EFFECT OF DIET ON THE GUT MICROBIOME

UO-CHC 441H/431H: Microbes + Social Equity

Lecture 5

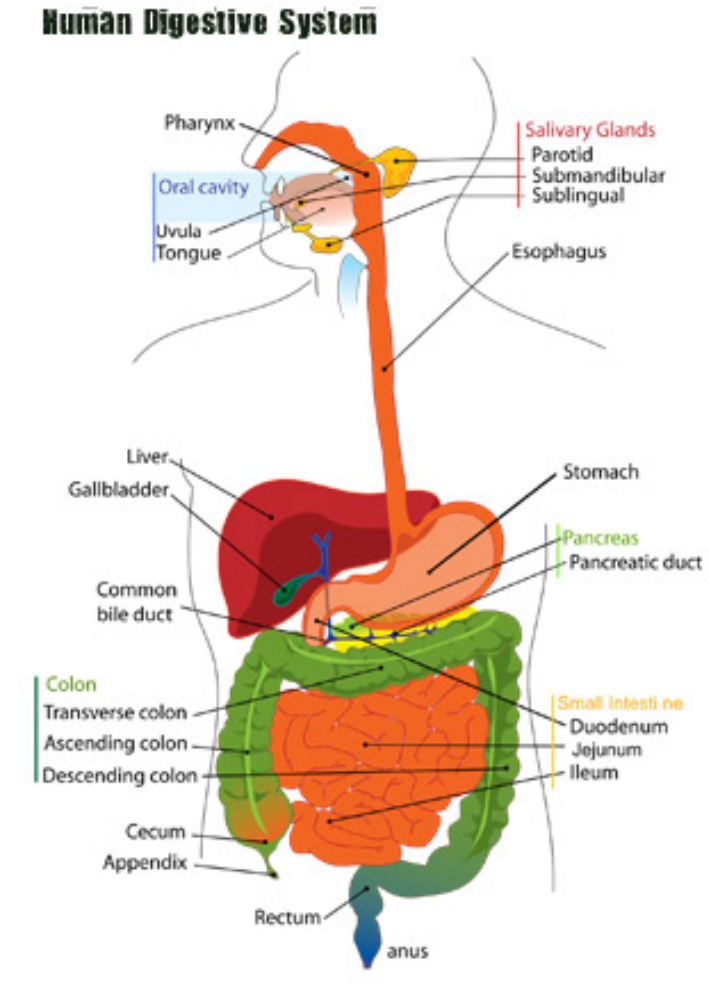
Dr. Sue Ishaq Pellegrini

Learning objectives

- The human gastrointestinal tract
- How diet drives gut microbial diversity
  - ‘If you feed them, they will come’
  - Nutritional biochemistry is complex
- Importance of fiber
- Some relevance to health (more on that next lecture)
- Discussion: do we have the right to tell people what to eat?

ANATOMY AND ECOSYSTEMS

The Digestive Tract- Monogastrics



untamedscience.com

- Monogastric = 1 stomach (or stomach chamber)
  - *Carnivores*
  - *Omnivores*
  - *Frugivores*
  - *Some herbivores*
- Generally:
  - *Intestines in carnivores are shorter than in herbivores*
  - *Relatively fast transit of material through GI tract*
    - Faster in carnivores (~2 days) than herbivores (>2 days)

The Stomach

- Muscular to help mix
- Absorbs water through lining
  - and many water-soluble chemicals
- Secretes pepsin enzyme
  - Digest proteins
- Secretes hydrochloric acid
  - **Very acidic**: pH 1.5 to 3.5
- Transit of food through controlled by Pyloric sphincter
  - Allows ~ 6 ml until the pH in duodenum is acidic, then closes again

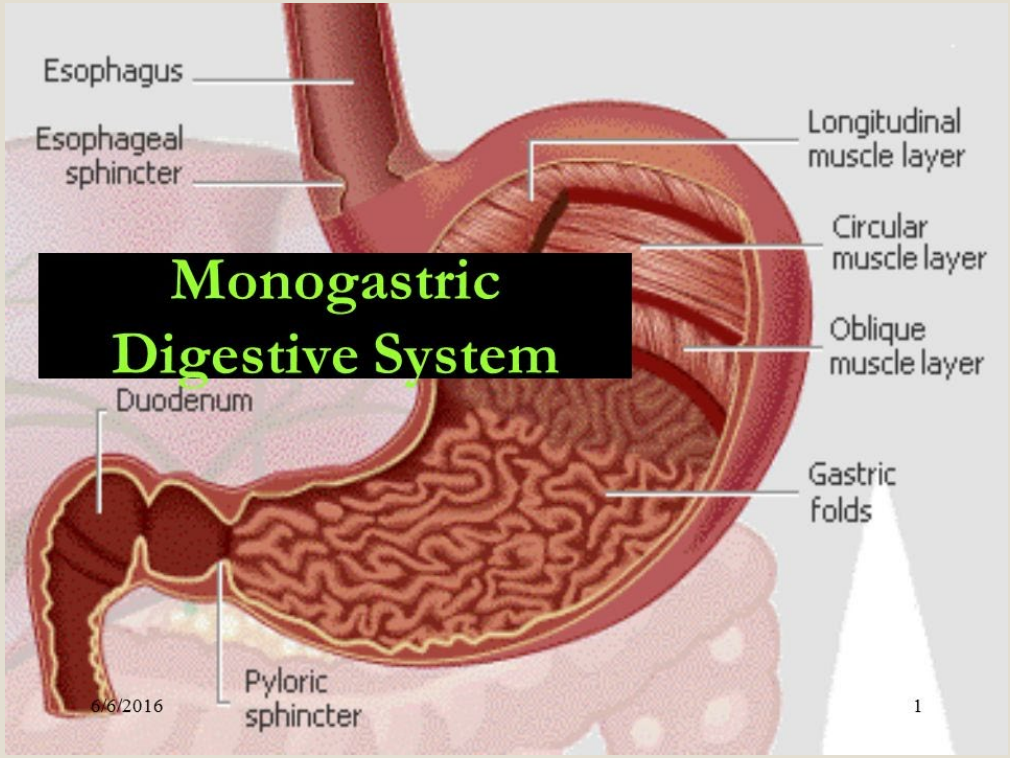
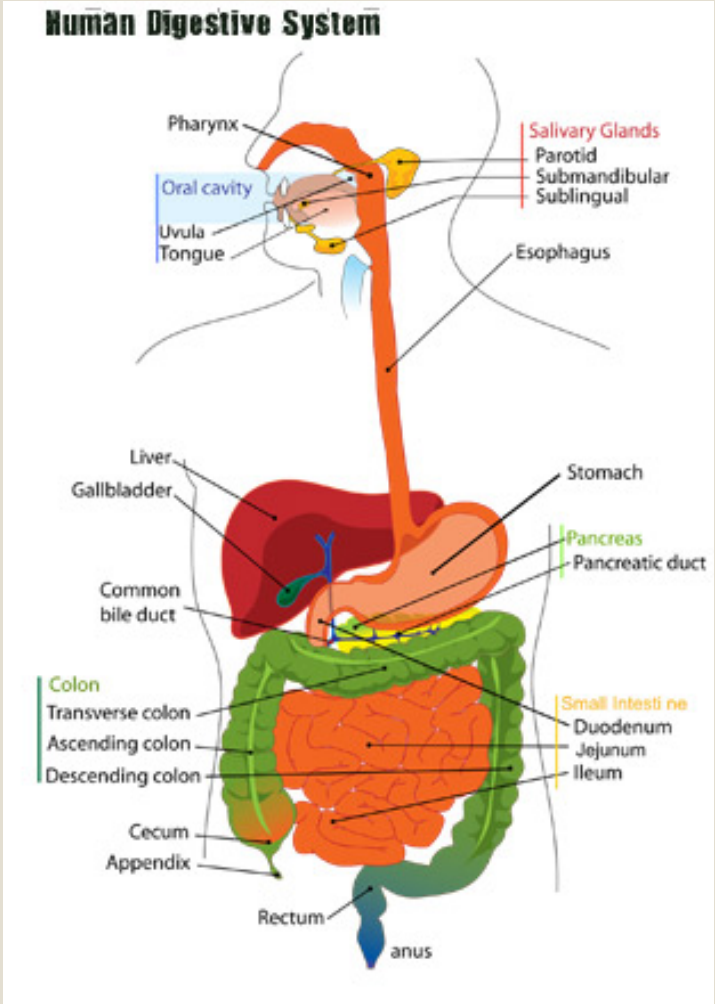


Image and slides of monogastric digestive tracts: https://slideplayer.com/slide/10217176/

The Small intestines

- Long tubes of soft tissue with thin muscle wrapper
  - *~34.4 ft long in humans*
  - *1 in wide in humans*
- For nutrient absorption
  - *Lots of blood vessels and nerves*
- Length is roughly proportionate to how long it takes to digest the diet
  - *Strict carnivores have shorter SI than strict herbivores*



untamedscience.com

Three sections of the small intestines

Duodenum

- Where stomach contents mix with bile from gallbladder and enzymes from pancreas

Jejunum

- Nutrient absorption, lots of blood flow

Ileum

- Nutrient absorption, transition to large intestines

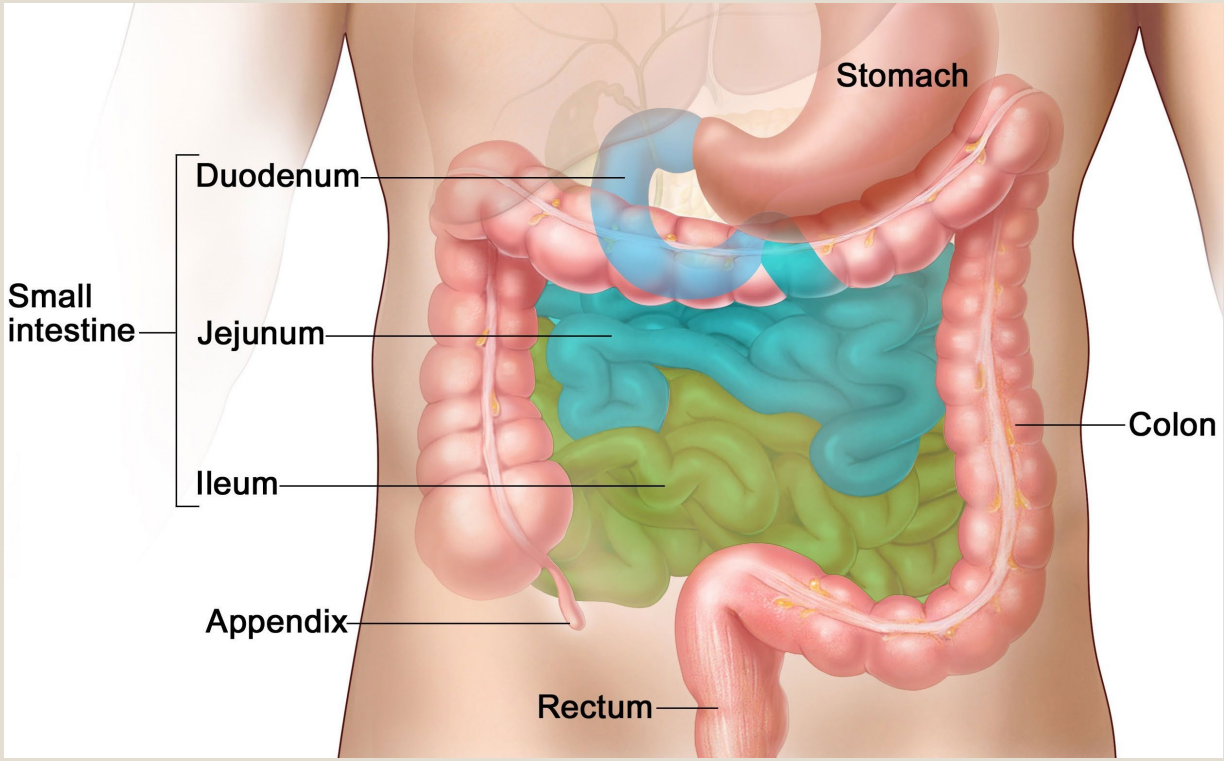
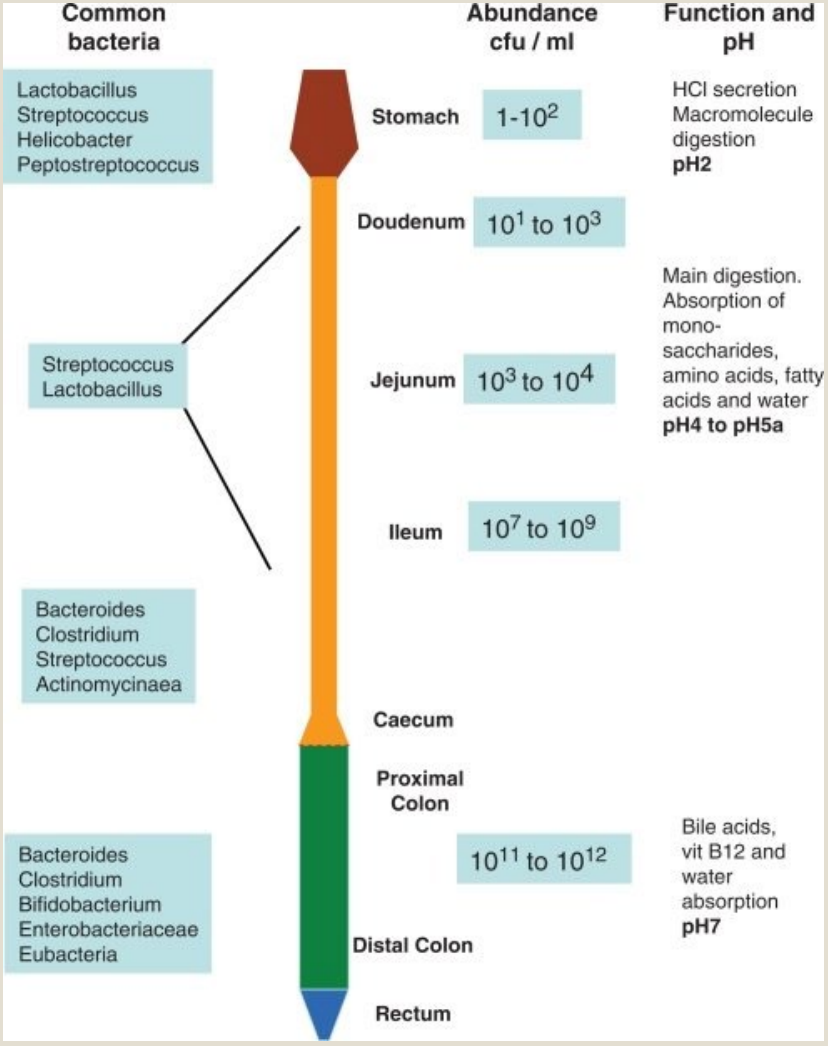


Image: Medical Xpress

Lots of bacteria, fungi, archaea, viruses (maybe protozoa) in small intestines

- Duodenum
  - *Where stomach contents mix with bile from gallbladder and enzymes from pancreas*
  - *tough environment, low diversity*
- Jejunum
  - *Nutrient absorption, lots of blood flow*
  - *lots more diversity*
- Ileum
  - *Nutrient absorption, transition to large intestines*
  - *lots more diversity*



Korecka and Arulampalam, 2012

Villi of the small intestines: absorb nutrients, create microecosystems

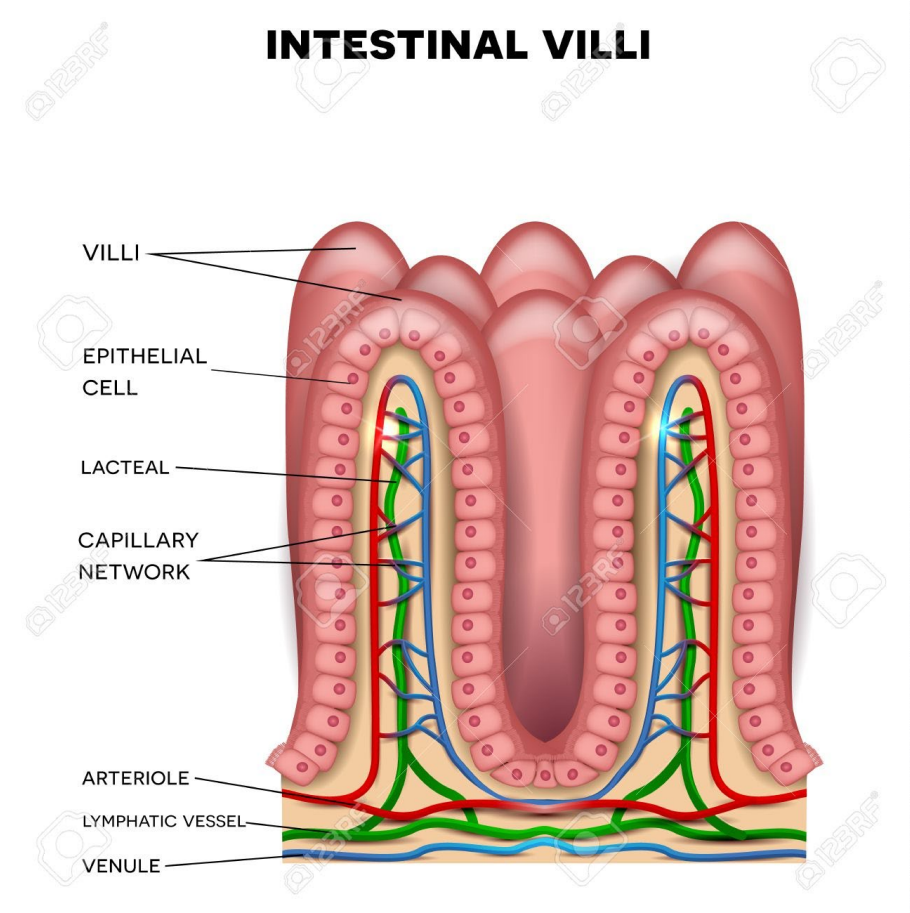


Image:123RF.com

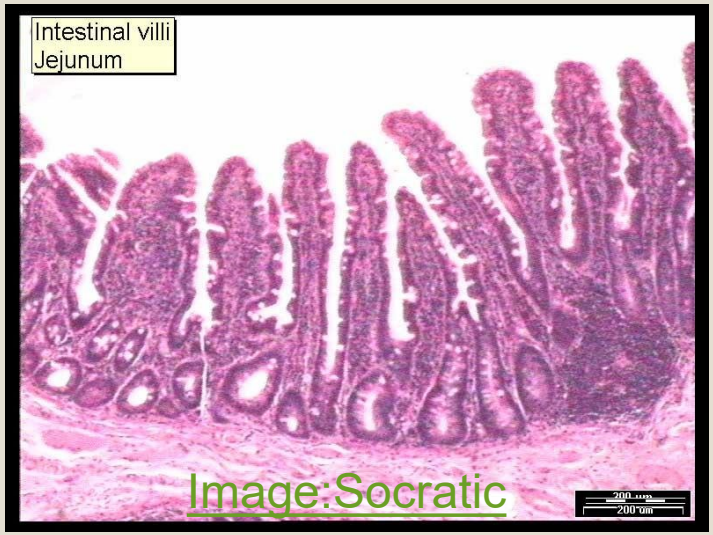


Image: fotolia.com

Large intestines (bowels, colon)

