Passage 24 A #6

Simple population dynamics

Let N_t represent the population size at year t. We here ignore age distribution.

Then the population size at year t+1, N_{t+1}, is given by

$$N_{t+1} = b\,N_t + s\,N_t \qquad (1)$$

where b is the birth rate (number of babies per individual) and s is the annual survival probability at year t.

The above equation (1) can be rearranged as

$$\Delta N = N_{t+1} - N_t = b\,N_t + \mathrm{s}\,N_t - N_t = b\,N_t - (1 - s)\,N_t = b\,N_t - d\,N_t \qquad (2)$$

here d = 1 - s is the annual death probability. If b - d > 0, the population increases. If not, it decreases.

b and d can change over time, depending on various factors.

Demographic transision

There has been an empirical view that birth and death rates change with time folowing the below three stages as society develops and matures.

1) High birth rate and high mortality (death rate): Population growth is low.

2) High birth rate and low mortality: Population growth is high, realized by enough food production and development of public health, etc.

3) Low birth rate and low mortality: Population growth is low. As society is matured, famility size decreases.

The timing of each transition is difficult to predict. It is perhaps influenced by various factors, e.g., economy and politics.

Many developed countries, but not all, have followed this transition in the past.

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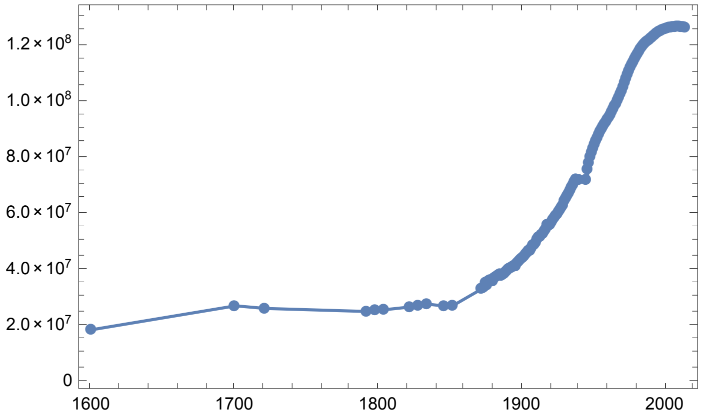
DateListPlot[CountryData["Japan", {"Population", All}], PlotMarkers → Automatic]
```




```
DateListPlot[CountryData["Germany", {"Population", All}],
 PlotMarkers → Automatic]
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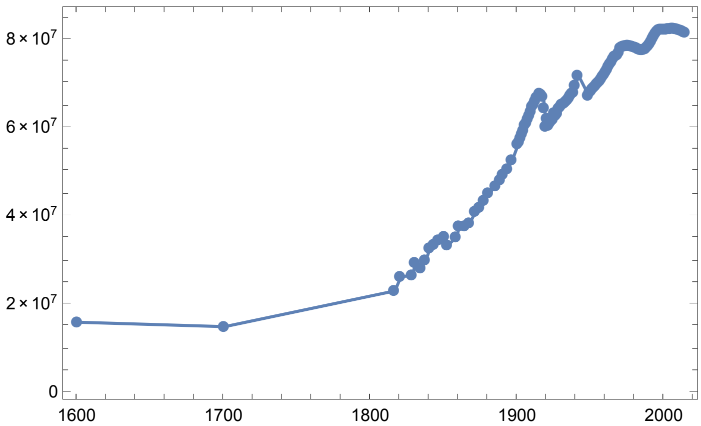


```
DateListPlot[CountryData["USA", {"Population", All}], PlotMarkers → Automatic]
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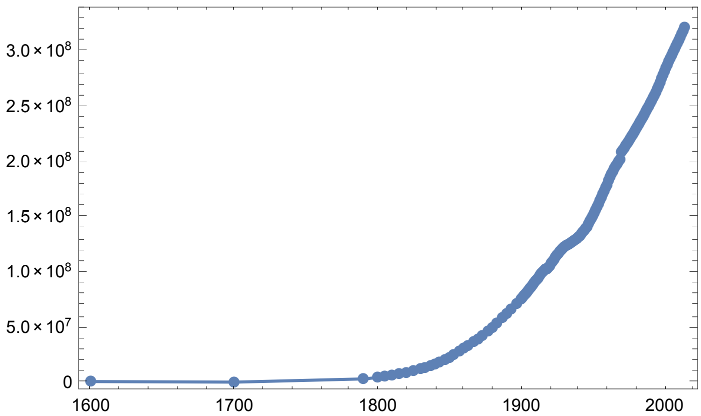

See “Demographic transition” at https : // en.wikipedia.org/wiki/Demographic_transition

Future of the World Population: What can limit the maximum world population?

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DateListPlot[CountryData["World", {"Population", All}], PlotMarkers → Automatic]
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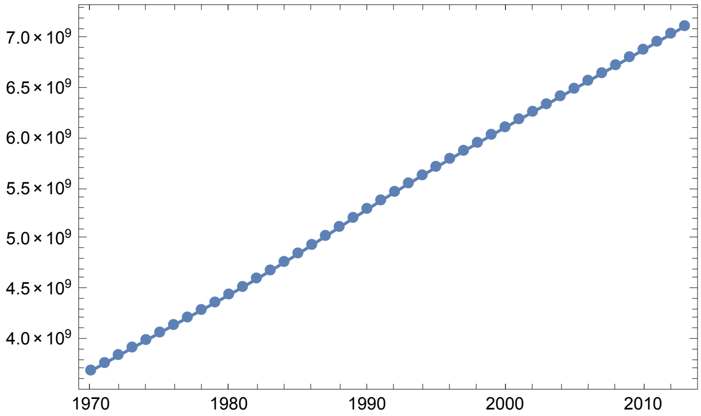

The world popualtion has been steadly increasing. Annual growth rate was 1.07% in 2015. If this growth rate is kept constant, the world population will be doubled, from 7.3 billion to 14.6 in 65 years (Remember how to calculate the doubling time for exponential growth).

