Is the concept of human carrying capacity useful for understanding why so many people are chronically hungry?

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Ecology & Evolution Seminar
University of Tokyo, Komaba Campus I
2019-07-03

20170510 Sawaguchiyama Sumata-kyo Shizuoka Japan

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Carrying capacity: origins

1. International shipping (1840s)
2. Nonhuman populations in natural systems (1870s), range & wildlife management (early 20th century)
3. K in logistic growth model (20th century)
4. Number of humans Earth can support (neo-Malthusians, since mid-20th century)

Sayre 2008 "Genesis, history, and limits of carrying capacity"

Carrying capacity in wildlife management: example

"A piece of land can support only so many animals on a continuous basis. …

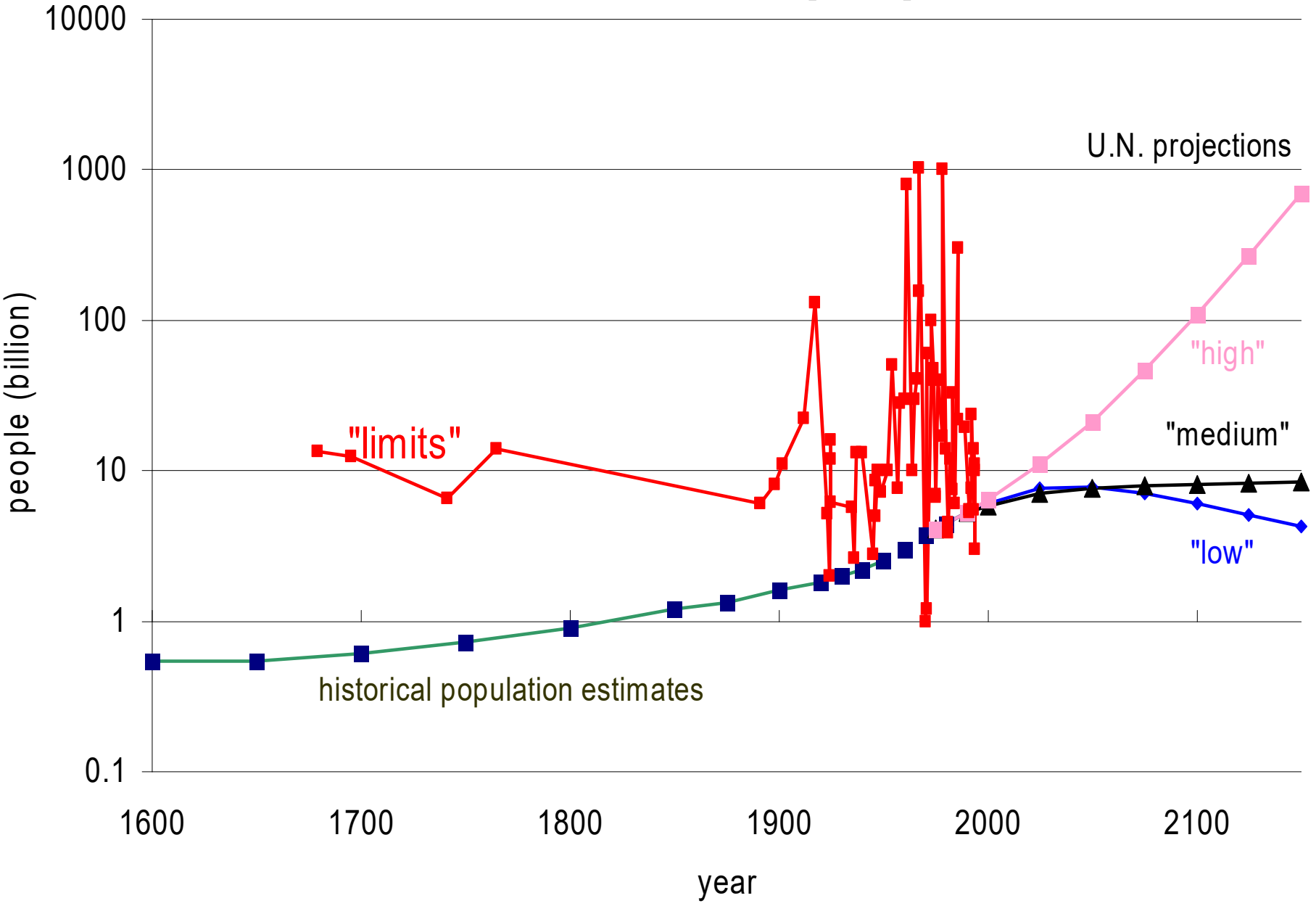
- Manage population levels to stay within carrying capacity; and
- Manage habitat to maintain or increase carrying capacity."

Knight, *Manage Your Land for Wildlife,* 2008

Existence of "carrying capacity" is weakly or not supported by data. Sayre 2008

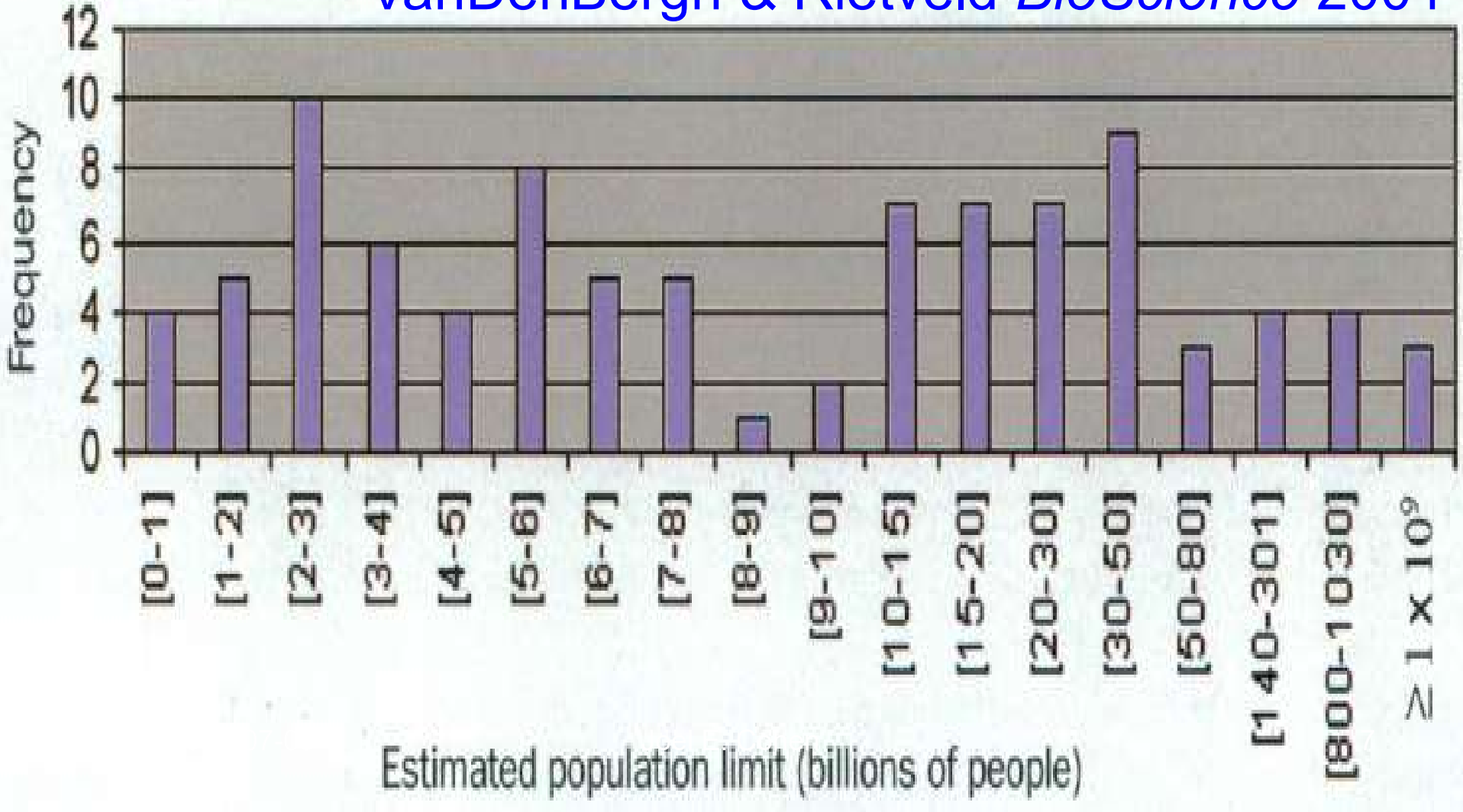
How many people can Earth support?
(1995)

“Limits” of human population

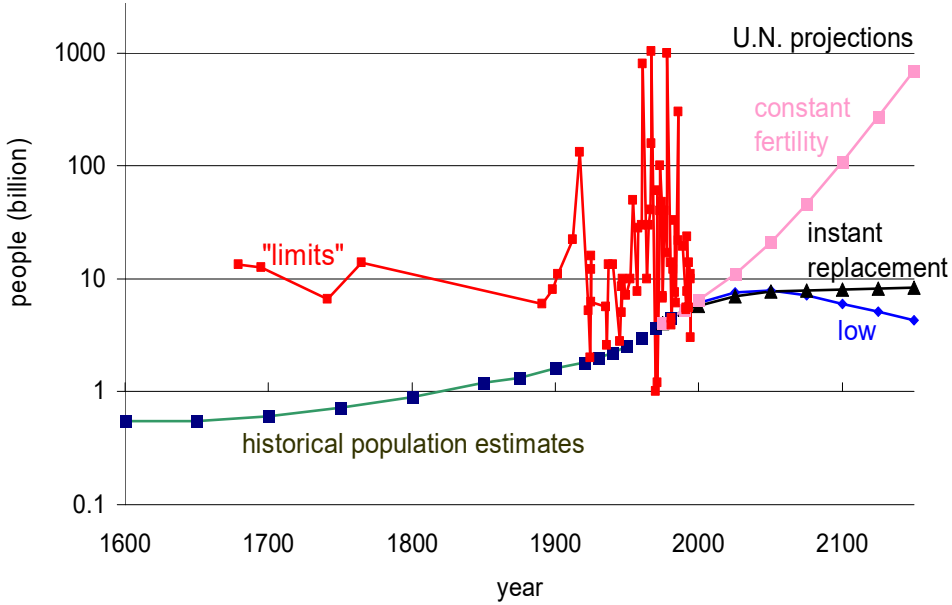


94 estimates ranged from 0.5 billion to 10^{21} billion.

VanDenBergh & Rietveld *BioScience* 2004



What do these estimates reveal?



1. Range in last 50 years: <1 billion to >1000 billion. They cannot all be right.

2. Variation of estimates increase with time.

Numbers are more political than scientific.

3. Half of estimates lie in range 4-16 billion.

Humans have entered a zone of concern.

Methods of estimating human carrying capacity

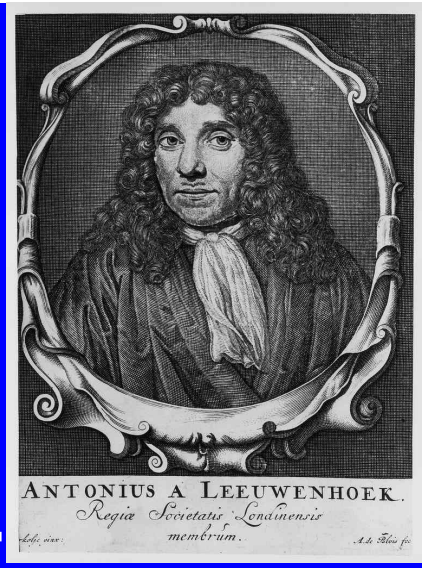
1. Assertion:

   It is true because I say so!

   Advantage: method requires few data.

   Disadvantage: estimates are highly uncertain.
   Even the uncertainty is uncertain.

Methods of estimating human carrying capacity



1. Assertion
2. Maximum density

Antoni van Leeuwenhoek 1679:
Holland has ~1 million people.
World could never be as dense as Holland.
Inhabited Earth is 13,385 times area of Holland.
Hence maximum population is 13,385 times 1 million = 13.385 billion.

Van Leeuwenhoek's method: applicable today?

Population of Holland (not Netherlands) in 2017 was ~6.47 million.

Therefore, is the human carrying capacity 6.47 million x 13,385 ~ 86.6 billion?

Methods of estimating human carrying capacity

1. Assertion
2. Maximum density by latitude

Gregory King 1695:

Maximum population depends on latitudinal bands on both sides of equator:

0-30°, 30-55°, 55-70°, 70-90°

Depending on assumed maximum density, maximum population is 6.3-12.5 billion.

