respiration (ER), and net ecosystem production (NEP)), and rates (uptake and decomposition rates) (see Fig. 1). We used all possible combinations of these categories and terms with similar meanings (see Table S1.1) in our systematic search. A first systematic search was conducted by using all possible combinations of the names of each ecosystem type, climatic zone and ecosystem variable of interest, with small variation when relevant (e.g. “decomposition OR decay” for decomposition flux and rates). The different terminologies used across various research fields to describe the same processes, and the fact that the data of interest were often located in different sections of the studies (Methods *versus* Results) limited the efficiency of standardized keyword search across the data types. We therefore complemented the dataset with multiple customized searches until we compiled a minimum number of ten independent values of each variable of interest (i.e. different stocks, fluxes, and decomposition rate) for each ecosystem x climatic zone combination. Figure S1.1 shows the flow of this recursive process and the associated decision tree to integrate studies in the data set. Our aim was not to be completely exhaustive but rather to provide representative ranges of variation for the different ecosystem variables. In total, we collected 4,479 values from 604 published studies (this count does not include the 512 GPP/ER ratios provided in the data table).

Calculations used for data extraction

When only one or two of three major fluxes (gross primary production, ecosystem respiration, and net ecosystem production (GPP, R_e , and NEP, respectively) were reported, we estimated the unreported flux:

$$NEP = GPP - R_e \quad [1]$$

$$NEP = NPP - R_h \quad [2]$$

$$NPP = GPP - R_a \quad [3]$$

NPP is the net primary production, R_h the heterotrophic respiration, and R_a the autotrophic respiration. The ratio GPP/R_e was also calculated to compare with the NEP data (see Appendix S2.3).

Uptake rates were rarely reported as such. Some relative growth rates (RGR) were documented, but often at species and not community level only and as instantaneous maximal values (potential growth). Since we wanted to analyse uptake rates relevant at the ecosystem level and at yearly timescale, we thus looked at studies reporting both GPP and biomass of autotrophs, B_a , at the same sites and calculated community uptake rates U :

$$U = GPP/B_a \quad [4]$$

As measures of decomposition rates, we collected values of k , the first order constant in the classical exponential decay model:

$$D_F = D_M(1 - e^{-kt}) \quad [5]$$

with D_F the decomposition flux and D_M the detritus stock. When not directly provided, we derived k with one of the equations proposed by (Cebrian & Lartigue, 2004) depending on the data available in the study:

$$D_t = D_{t_0} e^{-k(t-t_0)} \quad [6]$$

$$D_F = (D_P - E)(1 - e^{-kt}) \quad [7]$$

In Equation [6], D_t is the detrital mass at time t and D_{t_0} the initial detrital mass. This equation was used when decomposition was estimated as the proportion of detrital mass loss $(1 - D_t/D_{t_0})$ via a litter-bag experiment, a classical method in freshwater and terrestrial ecology. In equation [7], D_F is the (absolute) decomposition flux during the study period t , that is the flux from detritus stock to bacteria and other detritivores, D_P is the detritus production, and E the detritus export (e.g. sedimentation). In few cases of ocean pelagic data, we used the microbial loop of primary production *versus* bacterial production to parameterize D_P and D_F , respectively. If not available, the export rate was set to 0, leading to k underestimation, which is conservative in our cross-ecosystem comparison given that k is already at the higher end of the range in these pelagic systems.

Unit conversions

Once collected, we standardized values by converting them all into areal carbon units, that is, gC m^{-2} for stocks, and $\text{gC m}^{-2} \text{yr}^{-1}$ for fluxes, and $\text{g g}^{-1} \text{yr}^{-1}$ for mass-specific uptake rates, and yr^{-1} for decomposition rates. Figure S2.2 details this data processing.

Carbon conversion: We used data in carbon units (gC) when it was directly provided in the study, or we calculated the values using carbon content when reported in the study (79% of data points). Alternatively, we converted the data into carbon units using the most specific conversion factor available depending on the level of detail about the material of interest (see Table S1.2 for conversion factors). For uptake rates, mass-normalization often made conversions unnecessary. Data were converted for calculations to homogenize units of GPP and autotrophic biomass when needed. For decomposition rates, we did not transform units into carbon. We made the most parsimonious assumption that carbon loss rate is identical to loss rate in the unit provided (generally

dry weight or ash-free dry weight). While this is a simplification, we concluded that this best allowed us to keep measurements consistent across data sources, in the absence of more detailed information.

Time extrapolation: 65% of local fluxes or rates were already provided in yearly units. For the others, we extrapolated to the year by using the number of days in the growing season as reported in the study, or the ice-free period in cold climates. When growing season length (GSL) was not specified in the study we used averaged estimates detailed by Garonna et al. (2014) for the different climatic zones in Europe (Mücher, Klijn, Wascher, & Schaminée, 2010): 181 days for temperate climate (mean of “atlantic” and “continental”), 155 days for boreal, 116 days for arctic, and 163 days for arid systems (mean of “Mediterranean” and “steppic”). We assumed no strong seasonality in tropical climates (365 days of GSL). We did not apply any conversion if the value was measured on a study period longer than the above GSL for the corresponding climate.

Volume to area conversions and depth integration: Some data were given per unit of volume. For freshwater systems, we converted the data into area units by integrating them over the water column, using the mean depth of the river or lake. When not directly available in the study we calculated depth by dividing the volume per the area in lakes, or by estimating depth from discharge in rivers with the formula $\text{depth} = c \times Q^f$, with $c = 0.2$, $f = 0.4$ and Q the discharge in $\text{m}^3 \text{s}^{-1}$ (see Rodriguez-Iturbe & Rinaldo (1997)). For small catchment areas, that is $<1 \text{ km}^2$, we estimated the depth to be 5 cm based on known river scaling-properties (Rodriguez-Iturbe & Rinaldo, 1997). For marine data, notably production in the pelagic zone, studies generally provide a meaningful depth, which defines the euphotic zone such as the Secchi depth or the 1% light inflow depth. We integrated values in volume units over this depth, and to 100 m depth when only sampling depths were provided. For terrestrial and benthic marine ecosystems, carbon in soils or sediments was standardized by integrating it over the thirty first centimetres.

Statistical analyses

Firstly, we performed two-way analyses of variance (ANOVA) to determine the contribution of ecosystem type E and climatic zone C in explaining the variance within each ecosystem variable and within broad categories of variables, that is, stocks, fluxes and rates (see Methods in main text for details on broad categories, Fig.4, Tables S3.1, S3.2). The linear model used was $y \sim C + E + C:E$, with y being one of the seven ecosystem variables. Since variances were not homogenous, we performed non-parametric Kruskal-Wallis tests on ranks for multiple mean comparisons to test the mean differences among climatic zones (Table S3.3), among ecosystem types (Table S3.4), and climatic zone x ecosystem type combinations (Table S3.5). Results between parametric and non-parametric tests were identical. We analysed further climatic influence on GPP, ER and decomposition rate within each ecosystem type (excluding deserts and agro-ecosystems which are represented only in one climatic zone). We performed both one-way ANOVAs (Table S3.6) and non-parametric Kruskal-Wallis tests on ranks (Table S3.7), on those 18 ecosystem variables x ecosystem type combinations, with climatic zone as explanatory variable. For all the above analyses we used the initial five categories of climatic zones (i.e., arctic. boreal. temperate. tropical and arid),

but we also performed the non-parametric tests adding the pooled categories “Warm” (i.e., tropical + arid) and “Cold” (i.e., arctic, boreal, temperate) for marine systems to provide the groups corresponding to the figure displaying the data (Fig. 3; Table S3.12). After each Kruskal-Wallis test, we performed a post-hoc test of multiple comparisons on rank sums to get the groups. For that we performed a Dunn’s test using the `dunn.test` R-package (Dinno, 2017).

Secondly, we analysed the covariance between pairs of ecosystem variables across ecosystem types. We used a bootstrapping procedure to include the variance present in our data despite independent origins between ecosystem variables (see Methods in main text for more details on this procedure). We performed two-sided Pearson’s correlation tests on the set of 10,000 bootstrapped data for each pair of ecosystem variables. We display the distributions of the 10,000 Pearson correlation coefficients, and provide the mean of these distributions and the percentage of significant correlations to assess the direction and strength of the relationships between ecosystem variable pairs. In addition, we visualize the variability by showing both the standard deviation of ecosystem variables’ distributions (bars in Fig. 5, Fig. S4.1) and the 95% confidence interval (CI) derived from linear regressions made on the series of bootstrapped values (shaded areas). CIs were calculated for 1,000 values along the x-axis, for which we recorded the y-values predicted by each of the 10,000 linear regressions; the boundaries of the shaded area correspond to the 95% confidence interval of the y-values distributions along x-axis. Figures also show the ‘mean’ regression line defined by the mean slope and intercept (Fig. 5, Fig. S4.1). Note that we minimized the sum of orthogonal distances to the line rather than of residuals squares in these linear regressions to avoid side bias (we do not assume that one of the two variable explains the other one). Furthermore, we carried out a Principal Component Analysis (PCA) on median values of the variables in each E x C combination to examine the relative position of ecosystems in the space defined by all individual ecosystem variables (see Fig. S4.2). We corroborated our general findings by performing correlation tests on the subsets of data for which pairs of variables were available per site (see discussion in Appendix S2 section S2.4, Figs S2.10 and S2.11, and Table S3.13).

Thirdly, we analysed the correlations between ecosystem variables within each ecosystem type and latitude, using two-sided Pearson’s correlation tests. In Table S3.8, we report the results of all these tests, along with slopes and intercepts of the corresponding linear regressions when the test was significant.

Software

We analysed the data and plotted the figures with the open source software R version 3.6.1 (R Core Team, 2019) and different R-packages:

- Figure 1 (to show the map): *maps* (Becker & Wilks, 2018)
- Figures 5 and S4.1: *vioplot* (Adler, 2018) to show the distribution of correlation coefficients, *minpack.lm* (Elzhov, Mullen, Spiess, & Bolker, 2016) for the linear regression and, *ade4* (Dray & Dufour, 2007) to add a scatter plot;
- Figure 6: *plot3D* (Soetaert, 2017);

- Figure S4.2: *FactoMineR* for the PCA (Le, Josse, & Husson, 2008);
- Statistical tests: *pgirmess* (Giraudoux, 2018) (post-hoc tests of multiple mean comparison on rank sums), *dunn.test* (Dinno, 2017) (post-hoc test of multiple mean comparison on rank sums), *multcompView* (Graves, Piepho, Selzer, & with help from Dorai-Raj, 2015)(to find the groups);
- Figure S2.2: *RColorBrewer* (Neuwirth, 2014)for the colours.

Final artwork was realized with Illustrator CC 22.0.1.

Table S1.1 | Definitions of ecosystem and climate categories.

	Definition	Example ecosystems
Climatic zones		
Arctic	Extreme temperature limitation of growing season length, with abiotic conditions not supporting tree growth in arctic, subarctic, and alpine zones; OR high latitude oceans, generally above 66.5°	Tundra (grassland) Alpine grassland
Boreal	Strong temperature limitation of terrestrial growth, but environment supports tree growth. Covers northern parts of North America, Europe, and Russia from latitudes 50° to 55°; OR oceans between 50° and 66.5°	Taiga (forest) Sub-alpine forest
Temperate	Seasonal terrestrial growth with some temperature limitation. Covers latitudes between 23.5° and 50° to 55°, including oceans in this latitudinal range	Beech forest
Tropical	Warm terrestrial tropical, sub-tropical, equatorial systems not limited by drought between 0° to 23.5° latitude (including subtropical system), including oceans in this latitude range	Savanna (grassland), rainforest
Arid	Severely water-limited terrestrial systems at all latitudes, including arid, semi-arid, xeric, xerophytic, xeromorphic, Mediterranean systems, continental, warm or cold, and polar deserts	Garrigue (grassland), shrubland (grassland or forest, depending on the canopy), chaparral (grassland), steppe (grassland), caatinga (forest), cerrado
Ecosystems		
Forest	Complete vegetation cover with trees as dominant vegetation; tree canopy covers most of the surface	Rainforest, caatinga, woodland, some shrubland, cerrado
Grassland and shrubland	Complete vegetation cover. but with only very few or no trees; vegetation dynamics dominated by water limitation, fires, and grazing.	Steppe, savannah, meadow, prairie, tundra, old field, some shrublands, herbaceous rich-fen vegetation
Desert	Extreme growth limitation by water availability. with little vegetation distributed in remote patches	Sandy land
Agro-ecosystem	Ecosystems devoted to crop production or cattle grazing, often fertilized or irrigated to remove nutrient or water limitations for growth	Cropland, pasture, field, vineyard, orchard
Stream	Running freshwater and lotic systems of all sizes. including rivers	Creek, brook, river, stream
Lake	Standing (lentic) freshwater systems	Reservoir, lake, pond
Ocean	All salt water ecosystems with no emerged vegetation, including internal seas	Sea, ocean shelf, estuary, lagoon
Ocean pelagic	Ecosystems in the open water columns of oceans and seas	Upwelling system, open ocean
Ocean benthic	Ecosystems at the bottom of oceans and seas	Coral reef, sea grass bed, eelgrass meadow, kelp forest, deep-sea flour

Table S1.2 | Factors used for conversions into grams of carbon.

KJ = kilojoule; Kcal = kilocalorie; mol C = mole of carbon; g CO₂ = gram of carbon dioxide; g O₂ = gram of di-oxygen; mol O₂ = mole of di-oxygen; g WW = gram of wet weight; g DW = gram of dry weight; g AFDW = gram of ash-free dry weight. Values into brackets give the percentage of raw values converted using a given factor.

Type of material	KJ	Kcal	mol C	g CO ₂	g O ₂	mol O ₂	g Chla	g WW	g DW	g AFDW
Organic Tissue ^a	0.02 (0.08%)	0.09 (0.10%)	12 (3.01%)	0.2727 (2.46%)				0.09 (0.94%)	0.45 (2.70%)	0.5 (4.39%)
Productivity, photosynthetic quotient = 1.2 ^b					0.3125 (3.33%)	10 (0.26%)				
Respiration, respiratory quotient = 1 ^{ab}					0.375 (3.55%)	12 (0.26%)				
Non-woody primary producer terrestrial ^c									0.3* (3.11%)	
Algae, sea grasses ^c							50 (0.76%)	1/16.7 (0.12%)	1/2.92 (1.06%)	
Arthropods ^d									0.496 (0.22%)	

^a from Table 1 p26 in Weathers, Strayer, & Likens (2013), and references therein.

^b from supplementary references: Duarte et al., (2010); Huchette, Beveridge, Baird, & Ireland (2000); Irons III & Oswood (1997).

^c from Table 2.5 p26 in Opitz (1996) for conversions factor from WW and DW; Conversion factor for Chl-a from Peterson, Hobbie, & Corliss (1986).

^d from Small, Torres, Schweizer, Duff, & Pringle (2013).

* used general conversion factor 0.45 for DW in deserts and arid grasslands where the vegetation includes woody species.

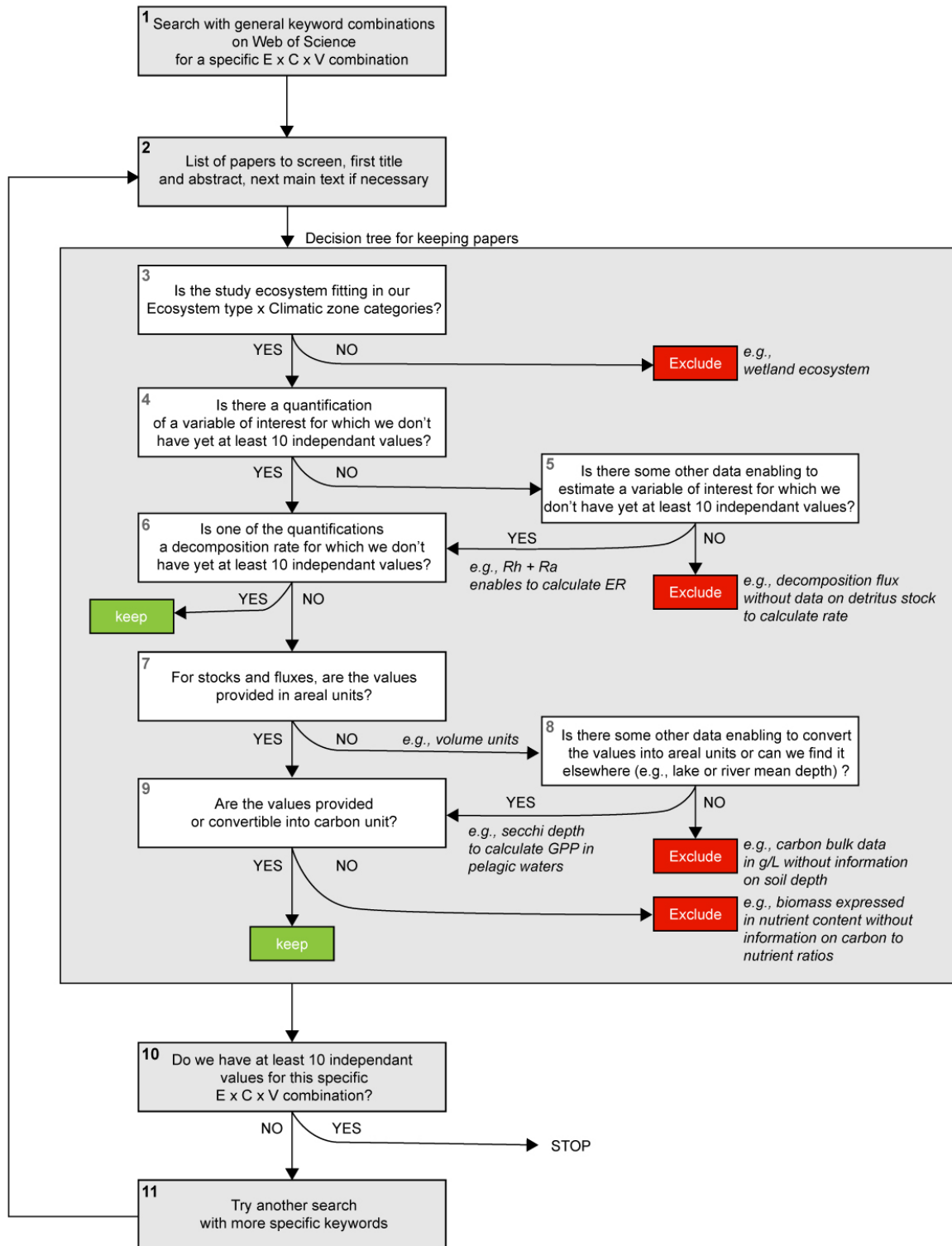


Figure S1.1 | Decision tree of the data collection process.

