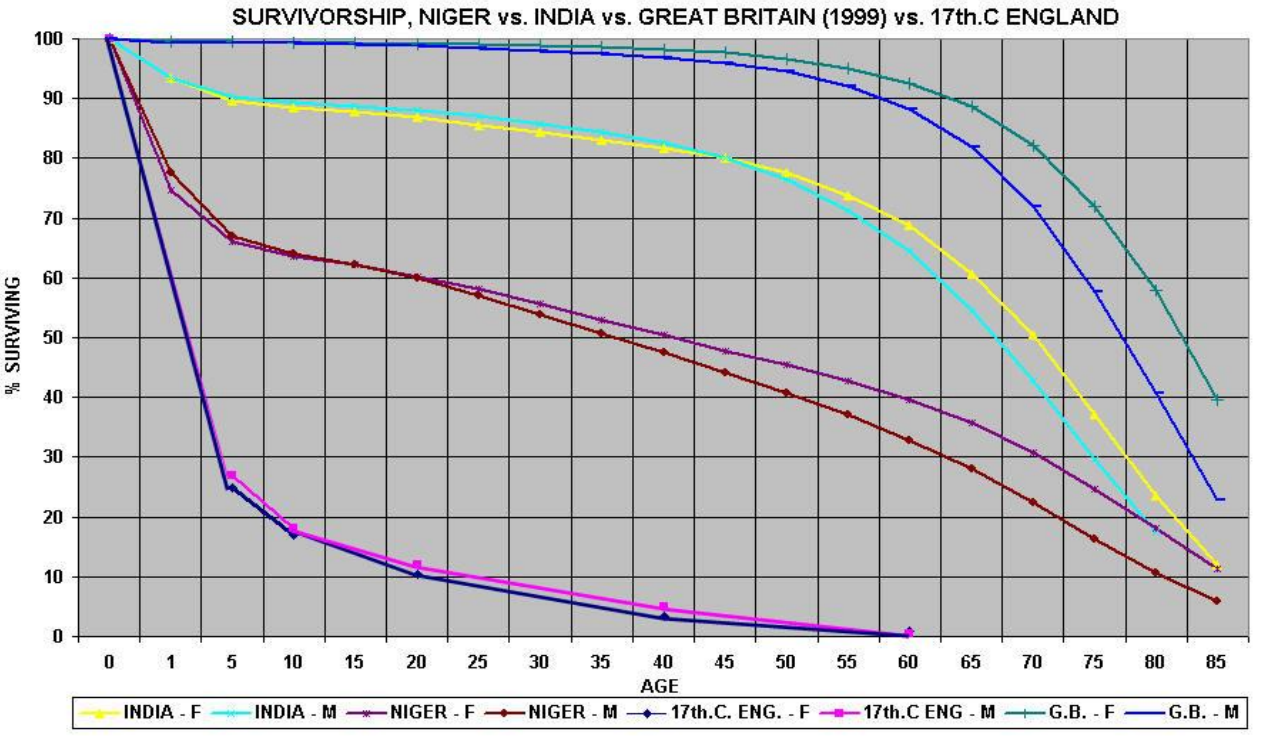
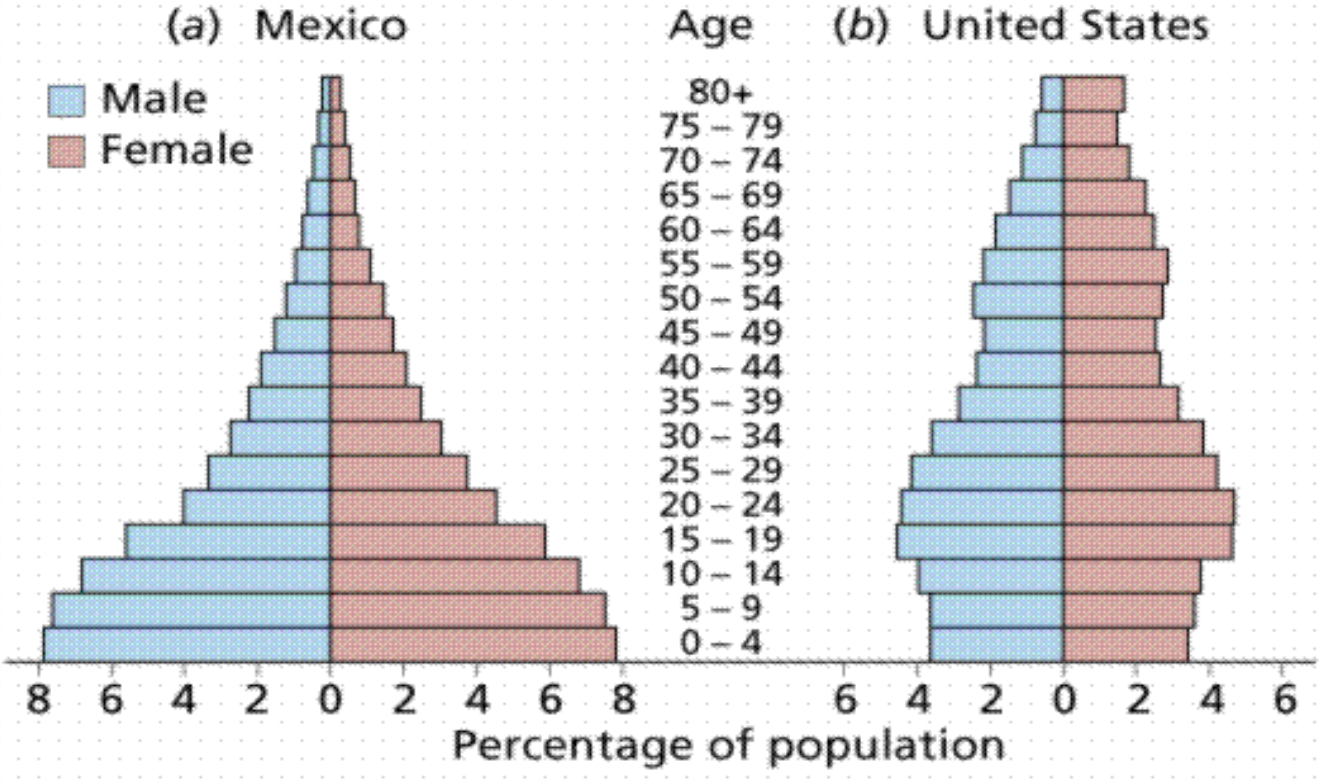