Methods of estimating human carrying capacity

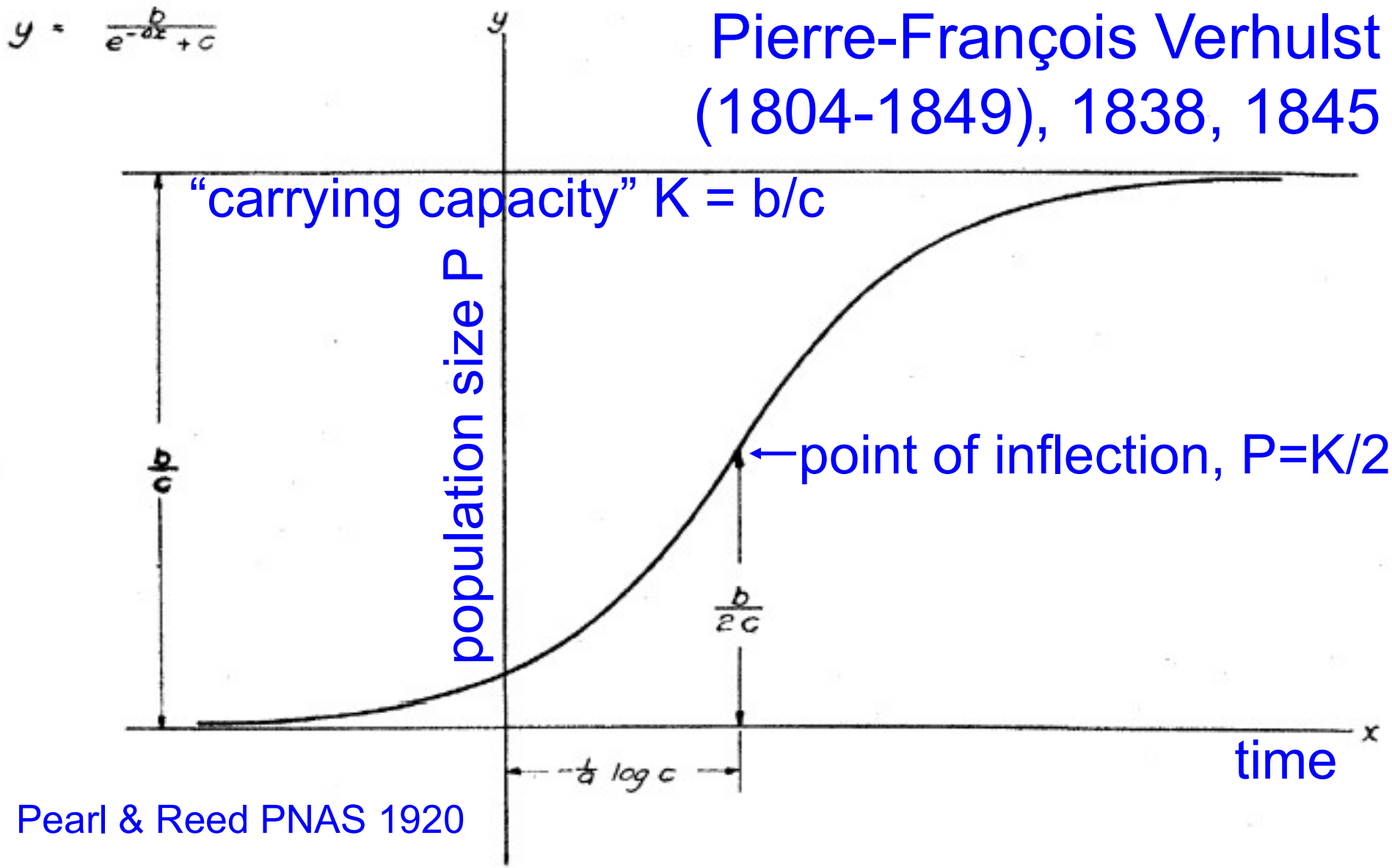
1. Assertion
2. Maximum density (by latitude)
3. Logistic curve (Verhulst 1838, Pearl 1920):

$P(t)$ = population at time t,

K = "carrying capacity" (not Verhulst's term)

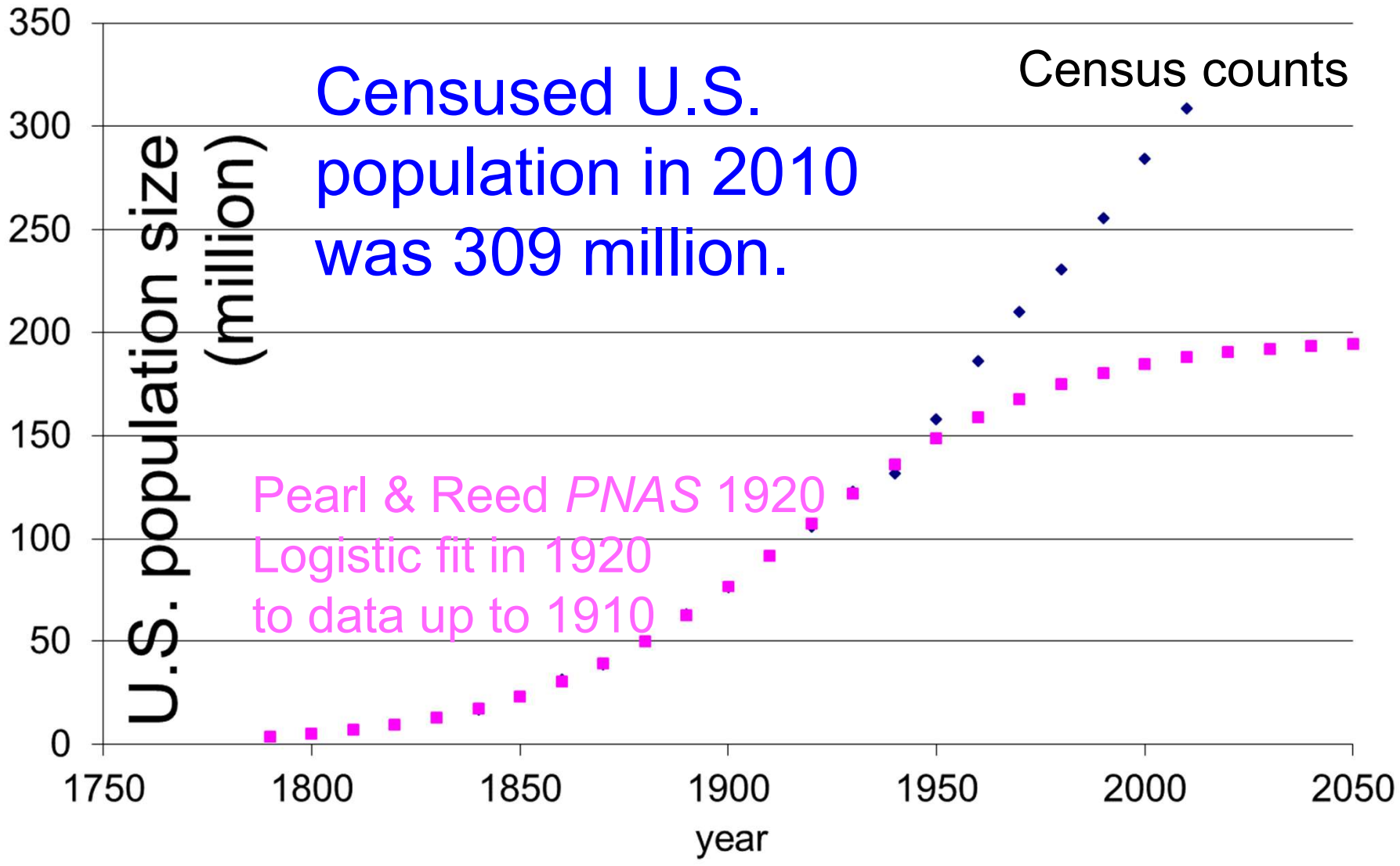
$$\frac{dP(t)}{dt} = rP(t)\big(K - P(t)\big).$$

Logistic model solves dP/dt = [r(K-P)]P.



Pearl & Reed PNAS 1920

Logistic predicted maximum U.S. population would be 197,274,000.



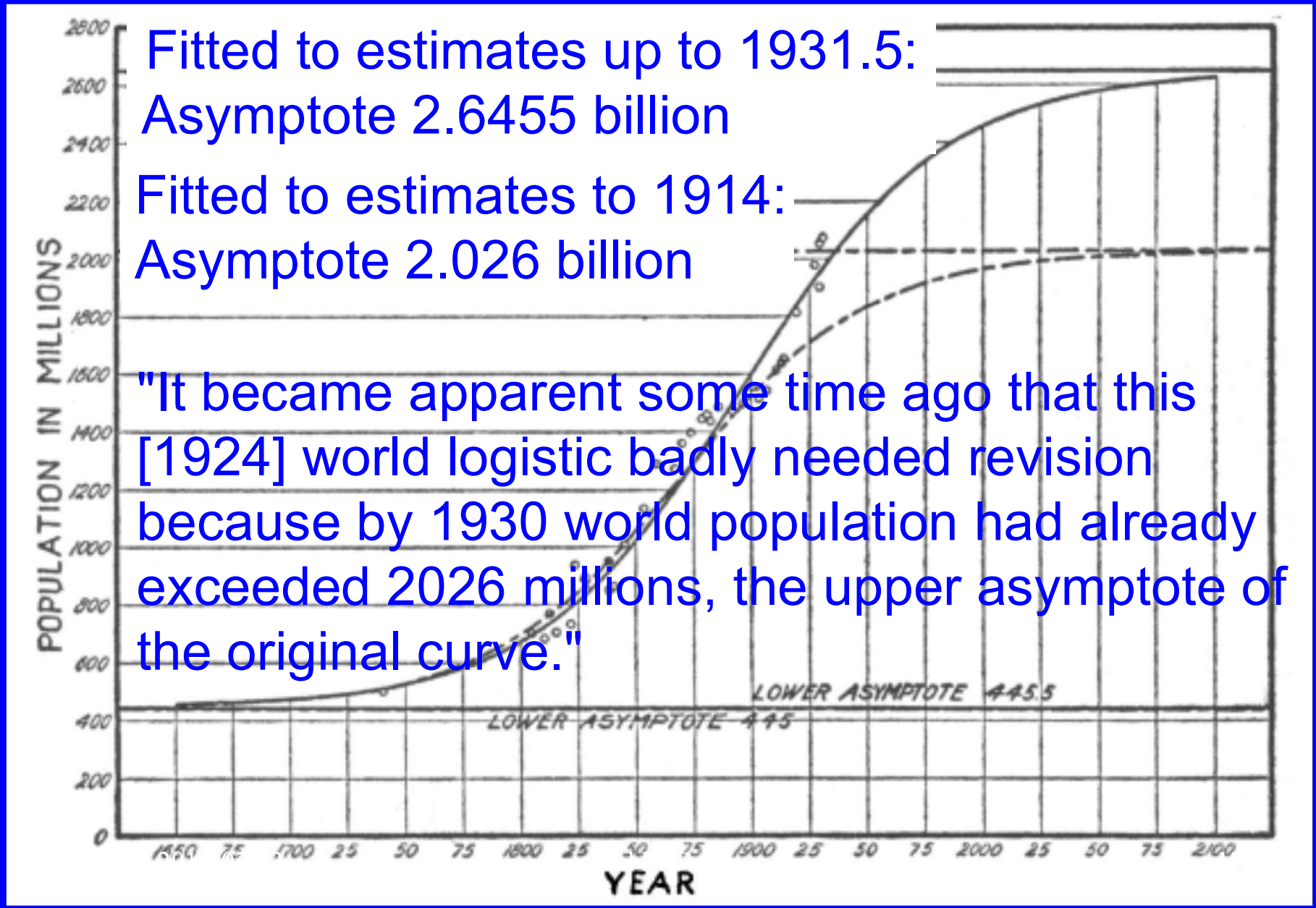
World population growth according to Pearl

Pearl, *Studies in Human Biology*, 1924 predicted world population would never exceed 2.026 billion.

World population passed 2 billion around 1927-1930.

If countries grow logistically, then global population (their sum) does not.

"World Population Growth," Pearl & Gould 1936



"World population growth"

Pearl & Gould *Human Biology* 1936

"A logistic curve fitted to the data on world population growth leads to an upper asymptotic value for the present cycle of 2,645.5 million, rather closely approached by about 2100 A. D."

"We wish to emphasize again that we have no inside information as to whether the asymptote … will reasonably accord with reality in the year 2100, and are not to be understood as advocating its absolute validity or significance."

Methods of estimating human carrying capacity

1. Assertion
2. Maximum density (by latitude)
3. Logistic curve
4. Single limiting factor:
   estimate total supply,
   estimate minimum requirement per person.