Steps 1, 2, 10, 12 describe the recursive steps of data search. Steps 3 to 9 describe the decision tree to include or not a paper in our collection.

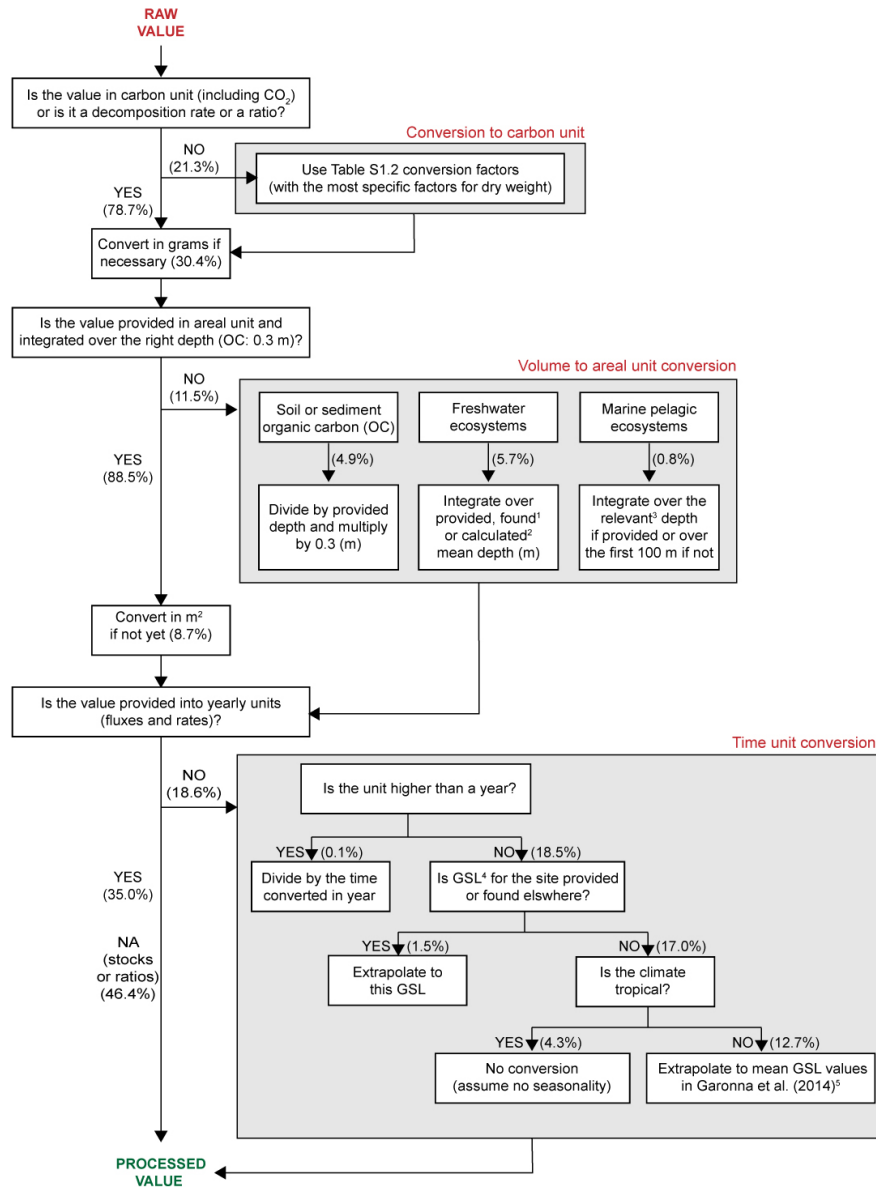


Figure S1.2 | Data treatment.

Conversions applied to raw value to homogenize units to g C m^{-2} , $\text{g C m}^{-2} \text{yr}^{-1}$, and yr^{-1} , for stocks, fluxes, and rates, respectively. Percentage refer always to the whole data set. Notes: ¹ Some lake mean depths were found elsewhere when not provided in the study. ² We estimated river mean depth with discharge and lake mean depth with area and volume when not directly provided. ³ Secchi or 1% light attenuation depths were used to integrate biological fluxes and stocks when provided. ⁴ GSL: Growing Season Length. ⁵ mean GSL values used to standardize: 116, 155, 163, and 181 days for arctic, boreal, arid, temperate climatic zones, respectively (see explanations and references in Appendix S1).

Appendix S2 – Data set presentation

This appendix presents the data set, relevant information on its content and on some identified possible sources of variability, to facilitate a nuanced interpretation of the observed patterns.

S2.1 Geographical location

Data are spread over the world (Fig. 2), with a typical under-representation of the southern hemisphere, notably for terrestrial and freshwater ecosystems. This tendency is illustrated by deserts, for instance, which are mainly represented by North American and Chinese deserts, and almost no data for African ones. Partitioning of individual variables shows no obvious geographical clustering (Fig. S2.1).

S2.2 Data set structuration among studies and sites

Half of the studies consider a single site, and less than 15% of the studies consider more than five sites (Fig. S2.2a, b). Similarly, most studies (46%) focus on a single ecosystem variable, while 34% of the studies consider two to three variables (Fig. S2.2c, d), which was often either several fluxes or several stocks; since a special collection effort was made on finding papers which provide both GPP and autotrophic biomass to estimate uptake rates, biomass is also recurrently found with flux data in our data set. The 15% studies considering more than four ecosystem variables are often studies on single sites, mostly aquatic ones, with a whole ecosystem budget perspective. This includes, for instance, studies on carbon budget in freshwater ecosystems, or studies gathering estimates to feed ECOPATH models in marine or lake ecosystems. Overall, we most often have only one ecosystem variable estimate per site (56%), which justified our bootstrapping approach to examine pairwise variable correlations (Figs. 5 and S4.1). For example, estimates of decomposition rates come mostly from decomposition experiments which do not provide any of the other focal variables we are considering here. By contrast, some variables are almost systematically measured together at the same site, such as GPP and ecosystem respiration (491 data points), biomass and detritus (213 data points), or biomass and GPP due to our search of uptake rate estimates (252 data points). Tables S3.13 and figures S2.10 and S2.11 display the significant correlations tests for available pairs of variables at the site-level (see also section S2.4 below).

S2.3 Data set composition and variance

Variance in our data set comes from both natural variation among and within the ecosystems looked at, and diversity and variability in what was measured and how (i.e. variation caused by the measurement and methods). These two levels of variation cannot be separated in our data set but we here discuss the individual components of our study (stocks, fluxes, and rates), their respective specificities with respect to data origin and specific possible biases. Coefficients of variation for each ecosystem variable are provided in Table S3.11.

Biomass

Biomass represents different components of the ecosystem depending on ecosystem type. Available estimates are most often representative for the organisms contributing the most to the biomass. In terrestrial ecosystems, or in benthic ecosystems such as dense seagrass beds or kelp forests, primary producers constitute most of the biomass (see Fig S2.3). In this case, methods are relatively standard (harvesting), but we gathered aboveground-only (A) and above+belowground (AB) estimates, which adds to natural variation (Fig S2.3b). Omitting roots necessarily underestimates biomass in terrestrial ecosystems, however, biomass increases significantly only in tropical forests when removing aboveground-only data (Fig. S2.4). In aquatic ecosystems, biomass also integrates heterotrophs (Fig S2.3b), especially when not dominated by macroalgae. In freshwater ecosystems, biomass measurements of the whole community are rare and estimates are often epilithon or macroinvertebrate-only data without fish. We thus acknowledge that at least half and a quarter of the data, for streams and lakes respectively, are obvious underestimations (Fig S2.3c). However, removing these partial data gives significantly higher mean biomass only in tropical streams (Fig S2.5). Overall, despite variability in the biomass estimates, we are confident that the strong among-ecosystem differences we observe are robust to those differences in documented biomass.

Organic carbon

Storage of decomposed organic carbon differs fundamentally in terrestrial-benthic versus freshwater-pelagic ecosystems. The estimates for the former are carbon stored in the first 30 cm of soils or sediments and reach areal amounts of magnitudes 1000–10,000 g m⁻². For the latter, estimates are organic carbon dissolved in the water column and range three to four orders of magnitude lower. Methods for both types of measurement are highly standardized and variance likely reflects the natural variation.

Detritus

Detritus is the ecosystem variable showing on average the highest coefficients of variation (Table S3.11). In terrestrial and macroalgae-dominated ecosystems detritus is most often the litter layer, sometimes also including dead standing stock. In freshwater ecosystems, detritus is not only autochthonous detritus but also detritus from terrestrial riparian systems in the form of fine or coarse particulate matter, and sometimes woody debris. Differences in adjacent terrestrial land use thus partly explain a high variance in freshwater detritus. In pelagic marine systems, detritus is particulate organic matter, which is either locally produced in the open ocean, or a combination of locally produced particulate organic matter and organic matter inflow from freshwater systems in estuaries. Sedimentation and fast decomposition through the microbial loop keep detritus stocks at low levels in the water column of these systems.

Ecosystem fluxes

The methods to measure ecosystem fluxes vary strongly among ecosystem types (Fig. S2.6). Notably, in terrestrial systems, CO₂ fluxes are mainly measured with the Eddy-covariance method from flux towers or chambers equipped with portable infrared gas analysers (73% of GPP estimates), but also satellite data (11% of GPP estimates; MODIS: MODerate Resolution Imaging Spectrometer) or more traditional methods involving the budget of biomass increment of plants (NPP) and autotrophic respiration (9%). In freshwater and benthic marine ecosystems, the dominant methods to estimate of photosynthesis and respiration are based on change of dissolved oxygen concentration in time or space (83% of GPP estimates), while in pelagic marine systems, incorporation of ¹⁴C into the biomass is the preferred method to estimate primary production (62%). This last method, however, gives estimates that lie between GPP and NPP depending notably on incubation time (Codispoti et al., 2013). To assess that this was not affecting our conclusions, we identified data which were estimated from this method with an incubation time longer than 6H or unknown (to be conservative), and were likely to underestimate GPP. This concerns 47/687 estimates of GPP and 18/309 of uptake rates (calculated from local GPP and producer biomass). We applied a factor of 0.5 to these estimates, which is also very conservative according to some studies providing both NPP and GPP (e.g., factor of 0.88 in Carstensen, Conley, & Müller-Karulis (2003)), and re-run the analyses. This obviously has some quantitative effect, for instance lowering the strength of the relationship between latitude and GPP but increasing the one with uptake rates in pelagic marine systems, or increasing the strength of the correlations observed in Fig5b, 5d and 5e between pairs of ecosystem variables. Importantly, the general qualitative cross-ecosystem differences and the gradient of ecosystem functioning still hold (Figs. S2.7 and S2.8). Thus, while there are differences in the technical approaches how ecosystem fluxes are assessed, these differences do not change the qualitative relationships documented here.

NEP versus GPP/ER

NEP, shown in figure 3f, is a classical metric to assess ecosystem heterotrophy. However, differences in methodologies to measure GPP and ER can inflate errors when calculating NEP and might skew cross-ecosystem comparisons (Honti & Istvánovics, 2019). We therefore also examined the GPP/ER ratio, which removes such potential biases (Fig. S2.9). These latter ratios confirm the global trends in ecosystem heterotrophy with values generally above one in terrestrial and pelagic systems (78%) and often below one in freshwater and benthic ecosystems (78% also). Significant differences among climatic zones are identical for GPP/ER ratios and NEP (Table S3.3). GPP/RE also increases significantly with latitude in streams, while the weak negative correlation found for NEP in grasslands disappears (Table S3.8 and Figure S4.5). General differences among ecosystem types are also confirmed, although slightly weaker than for NEP (Table S3.4).

Carbon uptake rates

The vast majority of our carbon uptake rate estimates is calculated from studies where both GPP and autotrophic biomass was provided. In terrestrial ecosystems, uptake rates might be slightly overestimated when only aboveground biomass is considered, while in aquatic ecosystems potential overestimations due to methods to estimate primary production (see above) did not lead to significant differences in mean uptake rates (Fig. S2.7). Our results are thus conservative regarding the higher uptake rates in aquatic compared to terrestrial ecosystems.

Decomposition rates

Decomposition rates are most often obtained from litter bag experiments in terrestrial, freshwater and benthic ecosystems. In terrestrial and benthic ecosystems, the litter used comes from the same type of ecosystem, often comparing the local decomposition of different leaf species found regionally, while in freshwater ecosystems litter is of terrestrial origin. Thus, differences between terrestrial and freshwater decomposition rates reflects mostly differences in physical factors and decomposer communities. It's likely that decomposition of autochthonous production would increase estimate values in freshwater ecosystems because aquatic primary producers are way more labile than terrestrial ones (Elser et al., 2000). The observed differences are therefore conservative. Variations in decomposition rates among litter types of different species contribute a lot to within-ecosystem variations.

Estimates for pelagic marine ecosystems were not easy to find and the variability of our values also reflects strong methodological heterogeneity: Decomposition of local production was often estimated by the microbial loop, notably in the open ocean: that is the ratio of bacteria to phytoplankton production, in other words the production processed by bacteria (e.g., Cho & Azam, 1988; Ducklow, 1999; Kirchman, Keel, Simon, & Welschmeyer, 1993). Our data set integrates also estimates from measurements of remineralization rates of dissolved or particulate organic carbon (e.g., Gan, Wu, & Zhang, 2016), which gives lower values than the bacterial loop, or from a classical decomposition experiment on salp carcasses (an important component of zooplankton in some places), which gave us a high-value outlier (Stone & Steinberg, 2016).

S2.4 Correlations between pairs of ecosystem variable: bootstrap *versus* site-level data

To examine the relationships between ecosystem variables we adopted a bootstrapping strategy (see Methods and Appendix S1) due to the low number of per-site data for some pairs of variables. For instance, despite very extensive targeted literature searches, we only found ten sites across all ecosystem types which had data to document both uptake and decomposition rates. Nevertheless, we also tested pairwise-variable correlations on subsets of our data set when estimates for both variables were provided (thereafter called 'empirical' correlations; see Table S3.13 for all significant correlations and figures S2.10 and S2.11). These empirical correlations support all the findings obtained from bootstrapped values. They also quantify some significant cross-ecosystem

relationships that are not indicated by our conservative bootstrap approach, for instance a negative relationship between detritus and decomposition, or positive relationships between ecosystem respiration and biomass or organic carbon (Table S3.13).

Additionally, correlation tests were performed within each ecosystem type for each ecosystem variable pair, which reveals whether relationships between variables emerge solely from cross-ecosystem differences or also from constraints operating at the ecosystem level. Notably, the positive relationship observed between biomass and organic carbon (Fig. 5a) clearly results from cross-ecosystem differences, with no within-ecosystem relationships detected (Fig. S2.10b), while the strong positive correlation between GPP and ER is also highly significant within each ecosystem type (Figs. 5b and S2.10d). This relationship is well-known and expected, notably in terrestrial ecosystems where ecosystem respiration is the sum of autotrophic respiration, which is causally connected with GPP, and heterotrophic respiration, which consists mostly in soil microbial respiration fed by plant detritus and exudates. Note, however, that this relationship is weaker and less systematically expected in aquatic ecosystems. In these ecosystems, respiration can result dominantly from the decomposition of allochthonous matter and be relatively disconnected from a low in-situ GPP (for example in rivers with high riparian cover or benthic ecosystems in deep or turbid water).