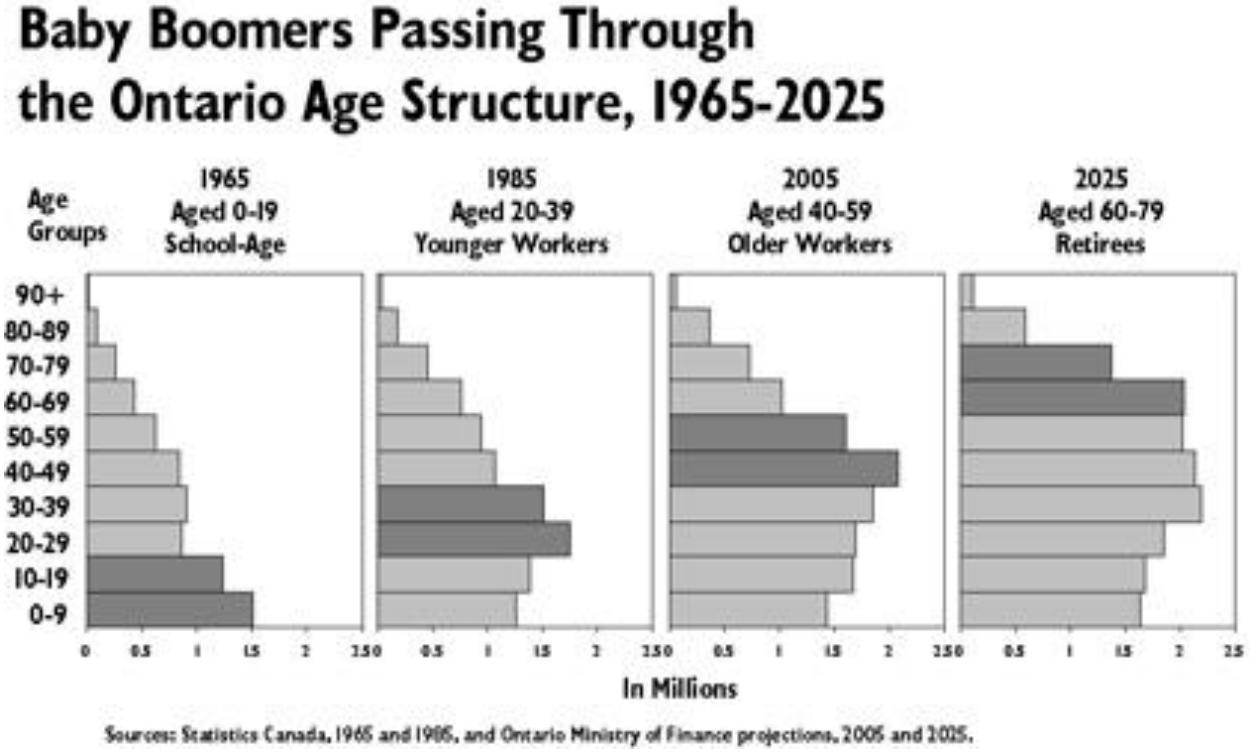


