Supplementary Information

for

GMWI-webtool: a user-friendly browser application for assessing health through metagenomic gut microbiome profiling

Daniel Chang *et al.*

Contents

1 Webtool Information

1.1 Implementation

Python and the Numpy (Harris et al., 2020) library were used to pre-compute GMWI, α-diversities, and taxonomic distributions of the pooled dataset. The scikit-learn (Pedregosa et al., 2011) library was used for Principal Component Analysis (PCA) of the pooled dataset. Access the data here. Regarding the front-end, GMWI-webtool is a client-side application written using JavaScript and the D3.js (Bostock, 2012) library. The Math.js (de Jong and Mansfield, 2018) library is used to project the input sample onto the first two principal components of the pooled dataset. α-diversities of the input sample, along with text parsing and validation, are implemented using JavaScript functions.

1.2 User Input

Users need to first upload (**Supplementary Fig. S1A**) the taxonomy profile (see **Section 3**). If the file has multiple samples, users can select the sample for analysis (**Supplementary Fig. S1B**). Users may choose to compare the input sample with healthy samples, nonhealthy samples, or all samples in the pooled gut microbiome dataset (**Supplementary Fig. S1C**). This selection pertains to the first two plots only. After making the proper selections, users can press the "display results" button (**Supplementary Fig. S1D**) to compute and visualize the analyses.

1.3 User Interaction and Exports

Users can change plot options (e.g., index, taxonomic level) by using the tabs above plots (**Supplementary Fig. S2A**). Additionally, users can hover their mouse over legend text (**Supplementary Fig. S2B**) to highlight information.

Users can export index data by clicking the "export as CSV" button (**Supplementary Fig. S1E**), and export plots by clicking links below them (**Supplementary Fig. S2C**).

Input Data

Please upload or paste your MetaPhlAn2 output file (.txt) ⑦

| Choose File | No file chosen |

ID	healthy_poop unhealthy_poop
k___Bacteria   100.0 100.0
k___Bacteria|p___Actinobacteria   10.87438
1.27414
k___Bacteria|p___Actinobacteria|c___Actino
bacteria   10.87438   1.27414

Example data   Clear

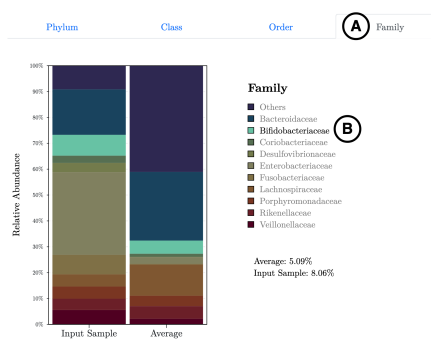Please select sample ⑦

healthy_poop

Please select health status for analyses ⑦

All

Display results   Export as CSV

Supplementary Fig. S1. The user input panel.

Taxonomic Distribution. Distribution of the relative abundances of the input sample microbes (left) and average relative abundances of the gut microbiome of 5026 healthy and nonhealthy persons (right) at the family level. Export as .svg Export as .png

**Supplementary Fig. S2.** Stacked bar plots of taxonomic distributions.

1.4 Data Tables

GMWI-webtool provides a table describing the relative abundances of health-prevalent/scarce species in the input sample, along with their median values in the healthy and nonhealthy populations in our pooled dataset **(Supplementary Fig. S3)**. Likewise, a table of the top three most abundant taxa of each taxonomic rank, including comparisons with the pooled dataset populations, is available **(Supplementary Fig. S4)**.

Health-prevalent and Health-scarce Species

Species Name	Presence	Relative Abundance	Median (Healthy)	Median (Nonhealthy)
Alistipes senegalensis	✅	0.086%	0.004%	0.000%
Bacteroidales bacterium__ph8	✅	0.093%	0.128%	0.000%
Bifidobacterium adolescentis	✅	4.700%	0.291%	0.000%
Bifidobacterium angulatum	✖	-	0.000%	0.000%
Bifidobacterium catenulatum	✅	0.400%	0.000%	0.000%
Lachnospiraceae bacterium__8__1__57FAA	✖	-	0.000%	0.000%
Sutterella wadsworthensis	✅	1.598%	0.000%	0.000%
Anaerotruncus colihominis	✖	-	0.000%	0.000%
Atopobium parvulum	✖	-	0.000%	0.000%
Bifidobacterium dentium	✖	-	0.000%	0.000%
Blautia producta	✅	0.026%	0.000%	0.000%
candidate division__TM7__single__cell__isolate__TM7c	✖	-	0.000%	0.000%
Clostridiales bacterium__1__7__47FAA	✅	0.036%	0.000%	0.000%
Clostridium asparagiforme	✅	0.012%	0.000%	0.000%
Clostridium bolteae	✅	0.010%	0.000%	0.018%
Clostridium citroniae	✅	0.222%	0.000%	0.000%
Clostridium clostridioforme	✅	0.003%	0.000%	0.000%
Clostridium hathewayi	✅	0.108%	0.000%	0.003%
Clostridium nexile	✅	0.059%	0.000%	0.000%