Interestingly, the strong negative relationship between ecosystem biomass and primary producer uptake rates holds both across and within ecosystem types (Fig. S2.10b). At cross-ecosystem level, the relationship likely emerges from contrasting differences among primary producers (e.g., size, composition in structural tissues), as discussed in the main text. Within ecosystems, the relationship can be interpreted as a result of both specific variation in producers and competition: higher biomass can result from more individuals which fix carbon at a lower rate due to mutual shading for instance.

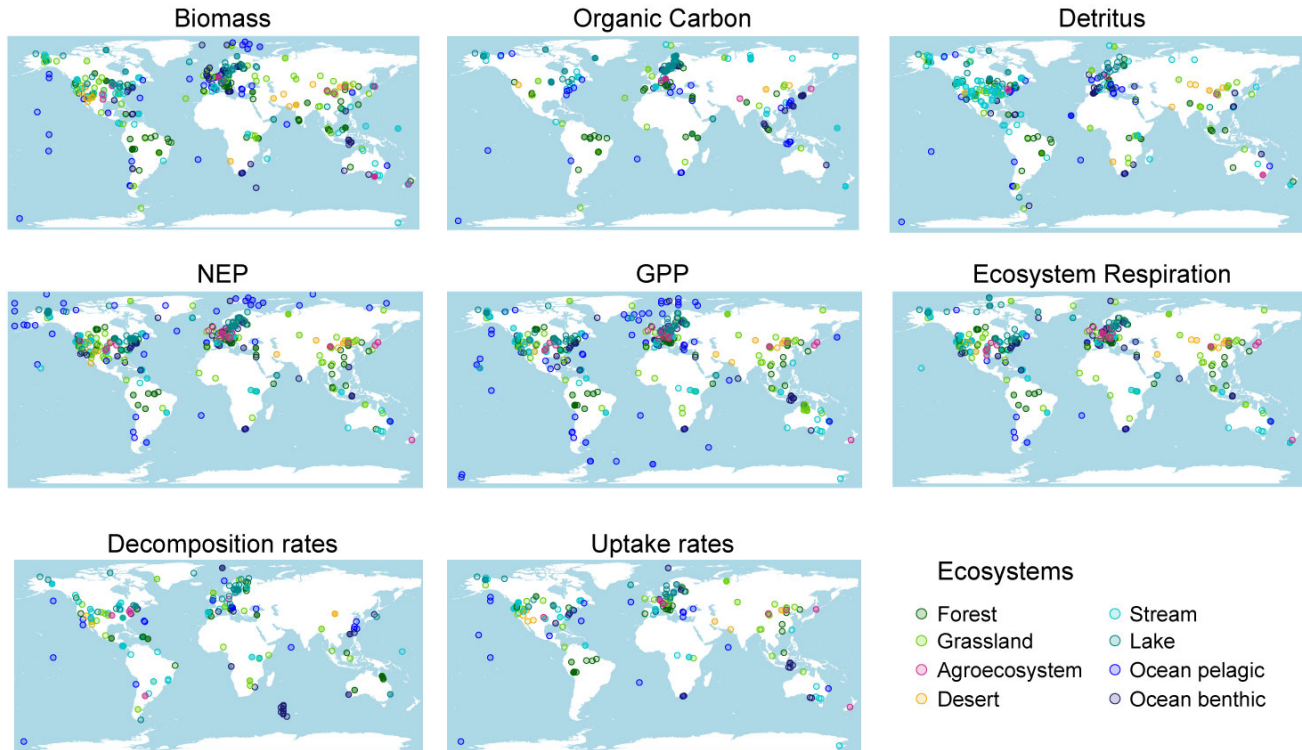


Figure S2.1 | Geographical distribution of data for each ecosystem variable.

Each dot shows the geographic location of sites from which we obtained data. Colours denote the different ecosystem types. For about 13% of the data either the coordinates are not provided or the geographical scale given is either too large or too coarse to be meaningfully reflected in the map. The map is made with Natural Earth. Free vector and raster map data @ naturalearthdata.com.

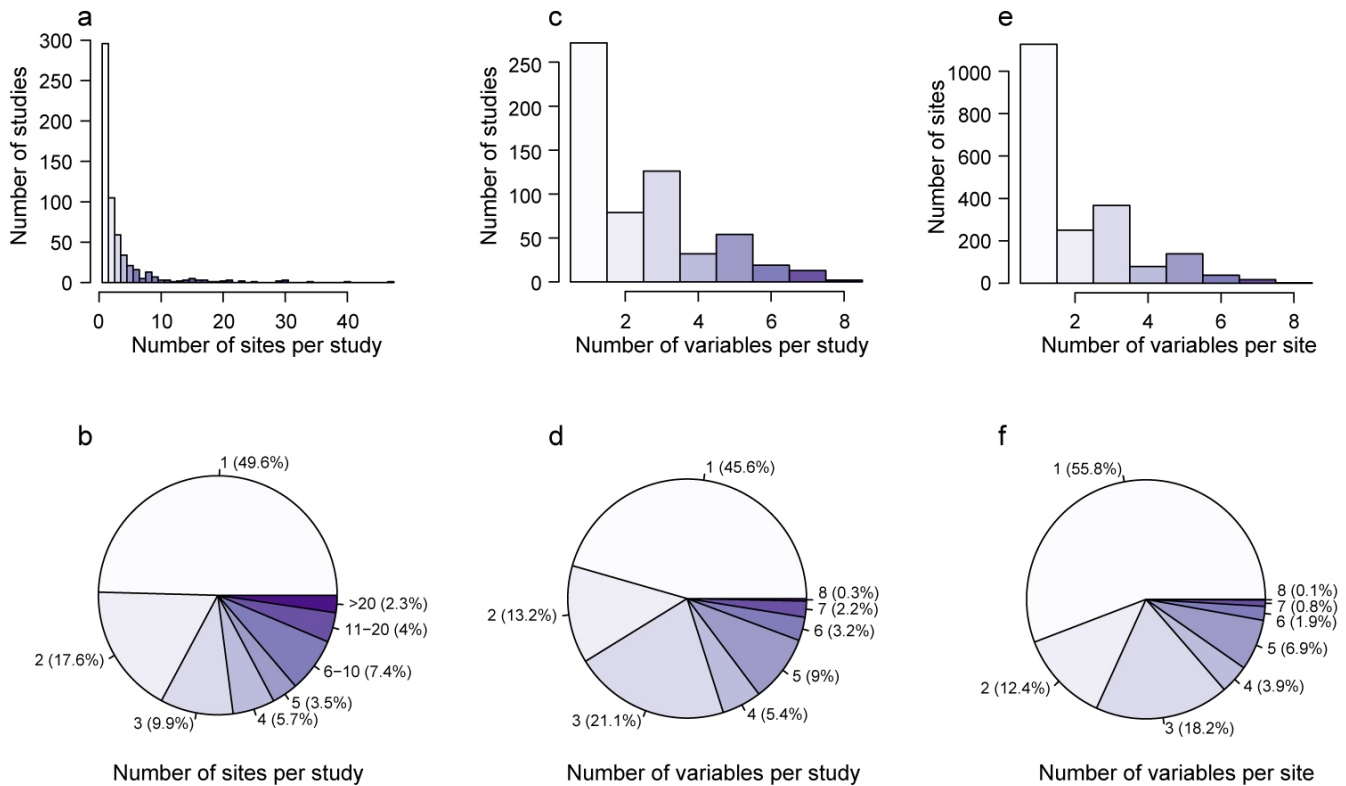


Figure S2.2 | Data distribution among studies, sites, and ecosystem variables.

Histograms (a, c, e) and pies (b, d, f) of (a, b) number of sites per study, (c, d) number of ecosystem variables per study and (e, f) number of ecosystem variables per site. The eight ecosystem variables considered here are: biomass, organic carbon, detritus stocks, gross primary production, ecosystem respiration, net ecosystem production, and uptake and decomposition rates. Some of the estimates were not directly provided but calculated from data provided in the studies (see Appendix S1). This analysis considers the data of 599 of the in total 604 studies in the complete synthesis; data from five studies had to be excluded as they provided only biome-scale estimates.

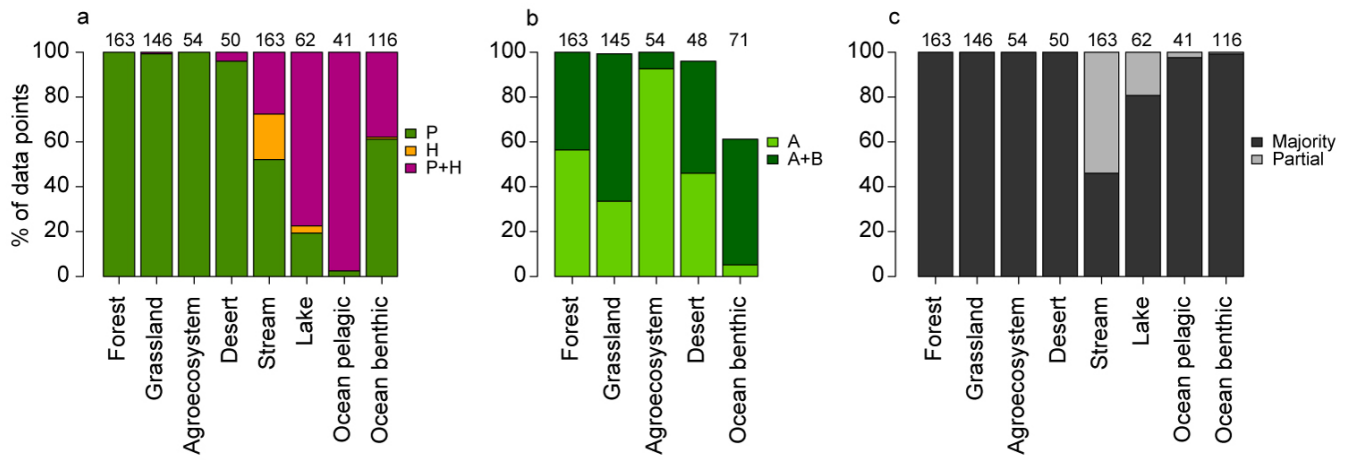


Figure S2.3 | Partitioning of biomass data.

Panel **a** shows the percentage of biomass estimates representing only primary producers (P), only heterotrophs (H) or both primary producers and heterotrophs (P+H). Panel **b** shows the percentage of estimates of primary producer biomass that include only aboveground (A) or both above and belowground biomass (A+B) in terrestrial and marine benthic ecosystems. Panel **c** shows the percentage of biomass estimates which are assumed to represent the majority of community biomass (in dark; e.g. trees in forests) or which are known to be only a partial estimate (in light grey). Estimates of complete communities were difficult to found in freshwater ecosystems. Numbers of data points are provided on the top of each panel.

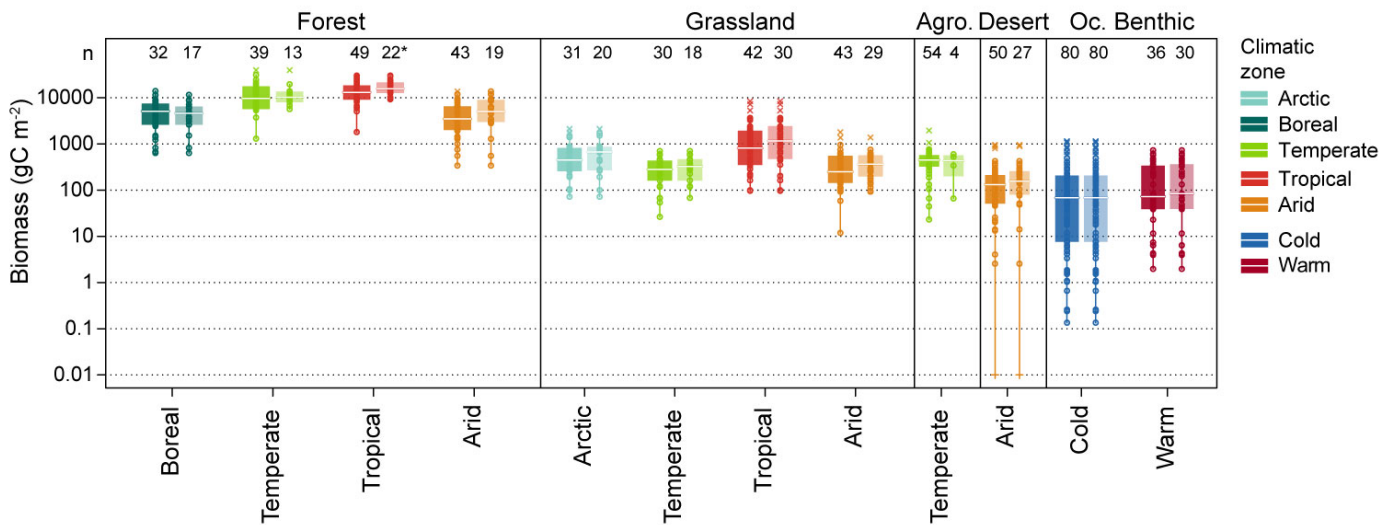


Figure S2.4 | Comparing data with or without aboveground-only biomass estimates.

Biomass data across different ecosystem types (left to right) and for different climatic zones (colours). Transparent colour boxes are for data from which we removed aboveground-only estimates of primary producer biomass while solid boxes are for the complete distribution. Points give values, with “x” denoting outliers. Zero values are replaced by 0.01 to be displayed despite log scales and are given as “+”. Boxplots give median (white line), 25% and 75% percentiles (box), extended by 1.5* inter-quartile range (whiskers). Numbers of data points (n) are given on the panel top. Only tropical forests show a significant difference, denoted by an asterisk) between data with or without aboveground-only data (Wilcoxon test $W=364$; $p\text{-value} = 0.03$).

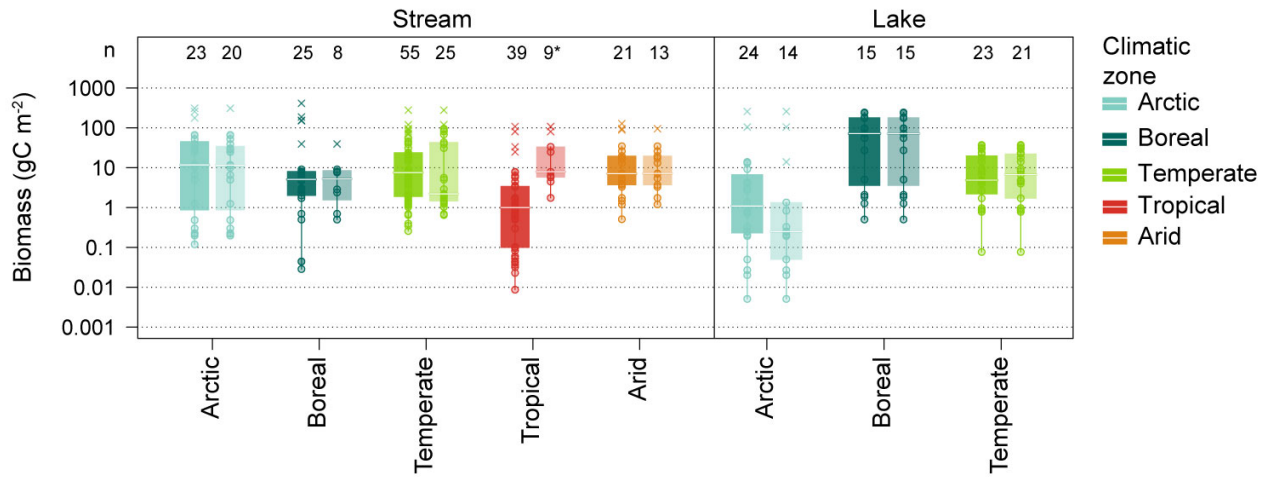


Figure S2.5 | Comparing freshwater data with or without partial biomass estimates.

Biomass data across different ecosystem types (left to right) and for different climatic zones (colours). Transparent colour boxes are for data from which we removed the data that clearly underestimate biomass (e.g., invertebrate-, fish-, periphyton- or epilithon-only data). Points give values, with “x” denoting outliers. Boxplots give median (white line), 25% and 75% percentiles (box), extended by 1.5* inter-quartile range (whiskers). Numbers of data points (n) are given on the panel top. Only tropical streams show a significant difference, denoted by an asterisk) between data with or without partial biomass estimates (Wilcoxon test $W=46.5$; $p\text{-value} < 0.001$).