HUMAN POPULATION BIOLOGY: Human survivorship curves. Most modern curves are 'Type I' -- typical of high-parental care species (like the Dall sheep); note the vertical axis is linear, not exponential; on exponential axis, all of these would look more like the Dall sheep curve, although those for pre-modern times would be closer to a Type II curve. NOTE that, for the last several centuries, the maximum age hasn't changed much (in fact, all the way back to Roman and Greek times, the oldest individuals lived to be around 100); what's changed is that a larger proportion of each cohort survives to old age. The largest change is in childhood mortality (think about why…). "Life expectancy" at birth is the average age of death for a full cohort; that is much lower if 30% of a cohort dies by age 4 (e.g., the Niger curve above). The largest contributing factor in dramatic increases in life-expectancy in 'developed' countries is decreased childhood mortality.

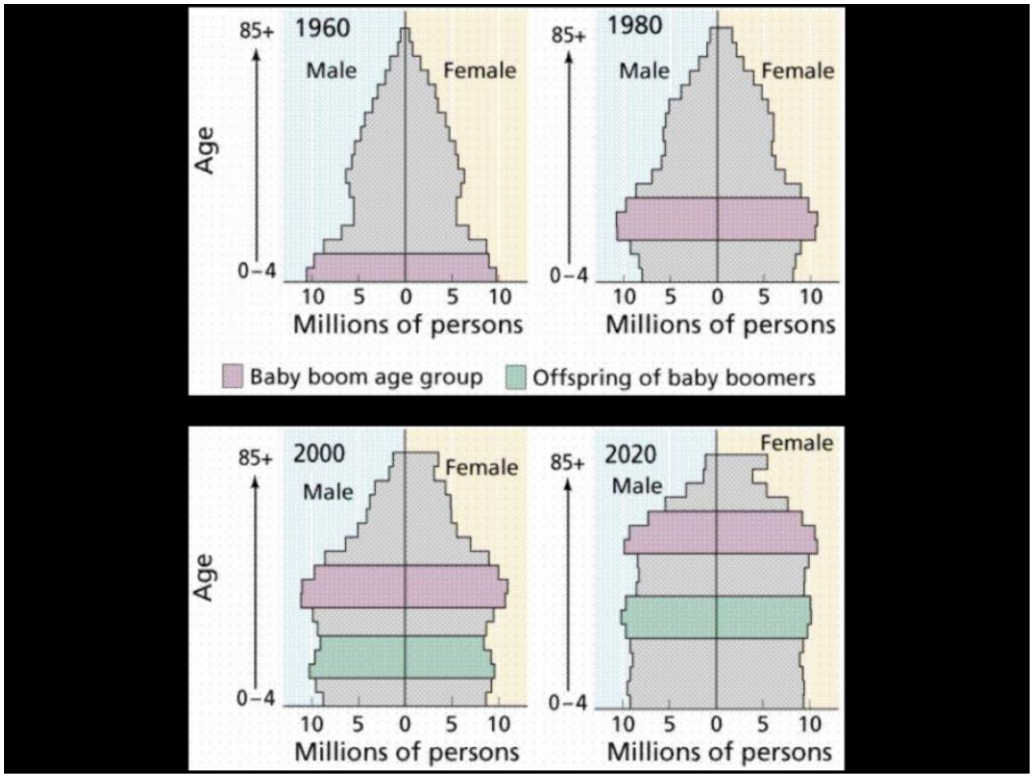


Human populations have a strong 'Type I' – mammal-like – survivorship curve with relatively high survivorship in early years, very low mortality through adult years, and rapid decline of cohort size only in senescence. This is generally associated with high levels of parental care.

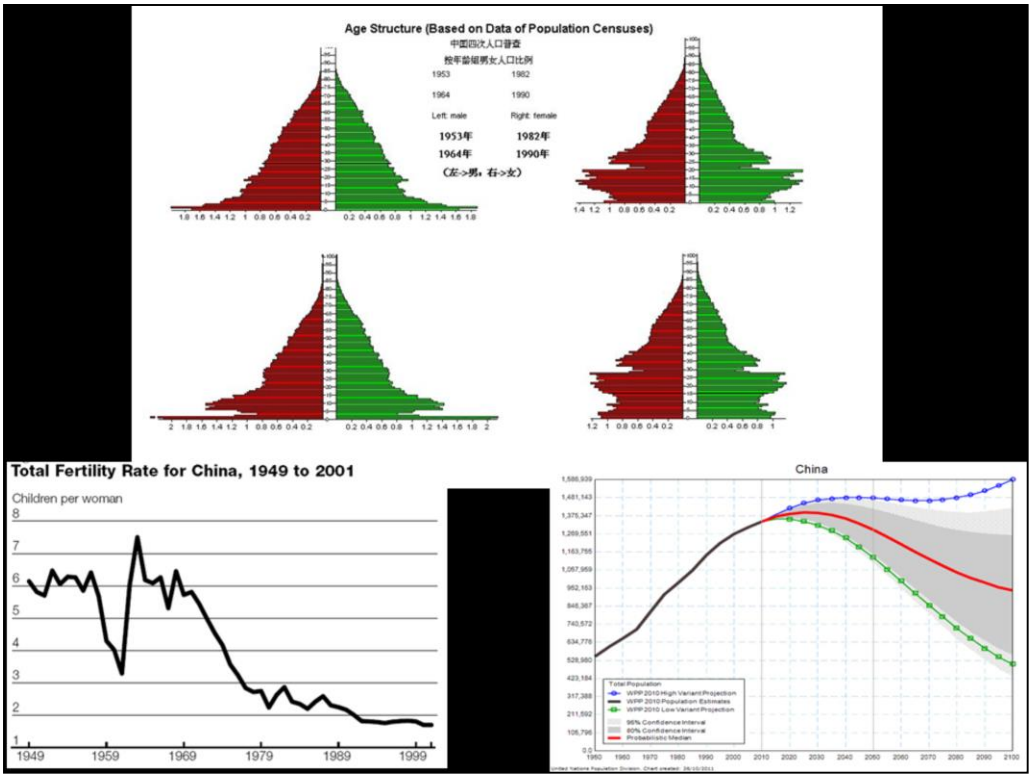
Here are some human AGE STRUCTURES for recent years; which of these AGE STRUCTURES, given similar survivorship curves of this sort (they are) can be approximately stable? (NOTE the axes for these graphs; it is standard for HUMAN DEMOGRAPHY to place age on the vertical axis).