Single limiting factor: food

G. H. Knibbs 1912, Albrecht Penck 1925:
maximum population =
maximal food supply divided by minimal individual food requirement.

$$\frac{\text{Food supply}}{\text{Requirement}}$$

G. H. Knibbs
statistician
1858-1929

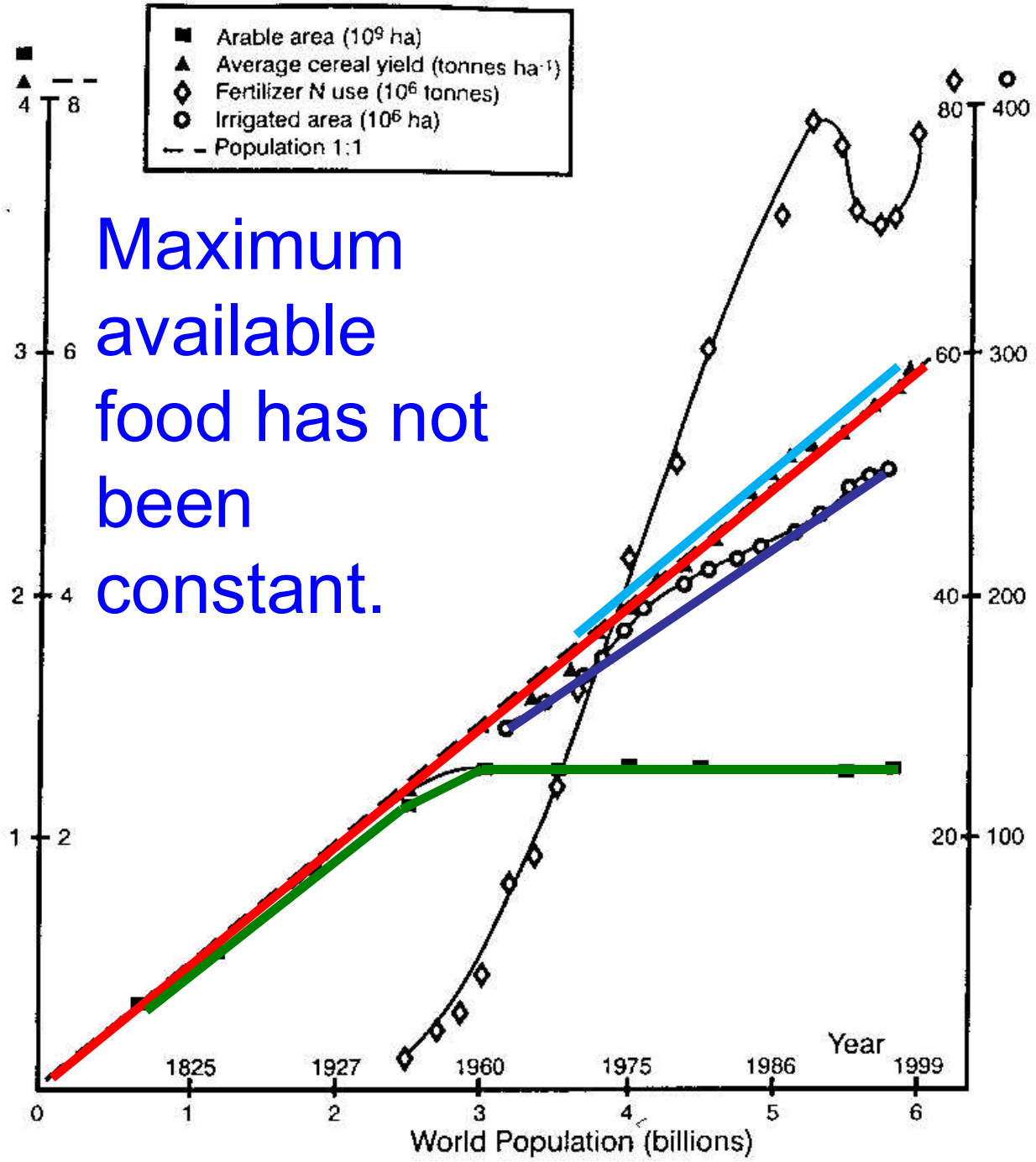
Albrecht Penck
geomorphologist
1858-1945

Food supply & demand are not constants of nature.

Maximal food supply depends on prices, subsidies, credit, cultivars, transport, refrigeration, storage, water, soil maintenance, control of biological competitors, climate, farmer education, fertilizers, irrigation, …

Food requirement per person depends on diet, activity, temperature (culture & environment), age, infectious disease, education, religion, …

As population surpassed 3 billion in 1960, arable area leveled off, but average cereal yield rose with increasing fertilizer nitrogen use and irrigation.



Urban & rural people have different food habits in developing countries.

Rural residents eat more cereals, tubers & roots.

Urban residents eat more meat, fruits & vegetables.

Diets rich in meats require feedgrains & meals, so demand more cereal than diets based on direct cereal consumption.

Changes in consumption patterns brought about by urbanization will affect global food supply, markets, & trade.

What is food?

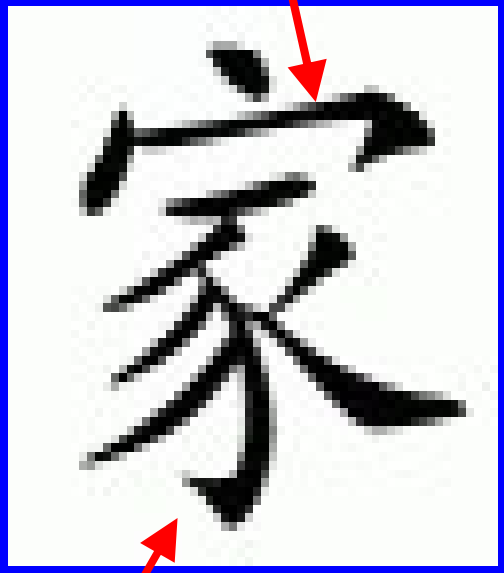
"… natural species are chosen not because they are 'good to eat' but because they are 'good to think.' "

Claude Levi-Strauss

(1962, *Le Totémisme aujourd'hui*)

“Home” in Chinese

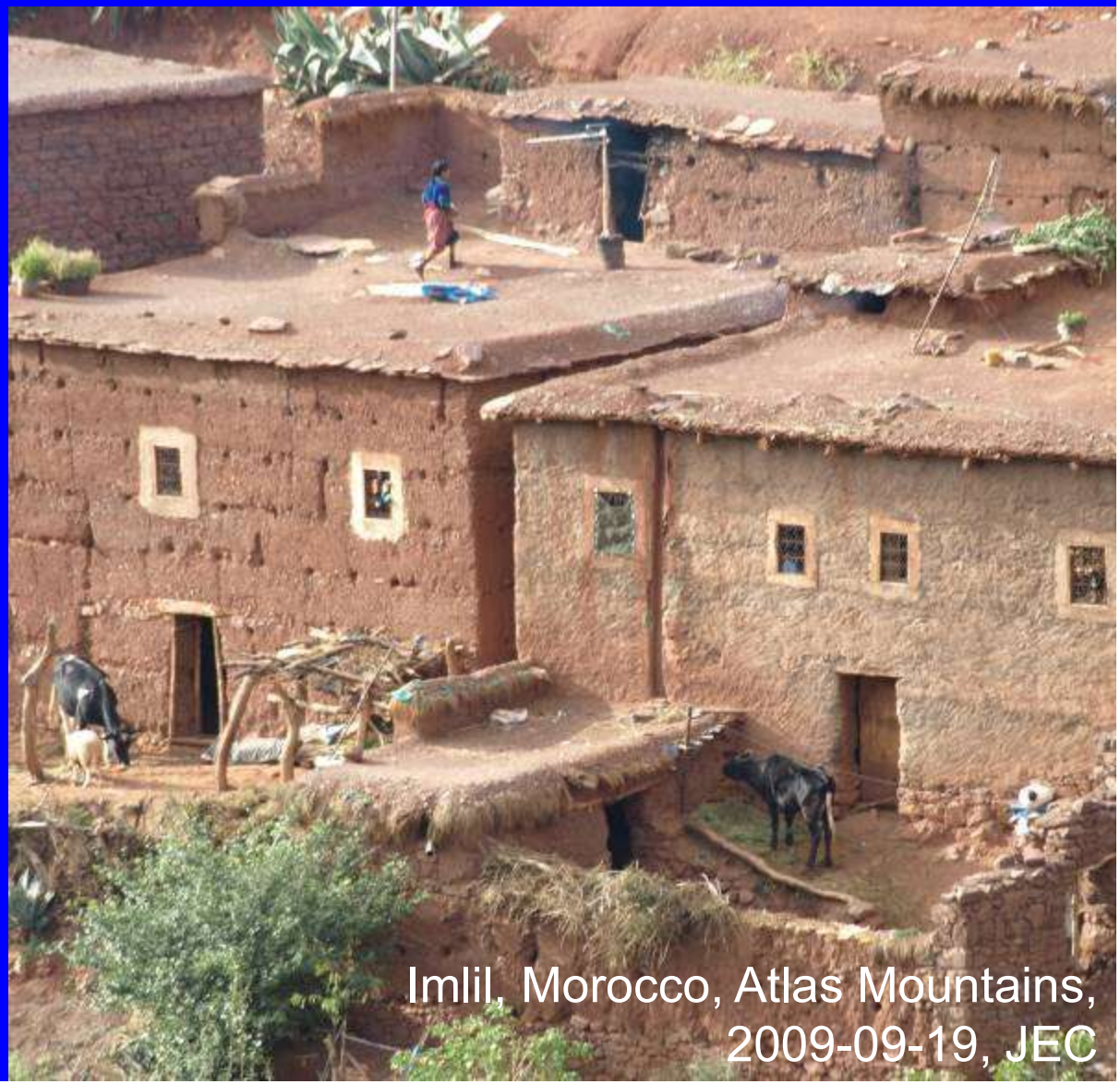
roof



pig

For >1 billion people, pig is part of home.

For >1 billion people, pig is forbidden.



Imlil, Morocco, Atlas Mountains, 2009-09-19, JEC

Photo credit: Peter Halasz

Green revolution coincided with decline of population growth rate.

Population growth rates fell in countries with more abundant food because of lower child mortality & lower birth rates.

The 1960s marked both the peak of the global population growth rate, which has since fallen by half, & the beginning of the "green revolution."

Is food the single limiting factor for human population?

Population growth is most rapid in some areas where food is scarcest.

Population growth is slowest in many areas where food is most abundant.

How can food be the single limiting factor for human population?

Single “limiting factors" for human population?

Water: ‘More than any other factor, availability of water determines the ultimate population capacity of a geographic province.’ Brian J. Skinner

1969, geologist at Yale University

Same claim for: food, land, energy, biologically accessible nitrogen, phosphorus, light, soil, space, diseases, waste disposal, nonfuel minerals, forests, biological diversity, & climatic change.

Many unsupported claims are in conflict!

Methods of estimating human carrying capacity

1. Assertion
2. Maximum density (by latitude)
3. Logistic curves
4. Single limiting factor
5. Single currency for multiple factors (e.g. land, energy, "ecological footprint")

“Ecological footprint”

Wackernagel *et al. PNAS* 2002 assumed that most resources humans consume & wastes humans generate "can be measured in terms of the biologically productive [land] area necessary to maintain these flows (those resource and waste flows that cannot are excluded from the assessment)."

Human needs are multidimensional.

If all energy production were nuclear, no "biologically productive land" would be needed to draw down emitted CO_2. But no amount of "biologically productive land" will dispose of spent nuclear fuels.

No amount of "biologically productive land" will restore lost biological species & habitat types.

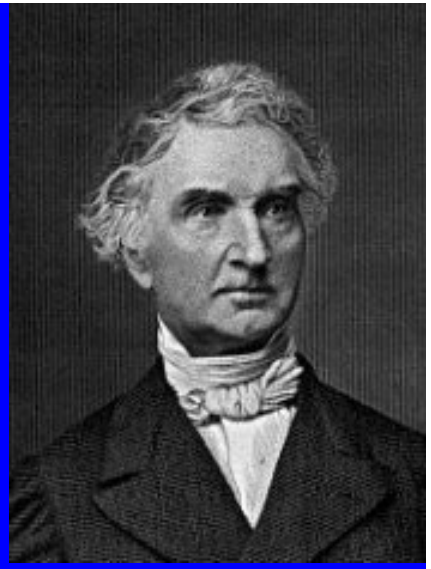
No amount of "biologically productive land" will provide ores & rare earths, discover new prevention or cures for diseases, generate technology, lead institutions for public order, or create art.

Methods of estimating human carrying capacity

1. Assertion
2. Maximum density (by latitude)
3. Logistic curves
4. Single limiting factor
5. Single currency for multiple factors
6. Law of the minimum for independent limiting factors

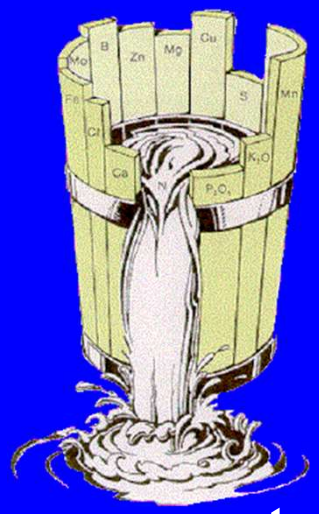
Karl Sprengel
1787-1859
stated it in
1828.

Justus von
Liebig
1803-1873
popularized it
~1855.