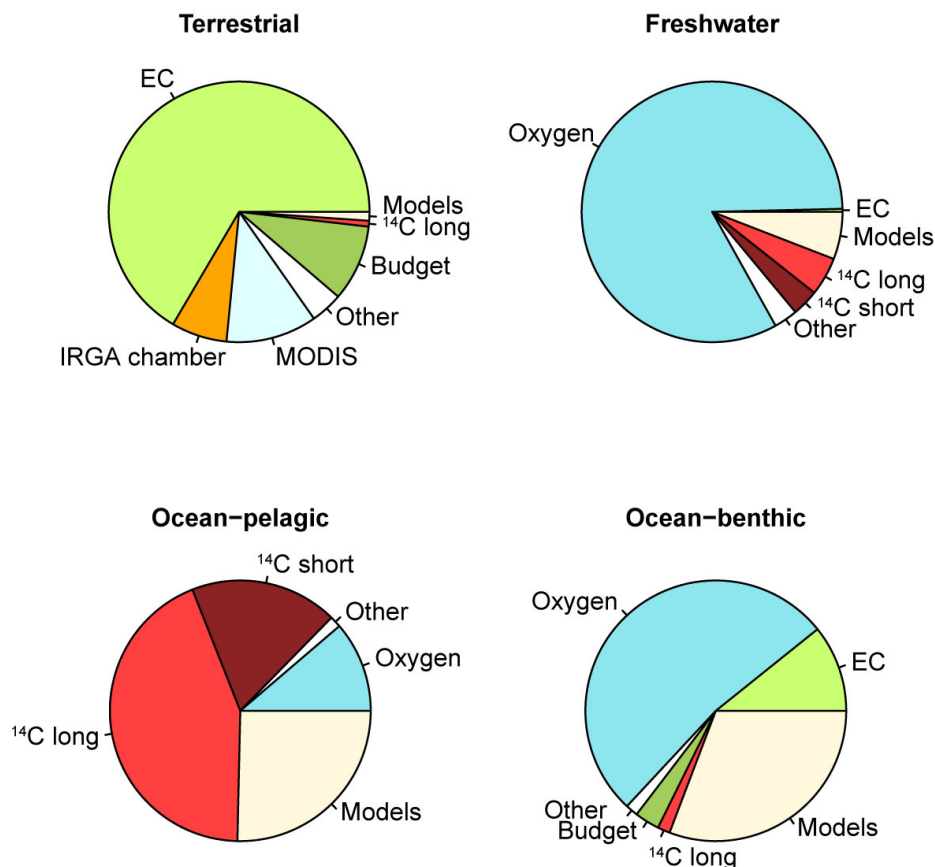


Figure S2.6 | Methods used to estimate GPP in our data set.

EC: Eddy-covariance methods; IRGA: Infrared Gas Analyser. MODIS: MODERate Resolution Imaging Spectrometer (satellite data); “Budget” refers to methods adding measures of autotrophic respiration and NPP estimates from biomass increment measures. “¹⁴C short” refers to methods measuring the incorporation of ¹⁴C into biomass with incubation times up to 6 hours. “¹⁴C long” refers to methods measuring the incorporation of ¹⁴C into biomass with incubation times higher than 6 hours, or when the incubation time is not specified (to be conservative). “Oxygen” refers to method based on change in dissolved oxygen concentration in time or space. “Models” refers to different empirical models (for instance involving the construction of chlorophyll-a – irradiance curves or outputs of ECOPATH models fed with empirical estimates). “Other” includes methods for instance measures of CO₂ based on pH titration or measure of nutrient uptake.

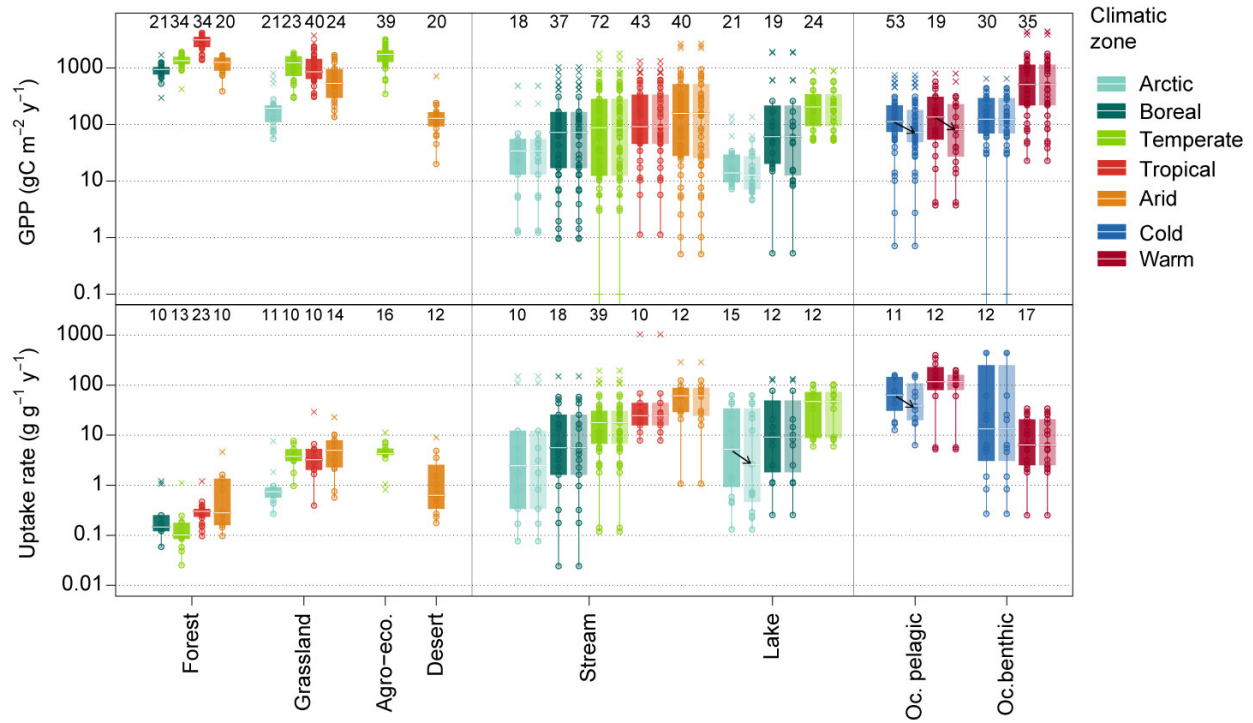


Figure S2.7 | Boxplots comparing data with or without correction of estimates from ^{14}C method.

GPP (top panel) and uptake rate data (bottom panel) across different ecosystem types (left to right) and for different climatic zones (colours). Transparent colour boxes are for data subsets in which estimates were divided by two when estimation involved the method of ^{14}C incorporation with a long incubation time because the primary production estimation is thought to be then closer to net than to gross primary production (Codispoti et al., 2013). This concerns 47/687 values of GPP and 18/309 of uptake rates, mainly in ocean pelagic and arctic lake ecosystems. Points give values, with “x” denoting outliers. Zero values are replaced by 0.1 to be displayed despite log scales and are given as “+”. Boxplots give median (white line), 25% and 75% percentiles (box), extended by 1.5* inter-quartile range (whiskers). Numbers of data points (n) are given on the panel tops. Arrows highlight the decrease in median values. None of the Wilcoxon tests performed on pairs of corrected/not corrected data (individual pairs of solid and transparent boxplot) showed a significant mean difference, thus indicating that, overall, both qualitative and even quantitative differences due methodological differences in ecosystem flux measurement methods, have minor consequences on global patterns.

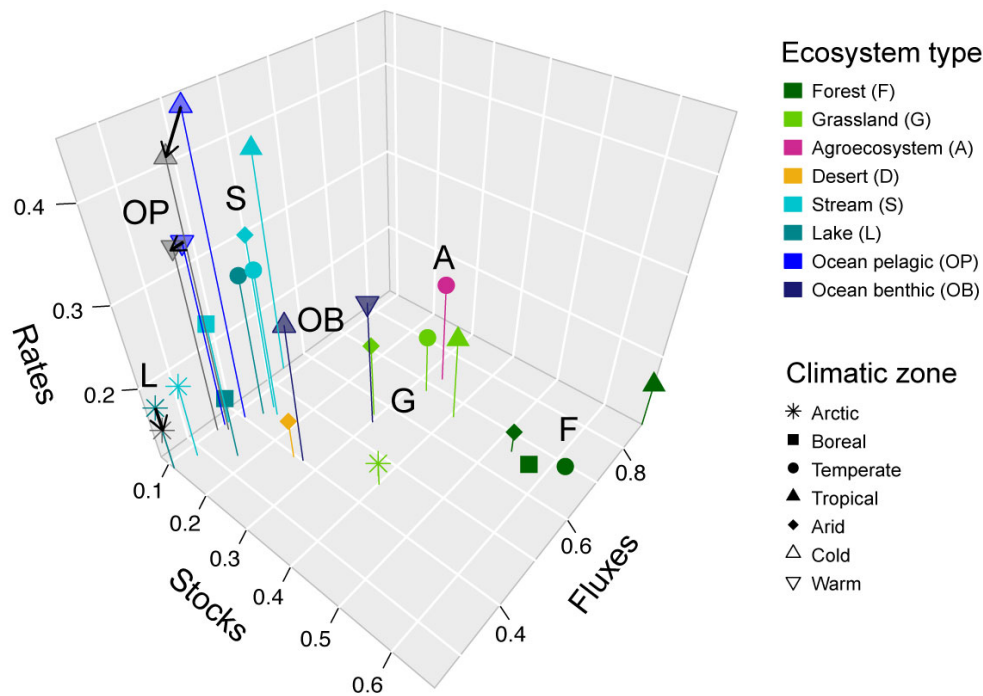


Figure S2.8 | Functioning type gradient including correction for ^{14}C method.

Relative positions of median ecosystem in the ecosystem functioning space: Ecosystem types (colours, labels) in each climatic zone (shapes) according to the medians of stocks (biomass, organic carbon, detritus), fluxes (gross primary production, ecosystem respiration), and rates (mass-specific uptake and decomposition rates). Values are scaled between 0 and 1 within each ecosystem variable before pooling them into broader categories (i.e., stocks, fluxes, and rates) to avoid biases resulting from different numbers of data points among ecosystem \times climate \times variable combinations. For purpose of clarity, scaled median values are double square root-transformed. Arrows and grey shapes show the new position of median ecosystems when a correction factor of 0.5 is applied on estimates of GPP and uptake rates which measurement involved the method of ^{14}C incorporation with a long incubation time. In this case, primary production estimation is thought to be then closer to net than to gross primary production (Codispoti et al., 2013).

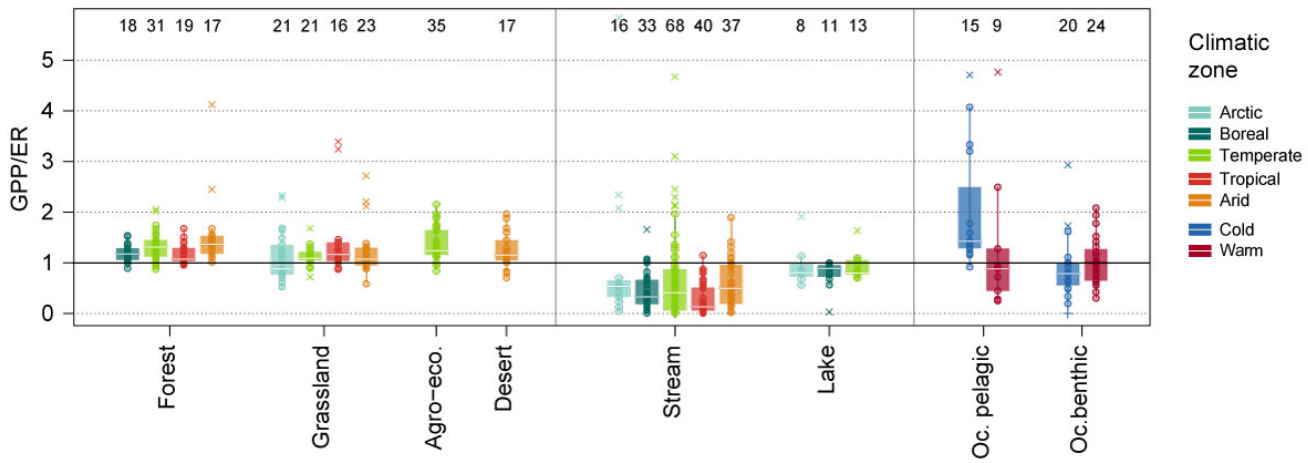


Figure S2.9 | GPP/ER ratios.

Ratios of gross primary production (GPP) to ecosystem respiration (ER) across different ecosystem types (left to right) and for different climatic zones (colours). Points give values, with “x” denoting outliers. Boxplots give median (white line), 25% and 75% percentiles (box), extended by 1.5* inter-quartile range (whiskers). Numbers of data points (n) are given on the panel top.

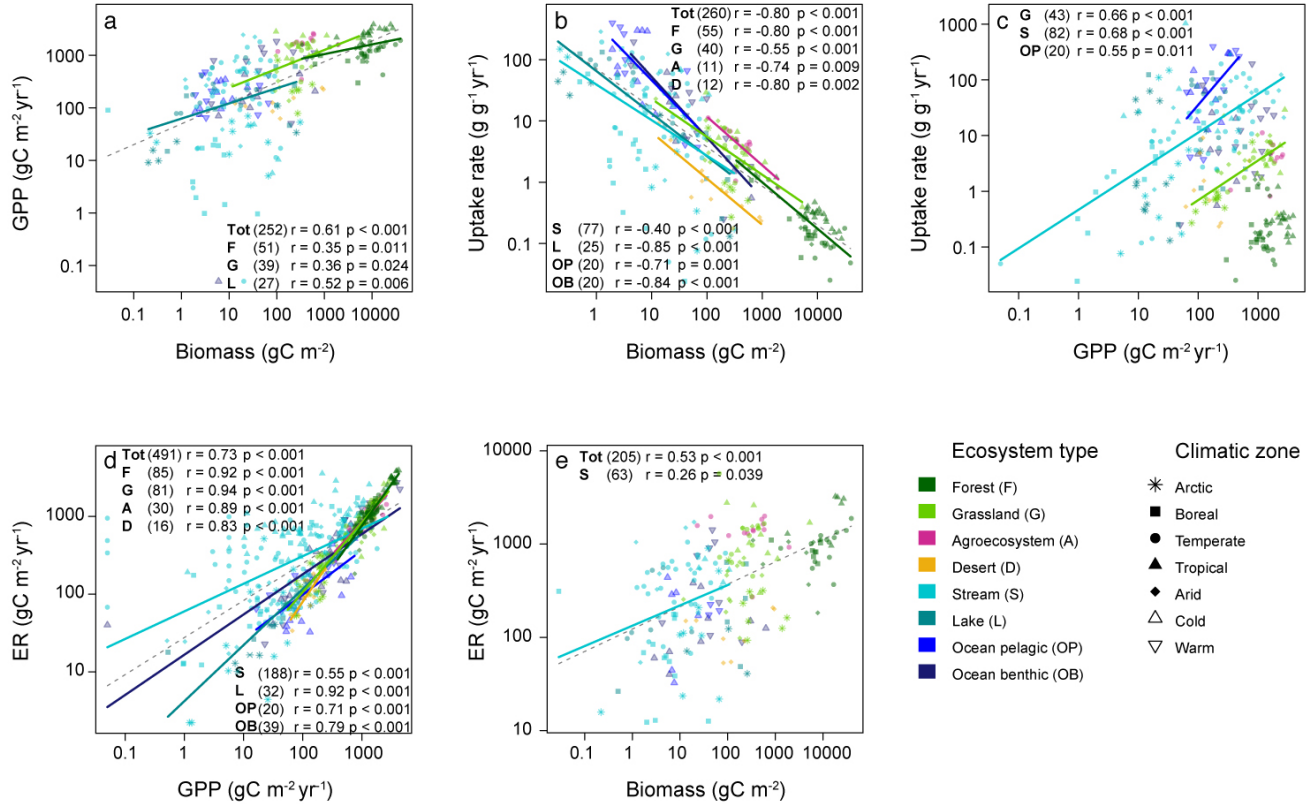


Figure S2.10 | Correlations among pairwise ecosystem variables (I-fluxes & rate).

Shapes show the data points in different climatic zones. Colours denote ecosystem types. Lines show regression lines for significant correlations between selected ecosystem variables in the different ecosystem types, based on two-sided Pearson's correlation tests. Pearson correlation coefficients and p-values are provided for these significant relationships, with the number of data points in brackets (see legend for abbreviations of ecosystem types). "ER" and "GPP" stands for ecosystem respiration and gross primary production, respectively. Uptake rates are GPP values divided by autotrophic biomass. Dotted lines show regression lines for significant correlation tests performed on all the points (all ecosystem types). "Tot" reports the corresponding statistics.