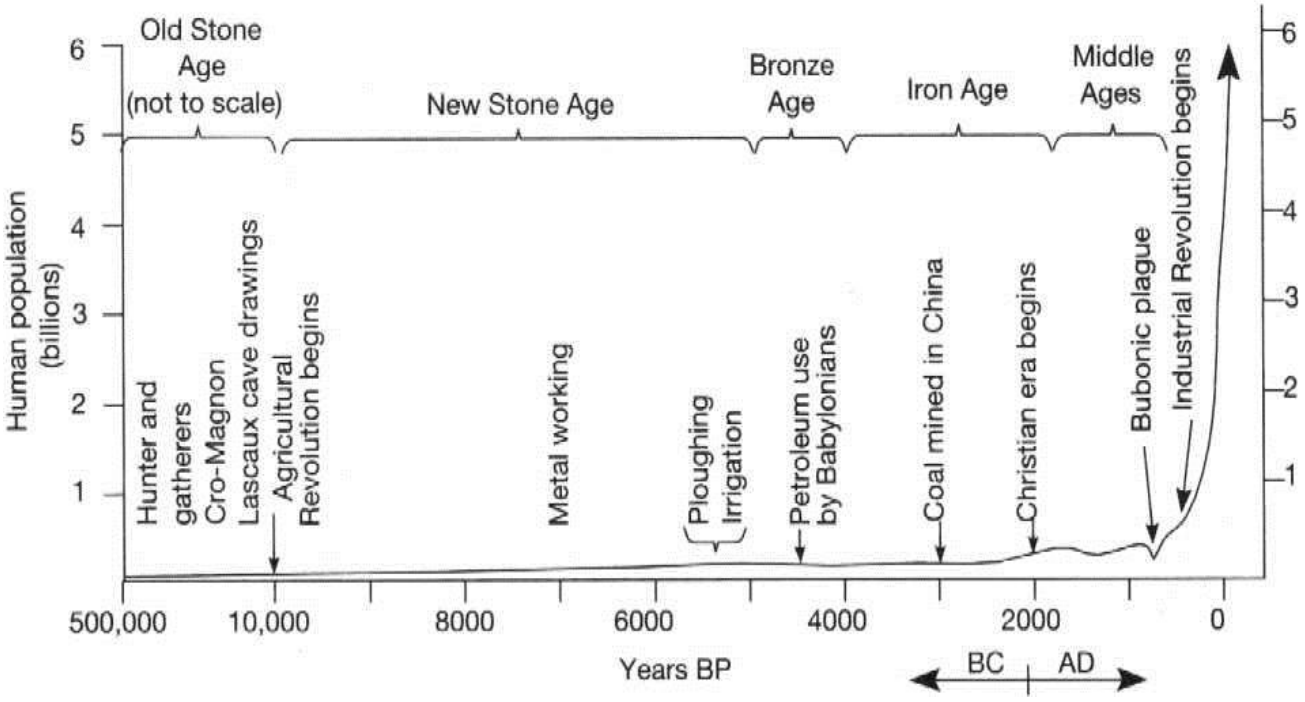
Unstable age structure due to baby boom; boomers create a ‘bump’ moving through the age structure over time.



So does the ‘baby boom echo’… (This is the Unigted States).



In China, catastrophic famines in the late 1950s, Mao's 'pro-natalist' policies in the 1960s and early 70s, and the subsequent establishment of the 1-child policy, have produced dramatic fluctuations in cohort sizes, reflected in changing age structures (top graph). FERTILITY RATE (bottom left) is the average number of children per female over her reproductive life, and is obviously related to population birth rate). NOTE that fertility rates actually started falling BEFORE the one-child policy established in 1980. Why might this happen? There've also been dramatic changes in survivorship affecting age structures. Even though birth rates in recent decades are well below 'replacement level', population is still growing because of the very large cohorts passing through child-bearing years. However, growth rate is slowing, and China's population is predicted to peak in about 10 years; after that it will decline, IF fertility rates remain below replacement level. Replacement level is slightly over 2; why?