- Water reclamation
- Further breakdown of diet
- Lots of bacteria, fungi, archaea
- Three sections by location:
  - *Ascending*
  - *Transverse*
  - *Descending (colon)*

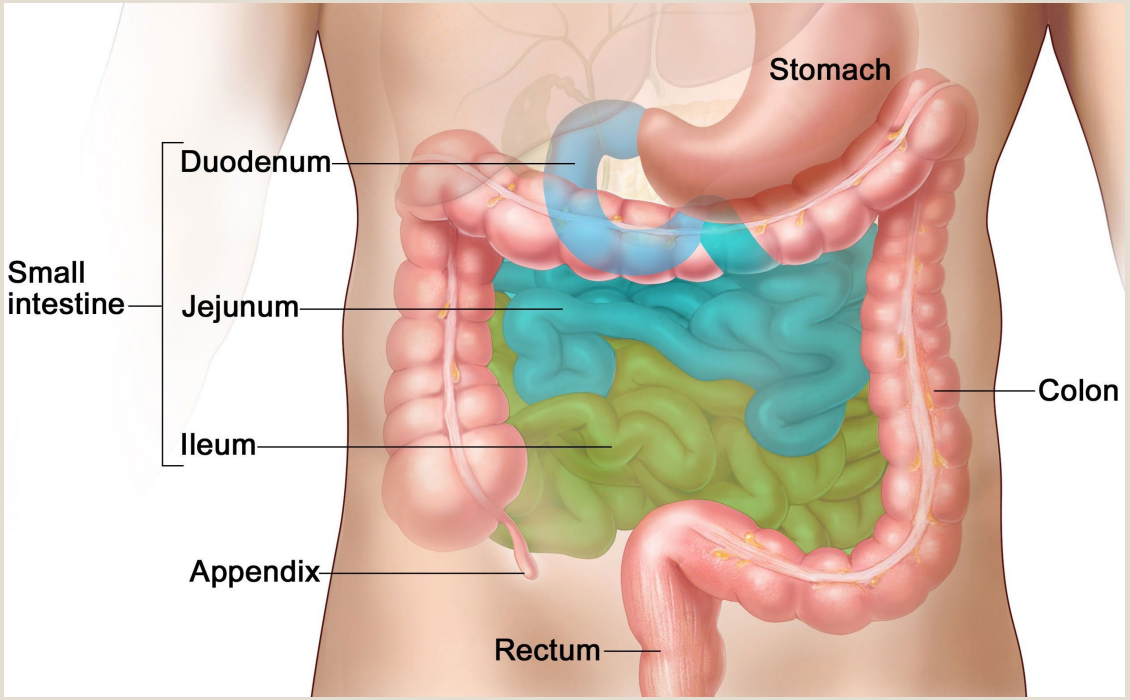
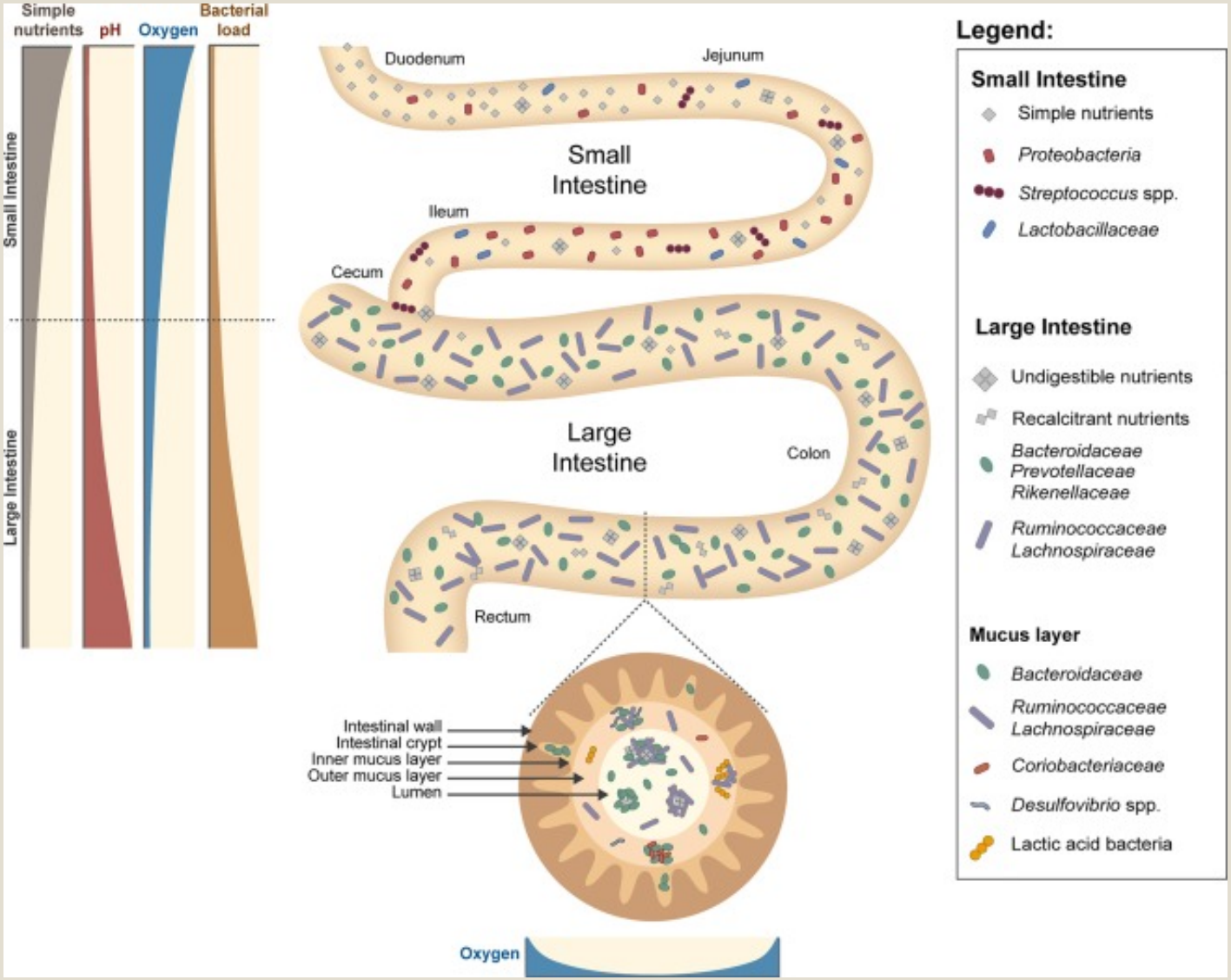


Image: Medical Xpress

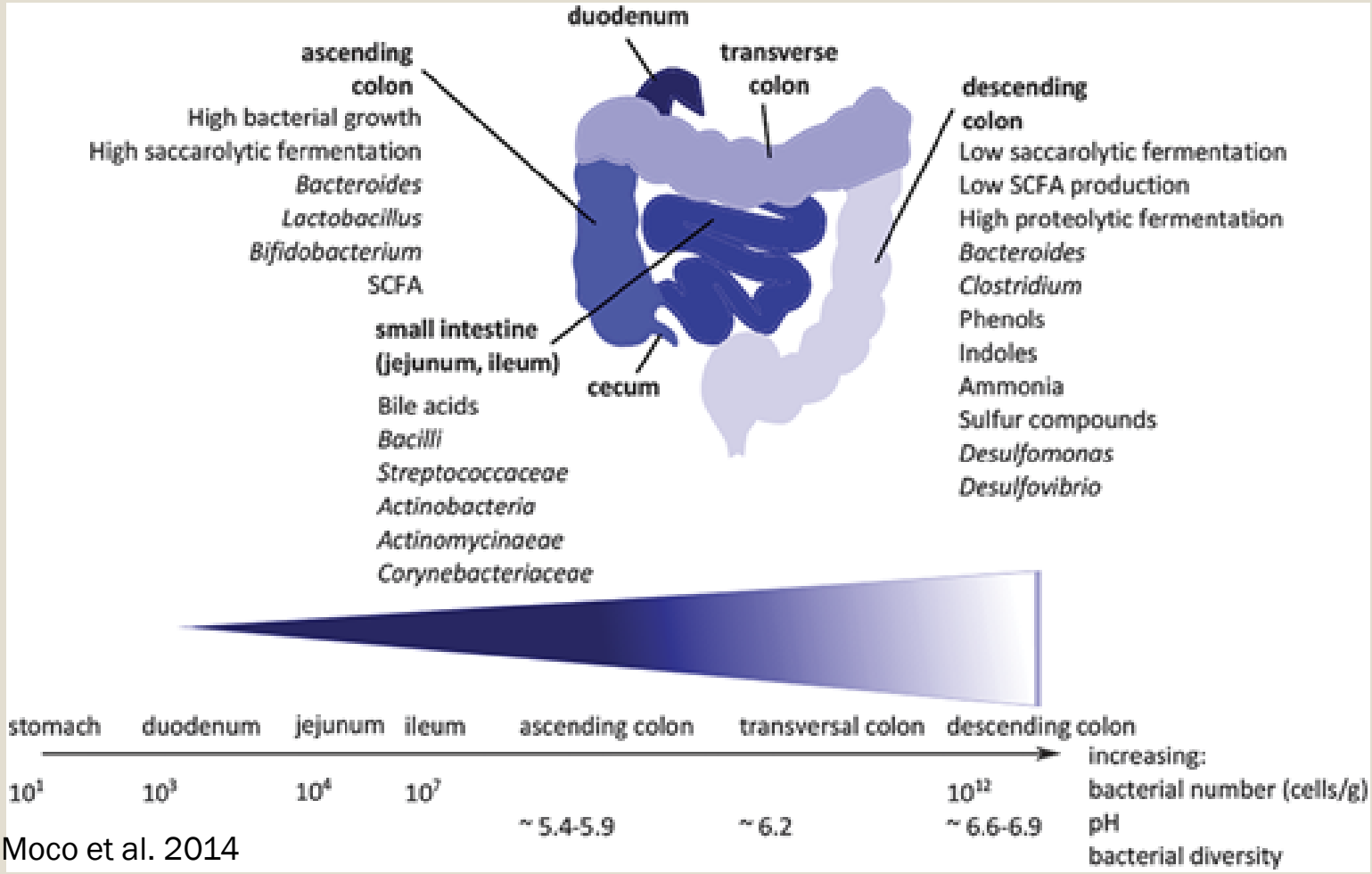
DYNAMICS OF GUT COMMUNITIES

Environmental changes drive localized bacterial diversity along gut



Pereira and Berry, 2017

Environmental changes drive localized bacterial diversity along gut



Moco et al. 2014

Different microbial community by GI ecosystem

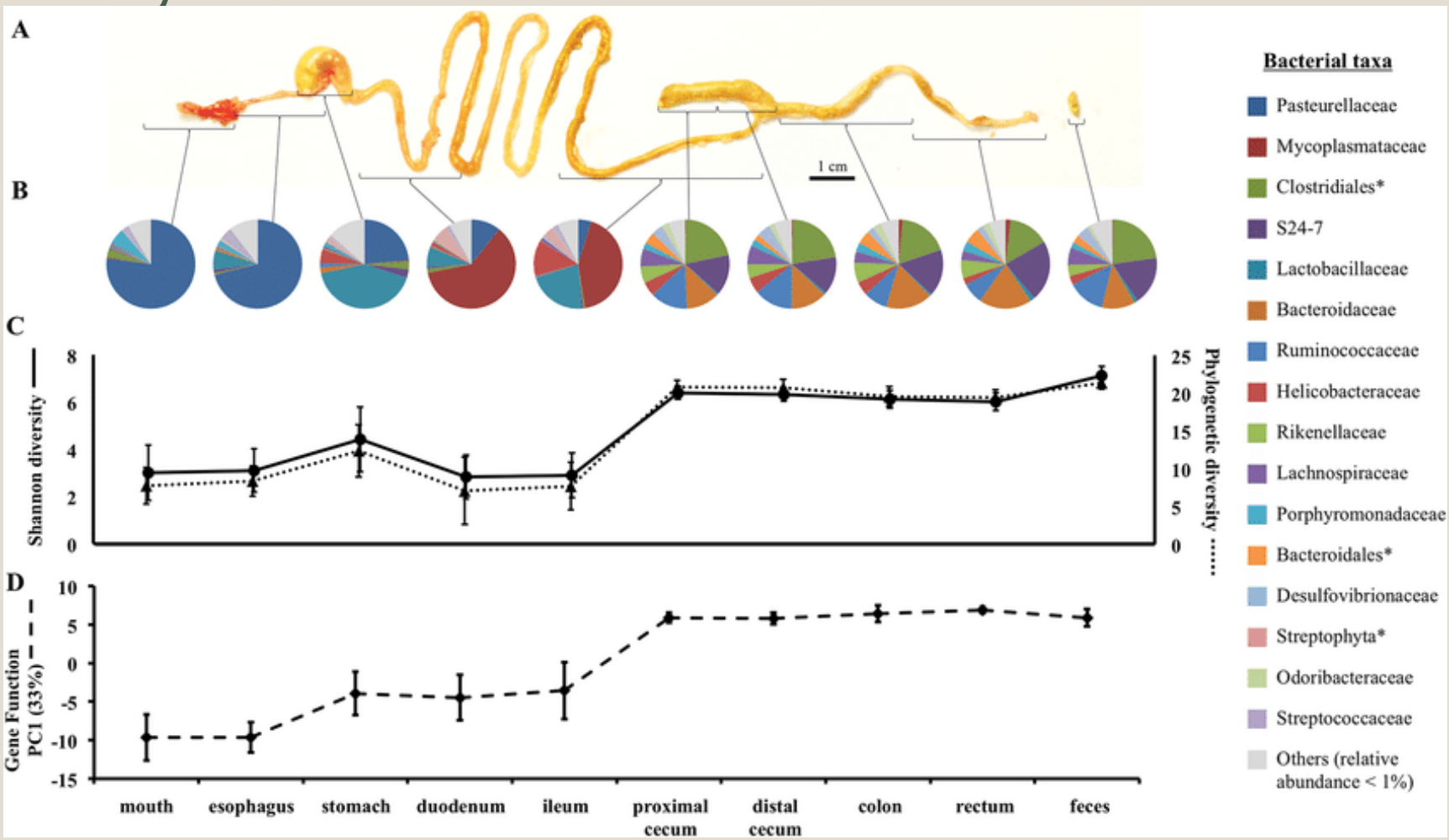
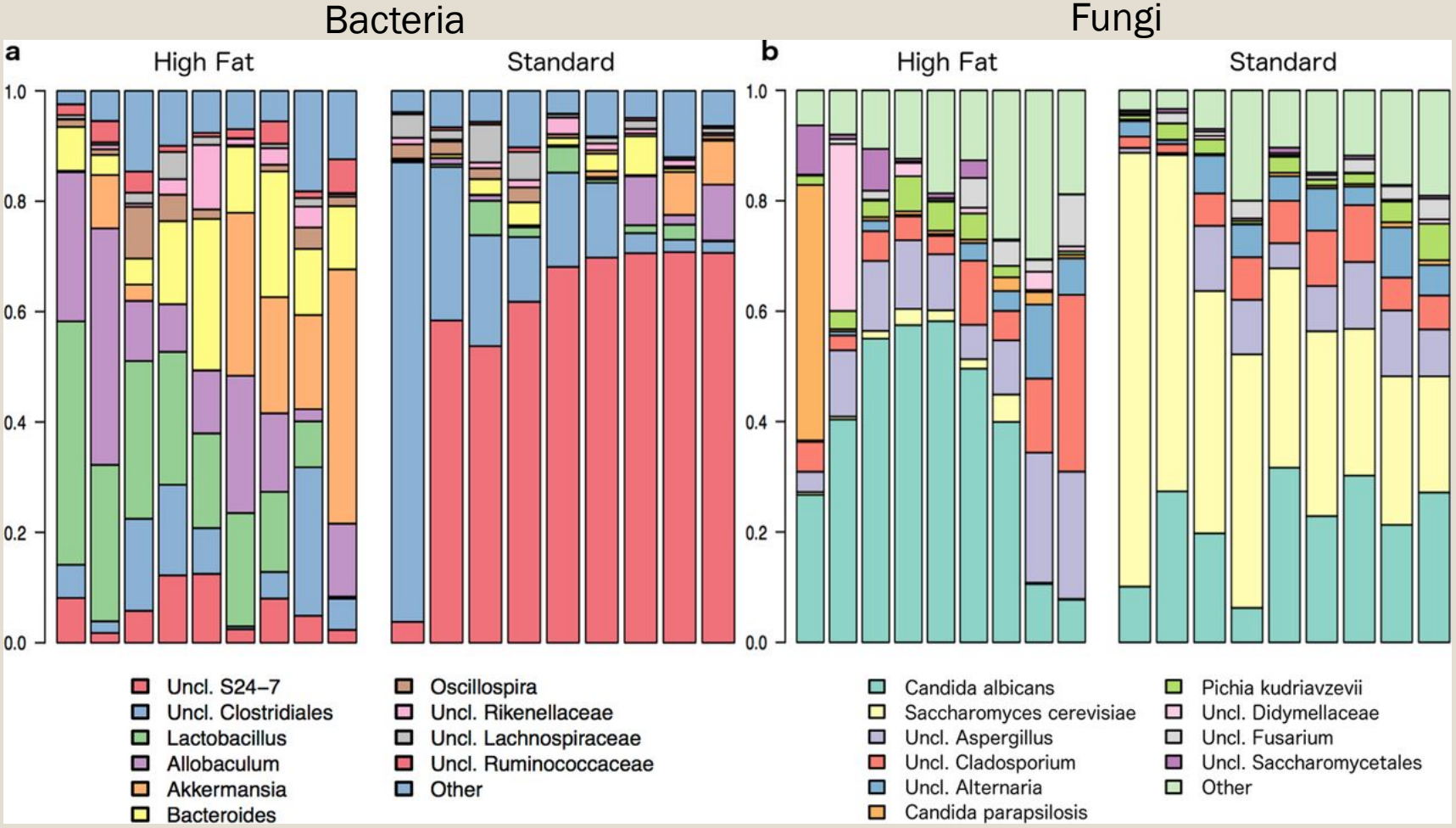