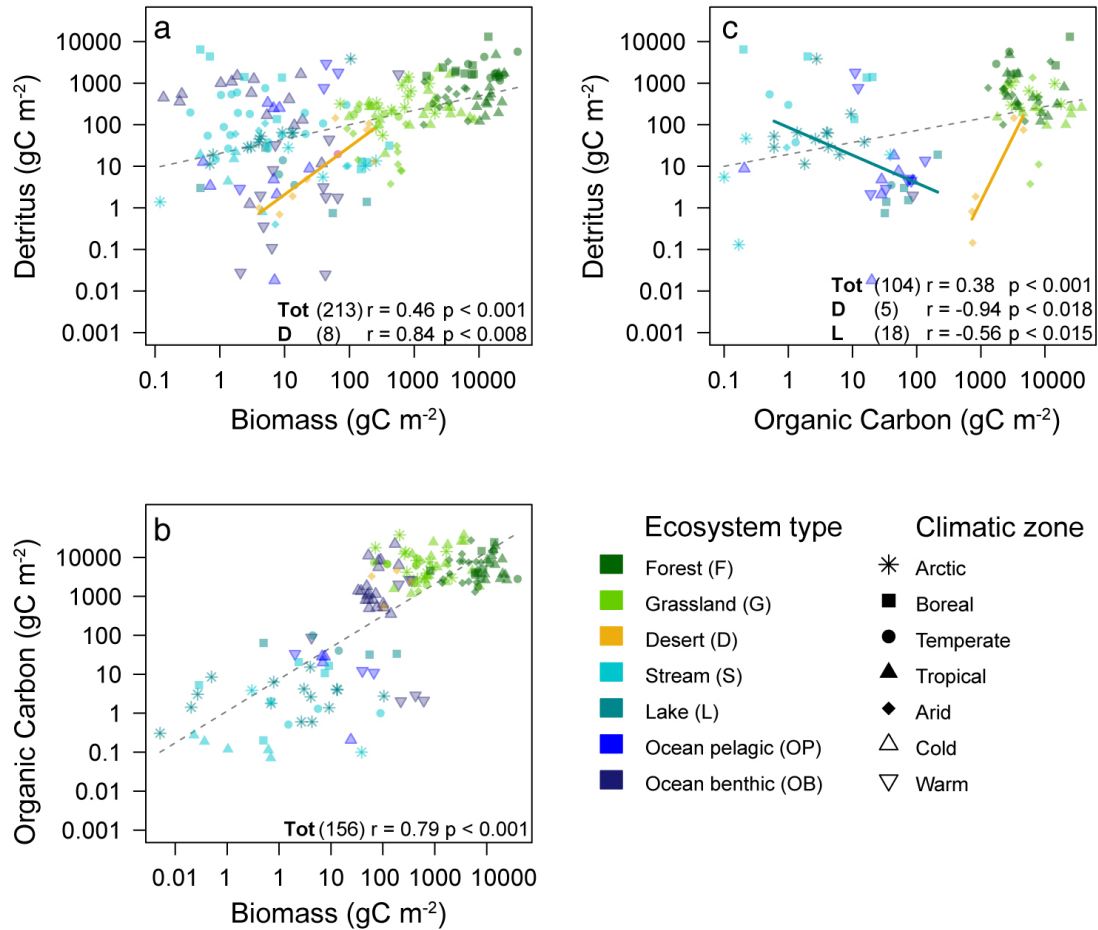


Figure S2.11 | Correlations among pairwise ecosystem variables (II – among stocks).

Shapes show the data points in different climatic zones. Colours denote ecosystem types. Lines show regression lines for significant correlations between selected ecosystem variables in the different ecosystem types, based on two-sided Pearson’s correlation tests. Pearson correlation coefficients and p-values are provided for these significant relationships, with the number of data points in brackets (see legend for abbreviations of ecosystem types). Dotted lines show regression lines for significant correlation tests performed on all the points (all ecosystem types). “Tot” reports the corresponding statistics.

Appendix S3 – Statistical results

Table S3.1 | Two-way ANOVAs on ecosystem variables.

Results of seven analyses of variance (ANOVA) performed on ecosystem variables with climatic zone (C) and ecosystem type (E) as explanatory variables; model: $y \sim C + E + C:E$ (statistics for Figure 4a). NEP, GPP, and ER stand for net ecosystem production, gross primary production, and ecosystem respiration, respectively. Degrees of freedom (DF), sum of squares (Sum Sq), F- and P-values of the significance tests, and proportion of variance explained, as well as of the explained variance for main and interaction effects are given.

Response Variable	Explanatory variable	DF	Sum Sq	% of variance explained	F-value	P-value	Sign. ¹	% of the explained variance
Biomass (log values)	C	4	425.1	5.23	45.73	<0.001	***	6.70
	E	7	5591.8	68.76	343.72	<0.001	***	88.03
	C:E	16	335.8	4.13	9.03	<0.001	***	5.29
	residuals	766	1780.2	21.89				
Organic Carbon (log values)	C	4	288.5	4.09	62.92	<0.001	***	4.46
	E	7	5990.8	84.85	746.56	<0.001	***	92.49
	C:E	14	197.9	2.80	12.33	<0.001	***	3.05
	residuals	509	583.5	8.26				
Detritus (log values)	C	4	164.68	5.23	12.95	<0.001	***	9.49
	E	7	1186.85	37.67	53.34	<0.001	***	68.37
	C:E	15	384.57	12.21	8.07	<0.001	***	22.16
	residuals	445	1414.46	44.90				
NEP	C	4	4004953	3.34	9.27	<0.001	***	8.51
	E	7	30288222	25.27	40.06	<0.001	***	64.38
	C:E	15	12742041	10.63	7.86	<0.001	***	27.08
	residuals	674	72804138	60.75				
GPP (log values)	C	4	382.52	16.85	63.69	<0.001	***	29.70
	E	7	844.34	37.19	80.33	<0.001	***	65.54
	C:E	16	61.19	2.70	2.55	<0.001	***	4.76
	residuals	654	982.01	43.26				
ER (log values)	C	4	400.22	31.45	107.33	<0.001	***	52.87
	E	7	319.26	25.09	48.93	<0.001	***	42.18
	C:E	15	37.50	2.95	2.68	<0.001	***	4.96
	residuals	553	515.60	40.51				
Uptake rate (log values)	C	4	52.95	3.34	6.60	<0.001	***	5.18
	E	7	887.84	55.96	63.24	<0.001	***	86.79
	C:E	16	82.12	5.18	2.56	0.001	**	8.03
	residuals	281	563.60	35.52				
Decomposition rate (log values)	C	4	246.2	17.79	47.76	<0.001	***	27.22
	E	7	571.85	41.33	63.39	<0.001	***	63.24
	C:E	15	86.13	6.23	4.46	<0.001	***	9.53
	residuals	372	479.38	34.65				

¹ Significance code (Sign.): 1 ≥ NS > 0.1 > ‘.’ ≥ 0.05 > ‘*’ ≥ 0.01 > ‘**’ ≥ 0.001 > ‘***’ ≥ 0.

Table S3.2 | Two-way ANOVAs on broad categories of ecosystem variables.

Results of three analyses of variance (ANOVA) performed on broad categories of ecosystem variables with climatic zone (C) and ecosystem type (E) as explanatory variables; model: $y \sim C + E + C:E$ (statistics for Figure 4b). Stocks (biomass, organic carbon, detritus), fluxes (gross primary production and ecosystem respiration), and turnover rates (decomposition rate) are pooled within each of these categories after the ecosystem variables (log values) are individually scaled. Degrees of freedom (DF), sum of squares (Sum Sq), F- and P- values of the significance tests, and proportion of variance explained, as well as of the explained variance for main and interaction effects are given.

Response Variable	Explanatory variable	DF	Sum Sq	% of variance explained	F-value	P-value	Sign. ¹	% of the explained variance
Stocks	C	4	58.48	3.25	37.68	<0.001	***	5.26
	E	7	1005.89	55.94	370.32	<0.001	***	90.61
	C:E	16	45.65	2.54	7.35	<0.001	***	4.11
	residuals	1773	687.99	38.26				
Fluxes	C	4	285.71	22.68	151.07	<0.001	***	42.24
	E	7	355.86	28.24	107.52	<0.001	***	52.60
	C:E	16	34.98	2.78	4.62	<0.001	***	5.18
	residuals	1234	583.45	46.31				
Rates	C	4	50.22	7.11	28.79	<0.001	***	12.26
	E	7	324.25	45.93	106.21	<0.001	***	79.20
	C:E	16	34.97	4.95	5.01	<0.001	***	8.54
	residuals	680	296.56	42.01				

¹ Significance code (Sign.): 1 ≥ NS > 0.1 > ‘.’ ≥ 0.05 > ‘*’ ≥ 0.01 > ‘***’ ≥ 0.001 > ‘****’ ≥ 0.

Table S3.3 | Non-parametric tests for climatic effect on ecosystem variables.

Results of Kruskal-Wallis tests on ranks (light headers) and groups given by multiple mean comparison post-hoc tests on rank sums (dark headers) performed on each individual ecosystem variable and on broader categories of ecosystem variables (i.e., stocks, fluxes and rates) testing the effect of climatic zone (C); model: $y \sim C$. Stocks (biomass, organic carbon, detritus), fluxes (gross primary production and ecosystem respiration), and turnover rates (uptake and decomposition rates) were pooled within each of these categories after the ecosystem variables were individually scaled. See below the table for abbreviations. Degrees of freedom (DF), number of data points (n), Chi-squared and P- values of the Kruskal-Wallis tests are given. Significantly different groups have different letters.

Ecosystem Variable	Kruskal-Wallis test on ranks					Multiple mean comparison post-hoc tests				
	Chi-squared	DF	n	P-value	Sign. ¹	Arctic	Boreal	Temp.	Trop.	Arid
Biomass	39.04	4	795	<0.001	***	a	bc	b	c	bc
Organic carbon	22.10	4	535	<0.001	***	a	ab	c	bc	abc
Detritus	26.56	4	473	<0.001	***	a	ab	b	a	ab
GPP	121.78	4	687	<0.001	***	a	b	c	d	bc
ER	165.74	4	580	<0.001	***	a	b	c	d	b
NEP	21.29	4	701	<0.001	***	abc	c	a	bc	ab
GPP/ER	19.33	4	512	<0.001	***	abc	c	a	bc	ab
Uptake rate	10.76	4	309	0.030	*	a	a	a	a	a
Decomp. rate	69.51	4	399	<0.001	***	a	a	b	c	a
Stocks	76.74	4	1803	<0.001	***	a	c	b	b	b
Fluxes	284.71	4	1267	<0.001	***	a	b	c	d	b
Rates	26.16	4	708	<0.001	***	a	ab	bc	c	ab

¹ Significance code (Sign.): 1 ≥ NS > 0.1 > ‘.’ ≥ 0.05 > ‘*’ ≥ 0.01 > ‘***’ ≥ 0.001 > ‘****’ ≥ 0.

Abbreviations: GPP = gross primary production; ER = ecosystem respiration; NEP = net ecosystem production; Decomp. Rate = decomposition rate; Temp = temperate; Trop = tropical.

Table S3.4 | Non-parametric tests for ecosystem type effects on ecosystem variables.

Results of Kruskal-Wallis tests on ranks (light headers) and groups given by post-hoc tests on rank sums for multiple mean comparison (dark headers) performed on each individual ecosystem variable and on broader categories (i.e., stocks, fluxes and turnover rates) testing the effect of ecosystem type (E); models: $y \sim E$. Stocks (biomass, organic carbon, detritus), fluxes (gross primary production and ecosystem respiration), and turnover rates (decomposition rate) were pooled within each category after the ecosystem variables were individually scaled. Degrees of freedom (DF), number of data points (n), Chi-squared and P- values of the Kruskal-Wallis tests are given. Capital letters in dark headers are abbreviations for ecosystem types (see below the table). Significantly different groups have different letters.

Ecosystem Variable	Kruskal-Wallis test on ranks					Multiple mean comparison post-hoc tests							
	Chi-squared	DF	n	P-value	Sign. ¹	F	G	A	D	S	L	OP	OB
Biomass	619.29	7	795	<0.001	***	c	a	a	b	d	d	d	b
Organic carbon	432.98	7	535	<0.001	***	a	a	ab	abc	e	d	cd	b
Detritus	210.81	7	473	<0.001	***	d	b	ab	ac	ab	c	c	b
GPP	374.01	7	687	<0.001	***	a	d	a	bc	b	b	bc	c
ER	246.14	7	580	<0.001	***	a	e	a	bcd	d	b	bc	cd
NEP	337.09	7	701	<0.001	***	a	bc	a	bcd	e	d	c	bd
GPP/ER	222.84	7	512	<0.001	***	a	abc	a	abc	d	bd	ac	bc
Uptake rate	163.44	7	309	<0.001	***	c	a	ab	ac	b	b	d	ab
Decomp. rate	181.69	7	399	<0.001	***	a	a	ab	a	b	a	b	b
Stocks	1010.9	7	1803	<0.001	***	d	a	a	bc	c	e	ce	b
Fluxes	588.34	7	1267	<0.001	***	a	d	a	bc	c	b	bc	c
Rates	226.54	7	708	<0.001	***	a	a	ab	a	c	bc	d	c

¹ Significance code (Sign.): 1 ≥ NS > 0.1 > ‘.’ ≥ 0.05 > ‘*’ ≥ 0.01 > ‘**’ ≥ 0.001 > ‘***’ ≥ 0.

Abbreviations: GPP = gross primary production; ER = ecosystem respiration; NEP = net ecosystem production; Decomp. Rate = decomposition rate; F = forest; G = grassland; A = agroecosystem; D = desert; S = stream; L = lake; OP = ocean pelagic; OB = ocean benthic.

Table S3.5 | Non-parametric tests of mean differences among E x C combinations.

Results of Kruskal-Wallis tests on ranks (light row headers) and groups given by post-hoc tests on rank sums for multiple mean comparison (dark row headers) performed on each individual ecosystem variable testing the effect of ecosystem type (E) x climatic zone (C) combinations; models: $y \sim EC$. Number of data points (n), degrees of freedom (DF), Chi-squared and P- values of the Kruskal-Wallis tests are given. Significantly different groups have different letters. Note that for space reasons results are displayed in column (one Kruskal-Wallis test per column). Same tests but with clumped climatic variables, “Cold” and “Warm” for marine systems are shown in Table S3.12. See below the table for abbreviations.

			Biom.	Org. C	Detritus	GPP	ER	NEP	Uptake	Dec.
Kruskal-Wallis test	n		795	535	473	687	580	701	309	399
	Chi-sq.		641.42	449.51	275.68	448.63	385.65	375.77	197.50	272.62
	DF		27	25	26	27	26	26	26	27
	P-value Sign.¹		<0.001 ***	<0.001 ***	<0.001 ***	<0.001 ***	<0.001 ***	<0.001 ***	<0.001 ***	<0.001 ***
	Eco	Clim								
Post-hoc test of multiple mean comparison	F	Boreal	bg	a	bc	abghi	abfghijk	abd	abd	ab
		Temp	g	a	b	abg	ab	ad	a	abc
		Trop	g	abc	bcd	a	a	abd	ab	abcdefg
		Arid	bg	abc	bcd	abgh	abfghi	ad	abcd	ab
	G	Arctic	abc	a	bcdf	cdefi	cdel	bceefgh	abcde	a
		Temp	acde	ab	abcdefg	abgh	abg	abd	abcdef	abcdef
		Trop	bcg	abc	cdfg	abgh	abfg	abcd	abcdef	abcdefgh
		Arid	acd	abcd	adefg	bcdghi	befghijkl	abcdef	abcdef	abcdef
	A	Temp	abc	abc	abcdefg	ab	ab	a	abcdef	abcdefg
		Arid	def	abcde	ae	cdef	cde	abcdef	abcde	abcd
	S	Arctic	efhi	ef	a	ef	de	ceefghi	abcdef	abcdefg
		Boreal	fhi	f	adefg	ef	cehjl	hi	cdef	defghi
		Temp	fhi	f	defg	ef	cehijkl	ghi	ef	efghi
		Trop	i	f	aefg	cef	bfgik	i	ef	i
	L	Arctic	fhi	f	adefg	cef	cehijkl	eghi	f	ghi
		Boreal	hi	f	adefg	e	d	bceefgh	bcdef	abcdef
		Temp	adefhi	def	aeg	cef	cde	ceefghi	cef	abcd
		Arid	fhi	ef	a	cdefi	cdehijkl	eghi	f	defghi
	OP	Arctic	defhi	abcdef	aefg	ef	cdejkl	abcdf	bcdef	abcdefghi
		Boreal	abcdefghi	-	-	bcdefghi	-	-	abcdef	-
Temp		fhi	cdef	adefg	cdghi	cdefghijkl	abd	f	hi	
Trop		adefhi	def	a	cdefghi	bcdefghijkl	abcdefgh	f	ghi	
OB	Arctic	fhi	bcdef	aefg	cdefi	cdel	abcdefghi	f	abcdefghi	
	Arctic	acdefhi	-	abcdefg	abcdefghi	bcdefghijkl	abcdefgh	abcdef	bcdefghi	
	Boreal	adefh	abcd	abcdefg	cdefi	cdel	abcdefghi	abcdef	defghi	
	Temp	adefh	abcde	bcdefg	cdefi	cdehijkl	efghi	f	cdefghi	
	Trop	acdefhi	abcde	aeg	abdghi	abfghijkl	abcdefg	cdef	efghi	
	Arid	acdefh	abcdef	bcd	cdefhi	cdefhijkl	bcdefghi	abcdef	abcdefghi	

¹ Significance code (Sign.): 1 ≥ NS > 0.1 > ‘.’ ≥ 0.05 > ‘*’ ≥ 0.01 > ‘**’ ≥ 0.001 > ‘***’ ≥ 0.

Abbreviations: Eco = Ecosystem type; Clim = Climatic zone; F = forest; G = grassland; A = agro-ecosystem; D = desert; S = stream; L = lake; OB = ocean benthic; OP = ocean pelagic; Temp = temperate; Trop = tropical; Biom. = Biomass; Org. C = Organic carbon; GPP = gross primary production; ER = ecosystem respiration; NEP = net ecosystem production; Dec.= decomposition rate; Prod. = Productivity rate.