History of human population growth reflects significant changes in factors regulating population – eitl

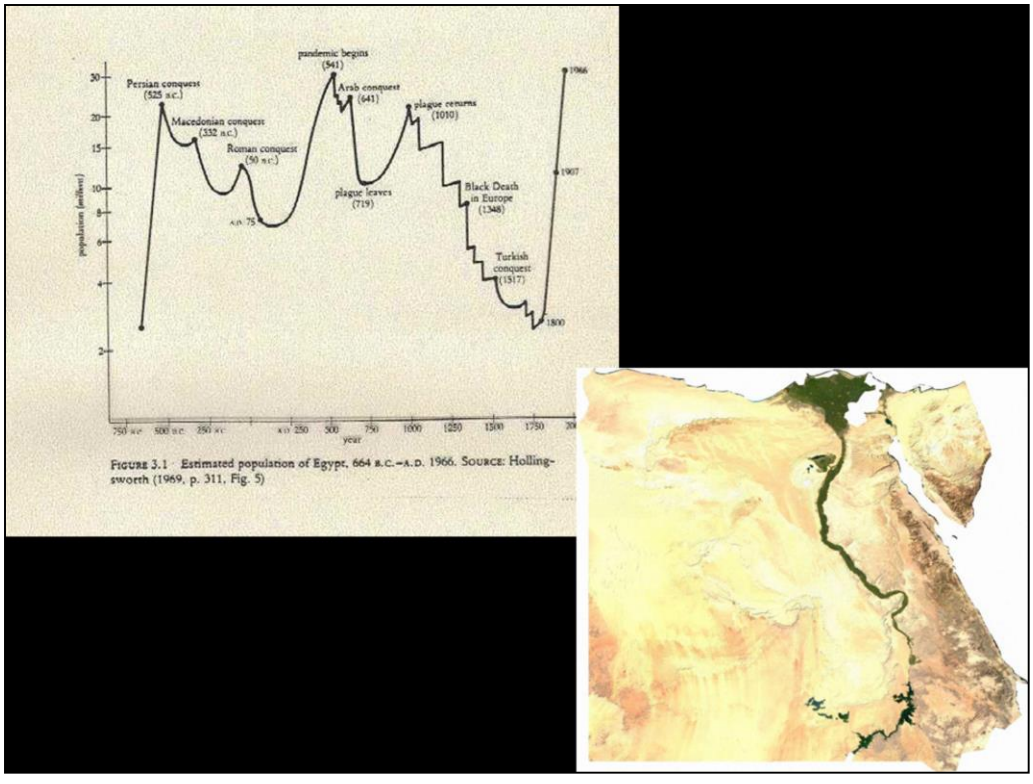
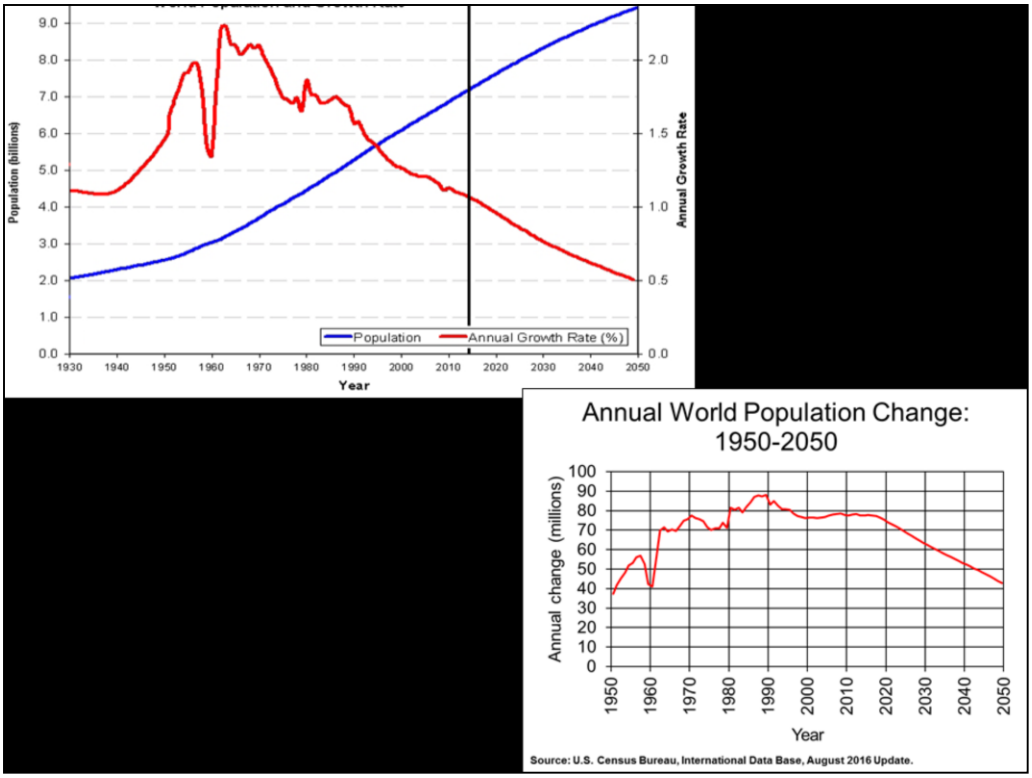
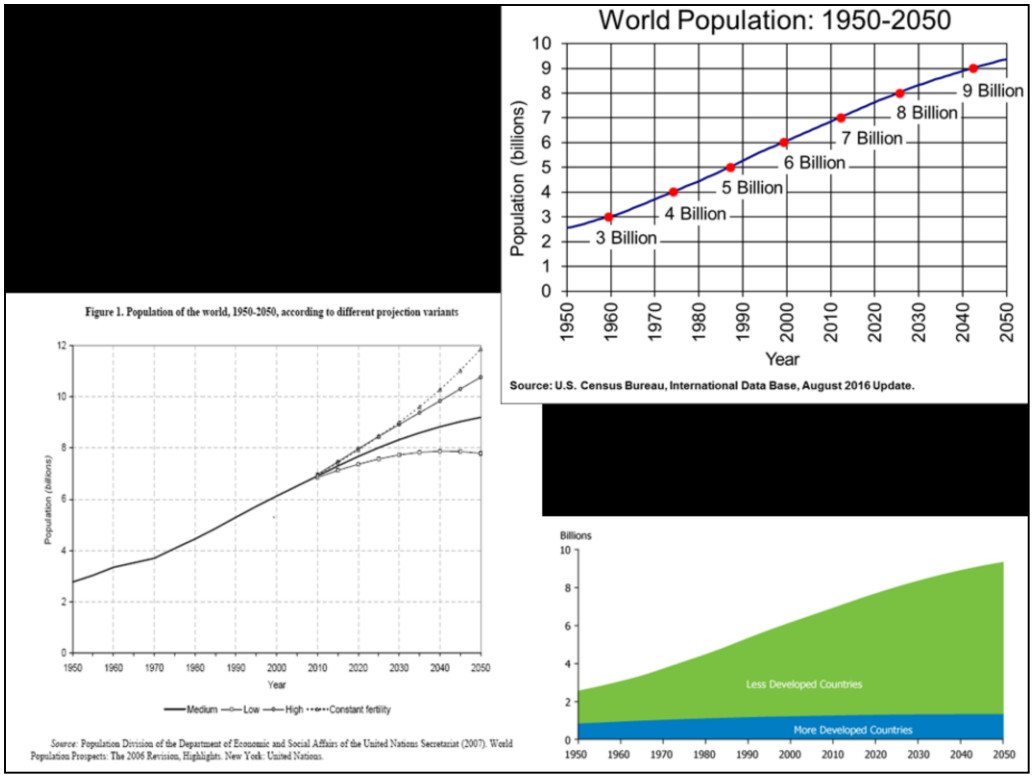