Image: Suzuki and Nachman 2016

DIET AND NUTRIENTS

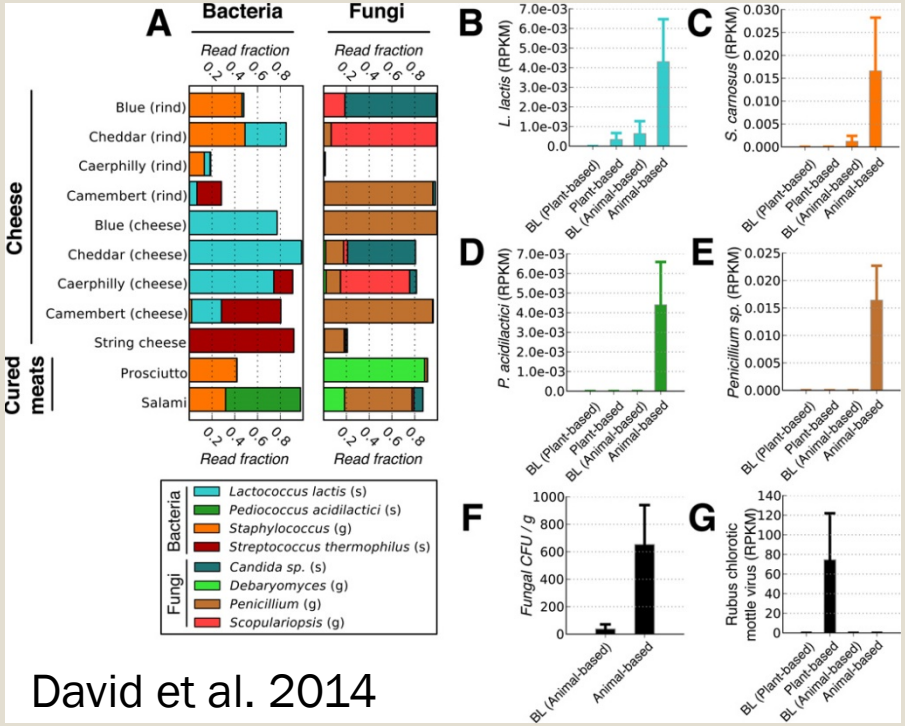
Diet drives which microbes are in GI tract



Heisel et al. 2017

Diet is a strong driver of gut diversity

- Type and availability of nutrients
  - *Selects for particular microbe phenotypes*
- Influx of food-born microbes
- Diet is a stabilizing factor (Gibbons et al. 2017)
  - *Tend to eat similar things regularly*



David et al. 2014

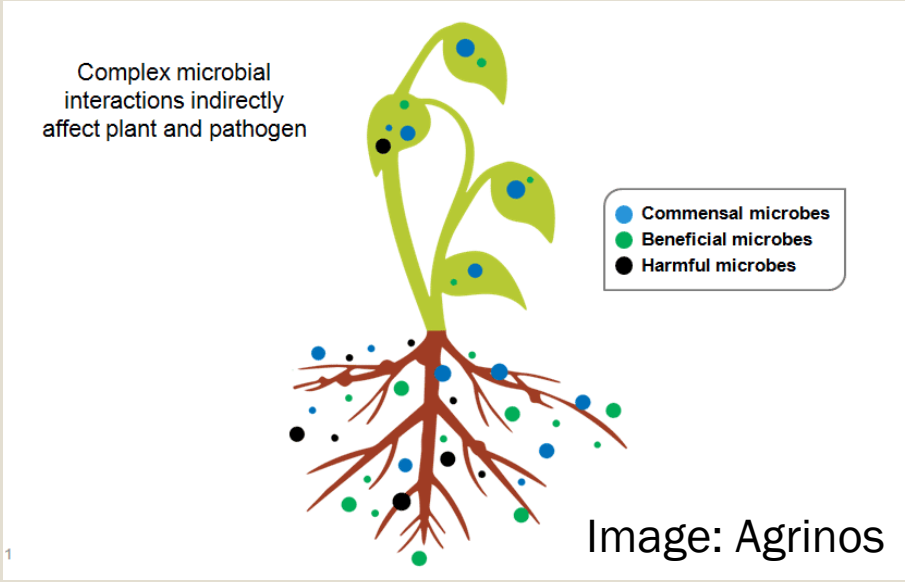
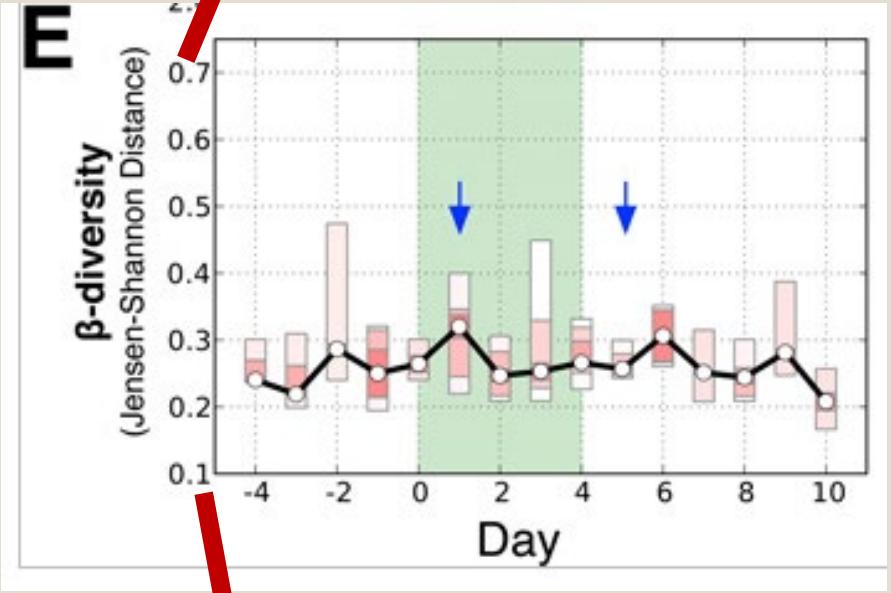


Image: Agrinos

Change your diet, even for a few days, to briefly change your microbiota

Samples had different bacterial community than before

Plant-based diet



Samples had same bacterial community as before

1. All volunteers on the same control diet -4 to 0 days
2. Volunteers switched to plant-based diet on day 0
3. Blue arrow 1: food-borne microbes could be found in feces 1 day after diet switch
4. Blue arrow 2: food-born microbes still in feces 1 day after stopped diet

David et al. 2014

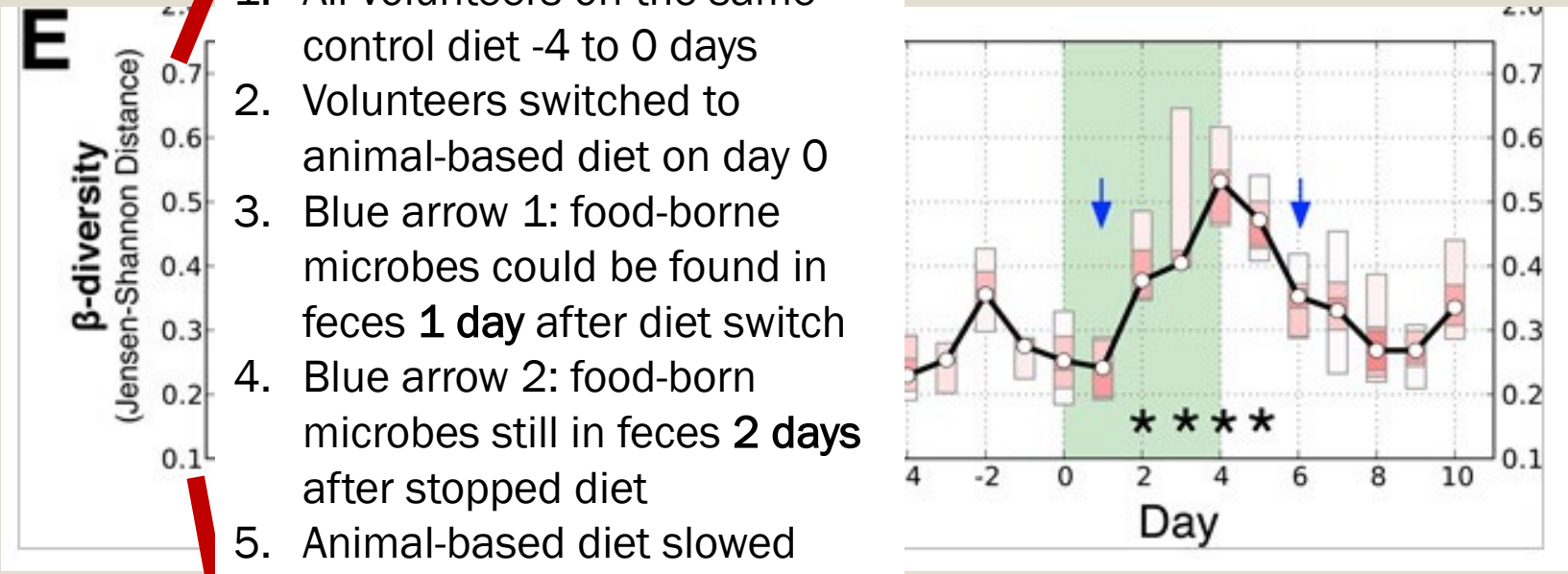
Change your diet, even for a few days, to briefly change your microbiota

Samples had different bacterial community than before

1. All volunteers on the same control diet -4 to 0 days
2. Volunteers switched to animal-based diet on day 0
3. Blue arrow 1: food-borne microbes could be found in feces **1 day** after diet switch
4. Blue arrow 2: food-born microbes still in feces **2 days** after stopped diet
5. Animal-based diet slowed digestion

