Supplementary Material for "Provisional Title"

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1 Supplementary Methods

1.1 Data processing

1.1.1 Examining community composition

We first analyze the composition of the communities assembled in each carbon source by examining the relative abundances of the exact sequence variants (ESVs) obtained from 16S rRNA gene sequencing. We define a vector $\mathbf{s} = (s_1, s_2, \cdots, s_M)$ such that s_i represents the relative abundance of the i-th ESV, being M the total number of unique ESVs. We assembled a total of 16 communities, 8 in glutamine and 8 in citrate (see Methods **[missing ref(s)]**), with 3 biological replicates of each. We start by comparing the composition of replicate communities in terms of their ESV relative abundances. To do this, we measure the distance d between two communities (with ESV abundances $\mathbf{s}$ and $\mathbf{s}'$ respectively) as

$$d(\mathbf{s}, \mathbf{s}') = \sqrt{\sum_i \left(s_i - s_i'\right)^2} \tag{S1}$$

We compute all the distances across replicates of the same community, obtaining a set of 48 distances (16 communities $\times$ 3 pairwise distances between the three replicates) that we will denote as $\{d\}$

$$\{d\} = \{d(\text{community } i \text{ replicate } j, \text{community } i \text{ replicate } j') \text{ for all } i, j, j' \neq j\} \tag{S2}$$

We then define a threshold d_T as

$$d_T = \text{Q3}(\{d\}) + 1.5\ \text{IQR}(\{d\}) \tag{S3}$$

Where Q3 and IQR represent the third quartile and the interquartile range respectively. Note that this threshold is analogous to the one used in standard boxplots to identify outliers.

Finally, we discard the samples that are at a distance larger than d_T from all other replicates of the same community. These are replicate 2 of community 1 in glutamine and replicate 2 of community 8 in citrate (see Figure S1 **[missing ref(s)]**). The remaining replicates were used in further analyses, taking the average ESV abundance across replicates when indicated.

1.1.2 Characterization of dominant species

As described in the main text Methods **[missing ref(s)]**, generationally stabilized communities were plated and the most abundant species (determined by counting of colony morphotypes) was isolated and allowed to regrow. We grew three biological replicates of each isolated species in monoculture and then performed 16S rRNA gene sequencing. We characterize the isolated species to, first, determine whether multiple communities share the same dominant and, second, to make sure that the dominants were correctly identified.

Analogous to what we did in the section above (Examining community composition), we start by estimating the sequencing error by comparing the distances between all pairs of replicates. We obtain an "error threshold" like we did in equation S3, and we discard replicates that fall at a larger distance from all other replicates of the same isolate. This eliminates one replicate from the monocultures of the isolates from glutamine communities 2 and 3, and an additional replicate from citrate community 1.

We then compare each isolate with one another. The distance between the vectors of ESV abundances of two different isolates being below our threshold indicates that both are the same species, or at the very least that we cannot distinguish them through 16S sequencing. These instances were removed from the dominant pairwise competition analysis. We find that indeed some communities share the same (or undistinguishable) isolated dominant. This leaves us with 9 unique isolates.

Table **S1** shows the relative ESV abundance of each unique isolate, as well as which communities they were isolated from. Table **[missing ref(s)]**shows the ESVs obtained from 16S sequencing of the monocultures. Note that three of the isolates partially share a same ESV; however, when growing them in pairwise competition there is always at least another ESV that is unique to only one of them. Further details can be found in the code for the analysis (see section Data & code availability of this Supplementary Material).

	Isolate 1 G-1, C-8	Isolate 2 G-2, G-5, C-3, C-5	Isolate 3 G-3	Isolate 4 G-4, G-6	Isolate 5 G-7, G-8	Isolate 6 C-1	Isolate 7 C-2, C-7	Isolate 8 C-4	Isolate 9 C-6
Sequence 1		1		0.86		0.63			
Sequence 2							1		
Sequence 3			1						
Sequence 4	1								
Sequence 5								1	
Sequence 6					1				
Sequence 7				0.14					
Sequence 8									1
Sequence 9						0.37			

Table S1. Species to ESVs map of the dominant species isolated from the communities. For every isolate we indicate the community (or communities if they share dominants) from which it was obtained. G-n and C-n (n = 1 to 8) denote the n-th community in glutamine and citrate respectively. Values in the table represent relative ESV abundances from 16S sequencing of monocultures. Empty entries of the table represent zeros.