FIGURE 3.1 · Estimated population of Egypt, 664 B.C.–A.D. 1966. SOURCE: Hollingsworth (1969, p. 311, Fig. 5)

But patterns look a lot different if you look at particular po



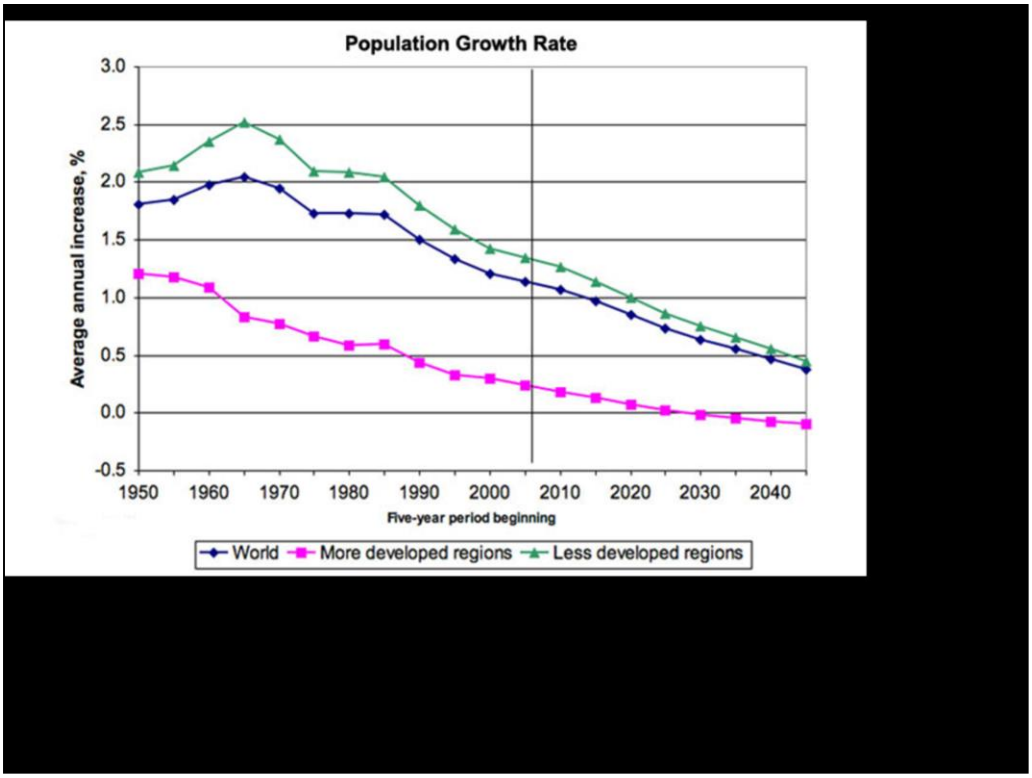
The world population growth rate rose from about 1.5 percent per year from 1950-51 to a peak of over 2 percent in the early 1960s due to reductions in mortality. Growth rates thereafter started to decline due to rising age at marriage as well as increasing availability and use of effective contraceptive methods. Note that changes in population growth have not always been steady. A dip in the growth rate from1959-1960, for instance, was due to the Great Leap Forward in China. During that time, both natural disasters and decreased agricultural output in the wake of massive social reorganization caused China's death rate to rise sharply and its fertility rate to fall by almost half.