Most Abundant Taxa

Rank	Most Abundant Taxa	Relative Abundance	Median in Healthy	Median in Nonhealthy	Median in All
Phylum	Proteobacteria	29.416%	1.104%	1.815%	1.322%
	Firmicutes	24.886%	47.080%	45.954%	46.657%
	Bacteroidetes	21.133%	38.169%	39.335%	38.829%
Class	Gammaproteobacteria	22.540%	0.199%	0.737%	0.331%
	Bacteroidia	21.133%	38.169%	39.335%	38.829%
	Actinobacteria	16.040%	2.803%	1.401%	2.001%
Order	Enterobacteriales	22.538%	0.098%	0.484%	0.195%
	Bacteroidales	21.133%	38.169%	39.335%	38.829%
	Bifidobacteriales	15.481%	1.809%	0.612%	1.177%
Family	Enterobacteriaceae	22.538%	0.098%	0.484%	0.195%
	Bifidobacteriaceae	15.481%	1.809%	0.612%	1.177%
	Bacteroidaceae	13.917%	15.781%	20.829%	17.452%
Genus	Escherichia	21.517%	0.077%	0.287%	0.137%
	Bifidobacterium	15.481%	1.809%	0.608%	1.168%
	Bacteroides	13.917%	15.781%	20.829%	17.452%
Species	Escherichia coli	16.809%	0.043%	0.226%	0.092%
	Fusobacterium varium	8.054%	0.000%	0.000%	0.000%
	Bifidobacterium longum	6.941%	0.333%	0.121%	0.223%

Supplementary Fig. S3. Table of health-prevalent and health-scarce species.

Supplementary Fig. S4. Table of the top three most abundant taxa of each taxonomic rank.

2 Case Example
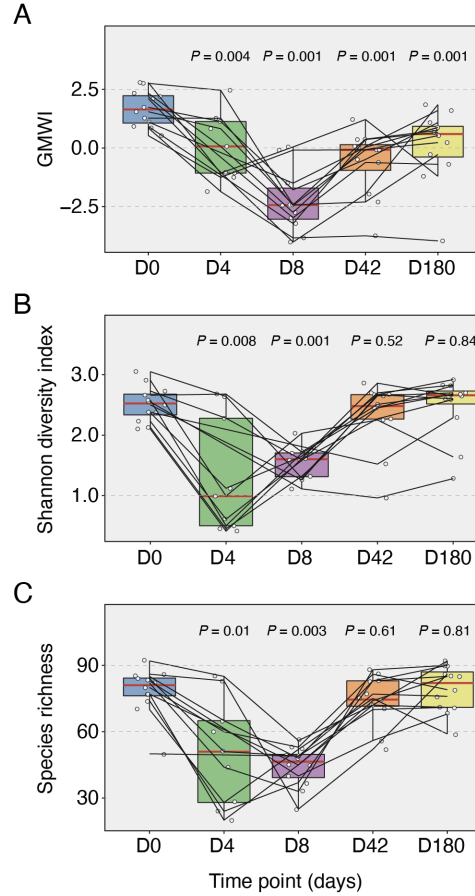
Supplementary Fig. S5. Using stool metagenomes from Palleja *et al.* (DOI: 10.1038/s41564-018-0257-9), we traced the changes in gut microbiome taxonomic composition following an intervention with a cocktail of three last-resort antibiotics (meropenem, gentamicin and vancomycin) in twelve healthy adults. Mainly, we identified changes in **(A)** Gut Microbiome Wellness Index (GMWI), **(B)** Shannon diversity index, and **(C)** species richness. The investigators in the Palleja *et al.* study collected stool samples at baseline before antibiotics intervention (D0), four days after the intervention (D4), and three further time points (8, 42, and 180 days after baseline; time-points designated as D8, D42, and D180, respectively). With respect to the baseline time-point Shannon diversity and species richness, the gut microbiome recovered within 42 days following antibiotics ($P = 0.52$ and $P = 0.61$, respectively; Wilcoxon signed-rank test); and remained stable even after 180 days ($P = 0.84$ and $P = 0.81$, respectively; Wilcoxon signed-rank test). On the other hand, GMWI scores at 8, 42, and 180 days after antibiotics show that the gut microbiome composition did not fully recover. In particular, at D180, the gut microbiome still exhibited significantly reduced GMWI (Wilcoxon signed-rank test; $P = 0.001$) compared to baseline.