Table S3.6 | One-way ANOVAs on fluxes and rates of each ecosystem type.

Results of 18 analyses of variance (ANOVA) performed on gross primary production (GPP), ecosystem respiration (ER) and decomposition rate within each ecosystem type, with climatic zone (C) as explanatory variable; model: $y \sim C$ (statistics for Figure 4c-e). Values were log-transformed and three zero values of GPP removed for that reason. Agro-ecosystem and desert ecosystems were removed because they are represented in only one climatic zone (temperate and arid, respectively). Degrees of freedom (DF), sum of squares (Sum Sq), F- and P- values of the significance tests, and proportion of variance explained are given.

	Response variable	Explanatory variable	DF	Sum Sq	% of variance explained	F-value	P-value	Sign. ¹
GPP	Forest	C	3	21.61	66.38	69.12	<0.001	***
		residuals	105	10.94				
	Grassland	C	3	45.31	50.45	35.30	<0.001	***
		residuals	104	44.50				
	Stream	C	4	30.01	-	2.35	0.055	NS
		residuals	201	640.83				
	Lake	C	2	61.17	38.07	18.75	<0.001	***
		residuals	61	99.49				
Ocean pelagic	C	4	26.82	20.73	4.38	0.003	**	
	residuals	67	102.52					
Ocean benthic	C	4	38.35	36.72	8.56	<0.001	***	
	residuals	59	66.09					
ER	Forest	C	3	17.85	58.78	39.45	<0.001	***
		residuals	83	12.52				
	Grassland	C	3	48.41	56.08	37.88	<0.001	***
		residuals	89	37.91				
	Stream	C	4	138.61	30.64	22.64	<0.001	***
		residuals	205	313.83				
	Lake	C	2	35.63	45.36	21.17	<0.001	***
		residuals	51	42.92				
Ocean pelagic	C	3	15.63	45.25	5.79	0.005	**	
	residuals	21	18.91					
Ocean benthic	C	4	33.69	30.05	5.37	0.001	**	
	residuals	50	78.43					
Decomp. rate	Forest	C	3	51.97	41.78	17.7	<0.001	***
		residuals	74	72.43				
	Grassland	C	3	46.62	32.05	9.75	<0.001	***
		residuals	62	98.84				
	Stream	C	4	117.50	54.56	30.62	<0.001	***
		residuals	102	97.86				
	Lake	C	2	36.88	24.56	8.30	<0.001	***
		residuals	51	113.26				
Ocean pelagic	C	3	52.52	50.86	9.32	<0.001	***	
	residuals	27	50.74					
Ocean benthic	C	4	15.44	33.36	4.00	0.010	**	
	residuals	32	30.84					

¹ Significance code (Sign.): 1 ≥ NS > 0.1 > ‘.’ ≥ 0.05 > ‘*’ ≥ 0.01 > ‘***’ ≥ 0.001 > ‘****’ ≥ 0.

Table S3.7 | Non-parametric tests on fluxes and rates of each ecosystem type.

Results of Kruskal-Wallis tests on ranks (light headers) and groups given by multiple mean comparison post-hoc tests on rank sums (dark headers) performed on gross primary production, ecosystem respiration, and decomposition rate within each ecosystem type testing the effect of climatic zone (C); model: $y \sim C$. Agro-ecosystem and desert ecosystems were removed because they are represented in only one climatic zone (temperate and arid, respectively). Degrees of freedom (DF), number of data points (n), Chi-squared and P-values of the Kruskal-Wallis tests are given. Significantly different groups have different letters.

Eco Var	Eco Type	Kruskal-Wallis test on ranks					Multiple mean comparison post-hoc tests				
		n	Chi-squared	DF	P-value	Sign. ¹	Arc.	Bor.	Temp.	Trop.	Arid
GPP	Forest	109	71.91	3	<0.001	***	-	a	b	c	ab
	Grassland	108	46.18	3	<0.001	***	a	-	c	bc	b
	Stream	210	9.51	4	0.05	.	a	a	a	a	a
	Lake	64	29.75	2	<0.001	***	a	b	b	-	-
	Oc. pelagic	72	17.60	4	0.001	**	a	ab	b	ab	a
	Oc. benthic	65	24.08	4	<0.001	***	ab	a	a	b	a
ER	Forest	87	42.33	3	<0.001	***	-	a	a	b	a
	Grassland	93	51.14	3	<0.001	***	a	-	c	c	b
	Stream	210	44.70	4	<0.001	***	a	ab	b	c	b
	Lake	54	26.91	2	<0.001	***	a	b	b	-	-
	Oc. pelagic	25	12.36	3	0.006	**	a	-	b	ab	a
	Oc. benthic	55	18.48	4	<0.001	***	ab	a	ab	b	ab
Dec.	Forest	78	38.32	3	<0.001	***	-	a	a	b	a
	Grassland	66	26.19	3	<0.001	***	a	-	b	b	ab
	Stream	107	61.97	4	<0.001	***	a	ab	ab	c	bc
	Lake	54	16.23	2	<0.001	***	a	a	b	-	-
	Oc. pelagic	31	16.48	3	<0.001	***	ab	-	b	b	a
	Oc. benthic	37	11.74	4	0.019	*	a	a	a	a	a

¹ Significance code (Sign.): 1 ≥ NS > 0.1 > ‘.’ ≥ 0.05 > ‘*’ ≥ 0.01 > ‘**’ ≥ 0.001 > ‘***’ ≥ 0.

Abbreviations: Eco Var = ecosystem variable; Eco Type = ecosystem type; GPP = gross primary production; ER = ecosystem respiration; Dec.= decomposition rate; Oc. = Ocean; Arc. = arctic; Bor. = boreal; Temp. = temperate; Trop. = tropical.

Table S3.8 | Correlations between ecosystem variables and latitude.

Results of Pearson's two-sided correlation tests between ecosystem variables within each ecosystem type and latitude (light headers) and slope and intercept of corresponding linear regression (dark headers) for significant correlations (P-value < 0.05) (statistics for Figs 7, S4.3, S4.4, and S4.5). Statistic t, degrees of freedom (DF), correlation coefficient (r), r squared, and P-values of the correlation tests are given.

Ecosystem Variable	Ecosystem type	Pearson's two-sided correlation test						Linear regression	
		t-stat.	DF	r	r^2	P-value	Sign. ¹	Slope	Intercept
Biomass	Forest	-2.48	114	-0.23	0.05	0.014	*	-84.27	13009
	Grassland	-0.97	111	-0.09	0.01	0.332	NS		
	Stream	1.57	125	0.14	0.02	0.118	NS		
	Lake	0.98	60	0.13	0.02	0.329	NS		
	Oc. pelagic	2.46	39	0.37	0.13	0.018	*	0.11	0.69
	Oc. benthic	-0.43	93	-0.04	0	0.668	NS		
Org. C	Forest	2.19	70	0.25	0.06	0.032	*	70.15	5134
	Grassland	-0.02	43	0	0	0.981	NS		
	Stream	2.33	90	0.24	0.06	0.022	*	0.30	-6.68
	Lake	-1.52	98	-0.15	0.02	0.131	NS		
	Oc. pelagic	1.55	28	0.28	0.08	0.132	NS		
	Oc. benthic	1.21	43	0.18	0.03	0.234	NS		
Detritus	Forest	1.90	92	0.19	0.04	0.06	NS		
	Grassland	-0.37	60	-0.05	0	0.709	NS		
	Stream	1.03	135	0.09	0.01	0.306	NS		
	Lake	1.62	41	0.25	0.06	0.113	NS		
	Oc. pelagic	0.42	32	0.07	0.01	0.678	NS		
	Oc. benthic	-0.40	44	-0.06	0	0.691	NS		
GPP	Forest	-12.92	95	-0.80	0.64	<0.001	***	-42.83	3280.4
	Grassland	-5.35	102	-0.47	0.22	<0.001	***	-15.59	1439.5
	Stream	-1.82	177	-0.14	0.02	0.07	.		
	Lake	-2.08	62	-0.26	0.07	0.042	*	-7.61	631.42
	Oc. pelagic	-3.94	68	-0.43	0.19	<0.001	***	-4.12	394.29
	Oc. benthic	-3.46	61	-0.41	0.16	0.001	**	-20.55	1347.5
ER	Forest	-10.51	77	-0.77	0.59	<0.001	***	-39.17	2844.2
	Grassland	-5.29	88	-0.49	0.24	<0.001	***	-20.57	1691.8
	Stream	-6.34	185	-0.42	0.18	<0.001	***	-14.86	1068.3
	Lake	-3.56	51	-0.45	0.20	0.001	**	-6.35	519.27
	Oc. pelagic	-0.7	21	-0.15	0.02	0.493	NS		
	Oc. benthic	-5.50	52	-0.61	0.37	<0.001	***	-18.57	1145.35
NEP	Forest	-1.34	97	-0.13	0.02	0.184	NS		
	Grassland	-2.01	96	-0.20	0.04	0.047	*	-3.07	242.25
	Stream	5.82	179	0.40	0.16	<0.001	***	11.77	-769.57
	Lake	1.83	87	0.19	0.04	0.071	NS		
	Oc. pelagic	-1.56	49	-0.22	0.05	0.126	NS		
	Oc. benthic	-1.38	53	-0.19	0.03	0.172	NS		
GPP/ER	Forest	0.96	75	0.11	0.01	0.340	NS		
	Grassland	-0.86	76	-0.10	0.01	0.39	NS		
	Stream	3.89	167	0.29	0.08	<0.001	***	0.01	0.08
	Lake	-0.52	30	-0.10	0.01	0.605	NS		
	Oc. pelagic	-0.39	20	-0.09	0.01	0.700	NS		
	Oc. benthic	0.72	41	0.11	0.01	0.478	NS		
Uptake rate (log values)	Forest	-0.65	46	-0.1	0.01	<0.001	NS		
	Grassland	-3.80	40	-0.51	0.27	<0.001	***	-0.03	2.42

	Stream	-2.56	59	-0.33	0.11	0.010	*	-0.04	3.82
	Lake	-3.88	37	-0.54	0.29	<0.001	***	-0.13	10.16
	Oc. pelagic	-2.39	21	-0.46	0.21	0.026	*	-0.04	5.56
	Oc. benthic	-1.03	27	-0.19	0.04	0.314	NS		
Dec. rate (log values)	Forest	-2.82	30	-0.46	0.21	0.008	**	-0.03	2.30
	Grassland	-6.13	38	-0.70	0.50	<0.001	***	-0.03	0.67
	Stream	-9.81	101	-0.70	0.49	<0.001	***	-0.05	3.13
	Lake	-3.04	47	-0.40	0.16	0.004	**	-0.06	2.77
	Oc. pelagic	-2.38	25	-0.43	0.19	0.025	*	-0.05	3.98
	Oc. benthic	-2.82	30	-0.46	0.21	0.008	**	-0.03	2.30

¹ Significance code (Sign.): 1 ≥ NS > 0.1 > ‘.’ ≥ 0.05 > ‘*’ ≥ 0.01 > ‘**’ ≥ 0.001 > ‘***’ ≥ 0.

Abbreviations: Org. C = organic carbon; NEP = net ecosystem production; GPP = gross primary production; ER = ecosystem respiration; Dec.= decomposition rate; Oc. = Ocean.

Table S3.9 | Non-parametric tests for climatic effect on NEP of each ecosystem type.

Results of Kruskal-Wallis tests on ranks (light headers) and groups given by multiple mean comparison post-hoc tests on rank sums (dark headers) performed on net primary production (NEP), within each ecosystem type testing the effect of climatic zone (C); model: $y \sim C$. Agro-ecosystem and desert ecosystems were removed because they are represented in only one climatic zone (temperate and arid, respectively). See below the table for abbreviations. Number of data points (n), degrees of freedom (DF), Chi-squared and P- values of the Kruskal-Wallis tests are given. Significantly different groups have different letters.

Ecosystem Type	Kruskal-Wallis test on ranks					Multiple mean comparison post-hoc tests						
	n	Chi-squared	DF	P-value	Sign. ¹	Arc.	Bor.	Temp.	Trop.	Arid	C	W
Forest	107	4.61	3	0.203	NS							
Grassland	102	12.54	3	0.006	**	a	-	b	b	ab	-	-
Stream	203	41.56	4	<0.001	***	a	a	a	b	a	-	-
Lake	99	29.28	2	<0.001	***	a	b	b	-	-	-	-
Oc. pelagic	73	5.32	1	0.021	*	-	-	-	-	-	a	b
Oc. benthic	58	1.29	1	0.256	NS							

¹ Significance code (Sign.): $1 \geq \text{NS} > 0.1 > ' \geq 0.05 > '* \geq 0.01 > '***' \geq 0.001 > '****' \geq 0$.

Abbreviations: Oc. = ocean; Arc. = arctic; Bor. = boreal; Temp. = temperate; Trop. = tropical; C = cold; w = warm.

Table S3.10 | Non-parametric tests for climatic effect within forests.

Results of Kruskal-Wallis tests on ranks (light headers) and groups given by multiple mean comparison post-hoc tests on rank sums (dark headers) performed on each ecosystem variable within forest ecosystems testing the effect of climatic zone (C); model: $y \sim C$ (statistics for figure S4.5). See below the table for abbreviations. Number of data points (n), degrees of freedom (DF), Chi-squared and P- values of the Kruskal-Wallis tests are given. Significantly different groups have different letters.

Ecosystem variable	Kruskal-Wallis test on ranks					Multiple mean comparison post-hoc tests			
	n	Chi-squared	DF	P-value	Sign. ¹	Bor.	Temp.	Trop.	Arid
Biomass	163	65.06	3	<0.001	***	a	b	b	a
Organic Carbon	113	11.54	3	0.010	*	ab	b	ab	a
Detritus	99	25.37	3	<0.001	***	b	b	a	a
NEP	107	4.61	3	0.203	NS				
GPP	109	71.91	3	<0.001	***	a	b	c	ab
ER	87	42.33	3	<0.001	***	a	a	b	a
Uptake rate	56	15.31	3	0.002	**	ab	b	a	a
Decomposition	78	38.32	3	<0.001	***	a	a	b	a

¹ Significance code (Sign.): $1 \geq \text{NS} > 0.1 > \text{'.'} \geq 0.05 > \text{'*'} \geq 0.01 > \text{'***'} \geq 0.001 > \text{'****'} \geq 0$.

Abbreviations: NEP = net ecosystem production; GPP = gross primary production; ER = ecosystem respiration; Bor. = boreal; Temp. = temperate; Trop. = tropical.

Table S3.11 | Mean values, coefficients of variation and numbers of data points.

For each combination of ecosystem type, climatic zone and ecosystem variable, the mean value is in black, the coefficient of variation in grey and in brackets, the number of data points in red and in italics. See abbreviations below.