Law of the minimum for independent limiting factors

Law of minimum for population size



Maximum human population

= minimum of

{

Max food supply / min food requirement,

Max wood supply / min wood requirement,

Max water supply / min water requirement

}

Challenges to law of the minimum

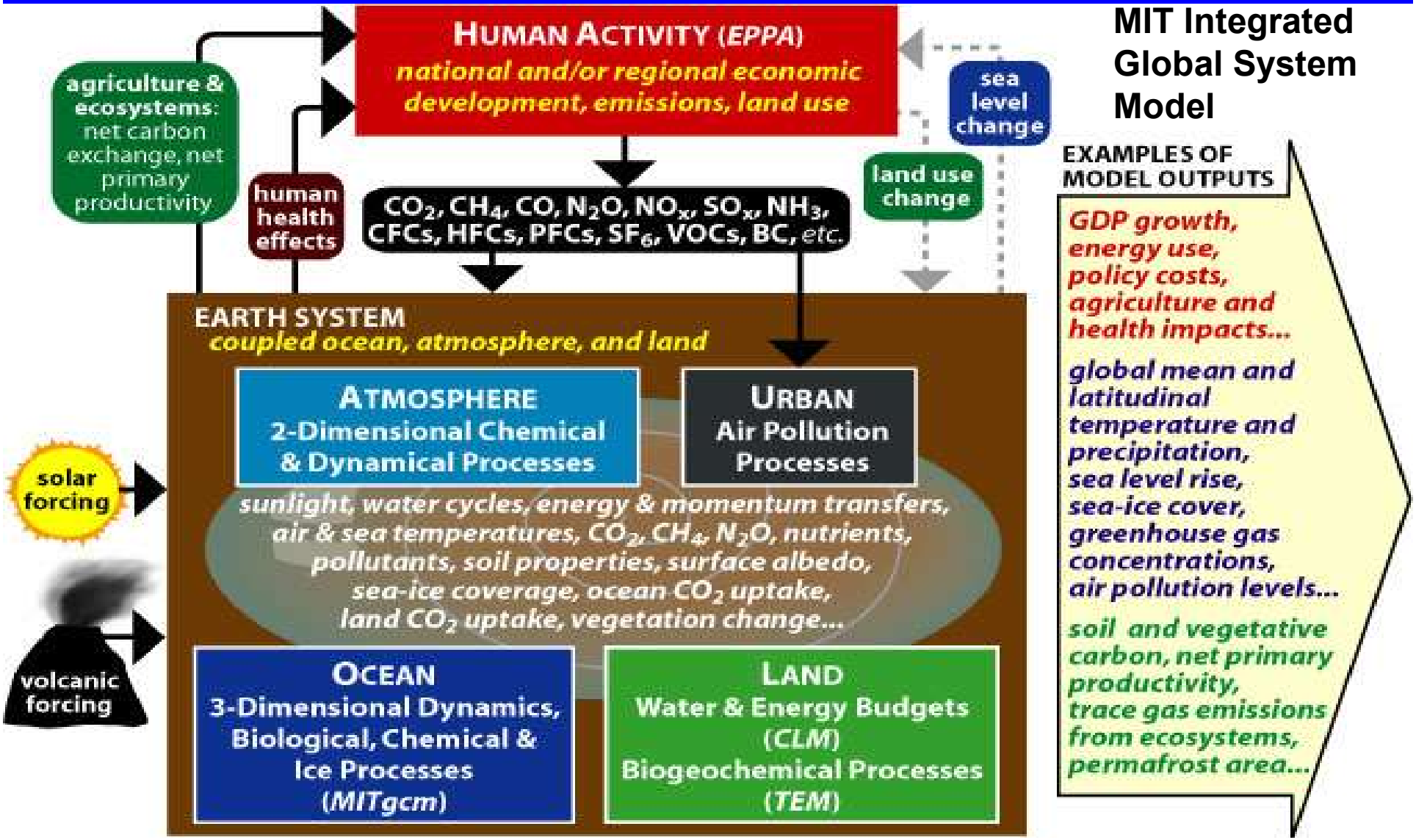
What if human carrying capacity depends on the right mix (proportions) of non-substitutable factors?

E.g., what if there are trade-offs in use of water for forests & food?

Methods of estimating human carrying capacity

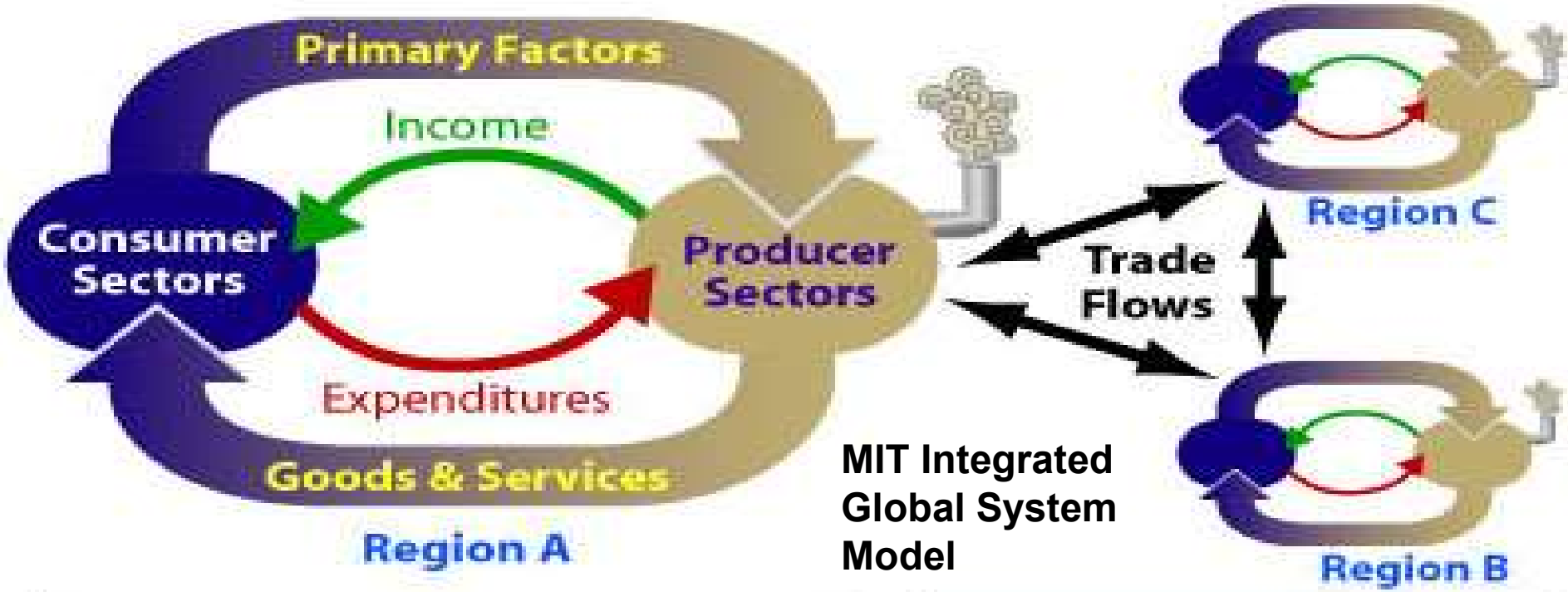
1. Assertion
2. Maximum density (by latitude)
3. Logistic curves
4. Single limiting factor
5. Single currency for multiple factors
6. Independent limiting factors
7. Multiple interacting limiting factors

Multiple interacting limiting factors: system models



Human activity submodel

MIT Emissions Prediction and Policy Analysis (EPPA) Model



MIT Integrated Global System Model

Model Features

- All greenhouse-relevant gases
- Flexible regions
- Flexible producer sectors
- Energy sector detail
- Welfare costs of policies

Mitigation Policies

- Emissions limits
- Carbon taxes
- Energy taxes
- Tradeable permits
- Technology regulation

Human carrying capacity has not been defined & measured in any clear, persuasive way.

Why are so many people chronically hungry?
Food is superabundant.

BUSINESS NEWS | Tue Apr 11, 2017 | 11:10pm IST

Grains piled on runways, parking lots, fields amid global glut

Reuters

A mountain of grain sits in a storage pile, as midwestern grain farmers and merchants struggle to find storage space after three years of record harvests, near Minburn, Iowa, U.S., March 11, 2017. REUTERS/Scott Morgan

1/4

“World stockpiles of corn and wheat are at record highs.”

REUTERS BUSINESS NEWS Tue Apr 11, 2017 11:10pm IST

Farmers face similar problems across the globe. World stockpiles of corn and wheat are at record highs. From Iowa to China, years of bumper crops and low prices have overwhelmed storage capacity for basic foodstuffs.

Global stocks of corn, wheat, rice and soybeans combined will hit a record 671.1 million tonnes going into the next harvest - the third straight year of historically high surplus, according to the U.S. Department of Agriculture (USDA). That's enough to cover demand from China for about a year.

“Never has the world produced so much more food than can be consumed in one season.”

“A global grains glut is now in its fourth year, with supplies bloated by favorable weather, increasingly high-tech farm practices and tougher plant breeds.”

Reuters September 27, 2017 / 7:06 AM

Markets

Lack of Grain Storage Is Bad News for Midwest Farmers

The trifecta of tariffs, lackluster prices and near-perfect growing conditions means space is limited.

By David Fickling
October 4, 2018 18:30

https://www.bloomberg.com/opinion/articles/2018-10-04/trade-war-is-making-the-grain-glut-worse

2019-07-03

The trade war is backfiring in Trump Country. *Photographer: Scott Olson/Getty Images North America*

FAO, *World Food Situation*, 01 Nov 2018

Cereal grains 2017/18:
>2.6 billion tonnes production & use,
815 million tonnes ending stocks

1 tonne (1000 kg) of carbohydrate supplies enough energy for 4-5 people for 1 year.

200 kg of this grain provides	kilocalories per day for a year
Rice	2,000
Wheat pasta	2,032
Corn (maize)	1,984
Oatmeal	2,028

2.6 bln tonnes of cereal could feed 10-13 billion people.

Scarcity of food does not limit global population growth, contrary to Malthus.

Malthus theorized that exponential population growth must outstrip linear increase of agricultural production.

People grow more than enough cereals to provide adequate food energy for all people.

Malthus's theory fails to explain today's massive chronic hunger.

Many people, especially children, are hungry.

Famine differs from chronic undernourishment.

Famine makes news.

Chronic hunger rarely makes news.

These are famine victims.

Reuters / Friday, September 09, 2016
A malnourished boy lies on a bed at a hospital in the Red Sea port city of Houdieda, Yemen.
USED WITH PERMISSION OF REUTERS

Houdieda, Yemen, Sept. 9, 2016.
REUTERS/Abduljabbar Zeyad
Used by permission.

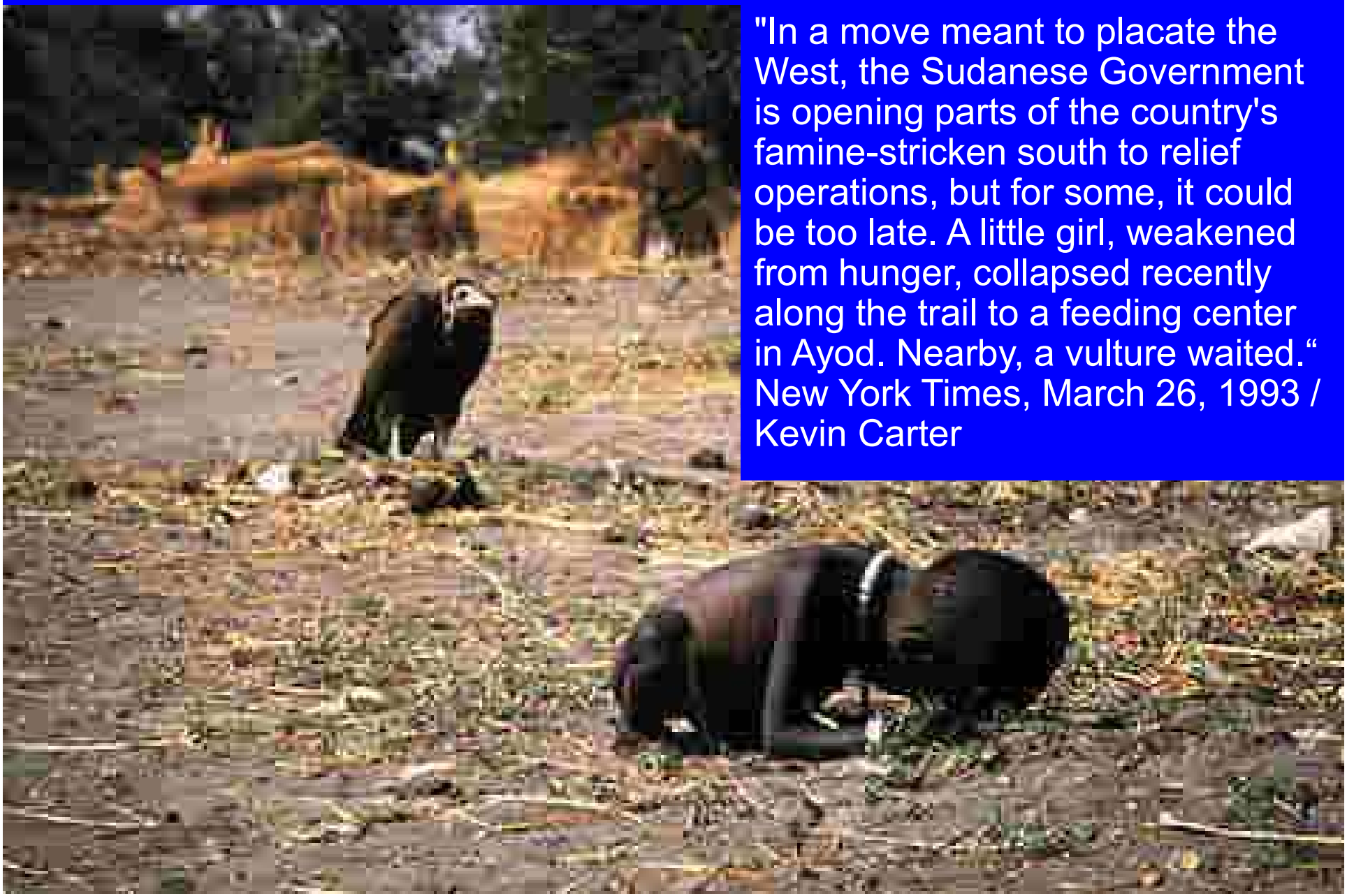

“Malnourished girl Jamila Ali Abdu, 7, lies on a hospital bed before she died in the Red Sea port city of Hodeidah, Yemen, May 2, 2017. REUTERS/ Abduljabbar Zeyad”