3 Pipeline

Prior to using GMWI-webtool, users need to profile their metagenome .fastq files using MetaPhlAn2 (Truong et al., 2015). The following is the pipeline used to preprocess and profile the stool metagenomes used to compute GMWI (Gupta et al., 2020). However, users are free to use any other pipeline provided that taxonomic profiling uses MetaPhlAn2. For brevity, this pipeline assumes that paired-end metagenomes are used.

3.1 Setup

Install/update softwares:

- bbmap (repair.sh) v38.93 (Bushnell, 2014)

- fastqc v0.11.9 [Source]

- bowtie2 v2.4.4 (Langmead and Salzberg, 2012)

- samtools v0.1.19 (Li et al., 2009)

- bedtools v2.30.0 (Quinlan and Hall, 2010)

- trimmomatic v0.39 (Bolger et al., 2014)

- MetaPhlAn2 v2.x.x (Truong et al., 2015)

```
# make sure the paired end metagenome files are available
ls
    .
    ├── in1.fastq
    └── in2.fastq

# set this var to directory containing human reference genome (use GRCh38/hg38)
# example:
$HUMAN_REFERENCE_GENOME=/users/mynamejeff/human_genomes/GRCh38_noalt_as/

# set this var to desired number of parallel processes
# example:
$N_JOBS=16

# set this var to directory containing metaphlan2 clade markers
# example:
$CLADE_MARKERS=/users/mynamejeff/metaphlan2_data/clade_markers

# Prepare adapter sequence file
```

```
echo ">PrefixPE/1
TACACTCTTTCCCTACACGACGCTCTTCCGATCT
>PrefixPE/2
GTGACTGGAGTTCAGACGTGTGCTCTTCCGATCT" > TruSeq3-PE.fa
```

3.2   Repair fastq files using bbmap

```
repair.sh in1=in1.fastq in2=in2.fastq out1=repaired1.fastq \
out2=repaired2.fastq outs=garbage
```

3.3   Quality check and identification of overrepresented sequences

```
fastqc repaired1.fastq
fastqc repaired2.fastq
unzip repaired1_fastq.zip
unzip repaired2_fastq.zip
```

3.4   Extract probable adapter sequences from FastQC outputs

```
for f in repaired1_fastqc/fastqc_data.txt; do
    echo $f `grep -A100 ">>Overrepresented sequences" $f | \
    grep -m1 -B100 ">>END_MODULE" | \
    grep -P "Adapter|PCR" | \
    awk '{print ">overrepresented_sequences" "_" ++c "/1" $1}'` | \
    awk '{gsub(/\/1/,"/1\n")}1' | \
    awk '{gsub(/>/,"\n>")}1' | \
    awk '{gsub(/fastqc_data.txt/,"")}1' | \
    awk 'NF > 0';
done > adapter1.txt

for f in repaired2_fastqc/fastqc_data.txt; do
    echo $f `grep -A100 ">>Overrepresented sequences" $f | \
    grep -m1 -B100 ">>END_MODULE" | \
    grep -P "Adapter|PCR" | \
    awk '{print ">overrepresented_sequences" "_" ++c "/1" $1}'` | \
    awk '{gsub(/\/1/,"/1\n")}1' | \
    awk '{gsub(/>/,"\n>")}1' | \
    awk '{gsub(/fastqc_data.txt/,"")}1' | \
    awk 'NF > 0';
done > adapter2.txt
```

3.5   Remove human contaminants

```
bowtie2 -p $N_JOBS -x $HUMAN_REFERENCE_GENOME -1 repaired1.fastq \
-2 repaired2.fastq -S mapped.sam

samtools view -bS mapped.sam > mapped.bam

samtools view -b -f 12 -F 256 mapped.bam > human.bam

samtools sort -n human.bam human_sorted -@ $N_JOBS

bedtools bamtofastq -i human_sorted.bam -fq human1.fastq -fq2 human2.fastq
```

3.6   Remove adapter sequences and low quality reads

```
cat adapter1.txt adapter2.txt TruSeq3-PE.fa > adapters.txt

trimmomatic PE -threads $N_JOBS human1.fastq human2.fastq -baseout QC.fastq.gz \
ILLUMINACLIP:adapters.txt:2:30:10:2:keepBothReads LEADING:3 TRAILING:3 MINLEN:60
```

3.7   Profile the metagenome

```
metaphlan2.py QC_1P.fastq.gz,QC_2P.fastq.gz --bowtie2db $CLADE_MARKERS \
--bowtie2out --index mpa_v20_m200 --nproc $N_JOBS --input_type fastq \
-o profiled_metagenome.txt
```

After running the pipeline, users can upload the taxonomic profile "profiled_metagenome.txt" to GMWI-webtool. Users can also use MetaPhlAn2 to merge multiple taxonomic profiles:

```
ls
    .
    ├── profiled_metagenome1.txt
    ├── profiled_metagenome2.txt
    ├── profiled_metagenome3.txt

merge_metaphlan_tables.py profiled_metagenome*.txt > merged_abundance_table.txt
```

And upload the merged file "merged_abundance_table.txt" to GMWI-webtool.