Ecosystem type	Climatic zone	Biom.	Org. C	Detritus	GPP	ER	NEP	Uptake	Dec.
Forest	Boreal	5250 (0.64) <i>32</i>	8381 (0.75) <i>21</i>	3807 (1.57) <i>22</i>	914.5 (0.31) <i>21</i>	832.7 (0.33) <i>18</i>	164.8 (0.83) <i>21</i>	0.34 (1.23) <i>10</i>	0.21 (0.79) <i>12</i>
	Temperate	12228 (0.66) <i>39</i>	8723 (0.72) <i>31</i>	2428 (1.16) <i>45</i>	1364 (0.23) <i>34</i>	1072 (0.27) <i>31</i>	303.6 (0.82) <i>38</i>	0.19 (1.49) <i>13</i>	0.31 (0.81) <i>12</i>
	Tropical	13797 (0.50) <i>49</i>	5689 (0.77) <i>30</i>	791.3 (1.48) <i>16</i>	2921 (0.27) <i>34</i>	2731 (0.32) <i>19</i>	355.9 (1.05) <i>21</i>	0.32 (0.67) <i>23</i>	1.17 (0.67) <i>36</i>
	Arid	4679 (0.72) <i>43</i>	5174 (0.96) <i>31</i>	693.1 (1.07) <i>16</i>	1200 (0.3) <i>20</i>	854.8 (0.40) <i>19</i>	271.8 (0.69) <i>27</i>	0.96 (1.46) <i>10</i>	0.3 (0.68) <i>18</i>
Grassland	Arctic	670.8 (0.89) <i>31</i>	9111 (0.83) <i>28</i>	457.7 (0.85) <i>14</i>	232.7 (0.82) <i>21</i>	218.9 (0.72) <i>23</i>	6.40 (12.49) <i>21</i>	1.39 (1.52) <i>11</i>	0.22 (0.97) <i>20</i>
	Temperate	302.8 (0.60) <i>30</i>	8134 (0.85) <i>28</i>	167.2 (0.44) <i>10</i>	1164 (0.42) <i>23</i>	1242 (0.80) <i>26</i>	120.1 (1.45) <i>34</i>	4.03 (0.52) <i>10</i>	0.85 (0.90) <i>22</i>
	Tropical	1535 (1.21) <i>42</i>	7714 (1.21) <i>31</i>	371.6 (1.38) <i>29</i>	1138 (0.66) <i>40</i>	1213 (0.58) <i>18</i>	270.5 (1.60) <i>17</i>	5.87 (1.43) <i>10</i>	1.6 (0.59) <i>12</i>
	Arid	373.2 (0.93) <i>43</i>	3057 (0.75) <i>15</i>	160.2 (2.09) <i>16</i>	697.3 (0.7) <i>24</i>	599.3 (0.67) <i>26</i>	95.17 (2.61) <i>30</i>	6.25 (0.92) <i>14</i>	0.61 (0.71) <i>12</i>
Agro-ecosystem	Temperate	462.2 (0.61) <i>54</i>	6866 (0.64) <i>17</i>	175.2 (0.52) <i>14</i>	1730 (0.38) <i>39</i>	1275 (0.31) <i>37</i>	439.7 (0.94) <i>36</i>	4.73 (0.51) <i>16</i>	1.35 (0.46) <i>14</i>
Desert	Arid	175.7 (1.17) <i>50</i>	1717 (0.76) <i>17</i>	51.80 (1.39) <i>16</i>	157.0 (0.91) <i>20</i>	113.3 (0.49) <i>19</i>	29.95 (1.56) <i>23</i>	1.91 (1.41) <i>12</i>	0.55 (0.70) <i>12</i>
Stream	Arctic	48.9 (1.72) <i>23</i>	28.12 (1.84) <i>20</i>	13.66 (1.26) <i>14</i>	90.55 (1.67) <i>18</i>	168.2 (1.69) <i>20</i>	-90.24 (-1.78) <i>20</i>	28.28 (1.92) <i>10</i>	1.48 (0.84) <i>14</i>
	Boreal	40.97 (2.29) <i>25</i>	4.23 (1.10) <i>27</i>	689.0 (2.41) <i>21</i>	170.7 (1.45) <i>37</i>	398.3 (1.18) <i>35</i>	-245.3 (-1.17) <i>35</i>	22.22 (1.66) <i>18</i>	2.74 (0.88) <i>19</i>
	Temperate	25.33 (1.76) <i>55</i>	1.31 (0.67) <i>15</i>	321.2 (1.14) <i>47</i>	213.2 (1.54) <i>72</i>	398.5 (0.69) <i>74</i>	-152.3 (-2.41) <i>66</i>	30.15 (1.35) <i>39</i>	3.48 (0.82) <i>23</i>
	Tropical	7.80 (2.78) <i>39</i>	0.12 (0.51) <i>16</i>	106.2 (1.86) <i>29</i>	247.3 (1.30) <i>43</i>	986.3 (0.92) <i>43</i>	-748.6 (-1.13) <i>41</i>	127.7 (2.50) <i>10</i>	30.86 (1.36) <i>39</i>
	Arid	23.15 (1.54) <i>21</i>	0.15 (1.57) <i>14</i>	336.3 (1.59) <i>30</i>	403.9 (1.61) <i>40</i>	459.0 (1.14) <i>38</i>	-113.5 (-2.80) <i>41</i>	74.74 (1.01) <i>12</i>	5.44 (0.49) <i>12</i>
Lake	Arctic	18.14 (3.05) <i>24</i>	14.14 (1.24) <i>38</i>	369.9 (2.96) <i>12</i>	28.15 (1.21) <i>21</i>	33.01 (0.85) <i>24</i>	-5.09 (-2.57) <i>38</i>	18.97 (1.23) <i>15</i>	0.81 (1.45) <i>10</i>
	Boreal	95.99 (0.99) <i>15</i>	59.15 (1.03) <i>34</i>	39.98 (2.42) <i>12</i>	316.1 (1.85) <i>19</i>	179.2 (1.29) <i>16</i>	-27.61 (-1.05) <i>25</i>	33.25 (1.48) <i>12</i>	4.81 (4.08) <i>22</i>
	Temperate	11.60 (1.06) <i>23</i>	35.80 (1.06) <i>39</i>	7.66 (1.58) <i>19</i>	269.3 (0.89) <i>24</i>	270.0 (1.11) <i>14</i>	-36.49 (-1.53) <i>36</i>	47.57 (0.75) <i>12</i>	3.45 (0.89) <i>22</i>
Ocean pelagic	Cold	7.15 (1.02) <i>26</i>	51.33 (0.68) <i>11</i>	57.26 (1.95) <i>16</i>	182.3 (0.98) <i>53</i>	201.4 (0.86) <i>15</i>	80.42 (1.19) <i>54</i>	81.64 (0.73) <i>11</i>	45.89 (1.64) <i>16</i>
	Warm	3.04 (0.51) <i>15</i>	55.09 (0.89) <i>20</i>	13.27 (2.09) <i>20</i>	208.6 (1.06) <i>19</i>	104.5 (1.03) <i>10</i>	29.31 (2.04) <i>19</i>	154.4 (0.80) <i>12</i>	65.45 (3.08) <i>15</i>
Ocean benthic	Cold	199.1 (1.52) <i>80</i>	3000 (1.39) <i>37</i>	472.5 (1.13) <i>20</i>	182.5 (0.86) <i>30</i>	202.0 (1.03) <i>31</i>	-35.73 (-3.29) <i>30</i>	120.3 (1.60) <i>12</i>	6.62 (1.10) <i>19</i>
	Warm	184.5 (1.11) <i>36</i>	2617 (1.00) <i>15</i>	723.7 (1.36) <i>35</i>	929.0 (1.23) <i>35</i>	701.4 (1.03) <i>24</i>	175.3 (3.37) <i>28</i>	12.04 (0.93) <i>17</i>	4.9 (1.50) <i>18</i>

Abbreviations: Biom. = biomass; Org. C = organic carbon; NEP = net ecosystem production; GPP = gross primary production; Dec. = decomposition rate; Uptake; = uptake rate.

Table S3.12 | Non-parametric tests of mean differences among E x C combinations.

Results of Kruskal-Wallis tests on ranks (light row headers) and groups given by post-hoc tests on rank sums for multiple mean comparison (dark row headers) performed on each individual ecosystem variable testing the effect of ecosystem type (E) x climatic zone (C) combinations; models: $y \sim EC$. Degrees of freedom (DF), number of data points (n), Chi-squared and P- values of the Kruskal-Wallis tests are given. Significantly different groups have different letters. Note that for space reasons results are displayed in column (one Kruskal-Wallis test per column). These are same the tests than in Table S3.6 but with clumped climatic variables, “Cold” and “Warm” for marine systems. It gives the significantly different groups per ecosystem variable in Fig. 3 (boxplots). See below the table for abbreviations.

			Biom.	Org. C	Detritus	GPP	ER	NEP	Uptake	Dec.	
Kruskal-Wallis test	n		795	535	473	687	580	701	309	399	
	DF		21	21	21	21	21	21	21	21	
	Chi-sq.		640.40	448.47	250.97	435.45	347.75	369.12	187.86	261.24	
	P-value		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
	Sign.¹		***	***	***	***	***	***	***	***	
	Eco	Clim									
Post-hoc tests of multiple mean comparisons	F	Boreal	bfg	a	bi	abef	abfgh	abc	abc	ab	
		Temp	fg	a	i	abe	abf	ab	a	ab	
		Trop	f	a	bdi	a	a	abc	ab	acde	
	G	Arid	bfg	ac	bdi	abe	abfg	ab	abcd	ab	
		Arctic	abc	a	bdgi	cdf	cde	cdefg	abcd	b	
		Temp	acd	a	abcdefghi	abe	abf	abcd	abcde	abcd	
	A	Trop	bcg	a	bdfg	abe	abf	abcd	abcde	abcdef	
		Arid	acd	abc	acdefgh	bcef	cfgh	bcde	bcde	abcd	
		Temp	abc	a	abcdefgh	ab	ab	a	abcde	abcde	
	D	Arid	ade	abcde	ace	cd	cde	abcde	abcd	abcd	
		S	Arctic	ehi	ef	ae	d	de	efgh	abcde	abcde
		Boreal	ehi	f	acdefgh	d	ceh	gh	cde	cdefg	
	L	Temp	hi	f	dfgh	d	cegh	fgh	e	defg	
		Trop	h	f	acefgh	d	bfg	h	e	g	
		Arid	ehi	f	acdefgh	cd	cegh	efgh	e	efg	
	OB	Arctic	h	f	acdefgh	d	d	cdefg	cde	abcd	
Boreal		adehi	bdef	aceh	cd	cde	efgh	de	abc		
Temp		ehi	def	a	cdf	cdegh	efgh	e	cdef		
OP	Cold	hi	bedef	acefh	d	cde	abc	e	fg		
	Warm	ehi	bedef	a	cd	cde	abcdef	e	cdefg		
OB	Cold	dei	ac	bcdfgh	cd	cde	defg	de	efg		
	Warm	adei	abcd	cdefgh	cef	cfgh	cdef	de	cdefg		

¹ Significance code (Sign.): 1 ≥ NS > 0.1 > ‘.’ ≥ 0.05 > ‘*’ ≥ 0.01 > ‘**’ ≥ 0.001 > ‘***’ ≥ 0.

Abbreviations: Eco = Ecosystem type; Clim = Climatic zone; F = forest; G = grassland; A = agro-ecosystem; D = desert; S = stream; L = lake; OB = ocean benthic; OP = ocean pelagic; Temp = temperate; Trop = tropical; Biom. = Biomass; Org. C = Organic carbon; GPP = gross primary production; ER = ecosystem respiration; NEP = net ecosystem production; Dec.= decomposition rate; Prod. = Productivity rate.

Table S3.13 | Empirical relationships between pairs of ecosystem variables.

Significant Pearson's two-sided correlation tests between pairs of ecosystem variables across and within ecosystem types (light headers) in a log-log space (null values were removed from the analysis), and slope and intercept of corresponding linear regression (dark headers) (includes statistics for figures S4.6 and S4.7). Statistic *t*, degrees of freedom (DF), correlation coefficient (*r*), *r* squared and P-values of the correlation tests are given.

Ecosystem Variables	Ecosystem type	Pearson's two-sided correlation test						Linear regression	
		t-stat.	DF	<i>r</i>	<i>r</i> ²	P-value	Sign. ¹	Slope	Intercept
GPP ~ Biomass	All ecosystems	13.25	248	0.64	0.41	<0.001	***	0.38	4.03
	Forest	2.63	49	0.35	0.12	0.011	*	0.18	5.68
	Grassland	2.35	37	0.36	0.13	0.024	*	0.36	4.65
	Lake	3.01	25	0.52	0.27	0.006	**	0.29	4.13
Uptake rate ~ Biomass	All ecosystems	-22.36	257	-0.81	0.66	<0.001	***	-0.64	4.30
	Forest	-9.82	53	-0.80	0.65	<0.001	***	-0.76	5.24
	Grassland	-4.06	38	-0.550	0.30	<0.001	***	-0.62	4.55
	Agroecosystem	-3.31	9	-0.74	0.55	0.009	**	-0.79	6.11
	Desert	-4.26	10	-0.80	0.64	0.002	**	-0.75	3.61
	Stream	-3.84	74	-0.41	0.17	<0.001	***	-0.56	3.69
	Lake	-7.62	23	-0.85	0.72	<0.001	***	-0.69	4.18
	Ocean pelagic	-4.23	18	-0.71	0.50	<0.001	***	-0.93	5.97
	Ocean benthic	-6.62	18	-0.84	0.71	<0.001	***	-0.99	6.24
	Uptake rate ~ GPP	Grassland	5.58	41	0.66	0.43	<0.001	***	0.71
Stream		7.59	79	0.65	0.42	<0.001	***	0.69	-0.75
Ocean pelagic		2.83	18	0.55	0.31	0.011	*	1.26	-2.24
ER ~ GPP	All ecosystems	27.80	484	0.78	0.61	<0.001	***	0.57	2.80
	Forest	21.76	83	0.92	0.85	<0.001	***	1.07	-0.73
	Grassland	24.37	79	0.94	0.88	<0.001	***	0.89	0.55
	Agroecosystem	10.14	28	0.89	0.79	<0.001	***	0.83	1.03
	Desert	5.56	14	0.83	0.69	<0.001	***	1.14	-0.85
	Stream	11.56	182	0.65	0.42	<0.001	***	0.48	3.49
	Lake	12.76	30	0.92	0.84	<0.001	***	0.72	1.43
	Ocean pelagic	4.29	18	0.71	0.51	<0.001	***	0.65	1.54
ER ~ Biomass	All ecosystems	13.66	36	0.92	0.84	<0.001	***	0.84	0.98
	Stream	8.9	203	0.53	0.28	<0.001	***	0.24	4.81
Detritus ~ Biomass	Stream	2.11	61	0.26	0.07	0.039	*	0.22	4.89
	All ecosystems	7.54	211	0.46	0.21	<0.001	***	0.34	3.02
Detritus ~ Org. C	Desert	3.85	6	0.84	0.71	0.008	**	1.15	-1.90
	All ecosystems	4.2	102	0.38	0.15	<0.001	***	0.29	2.96

	Desert	4.68	3	0.94	0.88	0.018	*	3.11	-21.13
	Lake	-2.72	16	-0.56	0.32	0.015	*	-0.67	4.46
Org. C ~ Biomass	All ecosystems	15.8	154	0.79	0.62	<0.001	***	0.82	2.01
Org. C ~ GPP	All ecosystems	7.51	78	0.65	0.42	<0.001	***	1.26	-2.47
	Grassland	-2.35	10	-0.6	0.35	0.041	*	-0.51	11.98
	Stream	2.46	18	0.5	0.25	0.024	*	0.43	-2.97
	Ocean benthic	-10.6	3	-0.99	0.97	0.002	**	-2.06	15.13
Detritus ~ GPP	All ecosystems	4.41	50	0.53	0.28	<0.001	***	1.15	-2.35
Org. C ~ ER	All ecosystems	5.17	82	0.5	0.25	<0.001	***	1.45	-4.04
	Grassland	-2.38	14	-0.54	0.29	0.032	*	-0.51	11.86
	Stream	5.27	25	0.73	0.53	<0.001	***	0.90	-5.81
Detritus ~ ER	All ecosystems	5.09	44	0.61	0.37	<0.001	***	1.37	-3.42
	Ocean pelagic	2.67	12	0.65	0.42	0.024	*	1.90	-5.28
Biomass ~ Decomposition rate	All ecosystems	-7.38	33	-0.79	0.62	<0.001	***	-1.04	5.70
	Grassland	-4.39	7	-0.86	0.73	0.003	**	-0.64	5.65
	Ocean pelagic	-3.76	7	-0.86	0.74	0.013	*	-0.47	2.94
Decomposition rate ~ Org. C	All ecosystems	-3.37	17	-0.63	0.40	0.004	**	-0.32	2.07
Decomposition rate ~ Detritus	All ecosystems	-4.22	37	-0.57	0.32	<0.001	***	-0.31	1.53
	Grassland	-2.73	13	-0.6	0.36	0.017	*	-0.74	3.77
Uptake rate ~ Org. C	All ecosystems	-6.44	46	-0.69	0.47	<0.001	***	-0.41	2.85
	Grassland	-2.69	9	-0.67	0.45	0.025	*	-0.68	6.22
Uptake rate ~ Detritus	All ecosystems	-2.71	42	-0.39	0.15	0.01	*	-0.31	3.30
Uptake rate ~ ER	Grassland	4.7	41	0.59	0.35	<0.001	***	0.69	-3.40
	Agroecosy stem	2.33	9	0.61	0.38	0.045	*	0.89	-4.97
	Stream	5.27	67	0.54	0.29	<0.001	***	0.76	-1.65
	Ocean benthic	2.63	12	0.60	0.37	0.022	*	1.07	-3.89
Uptake rate ~ Decomposition	All ecosystems	3.2	10	0.71	0.51	0.009	**	0.62	1.86
	Ocean pelagic	3.76	4	0.88	0.78	0.02	*	0.94	1.21

¹ Significance code (Sign.): 1 ≥ NS > 0.1 > ‘.’ ≥ 0.05 > ‘*’ ≥ 0.01 > ‘***’ ≥ 0.001 > ‘****’ ≥ 0.

Abbreviations: Org. C = organic carbon; GPP = gross primary production; ER = ecosystem respiration; Dec.= decomposition rate; Oc. = Ocean.