Breaking it down to more recent growth patterns

and projections to 2050. NOTE that these graphs show three important things:

1) human population is no longer growing at a constant exponential rate; in recent decades, the slope has been constant or even decreasing.
2) But growth is not evenly apportioned among populations; in ‘more developed countries’, growth rate (“r”) is very close to zero (birth rates = death rates).
3) And a lot of expectations for the future depend on whether this pattern becomes increasingly true for ‘less developed countries’.



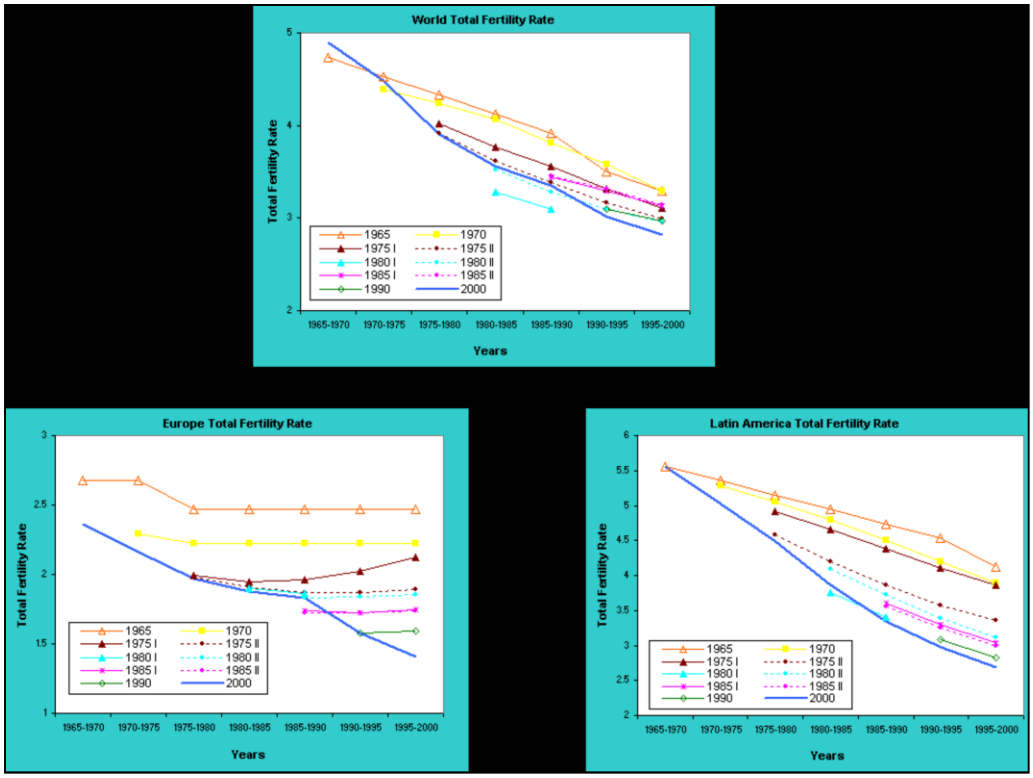
Breaking it down a bit more (this and most other data in these slides from either U.S. Census Bureau or U.N. Population Bureau)