Samples had same bacterial community as before

Animal-based diet



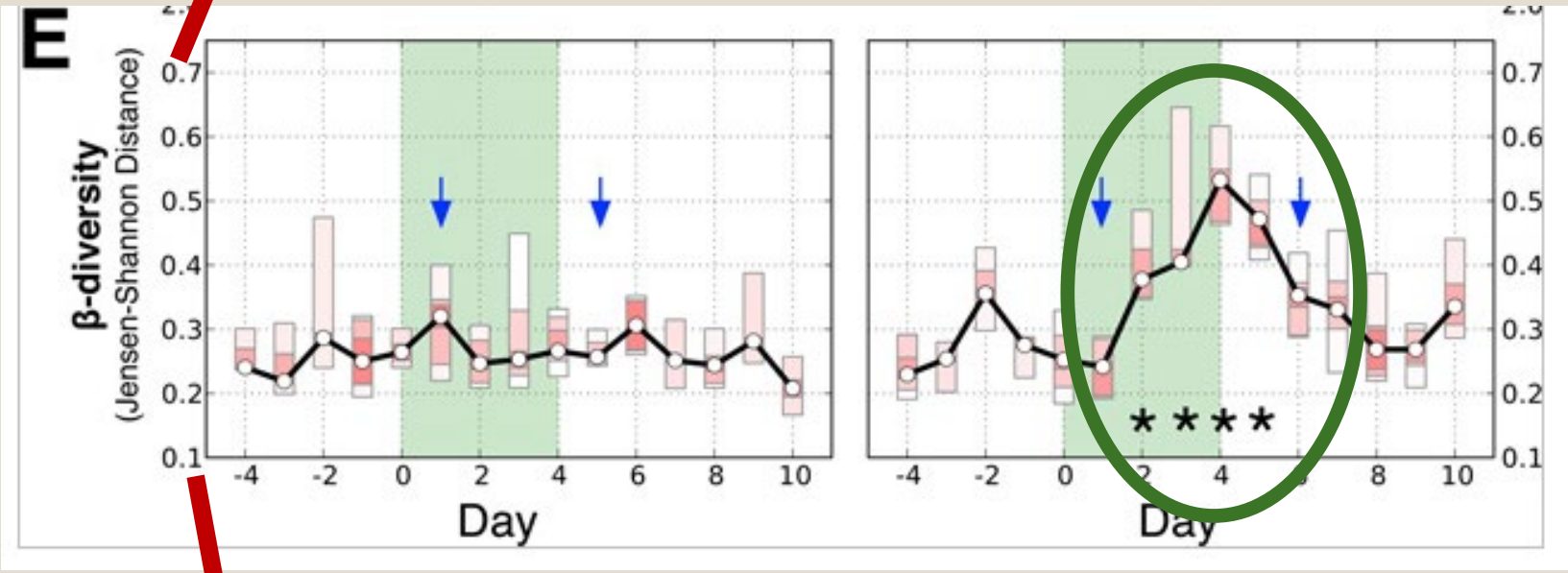
David et al. 2014

Animal-based diet changed the gut community but the plant-based diet didn't

Samples had different bacterial community than before

Plant-based diet

Animal-based diet



Animal-based diet had different

Samples had same bacterial community as before

David et al. 2014

Different protein selects for different microbes through amino acid profiles

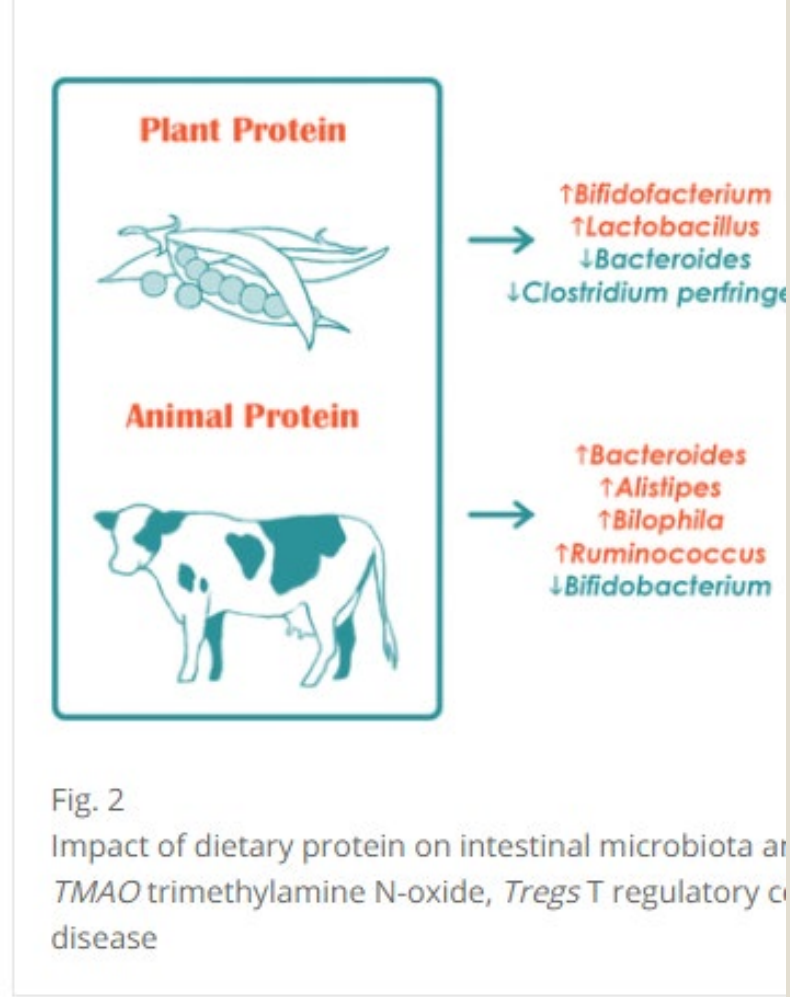
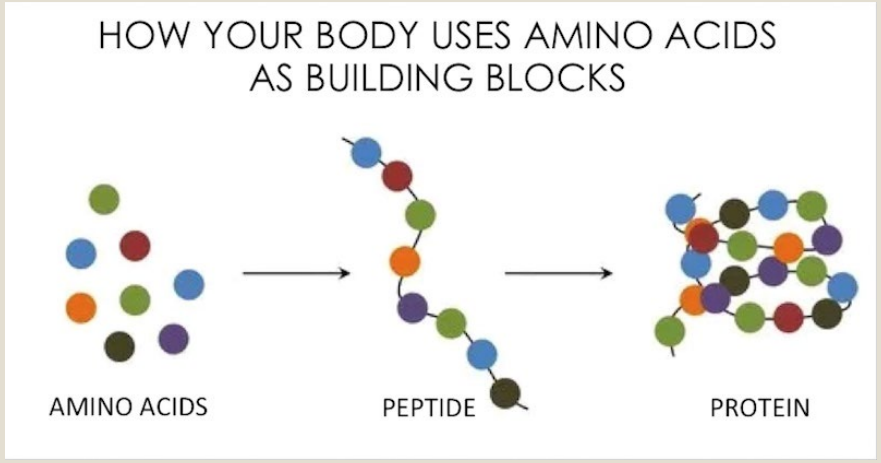
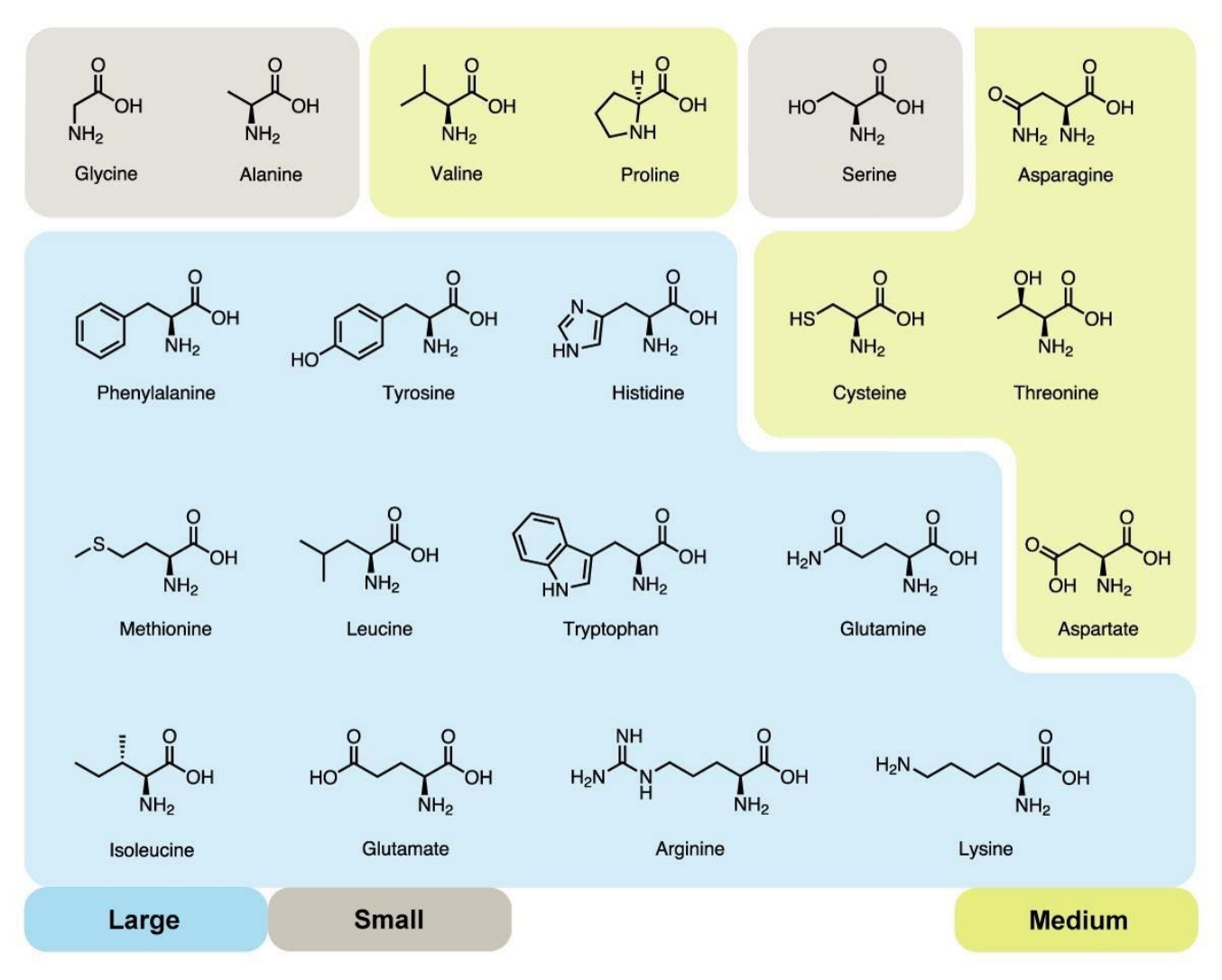


Fig. 2
Impact of dietary protein on intestinal microbiota ar
TMAO trimethylamine N-oxide, *Tregs* T regulatory c
disease



Singh et al. 2017

Amino acids combine to make proteins



You can make some amino acids

"non-essential amino acids"

You can NOT make certain amino acids

"essential amino acids"
Must be provided in diet

Animal protein has the amino acid profile that humans need

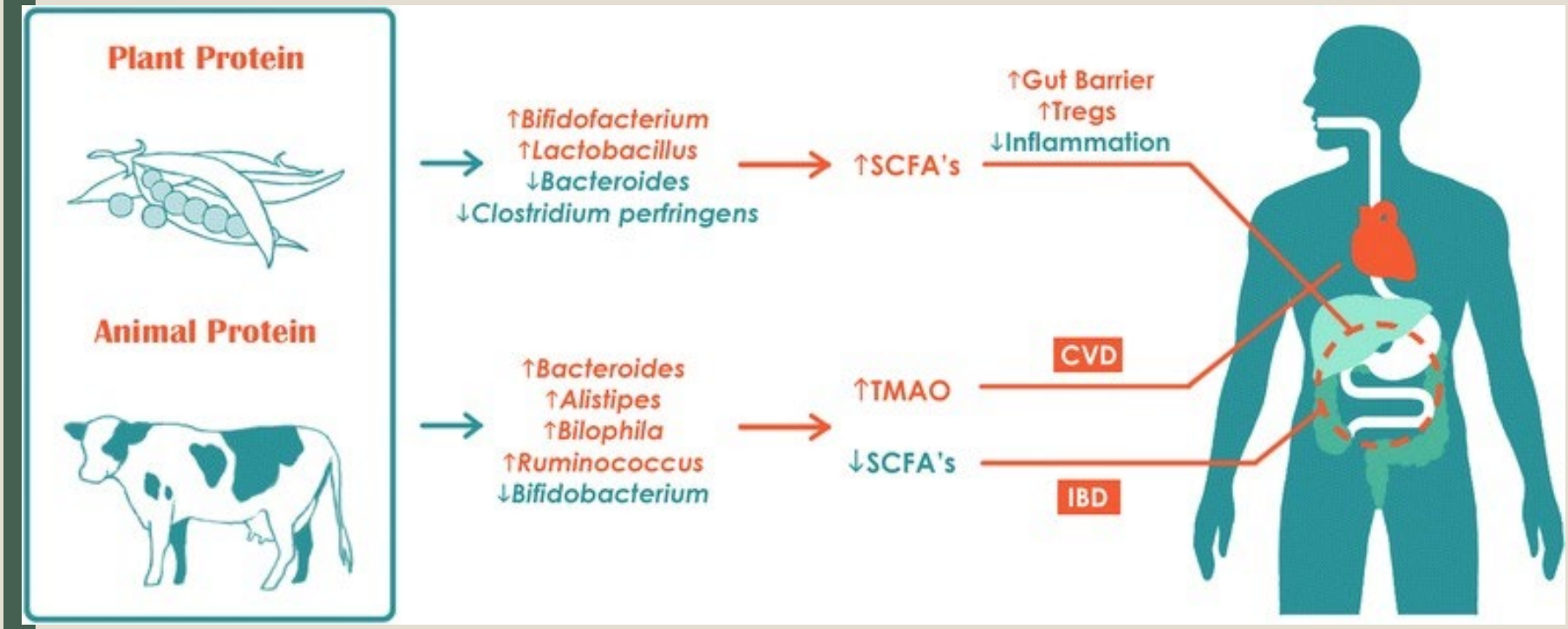
- Protein quality score
  - *Amino acid profile and suitability for the host animal consuming it*

Protein source	Protein quality score (%)			$PDCAAS_t$ – DIAAS (% points)
	$PDCAAS_t$	PDCAAS	DIAAS	
Wheat	46.3	46.3	40.2	6.1
Barley	59.1	59.1	47.2	11.8
Corn grain	47.3	47.3	42.4	4.9
Triticale	55.3	55.3	49.8	5.4
Rye	58.8	58.8	47.6	11.2
Peas	78.2	78.2	64.7	13.6
Soybean	100.0	102.0	99.6	0.4
Wheat bran	59.6	59.6	48.8	10.8
Soybean expeller	100.0	101.7	100.3	– 0.3
Soybean cake	99.4	99.4	97.0	2.4
Sunflower expeller	57.7	57.7	49.2	8.5
Sunflower cake	54.4	54.4	46.4	8.0
Rapeseed expeller	91.7	91.7	70.2	21.5
Rapeseed cake	91.7	91.7	70.2	21.5
Corn silage	47.3	47.3	42.4	4.9
Whole milk powder	100.0	116.1	115.9	– 15.9
Beef	100.0	114.0	111.6	– 11.6
Average plant input	69.8	70.0	61.1	8.7
Average animal output	100.0	115.0	113.7	– 13.7

Ertl et al. 2016

Plant protein has the amino acid profile that (”good”) microbes need

- This can provide good by-products for humans, too



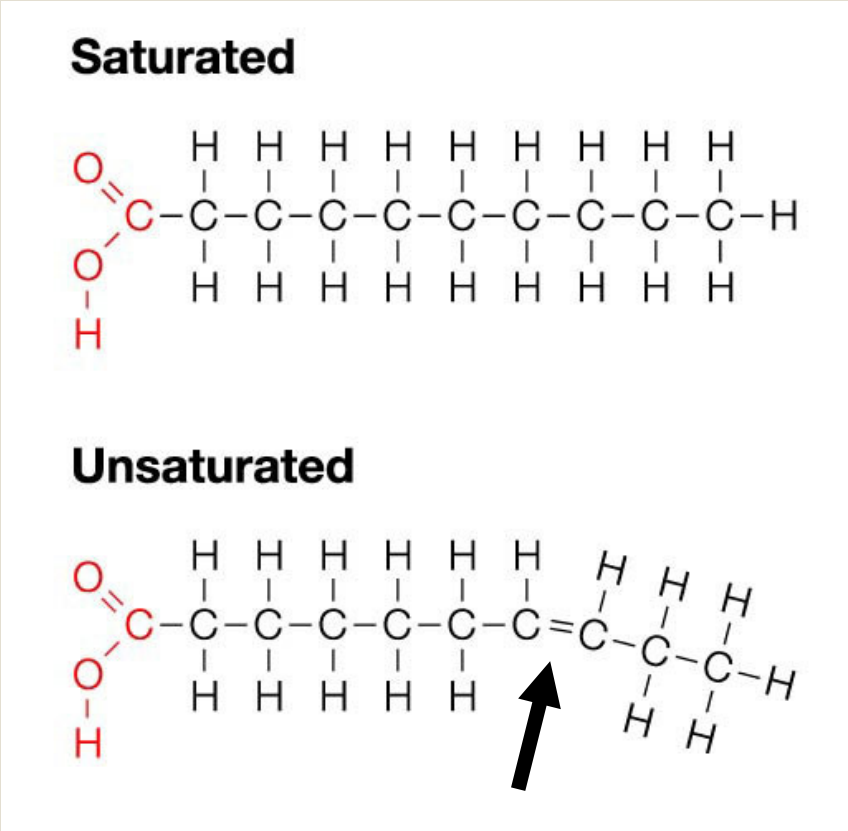
Singh et al. 2017

Classification of fats

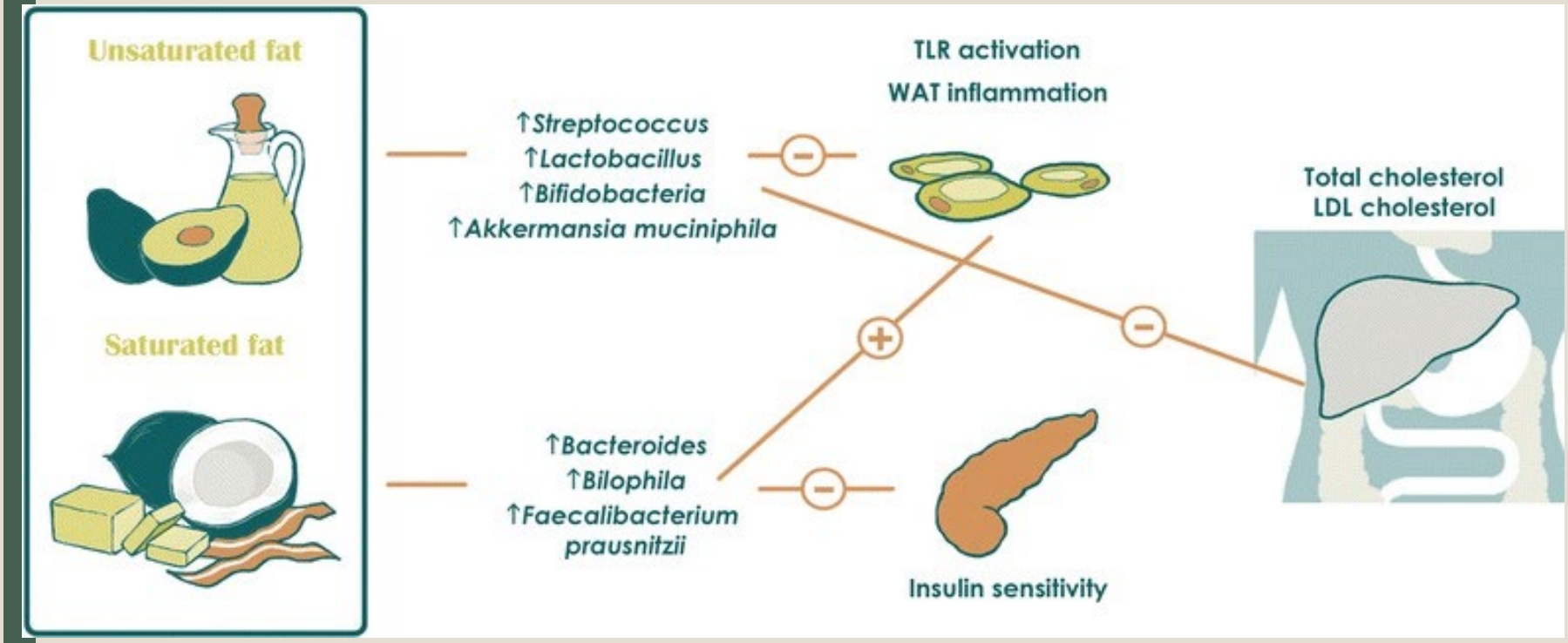
Saturation refers to the number of hydrogens bonds present.

If all of the bonds carbon came make are to hydrogens along the main backbone, the fat is saturated

Saturated fats are linear, so they stack more easily, and will become solid at room temperature