Appendix S4 – Supplementary figures

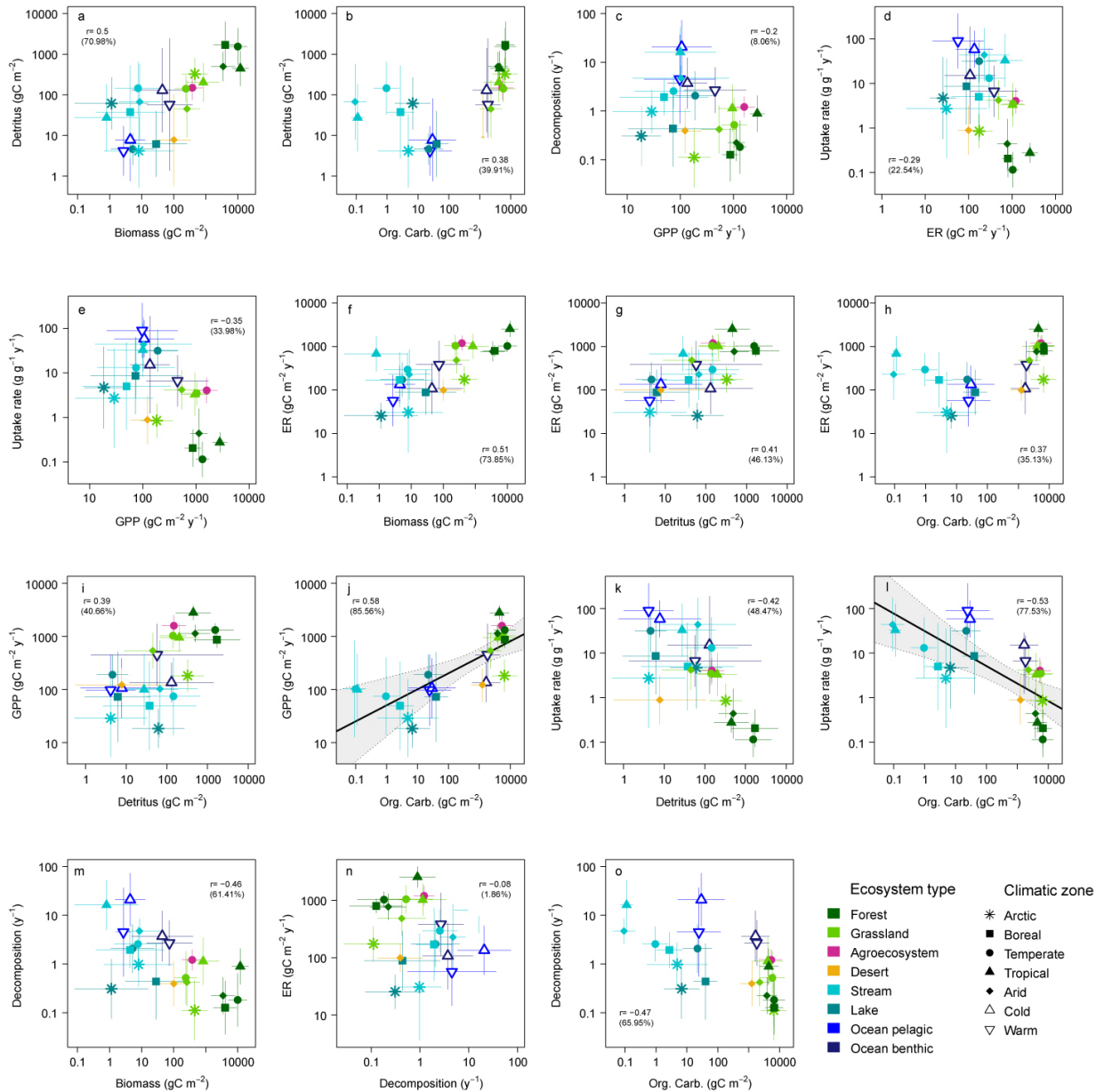


Figure S4.1 | Relationships between ecosystem variables.

Points and bars give median value and standard deviation respectively for the given ecosystem variables in each ecosystem type (colours) – climatic zone (shapes) combination. GPP and ER stand for gross primary production and ecosystem respiration, respectively, Black lines and grey areas give the median and the 95% confidence interval, respectively, of regressions realized in 10,000 iterations of bootstrapped values for each ecosystem x climatic zone combination (see methods). Text gives the median Pearson's correlation coefficient for these 10,000 series of bootstrapped values and the percentage of significant correlations into brackets. Median and quantile regressions are not displayed when less than 75% of the correlations are significant.

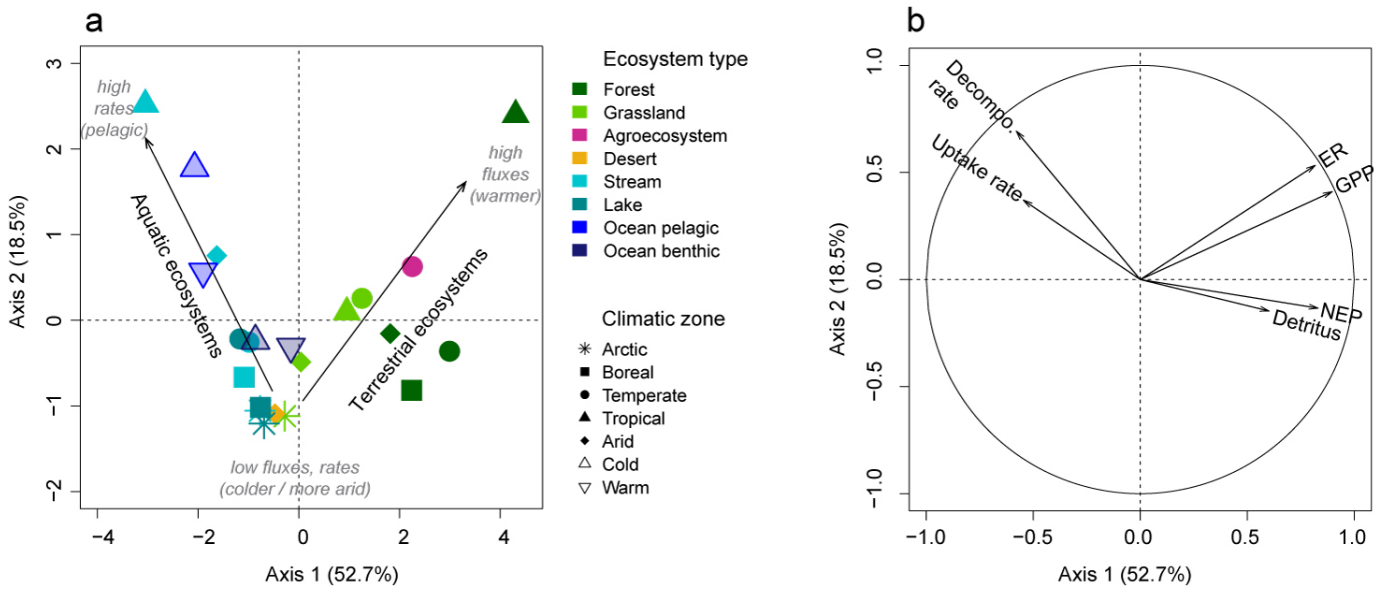


Figure S4.2 | Principal Component Analysis (PCA) on median ecosystems.

Quantitative variables included in the analysis are median values of biomass, organic carbon, detritus, gross primary production (GPP), ecosystem respiration (ER), net ecosystem production (NEP), decomposition rate (Decompo. rate), and uptake rate for each combination of ecosystem type (colours in panel a) and climatic zone (shapes in panel a). Panels a and b represent the median ecosystems and the map of active variables, respectively, in the two first dimensions of the PCA with the percentage of explained variance into brackets in axes' labels. In panel a, arrows highlight axes along which freshwater and terrestrial ecosystems are positioned according to changes in rates and fluxes from low to high, globally corresponding to colder or more arid to warmer climatic zones.

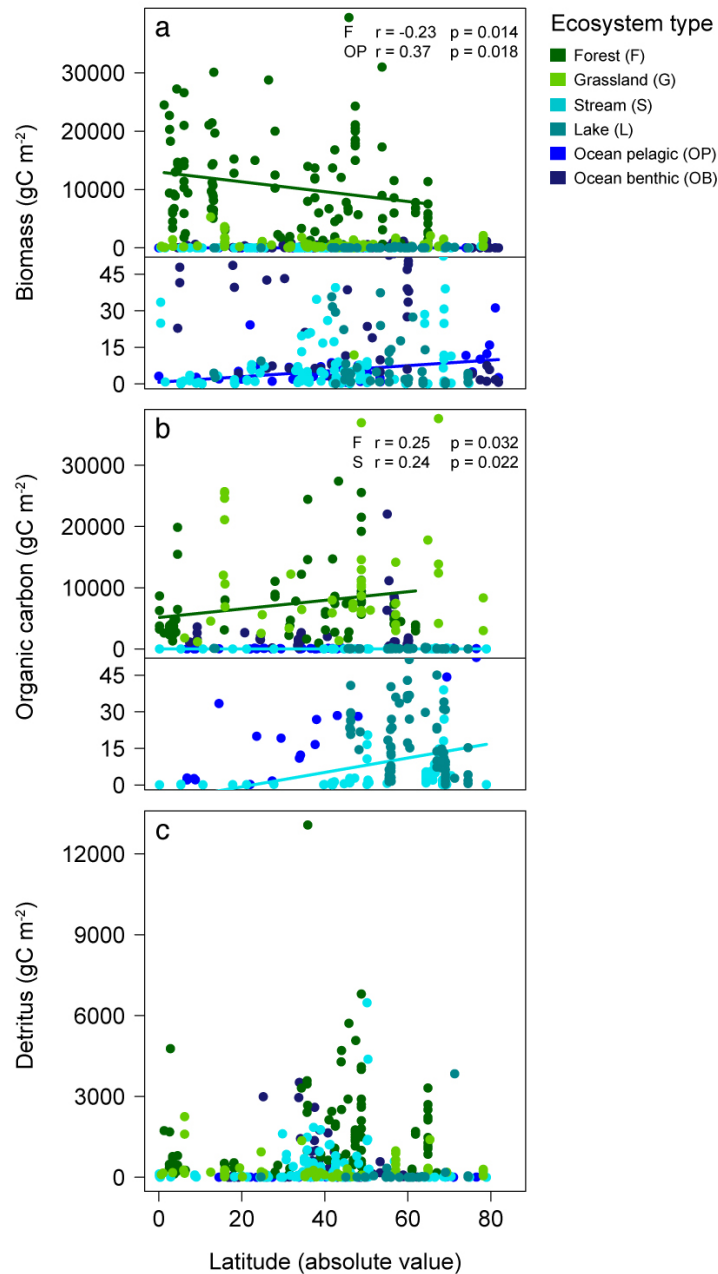


Figure S4.3 | Latitudinal trends in ecosystem stocks.

Solid circles show the data points. Colours denote ecosystem types. Lines show regression lines for significant correlations between latitude and stocks of **a** Biomass, **b** Organic carbon, or **c** Detritus, based on two-sided Pearson's correlation tests. Pearson correlation coefficients and p-values are provided for these significant relationships (see legend for abbreviations of ecosystem types). Bottom parts of panels are zooming in finer scales than the one of top parts.

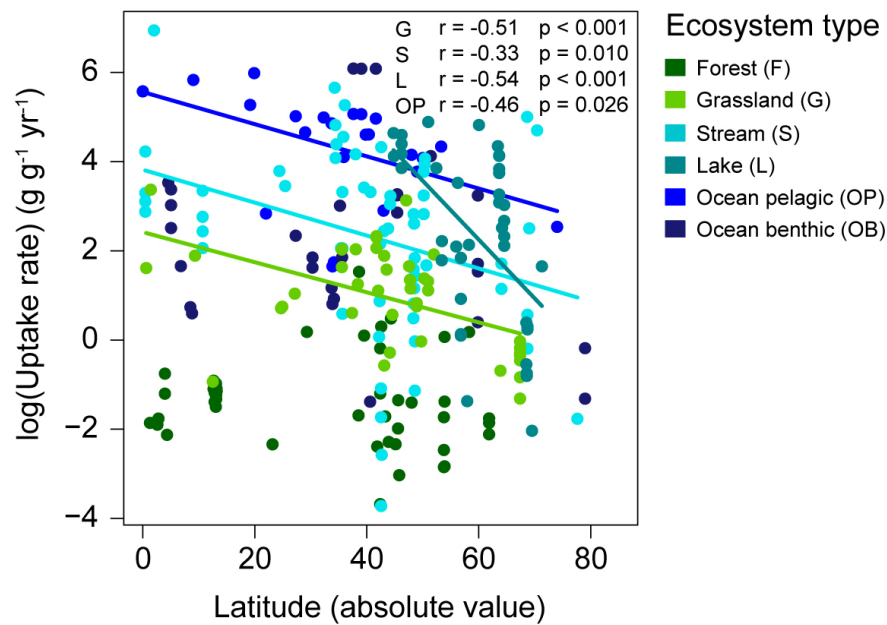


Figure S4.4 | Latitudinal trends in mass-specific uptake rates.

Solid circles show the data points. Colours denote ecosystem types. Lines show regression lines for significant correlations between latitude and uptake rates, based on two-sided Pearson's correlation tests. Pearson correlation coefficients and p-values are provided for these significant relationships (see legend for abbreviations of ecosystem types).

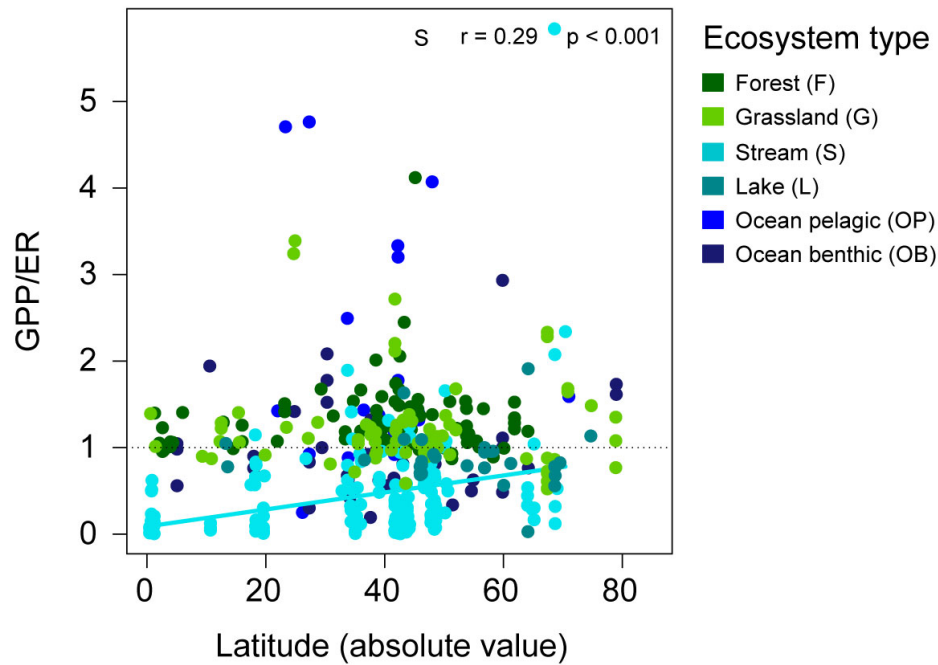


Figure S4.5 | Latitudinal trends in GPP/ER ratios.

Solid circles show the data points. Colours denote ecosystem types. Lines show regression lines for significant correlations between latitude and uptake rates, based on two-sided Pearson's correlation tests. Pearson correlation coefficients and p-values are provided for these significant relationships (see legend for abbreviations of ecosystem types). GPP and ER stand for gross primary production and ecosystem respiration, respectively.

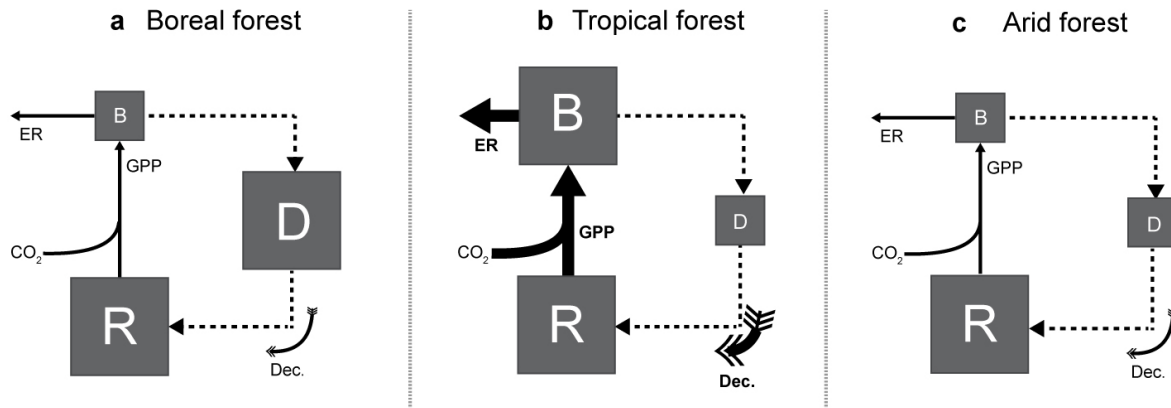


Figure S4.6 | Functioning shift of forests among climatic zones.

Diagrams of ecosystem functioning in (a) boreal, (b) tropical and (c) arid forests. Squares represent stocks of biomass (B), detritus (D), and organic carbon (R). Straight arrows represent fluxes of gross primary production (GPP) and ecosystem respiration (ER), and bent arrows decomposition rates. Significant differences among panels for the different ecosystem variables are highlighted by differences in size of boxes or arrows. For instance, biomass is higher in tropical than in boreal or arid forests, and not different between boreal and arid forest (see statistical tests in Table S3.10). Dotted arrows represent fluxes for which we have not collected data.

Appendix S5 – Supplementary references

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