Sequence 1	GCAAGCGTTA ATCGGAATTA CTGGGCGTAA AGCGCGCGTA GGTGGTTTGT TAAGTTGGAT GTGAAAGCCC CGGGCTCAAC CTGGGAACTG CATCCAAAAC TGGCAAGCTA GAGTACGGTA GAGGGTGGTG GAATTTCCTG TGTAGCGGTG AAATGCGTAG ATATAGGAAG GAACACCAGT GGCGAAGGCG ACCACCTGGA CTGATACTGA CACTGAGGTG CGAAAGCGTG GGG
Sequence 2	GCAAGCGTTA ATCGGAATTA CTGGGCGTAA AGCGCACGCA GGCGGTCTGT CAAGTCGGAT GTGAAATCCC CGGGCTCAAC CTGGGAACTG CATTCGAAAC TGGCAGGCTA GAGTCTTGTA GAGGGGGGTA GAATTCCAGG TGTAGCGGTG AAATGCGTAG AGATCTGGAG GAATACCGGT GGCGAAGGCG GCCCCCTGGA CAAAGACTGA CGCTCAGGTG CGAAAGCGTG GGG

Table S2. Exact Sequence Variants of the isolated dominant species. Sequence numbering as in table **S1**.

1.2 Inferring species abundances from sequencing data

Consider a community of N species with relative abundances represented by the components of a vector $\mathbf{x} = (x_1, x_2, \ldots, x_N)$ such that x_i is the relative abundance of the i-th species. Naturally, the conditions

$$\sum_i x_i = 1 \tag{S4}$$

and

$$0 \leq x_i \leq 1 \text{ for all } i \tag{S5}$$

are satisfied.

Performing 16S rRNA gene sequencing on such a community yields a list of sequences (exact sequence variants or ESVs) and their respective abundance. Normalizing by the total number of sequences, we can obtain a vector $\mathbf{s} = (s_1, s_2, \ldots)$ that also satisfies the normalization conditions of equations S4 and S5. Only if there are as many ESVs as species does $\mathbf{s}$ have length N (the same as $\mathbf{x}$), but in the most general case it is possible that *a)* multiple species share a same ESV and/or *b)* species carrying multiple copies of the 16S rRNA gene have different sequences for each copy [1]. We denote the length of $\mathbf{s}$ as M, which need not be equal to N.

By sequencing each species individually, we can build a $M \times N$ matrix $\mathbf{Q}$ such that the element in the (i, j) position, q_{ij}, represents the frequency of the i-th ESV when the j-th species is sequenced (see table **S1** and section Characterization of dominant species of this Supplementary Material). $\mathbf{Q}$ can be used to determine the fraction of sequences of a given ESV that are generated when sequencing a community with any arbitrary composition. In other words, $\mathbf{Q}$ maps $\mathbf{x}$ to $\mathbf{s}$:

$$\mathbf{Q} \cdot \mathbf{x} = \mathbf{s} \tag{S6}$$

Note that equation S6 is only true if all species have the same number of copies of the 16S rRNA gene. Otherwise, species with high copy numbers will yield more sequences, thus leading to an over-representation and vice-versa. Information on the 16S copy number for every species in the communities would be required to overcome this limitation, but this is not feasible when dealing with highly diverse communities. For our purpose in this work, we will need to assume that the copy numbers of the 16S are relatively conserved across species and equation S6 holds. Additionally, we have sequencing data from a subset of the species in our communities, but not from all of them. This means that we cannot build a complete $\mathbf{Q}$ matrix. To address this, we first identify every ESV obtained from community sequencing that we cannot map back to (at least) one of the species for which we have single-species sequencing

information. We then assume that each of those ESVs maps uniquely to a single species. This gives us a $\mathbf{Q}$ matrix of the form:

$$\mathbf{Q} = \begin{array}{r} \\ \text{sequence 1} \\ \text{sequence 2} \\ \text{sequence 3} \\ \vdots \\ \text{sequence } M-2 \\ \text{sequence } M-1 \\ \text{sequence } M \end{array} \begin{array}{c} \begin{array}{cccccccc} \text{species 1} & \text{species 2} & \text{species 3} & & \cdots & \text{species } N-2 & \text{species } N-1 & \text{species } N \end{array} \\ \begin{pmatrix} q_{11} & q_{12} & q_{13} & & & 0 & 0 & 0 \\ q_{21} & q_{22} & q_{23} & & \cdots & 0 & 0 & 0 \\ q_{31} & q_{32} & q_{33} & & & 0 & 0 & 0 \\ & \vdots & & & \ddots & & & \\ 0 & 0 & 0 & & & 1 & 0 & 0 \\ 0 & 0 & 0 & & & 0 & 1 & 0 \\ 0 & 0 & 0 & & & 0 & 0 & 1 \end{pmatrix} \end{array} \tag{S7}$$

While a one-to-one mapping between species and ESVs may not be true in all cases, in practice the ESVs for which we make this assumption have low relative abundances in the communities, minimizing the impact of any potential artifact.

Having built our $\mathbf{Q}$ matrix according to equation S7, obtaining species abundances from sequencing data is relatively straigthforward: we need to find the $\mathbf{x}$ that satisfies equation S6 for a given $\mathbf{s}$. However, in some cases sequencing error can introduce deviations in $\mathbf{s}$ that make it so the vector $\mathbf{x}$ that solves equation S6 does not meet the boundary conditions in equation S5, i.e., some x_i may be negative or greater than 1. These cases are obviously problematic, but we can avoid them by accounting for potential deviations in $\mathbf{s}$. We do this by solving the following nonlinear optimization problem: we want to obtain an estimate of the true community composition (we will denote the estimate as $\hat{\mathbf{x}}$) so that the product $\mathbf{Q} \cdot \hat{\mathbf{x}}$ is as close as possible to the $\mathbf{s}$ obtained from sequencing while having $\hat{\mathbf{x}}$ satisfy the normalization condition in equation S4 and the boundary conditions in equation S5. For every possible $\hat{\mathbf{x}}$, we can define a vector $\boldsymbol{\varepsilon} = \boldsymbol{\varepsilon}(\hat{\mathbf{x}}) = (\varepsilon_1, \varepsilon_2, \cdots, \varepsilon_M)$ as

$$\boldsymbol{\varepsilon}(\hat{\mathbf{x}}) = \mathbf{Q} \cdot \hat{\mathbf{x}} - \mathbf{s} \tag{S8}$$

and a function $f(\hat{\mathbf{x}})$ as

$$f(\hat{\mathbf{x}}) = |\boldsymbol{\varepsilon}(\hat{\mathbf{x}})|^2 = \sum_i \varepsilon_i^2(\hat{\mathbf{x}}) \tag{S9}$$

We can also define a function $h(\hat{\mathbf{x}})$ as

$$h(\hat{\mathbf{x}}) = 1 - \sum_i \hat{x}_i \tag{S10}$$

The best estimation for the species composition of a community will be the $\hat{\mathbf{x}}$ that minimizes $f(\hat{\mathbf{x}})$ while satisfying the normalization condition (eq. S4) and the boundary conditions (eq. S5). We solve this problem using the `nloptr` package for R [2], passing it $f(\hat{\mathbf{x}})$ as the function to minimize, $h(\hat{\mathbf{x}}) = 0$ as an equality constraint, and 0 and 1 as the lower and upper bounds for the entries of $\hat{\mathbf{x}}$, and using the augmented Lagrangian algorithm [3, 4]. Further details can be found in the code for the analysis (see section Data & code availability of this Supplementary Material).

2 Data & code availability

Data and code for the analyses in this article, as well as code for the `community-simulator` package updated with the new functionalities, is available at https://github.com/jdiazc9/coalescence.

3 Supplementary Results

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3.1 Example subsection

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4 Supplementay Figures

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5 Supplementary References

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