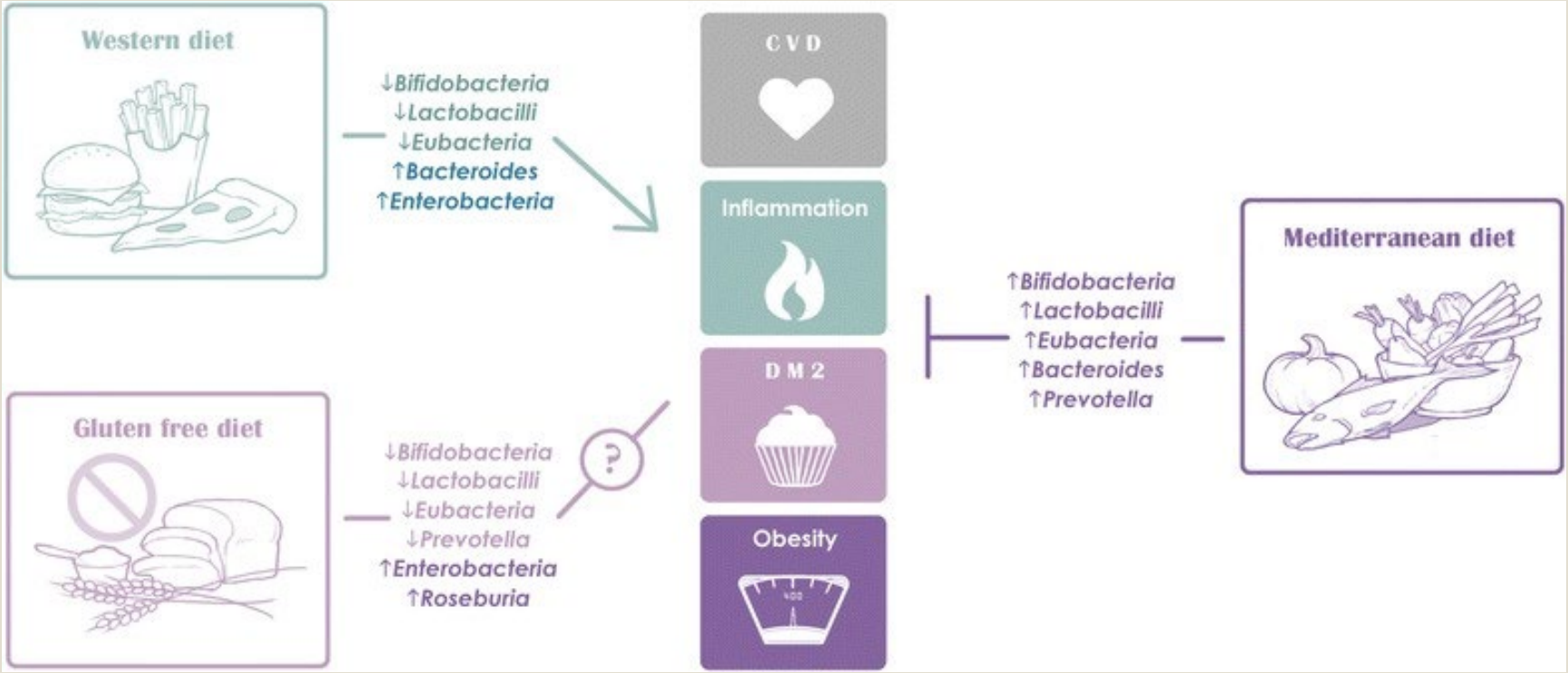


Dietary fat type affects microbial community and host



Singh et al. 2017

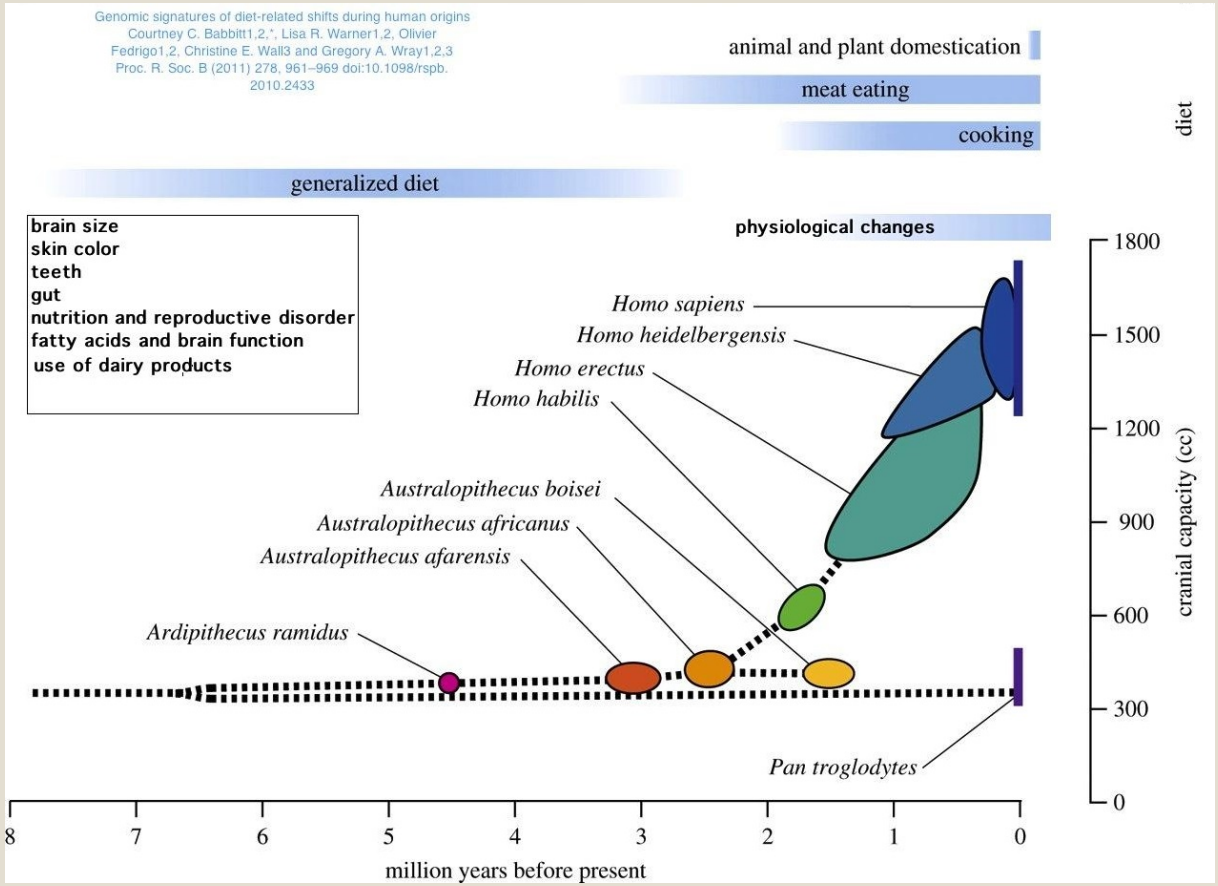
Is there a “best” diet?
Who knows - most are untested



Singh et al. 2017

But I should definitely cut out fat, right? … kinda but not really

- Humans developed on a protein, fat, and fiber based diet
- Simple sugars were primarily in fruits
- We eat way more simple sugar now than ever before
- We've always eaten a lot of red meat

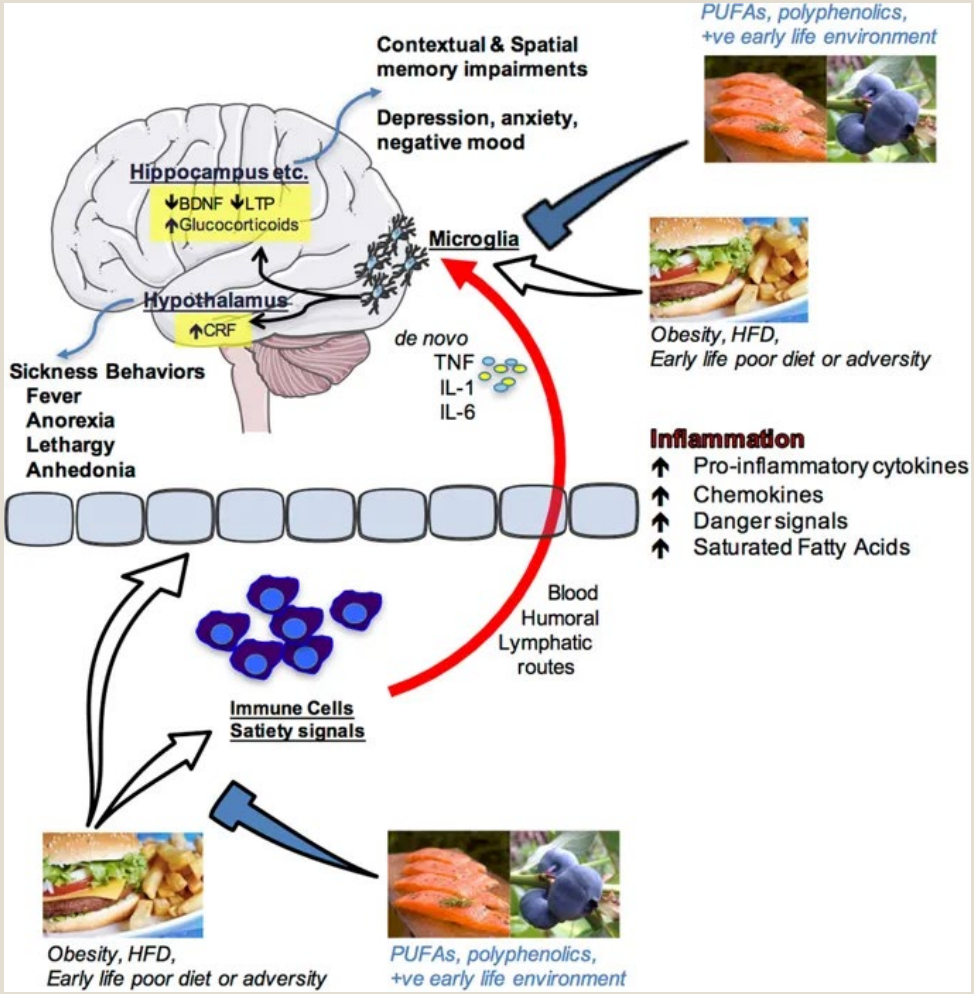


Babbitt et al. 2011

More fat? No, not that either

- Fat and protein take longer to digest than simple sugars
  - *Makes you feel satiated*
  - *End up eating less*

- But, a high-fat diet is linked to a LOT of negative microbial, mental, and health changes
  - *Reviewed in Spencer et al. 2017*



Spencer et al. 2017

So why does red meat get a bad rep?

- Portion size is 3.5 oz/day

- Full of iron
  - *Essential to your cells*
  - *Absorption in duodenum and jejunum where have less bacteria*
    - **You only absorb ~15%**
  - *Essential to microbes – they will kill for it*
    - *Ex. Legionella, Yersinia pestis*
    - Yilmaz and Li, 2018
    - Kortman et al. 2014

Diversity in your diet

- Bacterial pathogens are weak
  - *They need very specific circumstances*
  - *Lots of nutrients*
- Eating fiber increases microbial diversity, and microbial competition in the gut
- Diversity in your diet and plenty of fiber can override negative aspects of other foods

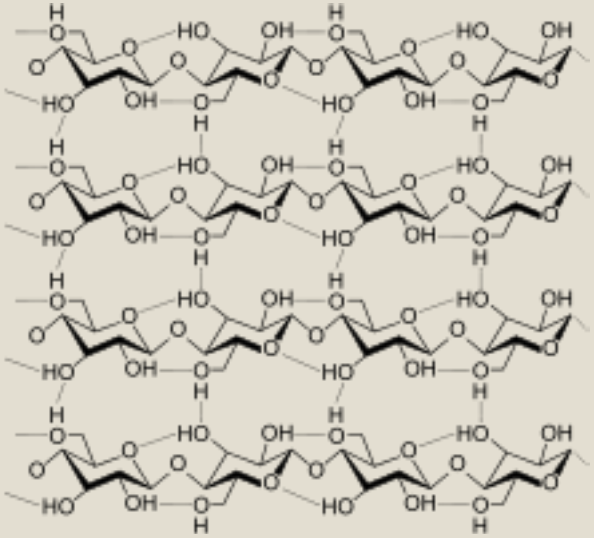
MORE FIBER IS ALWAYS BETTER

The strategy of eating a plant-based diet you can't digest

Fiber is a broad category

- Soluble or Insoluble (in water)
  - *Soluble can be viscous (gel forming) or non-viscous*
- Short-chain or long-chain carbohydrates (i.e. size of nutrient)
- Fermentable or non-fermentable
  - *Fermentation is to convert sugars (carbohydrates) into ethyl alcohol*

Cellulose, Image: Wikipedia

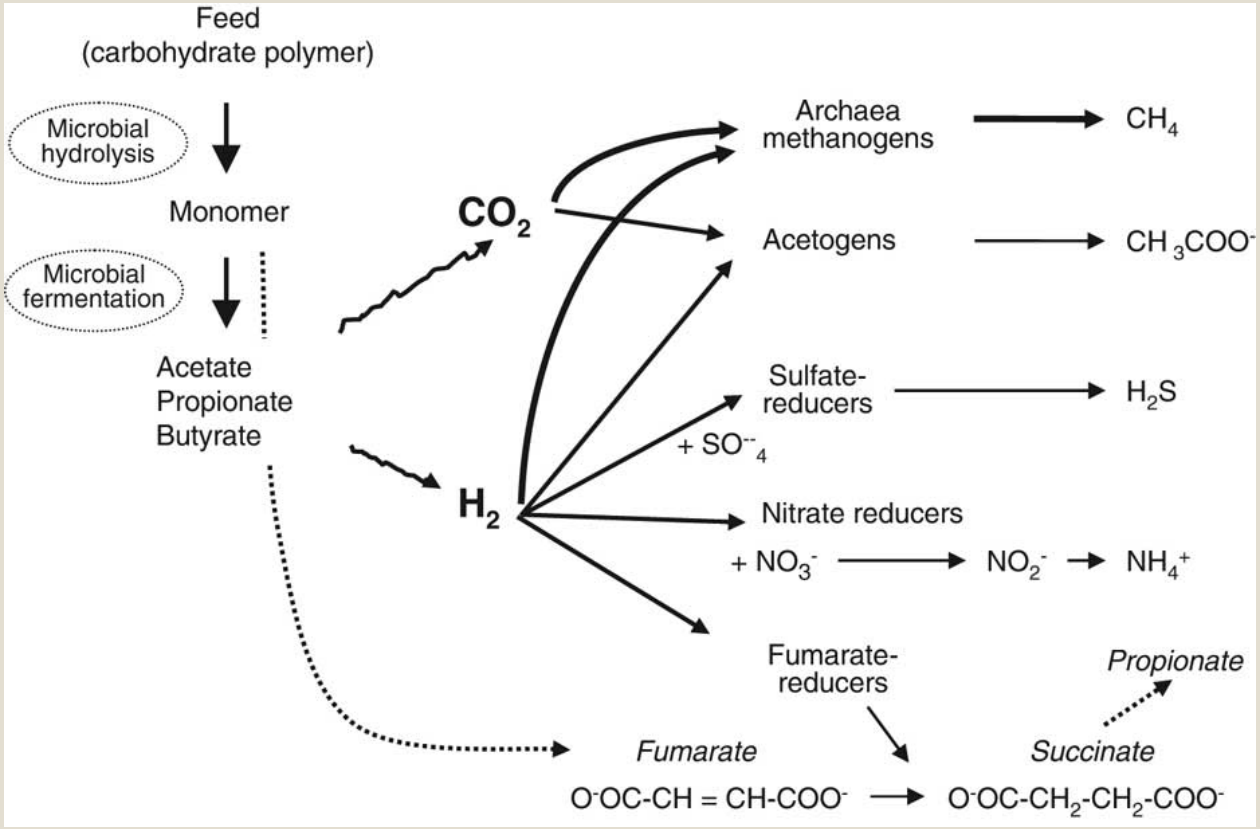


Types:

- Cellulose
- Inulin
- Pectins
- Beta Glucans
- Psyllium
- Lignin
- Resistant Starch

General benefits of fiber

- Large molecules, has a variety of breakdown products
  - *More available compounds, more diversity in microbiota*



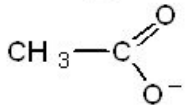
Morgavi et al. 2010

Volatile Fatty Acids

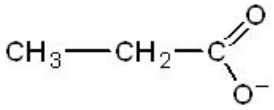
Carbohydrates —Microbial Fermentation→ VFA's

Glucose

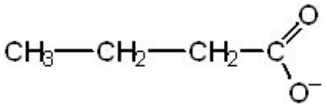
- Short-chain fatty acids produced by microbes
  - Rumen, cecum, colon
- 3 basic types:



Acetic acid (2c)



Propionic acid (3c)



Butyric acid (4c)

https://slideplayer.com/slide/5981255/

Benefits of fiber fermentation

Volatile fatty acids (VFAs)

- *Used by host for nutrition (70% of cow's energy from VFAs)*
- *Butyrate*
  - upregulates host immune system and mucin production,
  - alters toxic or mutagenic compounds
  - reduces the size/number of crypt foci (abnormal glands in intestinal epithelia that lead to colorectal polyps)
  - Kim and Milner 2007; Scheppach 1994

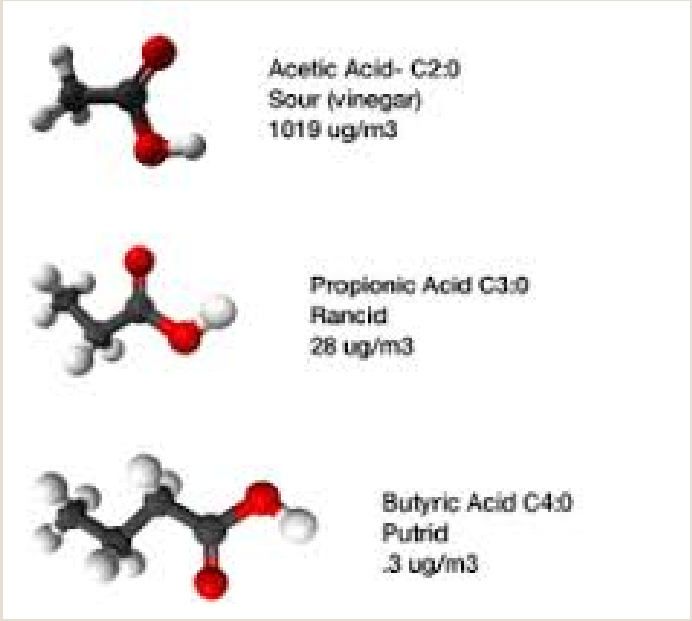


Image: Aquafix Inc.