"Amal Hussain, 7, is wasting away from hunger. The Saudi-led war in Yemen has pushed millions to the brink of starvation. (Tyler Hicks for The New York Times)" Amal Hussain died the day after this picture was taken. https://www.wnycstudios.org/story/photographingstarving-children-yemens-war 2018-10-31

"Bassam Mohammed Hassan, who suffers from severe malnutrition and cerebral palsy, at a hospital in Sana, Yemen. (Tyler Hicks for The New York Times)“ https://www.wnycstudios.org/story/photographingstarving-children-yemens-war 2018-10-31

Kevin Carter

Sudan 1993

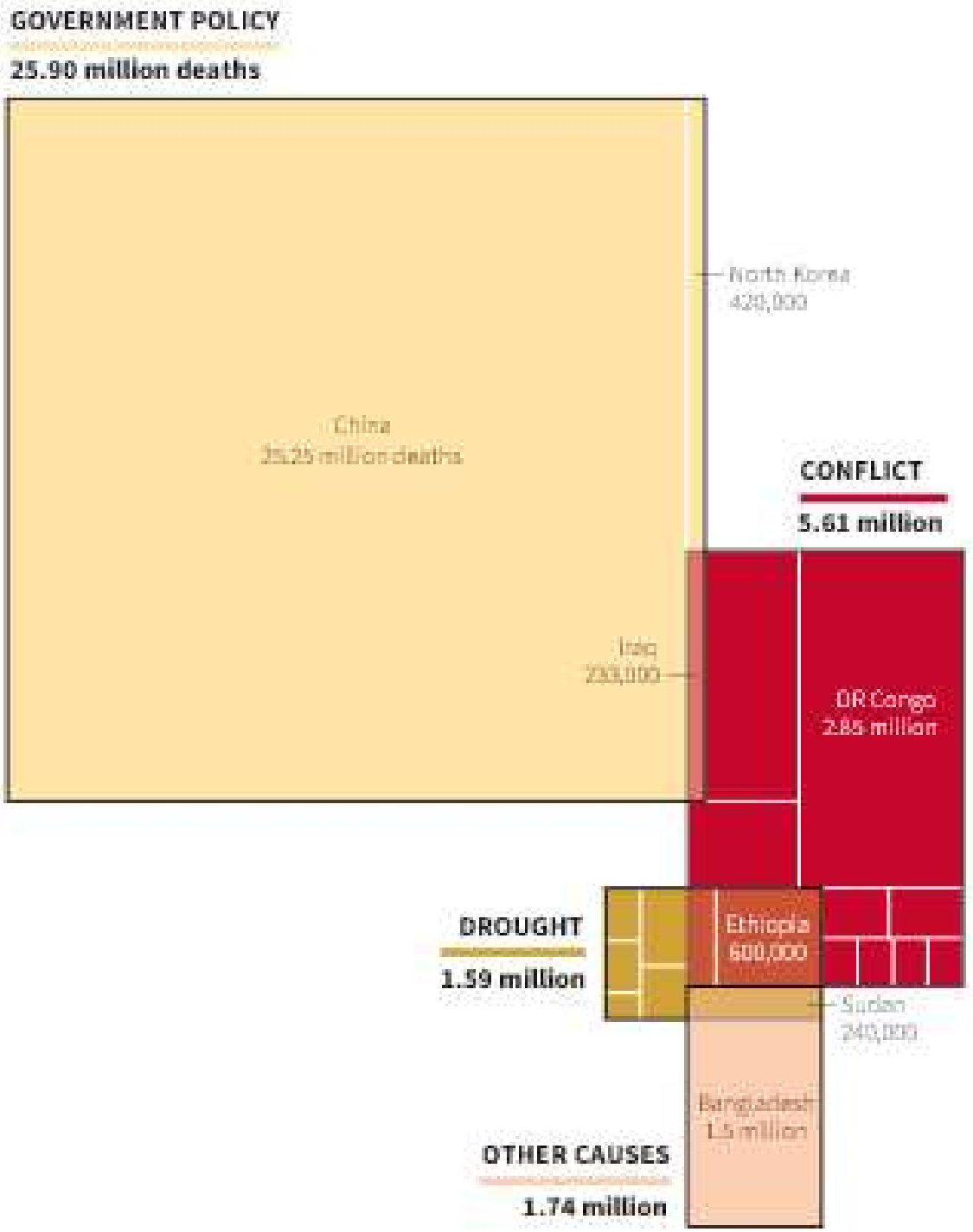


"In a move meant to placate the West, the Sudanese Government is opening parts of the country's famine-stricken south to relief operations, but for some, it could be too late. A little girl, weakened from hunger, collapsed recently along the trail to a feeding center in Ayod. Nearby, a vulture waited.“ New York Times, March 26, 1993 / Kevin Carter

Government policy, conflict, drought, & flooding killed ~35 million in major famines since 1950.

Reuters, Slipping into famine 2017-05-22, Tufts U World Peace Foundation

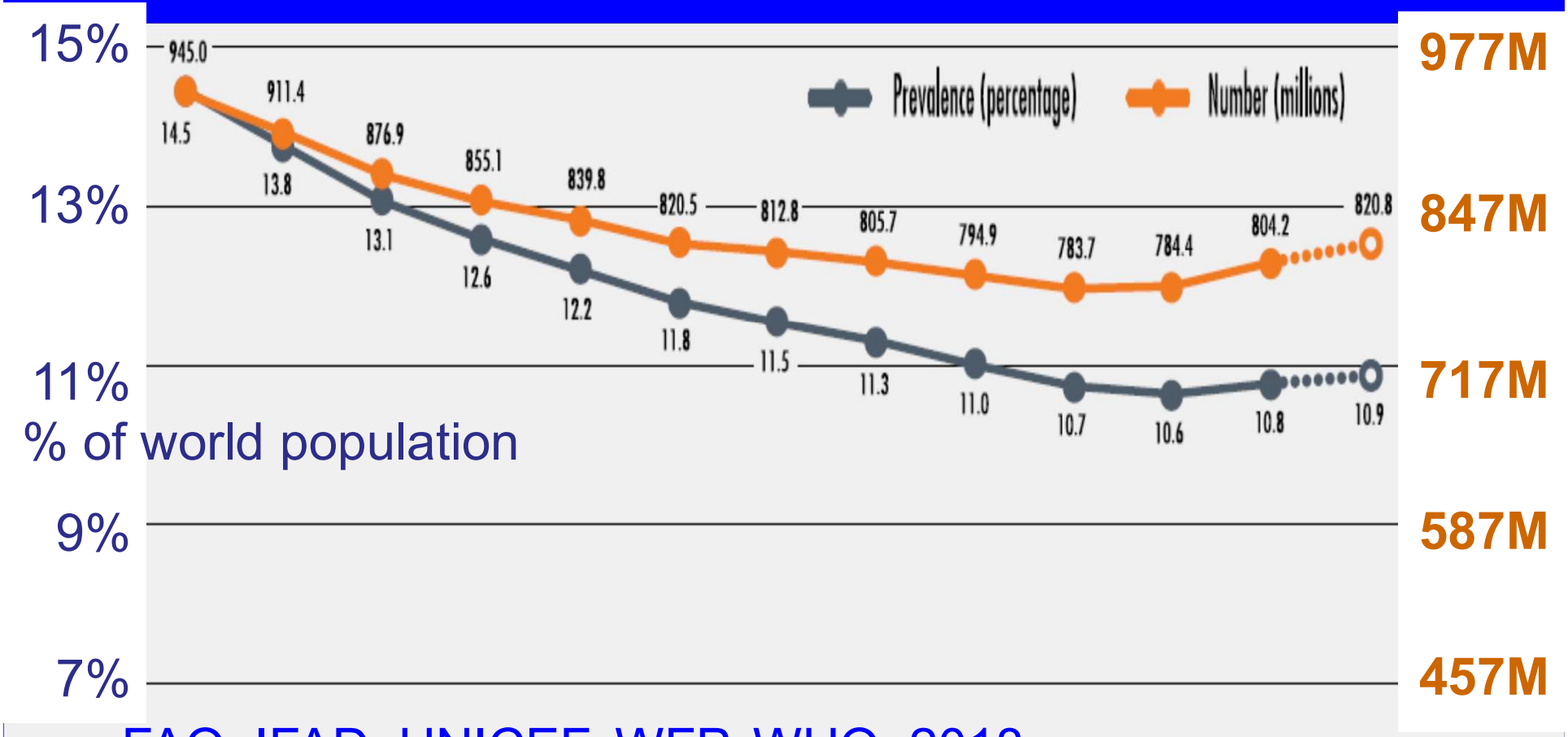
2019-07-03



Chronic hunger

"Undernourishment or chronic hunger is the inability of persons to consume enough food sufficient to meet dietary energy requirements." Food & Agricultural Organisation

Global number of chronically undernourished rose since 2014.



FAO, IFAD, UNICEF, WFP, WHO 2018

State of Food Security and Nutrition in the World 2018

4 anthropometric measures of hunger in children

Stunting: short height for age (chronic)

Wasting: low weight for height (acute)

Underweight: low weight for age (either/both)

Mid-upper arm circumference (MUAC): circumference of left upper arm midway between tip of shoulder (acromion) & tip of elbow (olecranon process) – best predictor of death

Child may be stunted & overweight, or stunted & wasted.

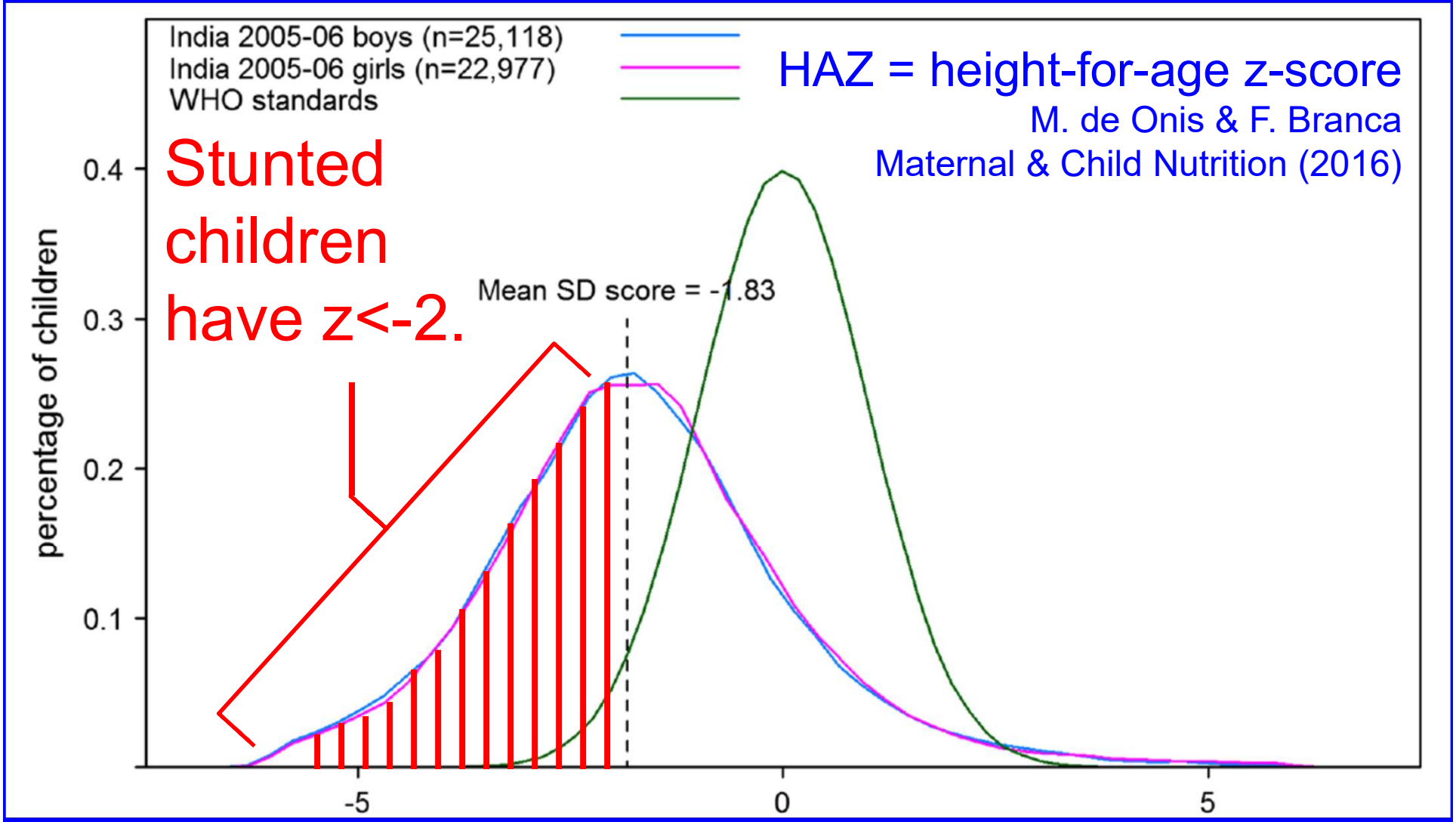
Stunting

Stunting indicates chronic undernutrition and/or chronic infection.