4 α-diversity Indices

GMWI-webtool computes a number of α-diversities from stool metagenome samples. Let p_i be the relative abundance of the ith species in the sample. For consistency with the original GMWI work, only the 313 species considered during the computation of GMWI were considered (Gupta et al., 2020). Let $S = 313$ be the maximum number of species in a single sample. Let $c = 0.00001$ be the presence threshold.

4.1 Richness

Richness R is the number of species with relative abundance greater than the presence threshold.

$$R = |\{\, i \mid p_i > c \,\}|$$

4.2 Shannon Diversity

Shannon Diversity H' is derived from Shannon entropy, and is a measure of the uncertainty associated with predicting the species of any microbe in the sample.

$$H' = -\sum_{\forall i[p_i>0]} p_i ln(p_i)$$

4.3 Evenness

Evenness E is a measure of close in number (or relative abundance) different species are.

$$E = \frac{H'}{ln(S)}$$

4.4 Simpson Diversity

Simpson diversity is equivalent to the probability that two randomly selected microbes are of the same species (SIMPSON, 1949).

$$\lambda = \sum_{\forall i[p_i>0]} ln(p_i)$$

4.5 Inverse Simpson

Inverse Simpson diversity is the reciprocal of Simpson diversity.

$$I = \frac{1}{\lambda}$$

5 References

Bolger, A. M., Lohse, M., and Usadel, B. (2014). Trimmomatic: a flexible trimmer for illumina sequence data. *Bioinformatics*, 30(15):2114–2120.

Bostock, M. (2012). D3.js - data-driven documents.

Bushnell, B. (2014). Bbmap: A fast, accurate, splice-aware aligner. 0(0).

de Jong, J. and Mansfield, E. (2018). Math.js: An advanced mathematics library for JavaScript. *Computing in Science &amp Engineering*, 20(1):20–32.

Gupta, V. K., Kim, M., Bakshi, U., Cunningham, K. Y., Davis, J. M., Lazaridis, K. N., Nelson, H., Chia, N., and Sung, J. (2020). A predictive index for health status using species-level gut microbiome profiling. *Nature Communications*, 11(1).

Harris, C. R., Millman, K. J., van der Walt, S. J., Gommers, R., Virtanen, P., Cournapeau, D., Wieser, E., Taylor, J., Berg, S., Smith, N. J., Kern, R., Picus, M., Hoyer, S., van Kerkwijk, M. H., Brett, M., Haldane, A., del Río, J. F., Wiebe, M., Peterson, P., Gérard-Marchant, P., Sheppard, K., Reddy, T., Weckesser, W., Abbasi, H., Gohlke, C., and Oliphant, T. E. (2020). Array programming with NumPy. *Nature*, 585(7825):357–362.

Langmead, B. and Salzberg, S. L. (2012). Fast gapped-read alignment with bowtie 2. *Nature Methods*, 9(4):357–359.

Li, H., Handsaker, B., Wysoker, A., Fennell, T., Ruan, J., Homer, N., Marth, G., Abecasis, G., and and, R. D. (2009). The sequence alignment/map format and SAMtools. *Bioinformatics*, 25(16):2078–2079.

Pedregosa, F., Varoquaux, G., Gramfort, A., Michel, V., Thirion, B., Grisel, O., Blondel, M., Prettenhofer, P., Weiss, R., Dubourg, V., Vanderplas, J., Passos, A., Cournapeau, D., Brucher, M., Perrot, M., and Duchesnay, E. (2011). Scikit-learn: Machine learning in Python. *Journal of Machine Learning Research*, 12:2825–2830.

Quinlan, A. R. and Hall, I. M. (2010). BEDTools: a flexible suite of utilities for comparing genomic features. *Bioinformatics*, 26(6):841–842.

SIMPSON, E. H. (1949). Measurement of diversity. *Nature*, 163(4148):688–688.

Truong, D. T., Franzosa, E. A., Tickle, T. L., Scholz, M., Weingart, G., Pasolli, E., Tett, A., Huttenhower, C., and Segata, N. (2015). MetaPhlAn2 for enhanced metagenomic taxonomic profiling. *Nature Methods*, 12(10):902–903.