Benefits of fiber fermentation

Hydrogen

- *reduces digesta transit time (slow growing methanogenic archaea are reduced)*
  - (Jahng et al. 2012)
- *Antioxidant because of oxygen-scavenging, may prevent inflammation and carcinogenesis in gut*
  - (Ohsama et al. 2007; Ohta 2011)
- *Can be used to make lots of different molecules*

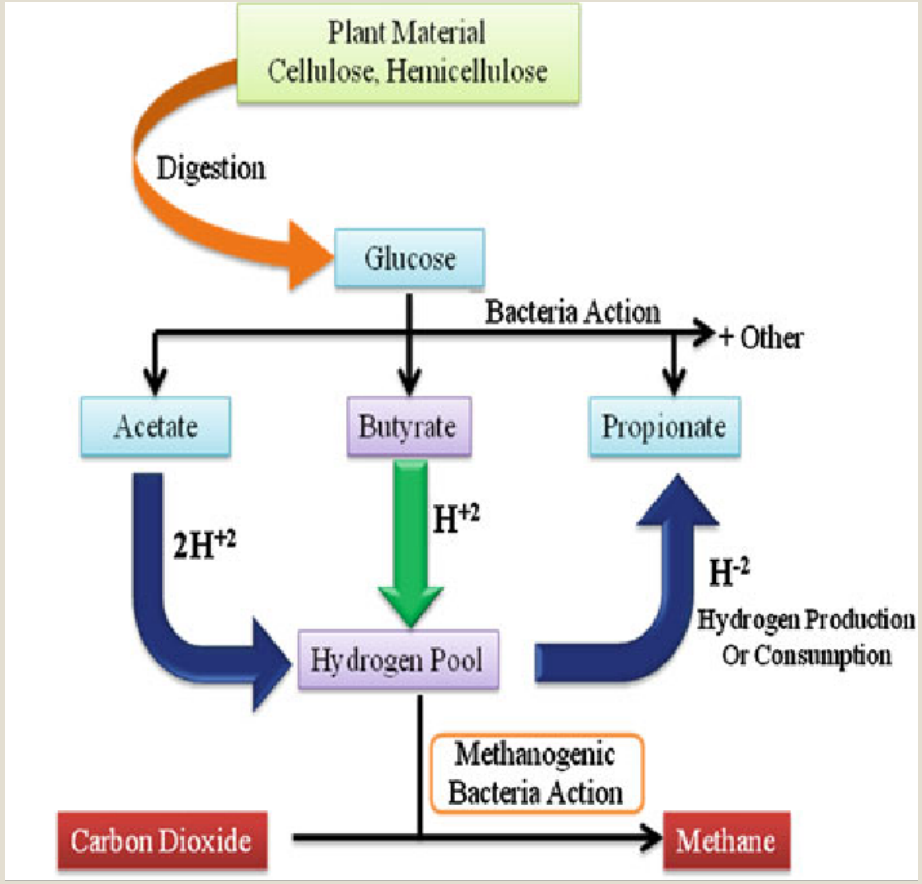
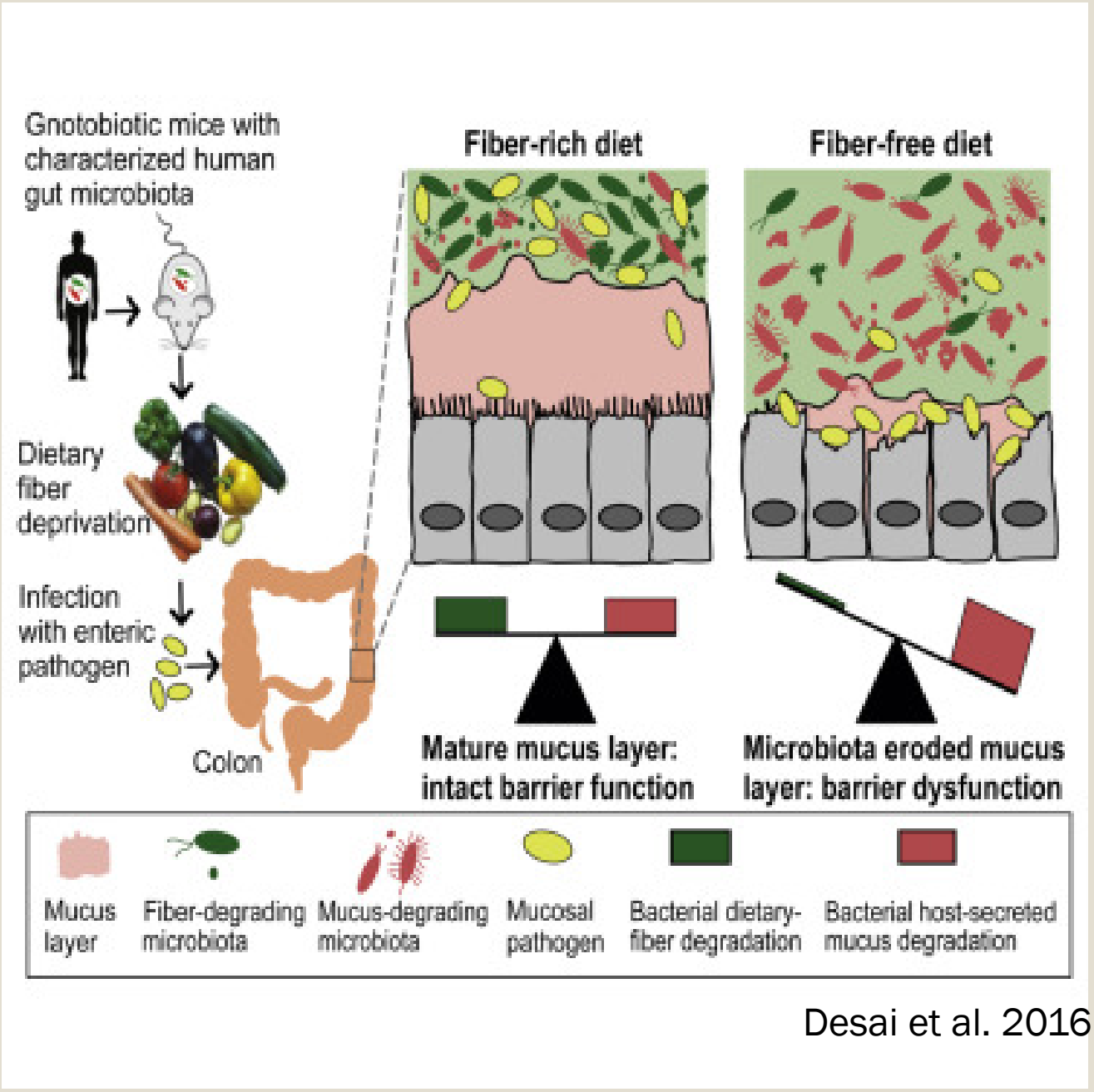


Image: Sejian et al. 2013

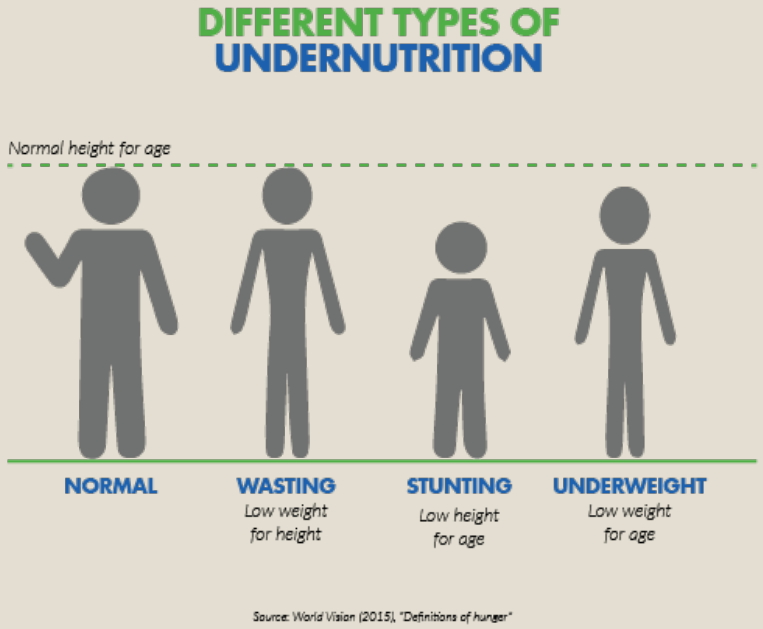


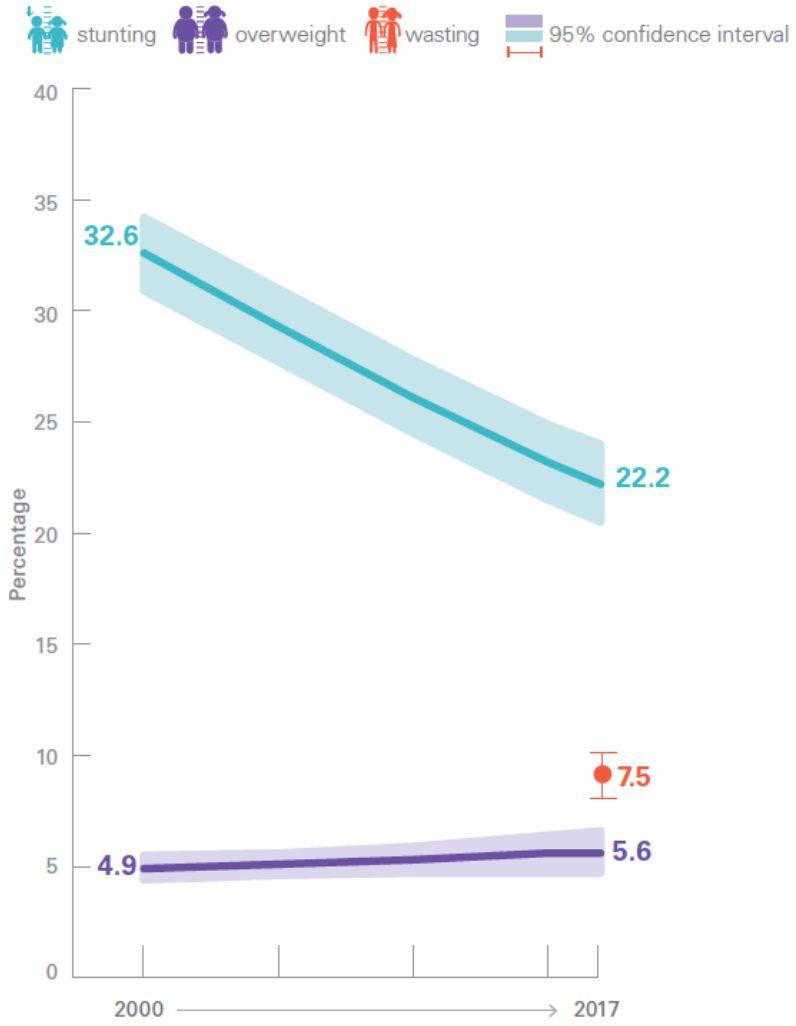
Desai et al. 2016

ROLE OF GUT MICROBIOTA IN MALNUTRITION

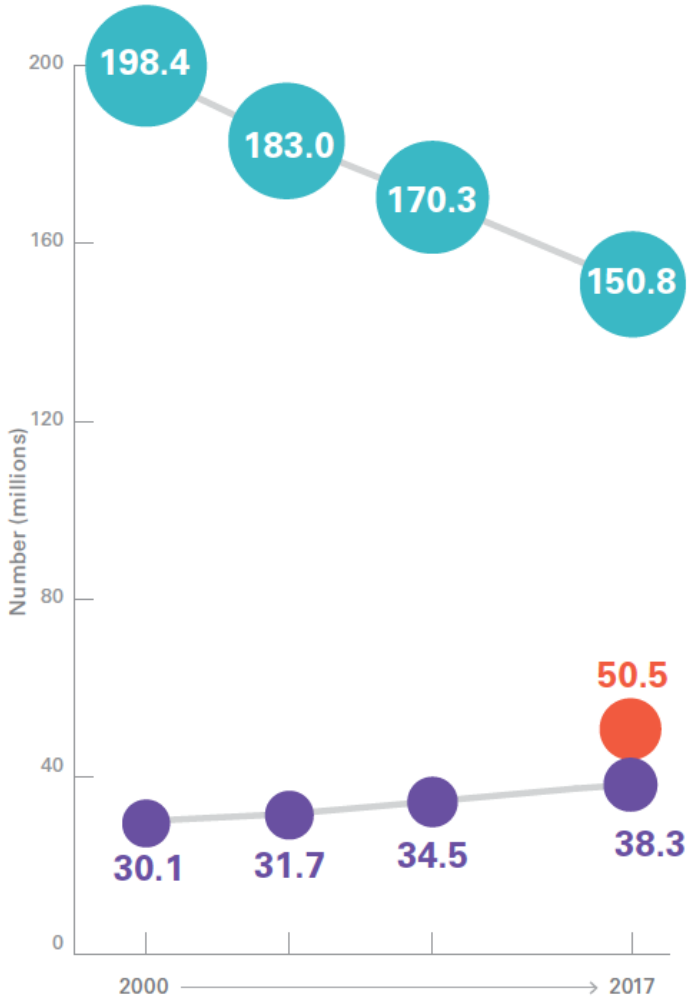
Nutrition and health status

- Overnutrition
  - *Fat deposition*
- Undernutrition/malnutrition
  - *Macronutrients (energy)*
  - *Micronutrients*
- Important to understand what microbes encourage weight gain/nutrient harvesting
  - *Can be used to recover malnourished populations*





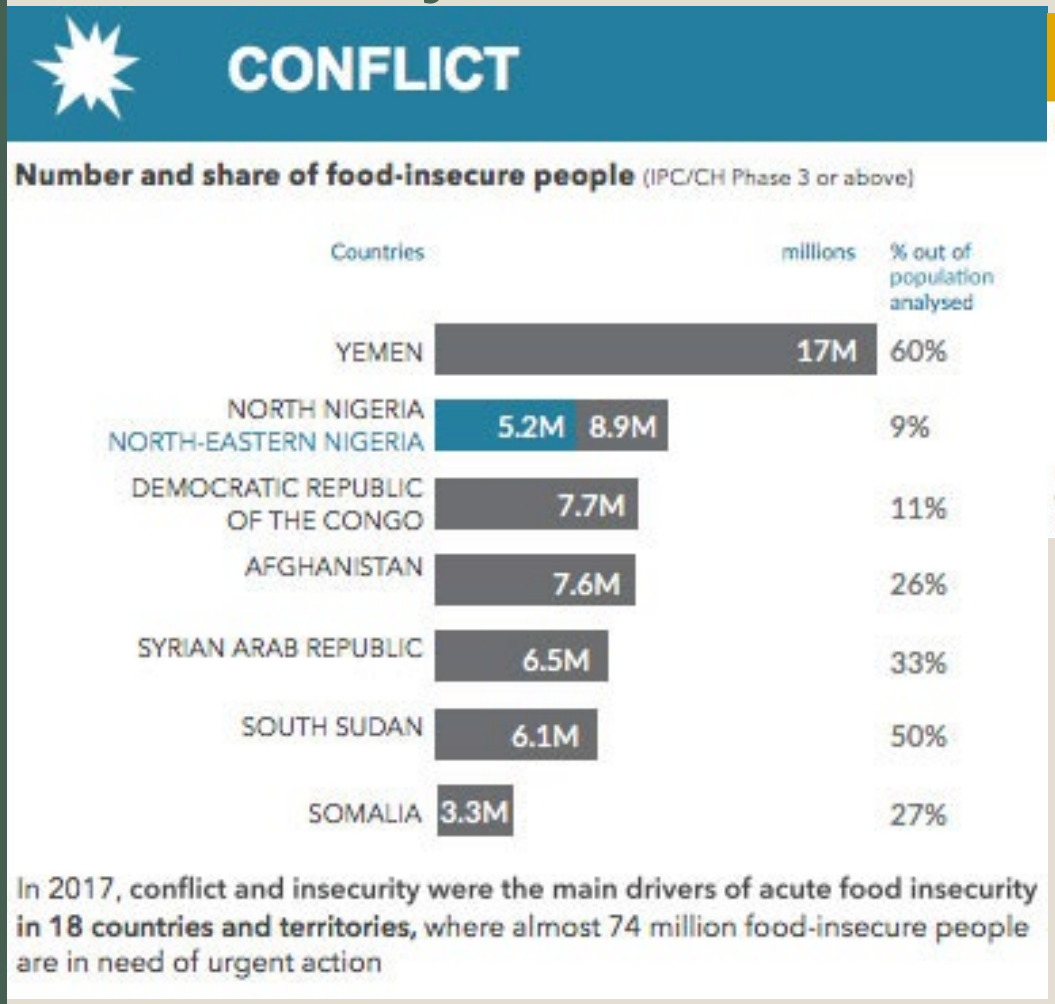
Percentage of stunted, overweight and wasted children under 5, global, 2000–2017



Number (millions) of stunted, overweight and wasted children under 5, global, 2000–2017

UNICEF/WHO/The World Bank 2018

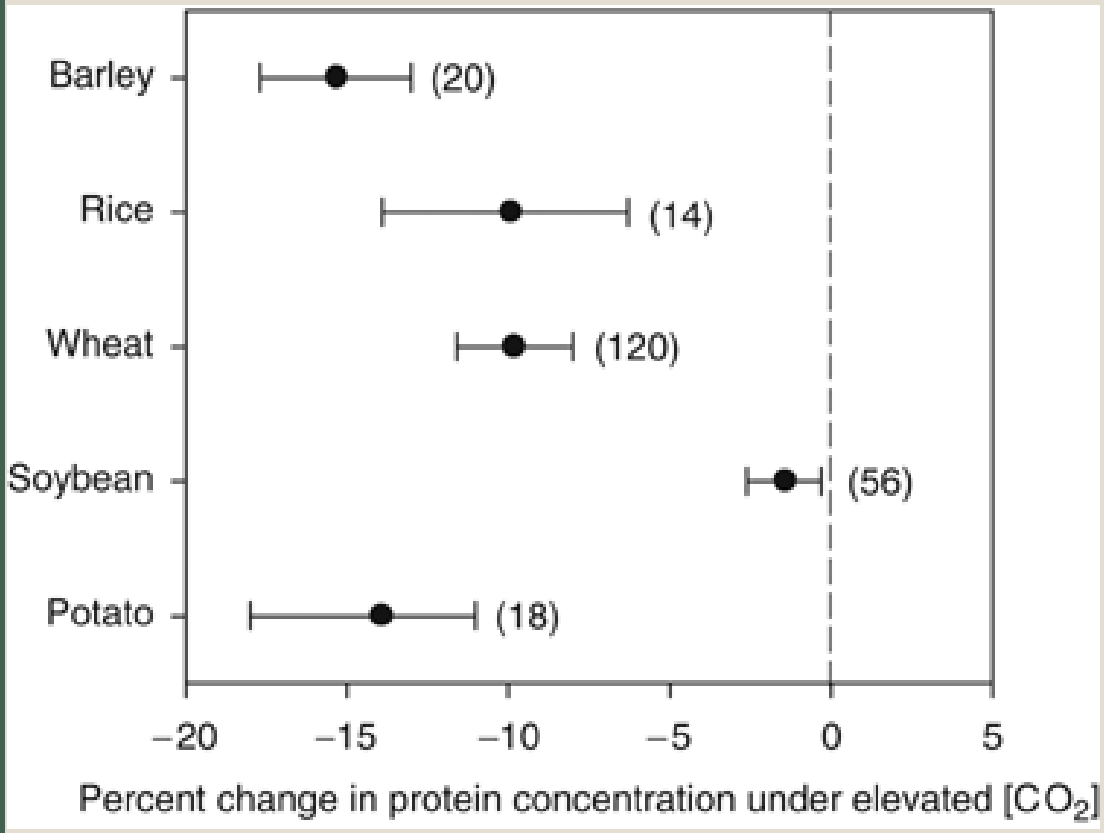
Climate change fuels conflict and food insecurity