Child suffers "stunting" if height of child falls below 2 standard deviations below median height of child of that age by WHO Child Growth Standards.

WHO Nutrition Landscape Information System

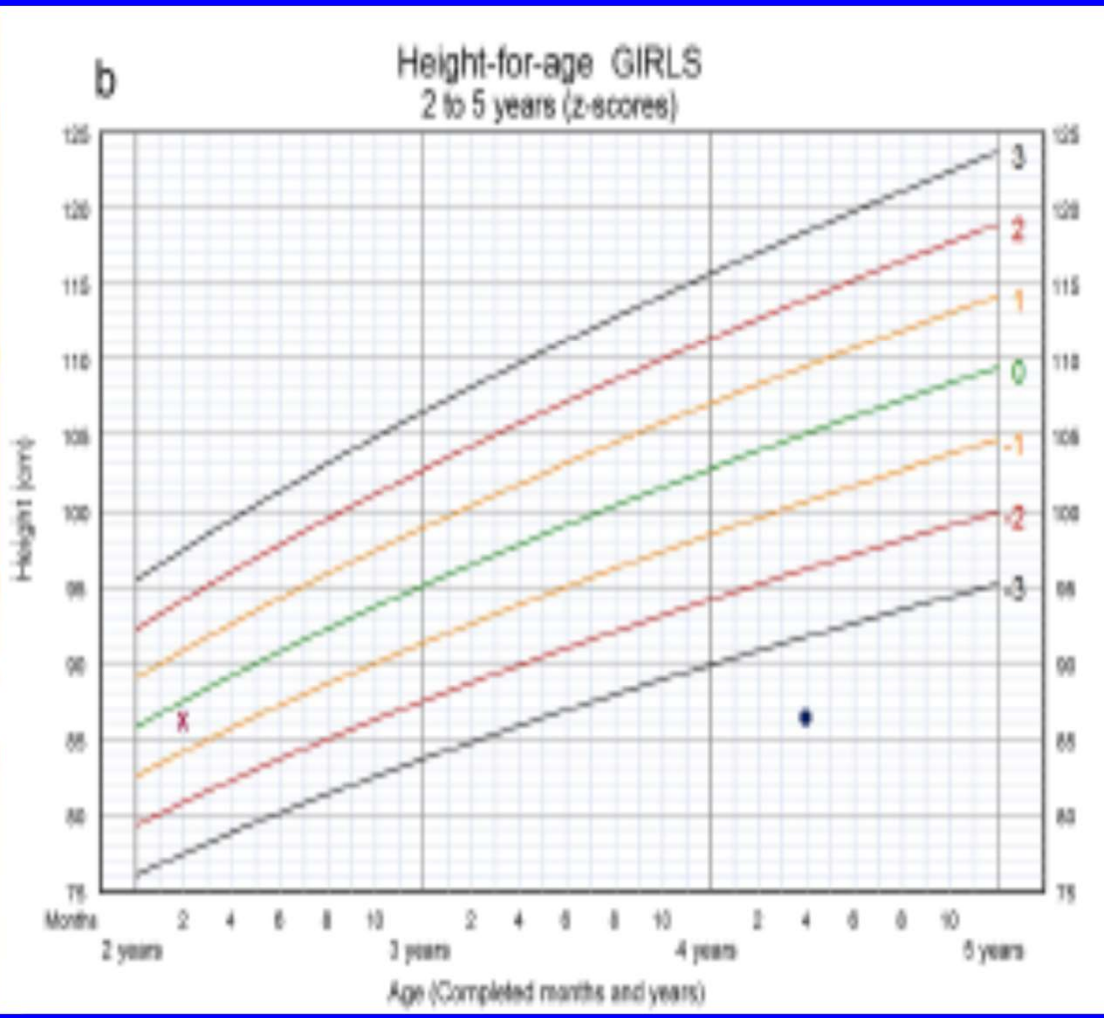
Example: stunting in India



z-score = standard deviations from median for age

Stunting is not obvious to eye.

2 girls in Maldives



M. de Onis & F. Branca *Maternal & Child Nutrition* (2016)

Guatemala: 45.7% of children under 5 y were stunted, 2017.

European Commission

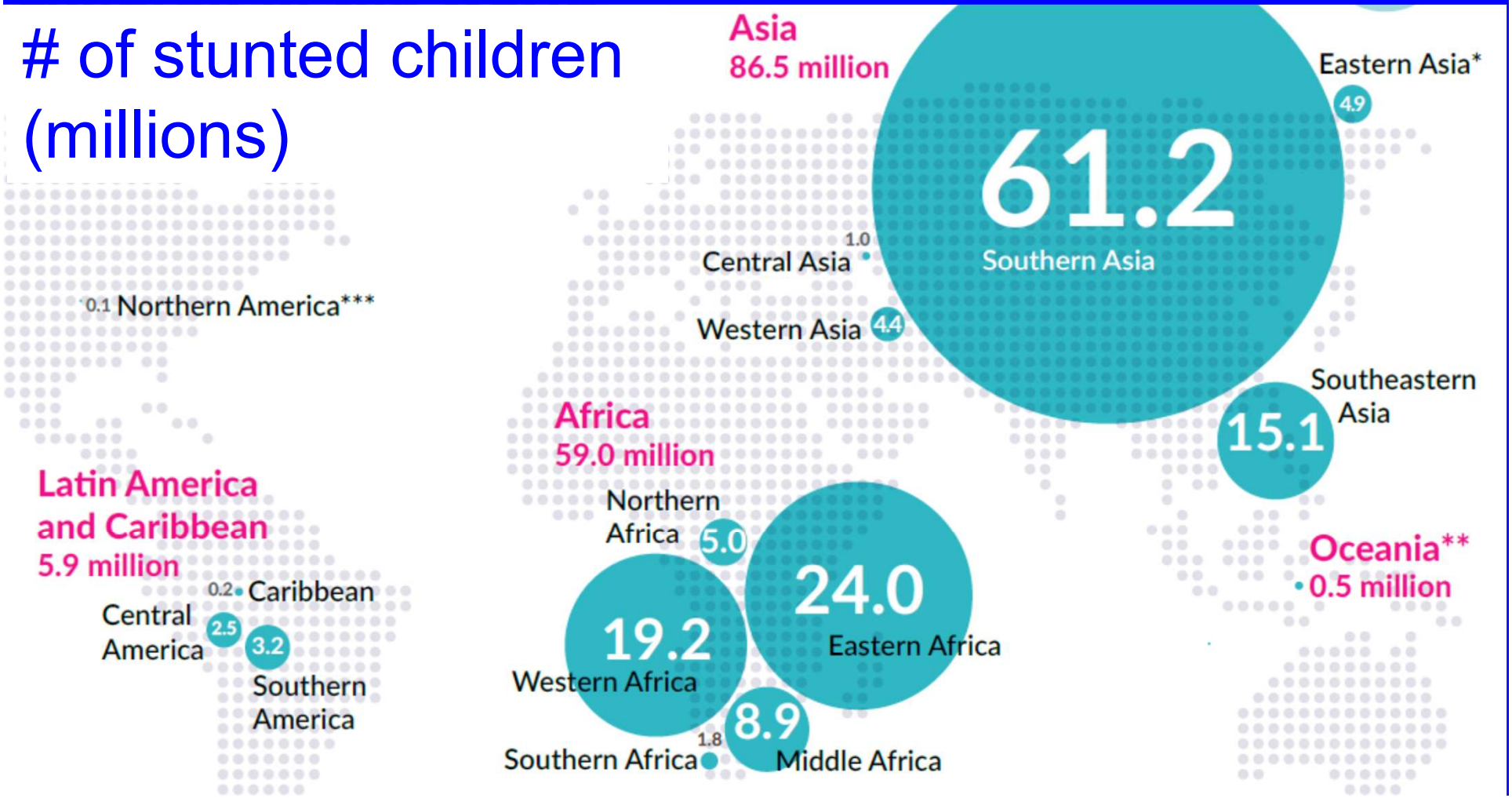
151 million children <5 were stunted in 2017.

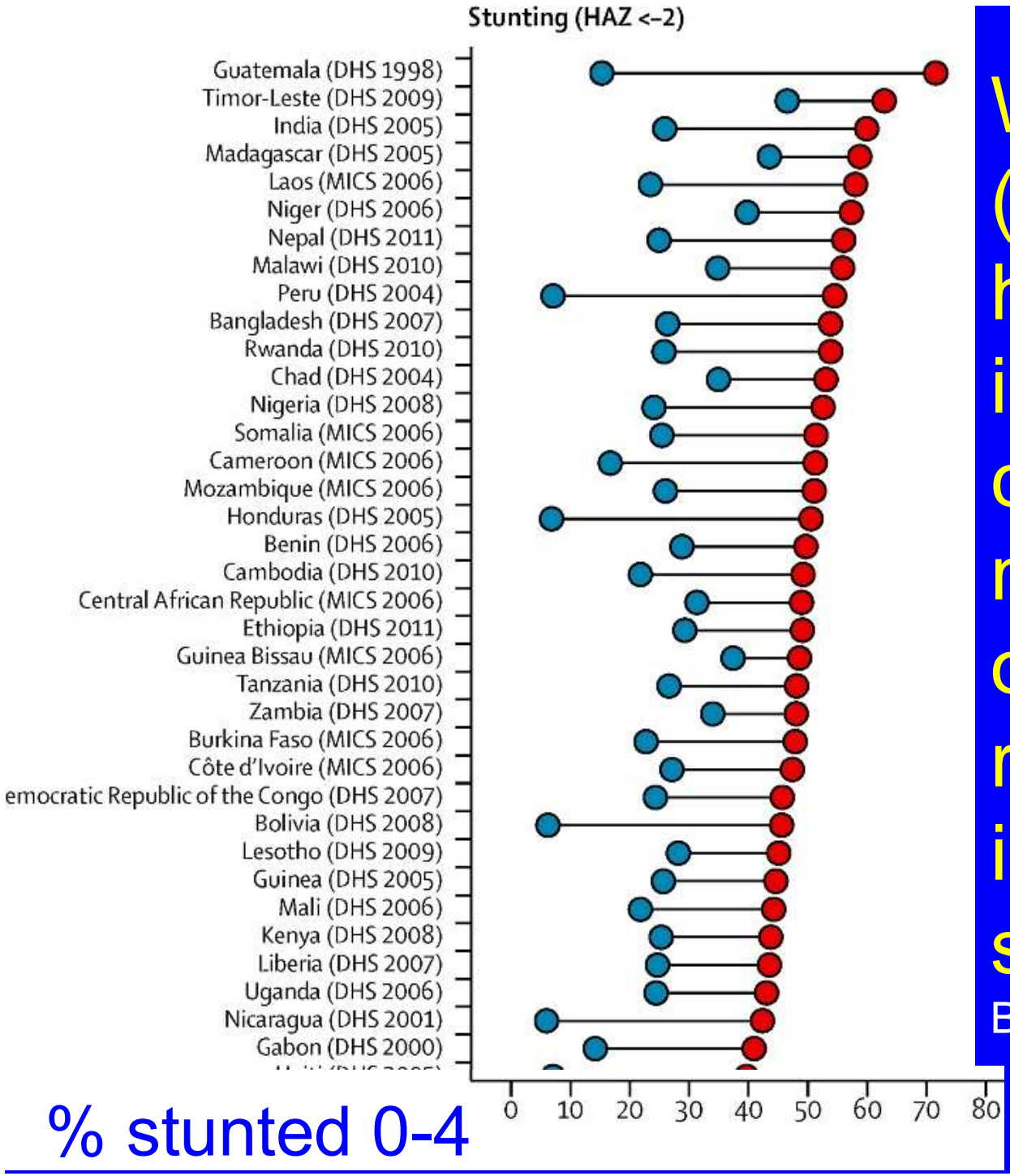
Global stunting of children 0-4
fell from 29.5% in 2005
to >22%, still nearly ¼, in 2017.