```
Log[2] / Log[1.0107]
```

```
65.1261
```

The world, however, is finite and there should be an upper limit of the world population. What factors limit the maximum world population?

An important factor is “food”. We need food to live, keep our metabolic activity in daily life.

An adult individual needs 2,740 kcal everyday. This amounts approximately one million kcal a year.

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2740 × 365
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```
1 000 100
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Source of the energy an individual needs a yaer ultimately comes from the sun as “sun light”. Plants convert the sun light energy into carbonhydrate as chemical energy by photosynthesis; Water + Carbon dioxide --> Carbonhydrate (Primary production).

Produced carbonhydate is consumed by various consumers (1st, 2nd, ..., consumers) through food chain. Human being usually locate themselve at the top of food chain.

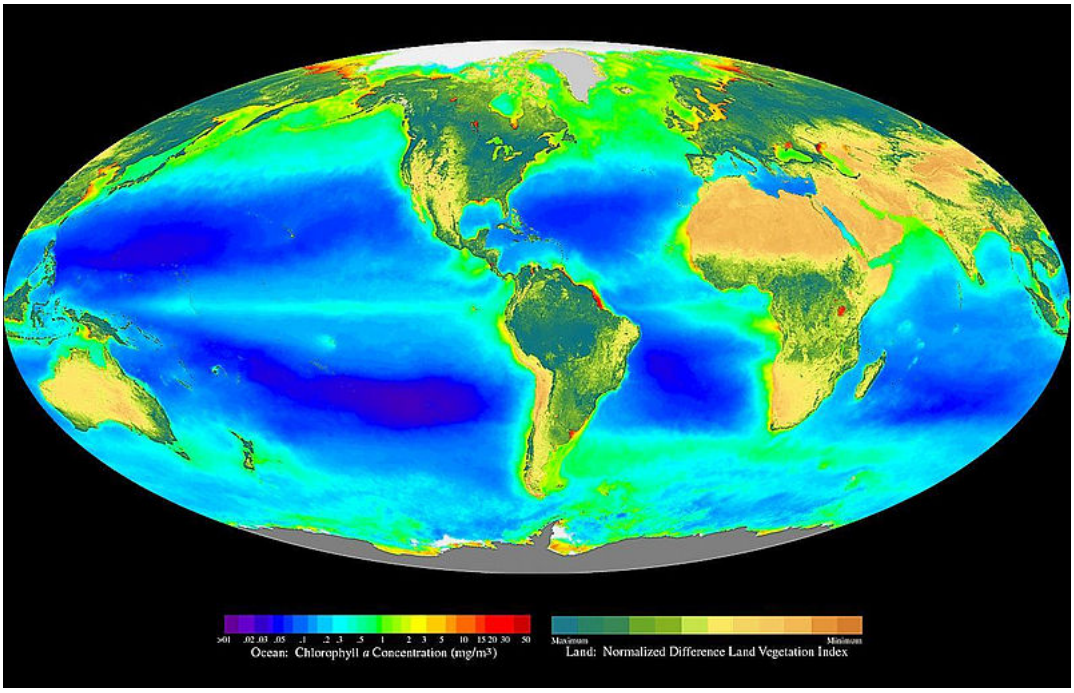
De Wit (1967) estimated the maximum suntainable world population *P* by assuming that photosynthesis is the sole limiting factor of population.

P = (Area) x (Energy production by photosynthesis per unit area) / (Energy an individual needs)

Energy production by photosynthesis largely depends on lattitude (average tempearture and precipitation, etc.).

His estimate was amazing, P = 1,022 billiion (one trillion!).

But this extreme estimate was based on a simple assumption that 1) all land good for agriculture is used, 2) no other factors such as land necessary for daily life (houses, roads, public organization, etc.) are considered.



Distribution map of the primay production: https://en.wikipedia.org/wiki/File:Seawifs_global_biosphere.jpg

Chekc the keywords "Primary production", “Food chain”, “Ecological pyramid”.

Other potential limiting factors of the world population

Use of fertilizer, irrigation system and water supply could be important to estimate the gross energy production.

Not only primary production can be consumed by human being; we need more energy to produce “meat” (food for poultry, pork and beef is necessary). E.g., to produce a lump of beef equivalent to 1 kcal, we need 10 kcal field corn as diet for cattle. This raises a serious question about how to cultivate food (vegetable or meat).

Maintenance of housing, commercial, and industrial activities. We have to spare these area for civilized life.

Outbreak of infectious diseases, pest for agricultural products, and establishment of public health.

Other energy sources such as oil or gas.

These factors could be potentially limit the maximum sustainable world population.

The maximum world population can vary depending on how we spend our life. It depends on our choice: what life we want to enjoy in future, what economical system, what kind of society we want to build?

The future is on our hands!