Cool interactive map: https://www.metoffice.gov.uk/food-insecurity-index/

Source: FAO, WFP, & EU, 2018

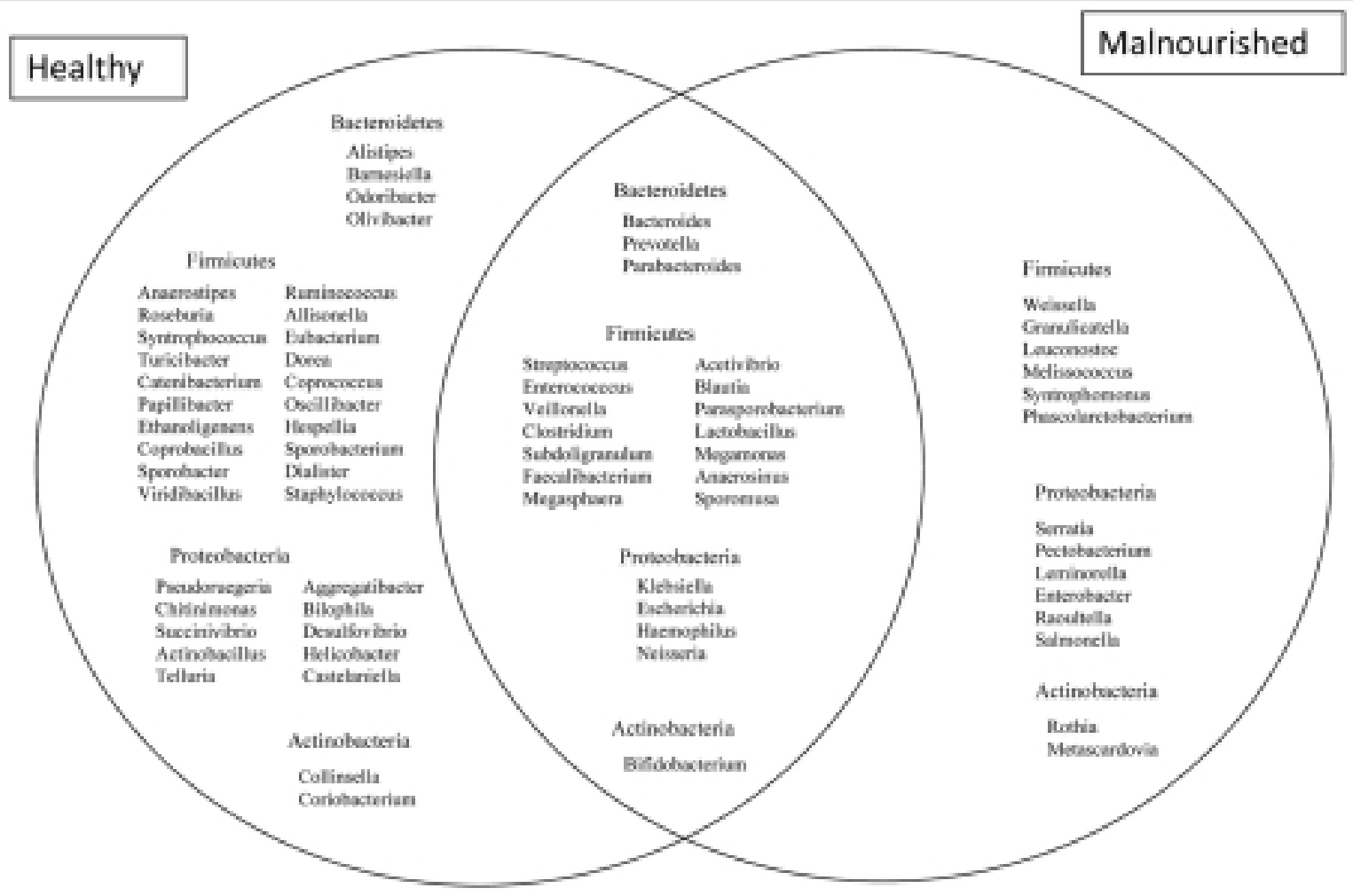
Climate change negatively affects plant nutrient content



Taub et al. 2007

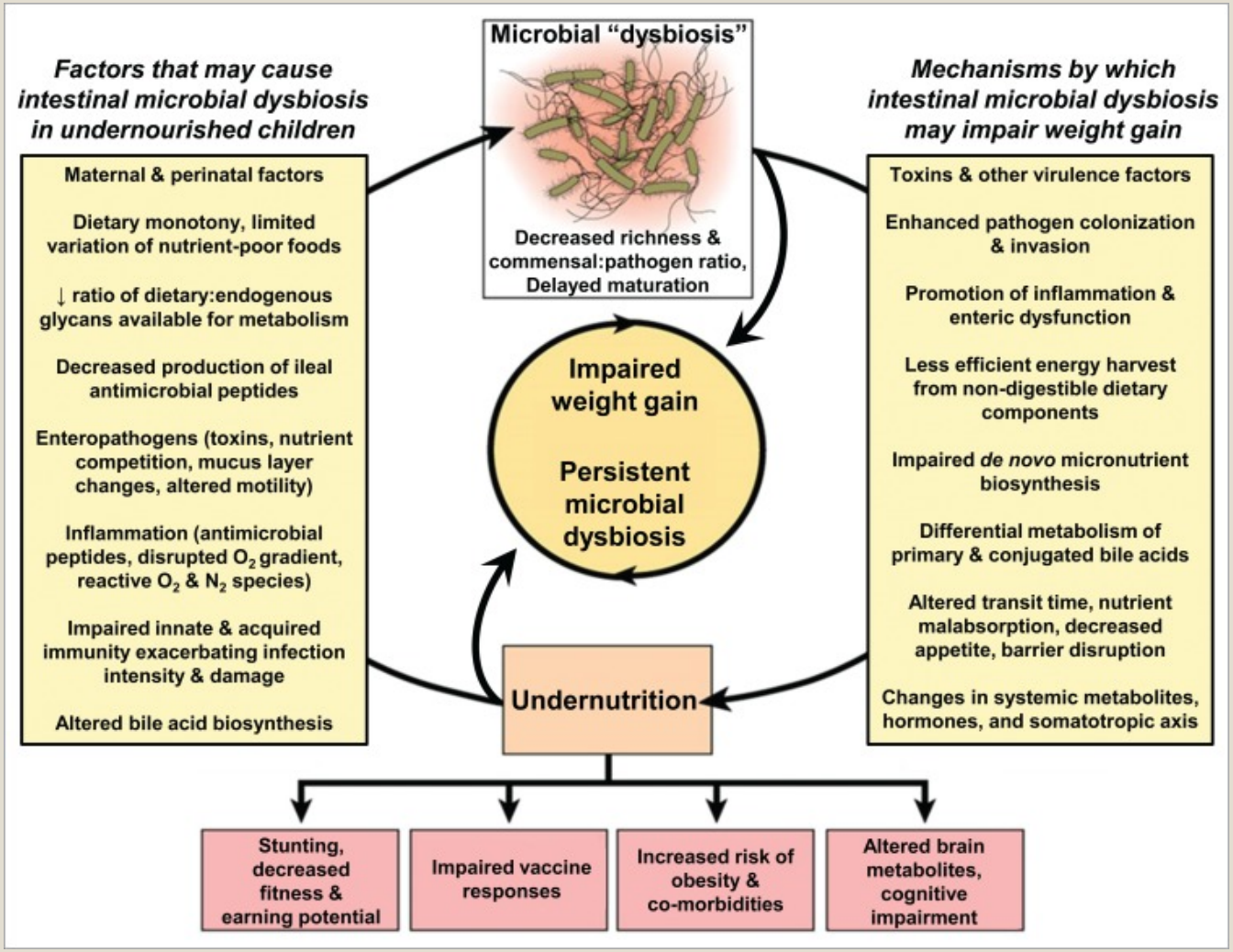
- Temperature and moisture affects
  - *Plant growth and nutrient content*
  - *Plant interactions with soil microbes*
  - *Soil nutrient cycling*

Poor diet reduces gut microbial diversity



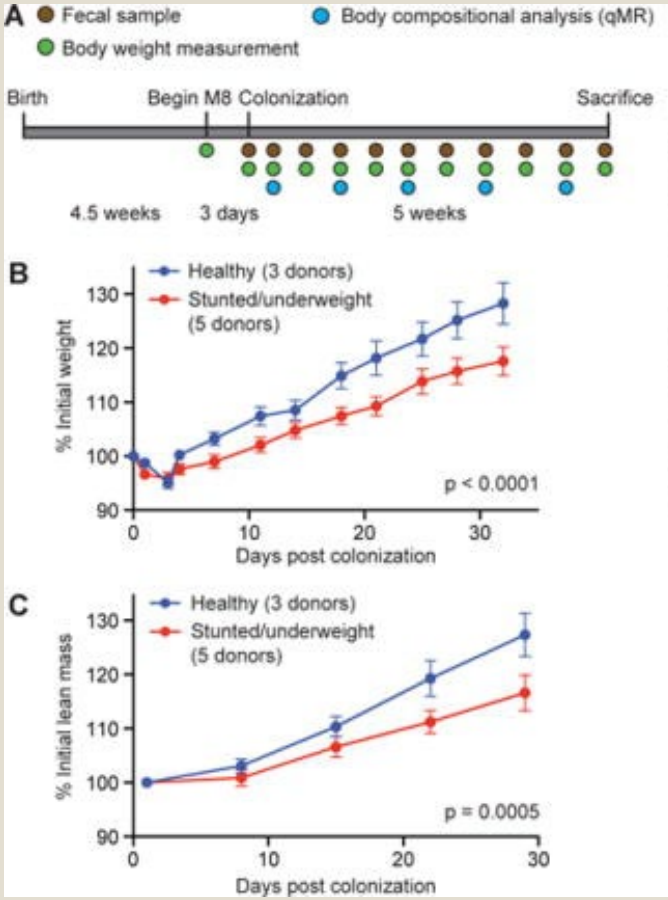
Monira et al. 2011

Poor diet and food insecurity can affect gut microbes



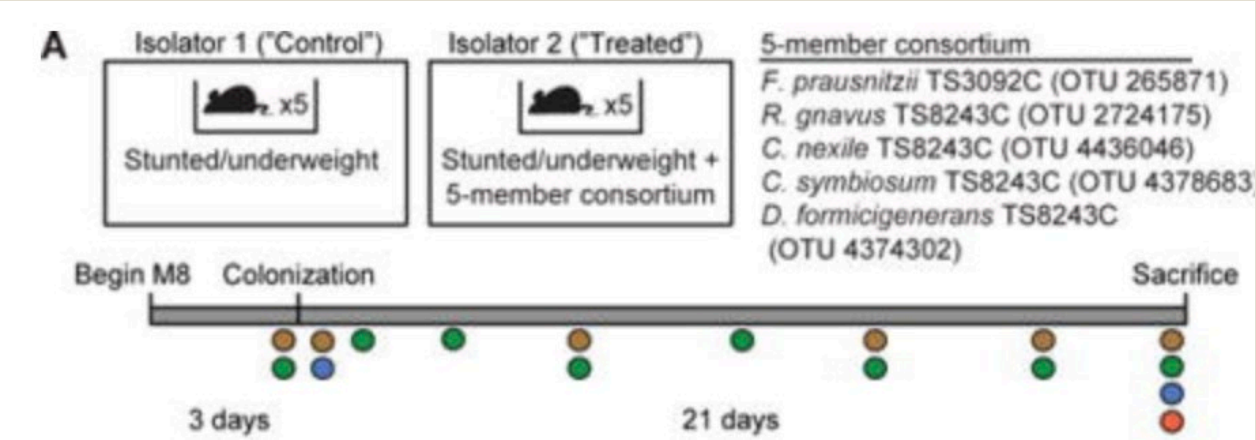
Velly et al. 2017

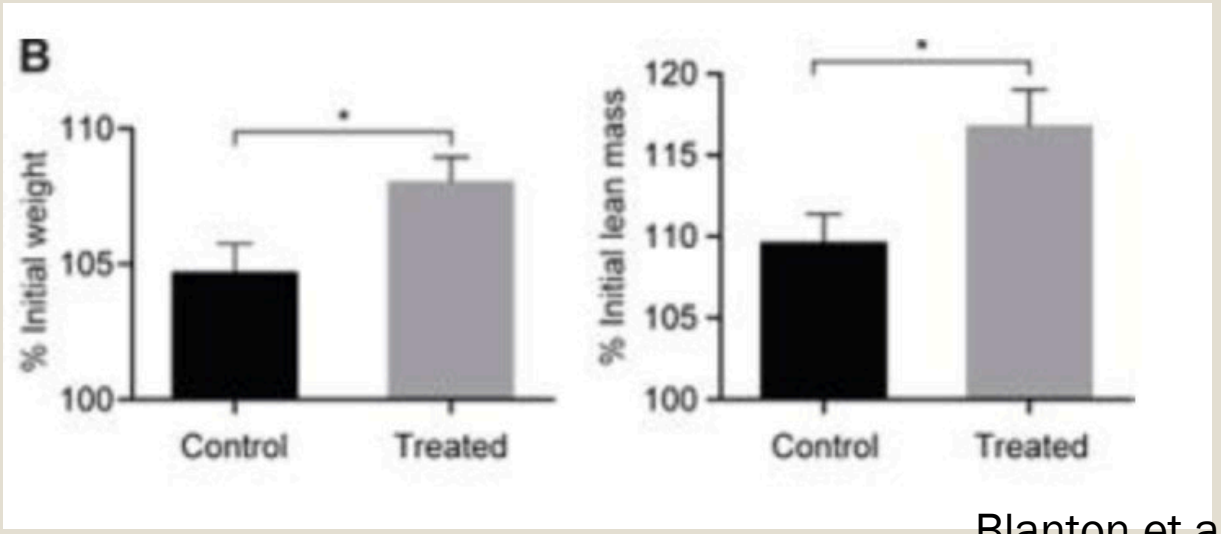
FMT from undernourished children to mice stunted growth in mice



Blanton et al. 2016

Microbes given to stunted mice to recover weight gain





Blanton et al. 2016

DISCUSSION AND HOMEWORK

Discussion

- Do we have the right to tell people what to eat?
- Wouldn't it be easier to provide a cheap meal service?

Homework

- **Assignment (3 pts)**: Peer-review of someone else's essay. **Due 7/3.**
  - *Canvas will randomly assign two essays*

- **Reading (pick 1):**
  - *Singh_2017_influence of diet*
  - *Telle-Hansen_2018_diet and inflammation*
  - *Valdes_2018_diet and health*
  - *Krajmalnik-Brown_2012_gut microbes nutrient harvesting*

Citations

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UNICEF/WHO/The World Bank, Levels and Trends in Child Malnutrition, 2018, p. 3