FAO, IFAD, UNICEF, WFP, WHO 2018
The State of Food Security and Nutrition in the World 2018.

2/5 of stunted children live in southern Asia (155 million, 2016).

FAO, IFAD, UNICEF, WFP, WHO 2017





Wealth quintile (lowest=red, highest=blue) influences child stunting more than sex or urban-rural residence influences stunting.

Black et al. *Lancet* 2013

The hungry are economically invisible in grain markets.

Lack of effective demand, i.e., demand supported by customers' orders and capacity to pay, for sufficient food contributes materially to widespread undernutrition of adults and children.

~800 million chronically undernourished people exercise less demand than those who demand meat, biofuels, & other non-food uses of grain.

The world uses >2.5 billion tonnes/year of cereal grains, but only 43% feeds people.

FAO GIEWS Food Outlook Nov 2017

Use 2016-17	Million metric tons	%
Food	1,103	43
Feed	905	35
Other	561	22
Total use	2,569	100

4 dimensions of food security

Physical availability

production, stocks, trade

Economic & physical access

income, prices, markets, transfer, infrastructure, household distribution

Use

food & nutrition knowledge, preparation, conservation, health, hygiene, care

Stability of other 3 dimensions

Consequences for child & adult

WHO conceptual framework

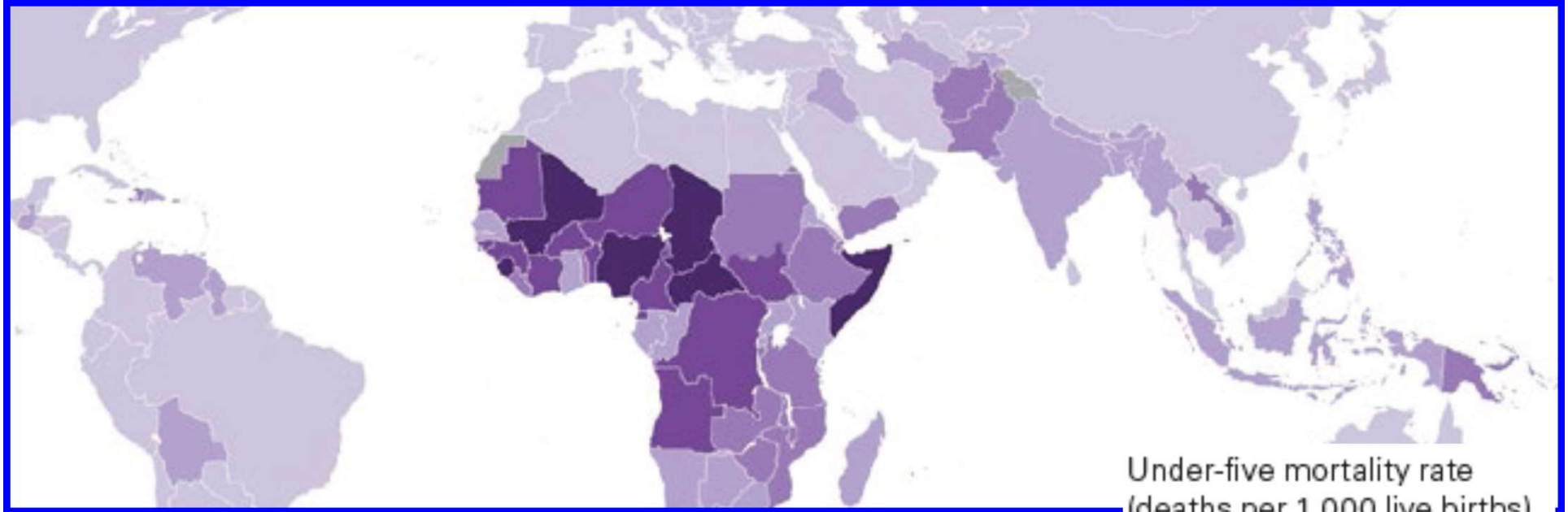
Concurrent problems and short-term consequences

- **Health:** ↑ Mortality, ↑ Morbidities
- **Developmental:** ↓ Cognitive, motor, and language development
- **Economic:** ↑ Health expenditures, ↑ Opportunity costs for care of sick child

Long-term consequences

- **Health:** ↓ Adult stature, ↑ Obesity and associated co-morbidities, ↓ Reproductive health
- **Developmental:** ↓ School performance, ↓ Learning capacity, Unachieved potential
- **Economic:** ↓ Work capacity, ↓ Work productivity

Almost half [45%] of deaths 0-4 are due to undernutrition. Black et al. *Lancet* 2013



Map from UNICEF, *Levels & Trends in Child Mortality Report 2018.* Estimates by UN Inter-agency Group for Child Mortality Estimation

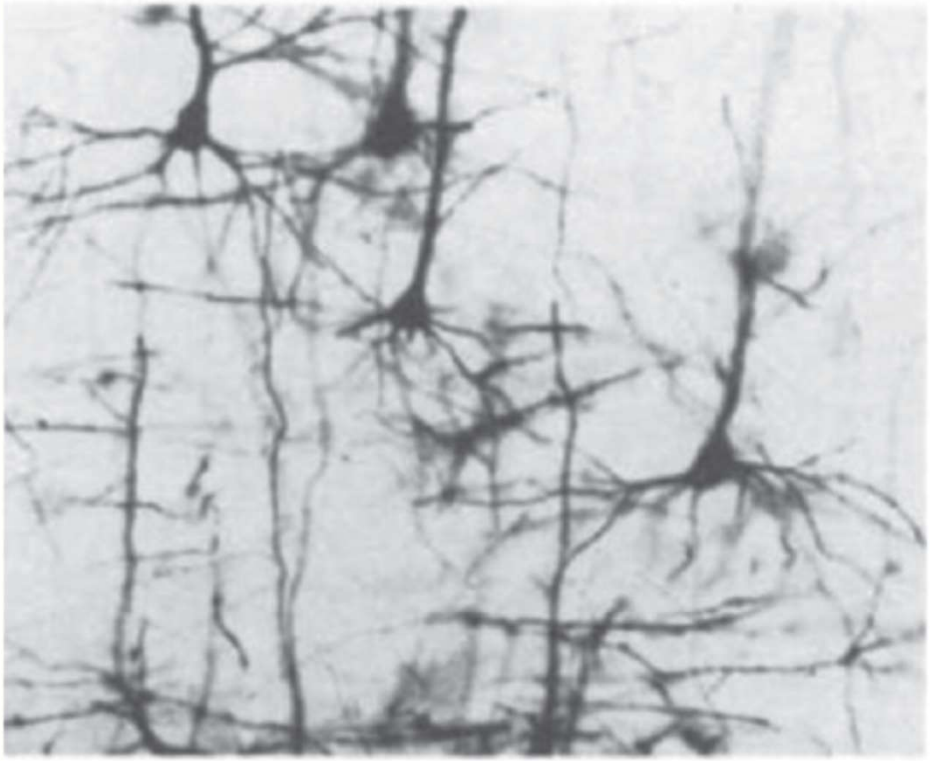
2019-07-03

Joel E. Cohen

Undernourishment alters brain.

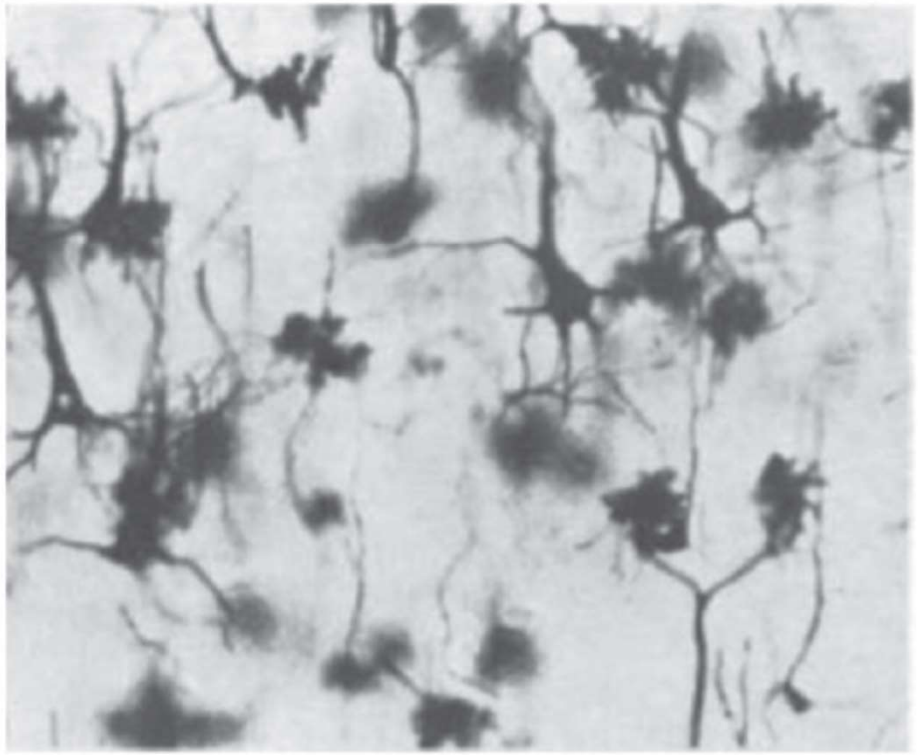
M. de Onis & F. Branca 2016 from Cordero et al. 1993

Well-nourished infant



Typical brain cells
Extensive branching

Undernourished infant



Impaired brain cells
Limited branching
Abnormal, shorter branches

Stunting threatens human development.

"The severe irreversible physical and neurocognitive damage that accompanies stunted growth poses a major threat to human development."

Mercedes de Onis, Francesco Branca

Maternal & Child Nutrition 2016

Stunting impedes schooling.

"Stunting … often results in delayed mental development, poor school performance and reduced intellectual capacity. This in turn affects economic productivity at national level."

WHO Nutrition Landscape Information System

Overview

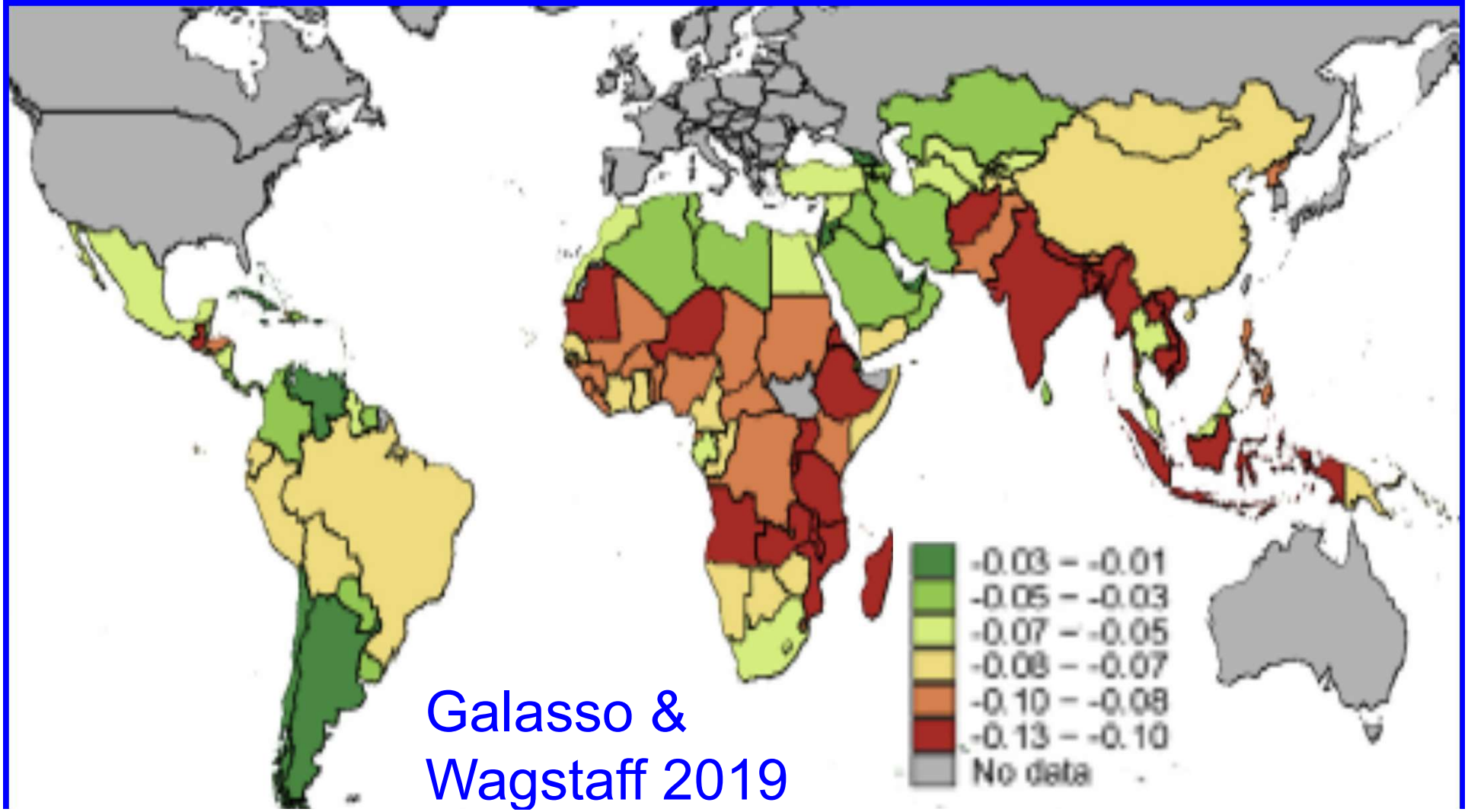
1. Stunting
2. Outcomes & costs
3. Feedbacks from outcomes to causes
4. Causes & context

Stunting in childhood of people working in 2014 lowered income/person by 5-7% in 140 developing countries compared to no stunting.

Mean reduction in income/person due to stunting was 9% in 47 countries of sub-Saharan Africa & 8 countries of south Asia.

Galasso & Wagstaff, *Economics and Human Biology* 2019

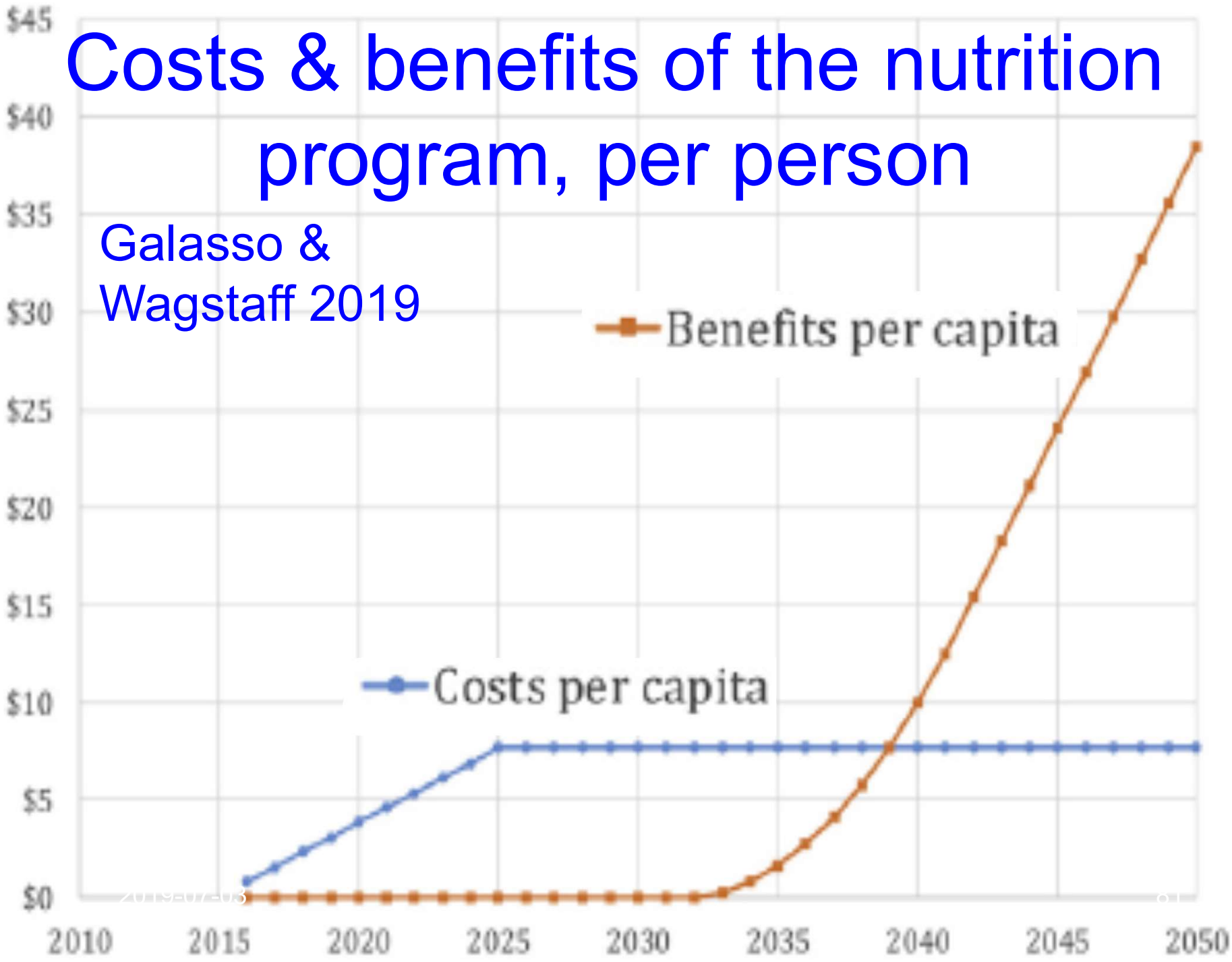
Effects of childhood stunting on income per person of 2014 workers



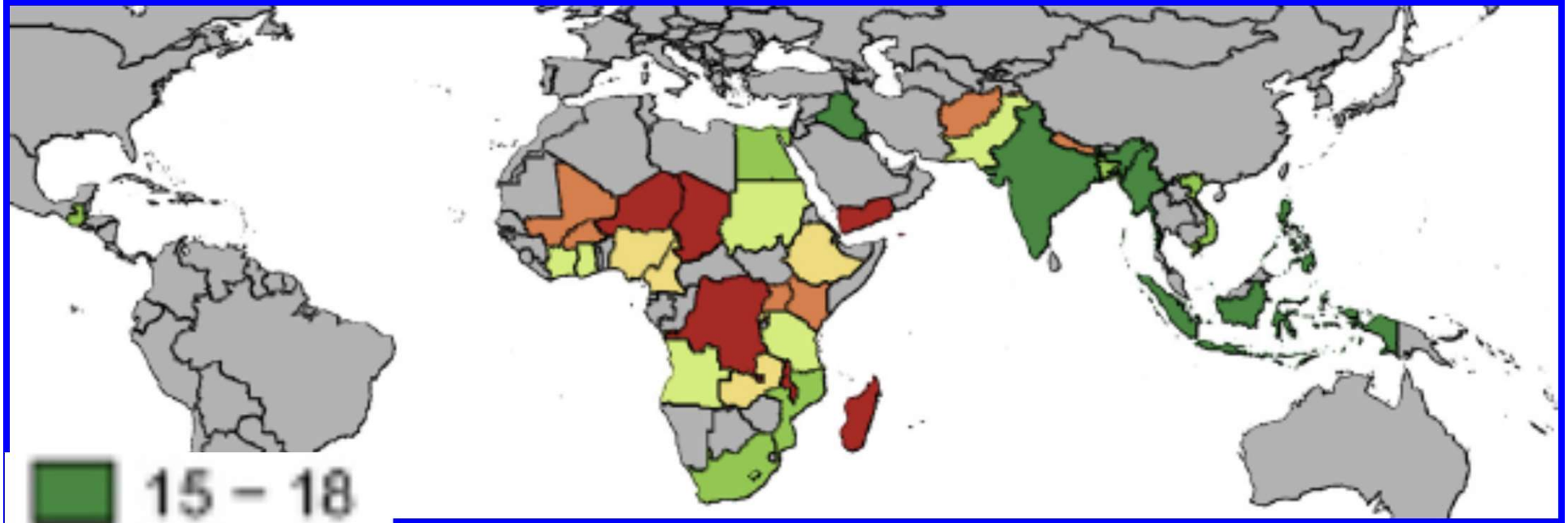
Galasso & Wagstaff 2019

Costs & benefits of the nutrition program, per person

Galasso & Wagstaff 2019



Internal rates of return to nutrition project



Galasso & Wagstaff (2019) estimate an internal rate of return of 12%.

Hunger bonds

Governments should sell bonds to their people & to patient investors to reap returns in the adult labor force of reduced stunting in childhood.

Actions to reduce stunting

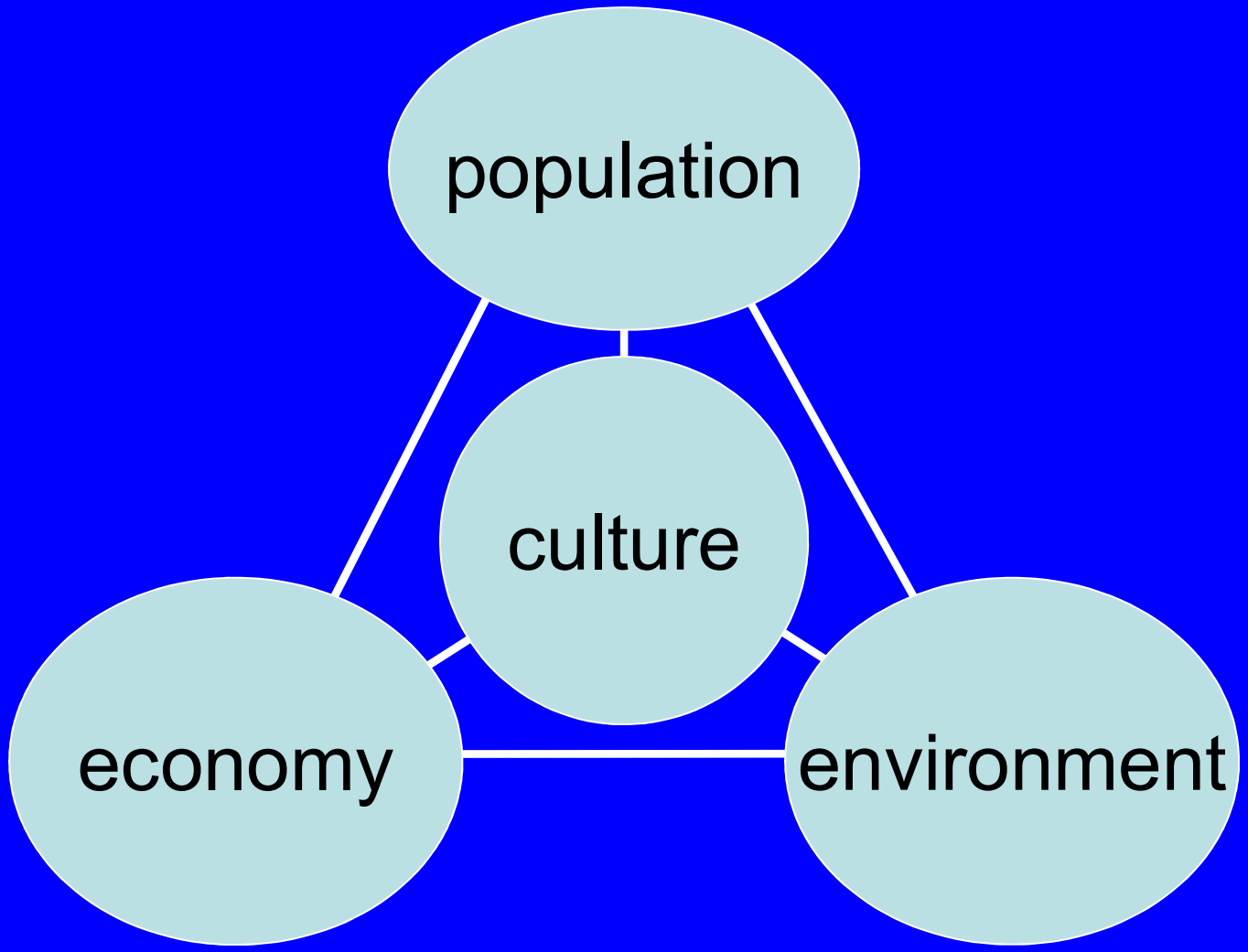
M. de Onis & F. Branca *Maternal & Child Nutrition* (2016)
FAO, IFAD, UNICEF, WFP, WHO. 2017.
The State of Food Security and Nutrition in the World 2017.

Improve:

- food & nutrition security
- education
- water, sanitation & hygiene
- health (infection, anemia)
- income
- status of women
- law & institutions, conflict resolution

J.M.W. Turner (1775-1851): The Slave Ship
1840 Museum of Fine Arts Boston

Population, economics, environment & culture interact.



Thank you! Questions?