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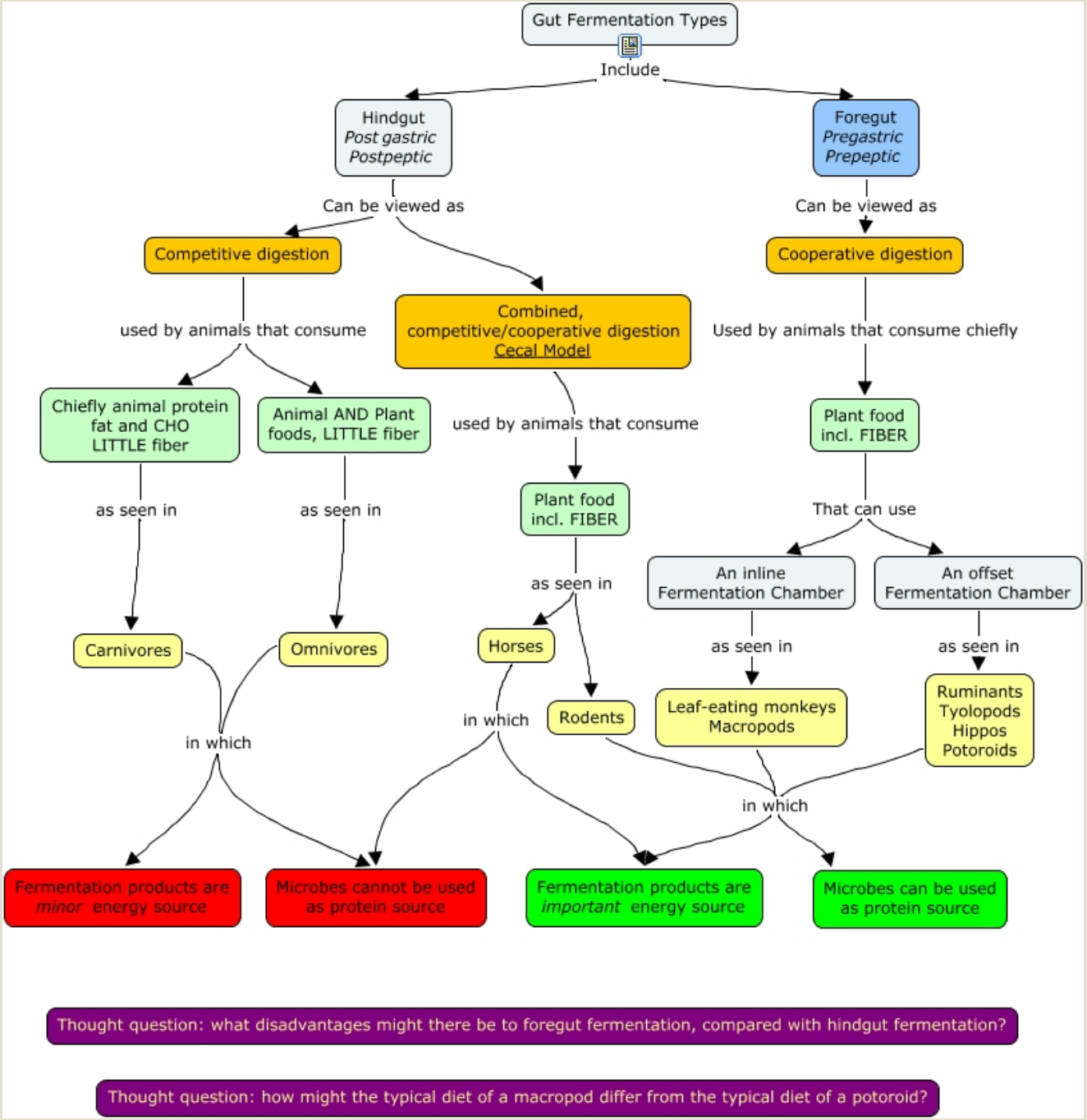
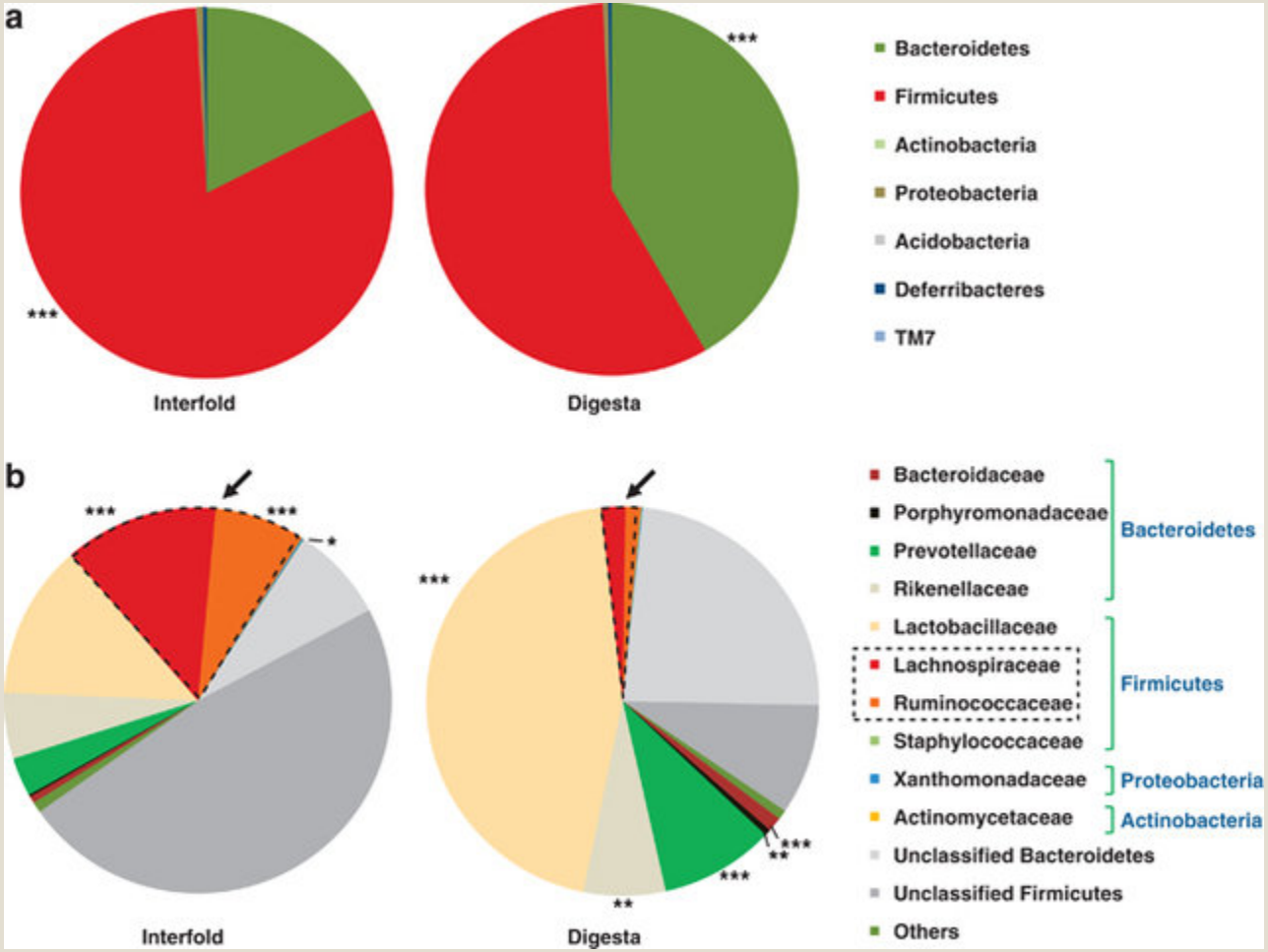
Yeoman et al. 2018 https://www.nature.com/articles/s41598-018-21440-8

Yilmaz and Li, 2018 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6315993/

END OF GENERAL LECTURE, ADDITIONAL INFO BEYOND


Gut Fermentation Types
Include
Hindgut
Post gastric
Postpeptic
Foregut
Pregastric
Prepeptic
Can be viewed as
Can be viewed as
Competitive digestion
Cooperative digestion
used by animals that consume
Combined, competitive/cooperative digestion
Cecal Model
Used by animals that consume chiefly
Chiefly animal protein fat and CHO LITTLE fiber
Animal AND Plant foods, LITTLE fiber
used by animals that consume
Plant food incl. FIBER
as seen in
as seen in
Plant food incl. FIBER
That can use
as seen in
An inline Fermentation Chamber
An offset Fermentation Chamber
Carnivores
Omnivores
Horses
as seen in
as seen in
Rodents
Leaf-eating monkeys Macropods
Ruminants Tyolopods Hippos Potoroids
in which
in which
in which
Fermentation products are minor energy source
Microbes cannot be used as protein source
Fermentation products are important energy source
Microbes can be used as protein source
Thought question: what disadvantages might there be to foregut fermentation, compared with hindgut fermentation?
Thought question: how might the typical diet of a macropod differ from the typical diet of a potoroid?

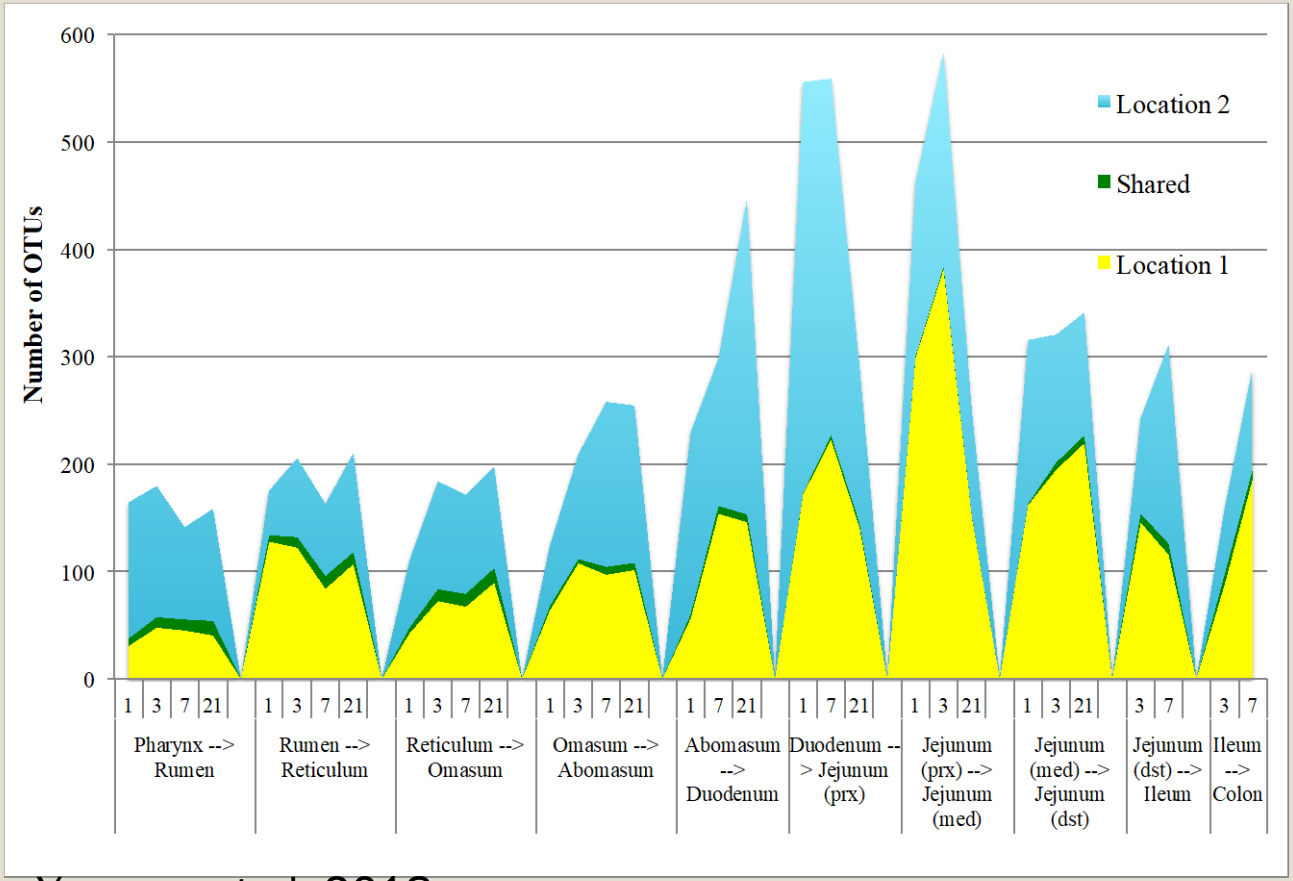
Digesta vs. epithelial (interfold) locations host different microbial populations



Nava et al. 2010

Diversity in GI tract not caused by a source: sink effect

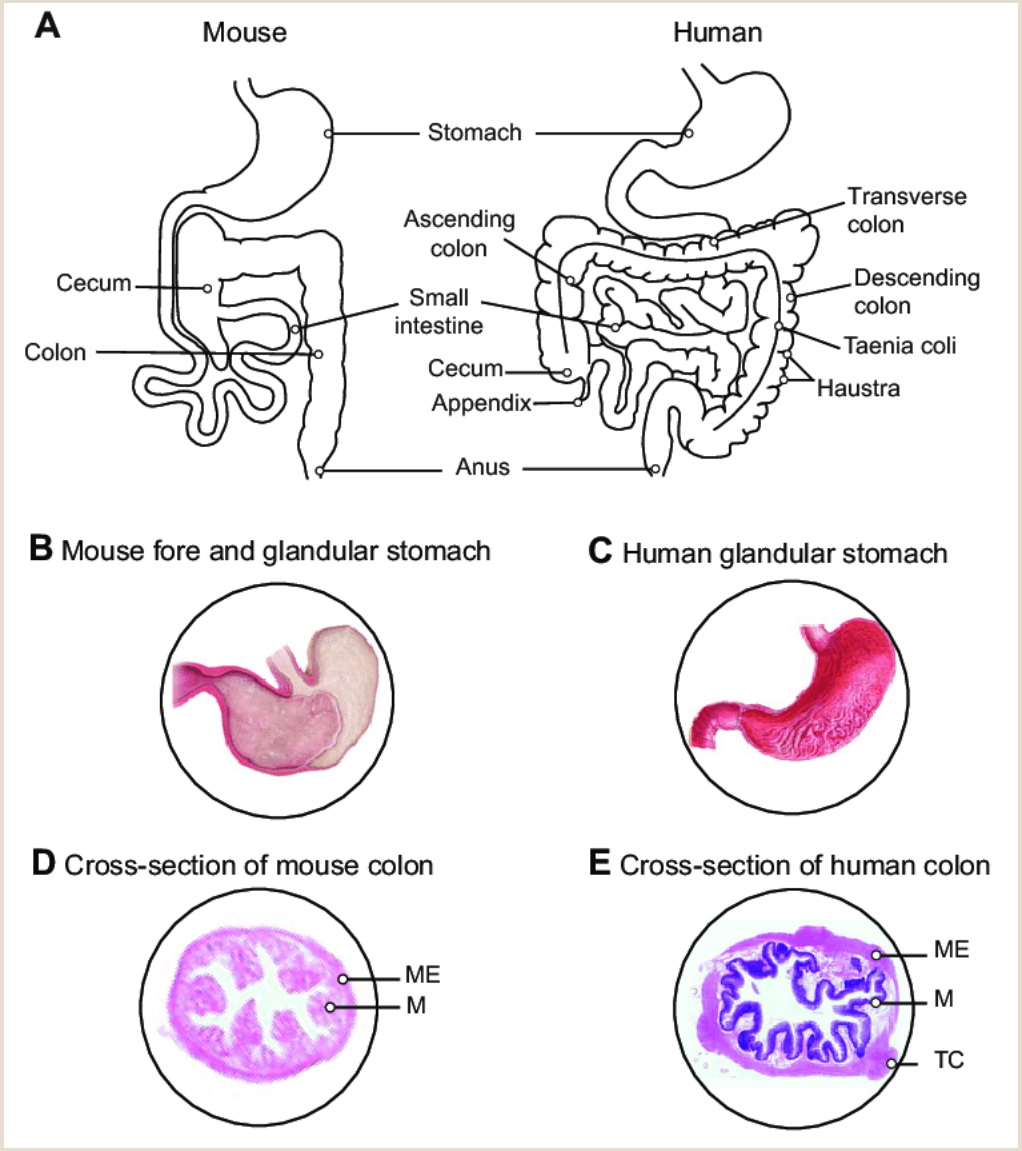
- Low number of taxa/OTUs shared with the downstream location
- Shared taxa were not always found in abundance in the downstream location



Yeoman et al. 2018

WHY MICE AREN'T A GREAT MODEL FOR HUMAN GUT STUDIES

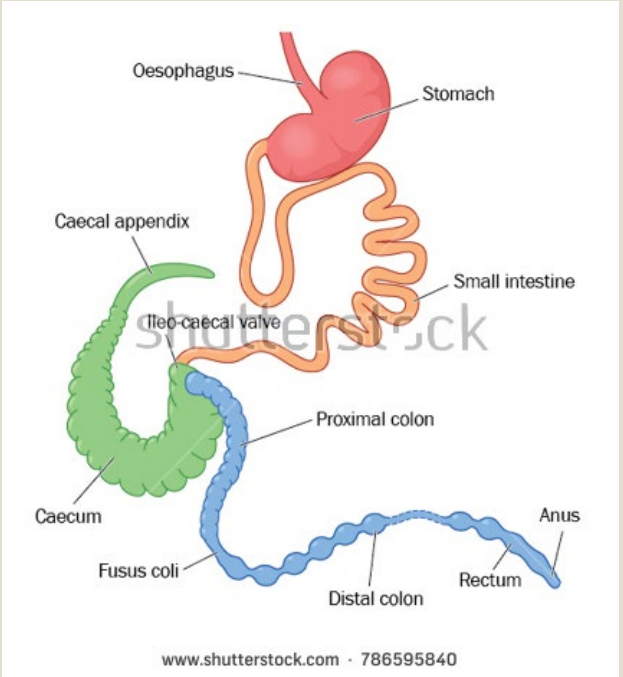
The Digestive Tract- Monogastrics

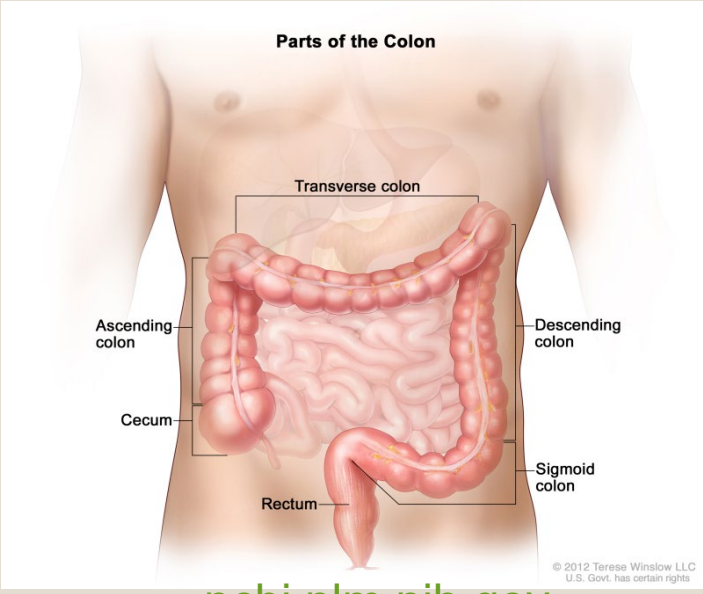


Nguyen et al. 2015

Cecum

- Blind sac (one opening)
  - *Branches off connection between small and large intestine*
  - *Digesta moves in, ferments, is moved back out*
  - *Different muscle contractions will make digesta move in/out*
- Acts as a fermentation chamber
- Allows hind-get fermenter herbivores to get more nutrition out of plants
  - *Horses and zebras*
  - *Rhinos*
  - *Rabbits and rodents*
  - *Elephants*
  - *Technically, humans, but basically non-functional*





ncbi.nlm.nih.gov

Coprophagy – eating feces