World
Total fertility (children per woman)
Medium variant
1950-2050

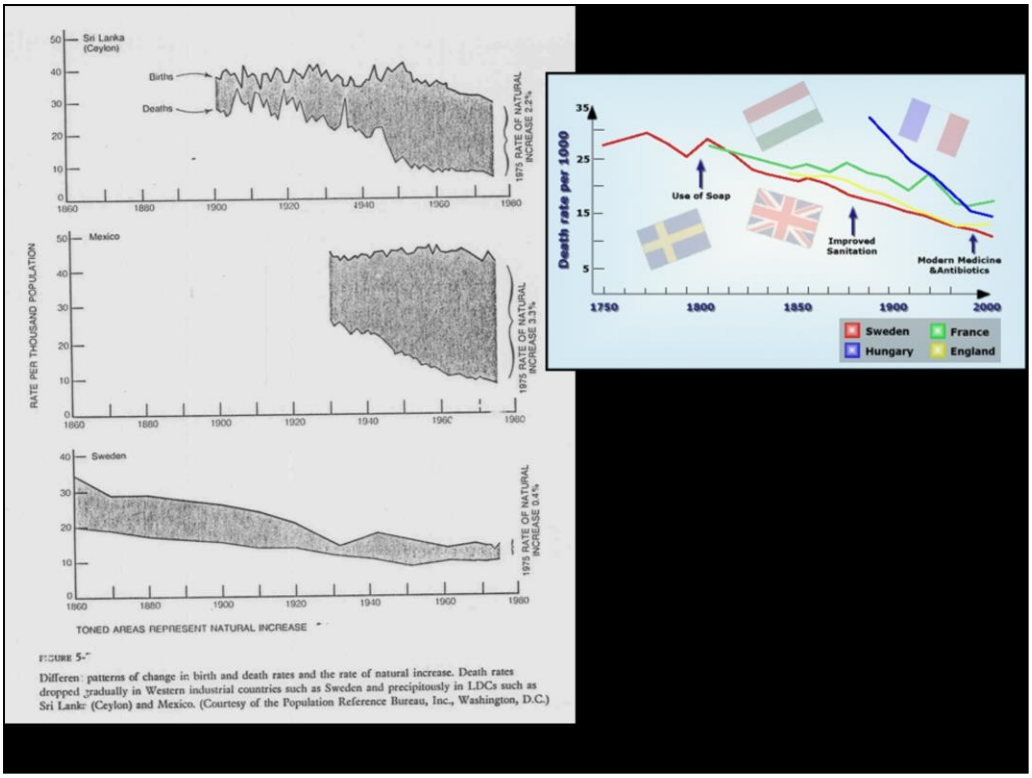
Period	Total fertility
1950-1955	4.92
1955-1960	4.81
1960-1965	4.91
1965-1970	4.78
1970-1975	4.32
1975-1980	3.83
1980-1985	3.61
1985-1990	3.43
1990-1995	3.08
1995-2000	2.82
2000-2005	2.67
2005-2010	2.56
2010-2015	2.49
2015-2020	2.40
2020-2025	2.30
2025-2030	2.21
2030-2035	2.15
2035-2040	2.10
2040-2045	2.06
2045-2050	2.02

Source: Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, *World Population Prospects: The 2008 Revision*, http://esa.un.org/unpp, Wednesday, September 09, 2009; 8:04:07 PM.

"Total fertility" is the average number of children per wom



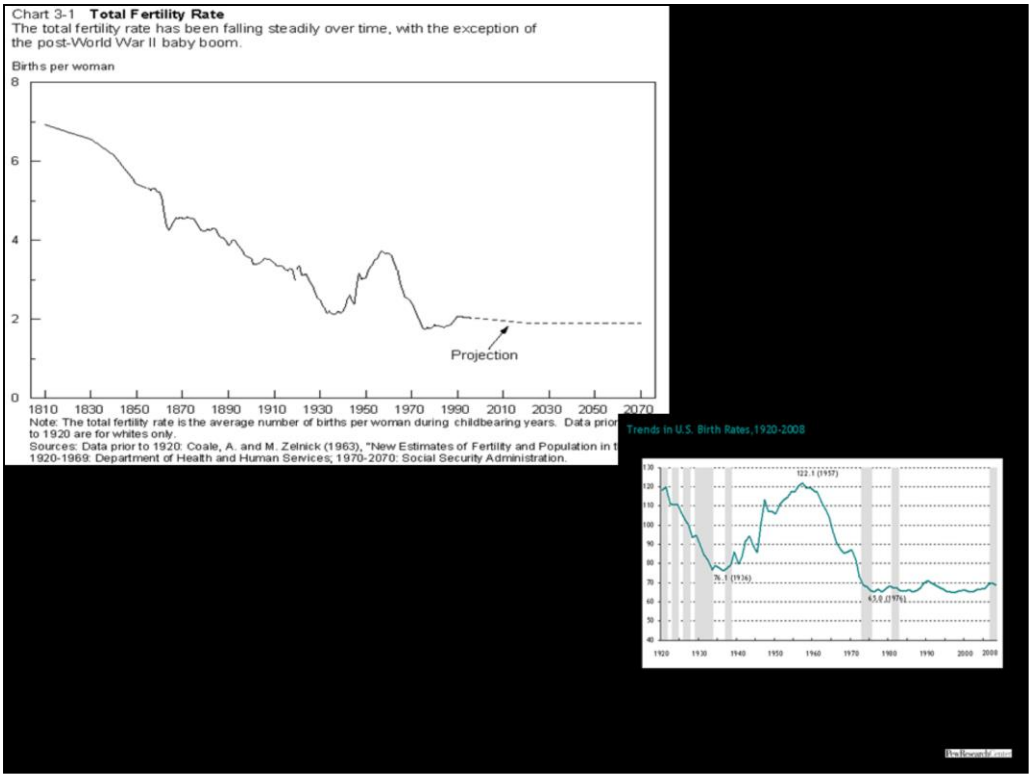
Some regional breakdowns



Different patterns of change in birth and death rates and the rate of natural increase. Death rates dropped gradually in Western industrial countries such as Sweden and precipitously in LDCs such as Sri Lanka (Ceylon) and Mexico. (Courtesy of the Population Reference Bureau, Inc., Washington, D.C.)

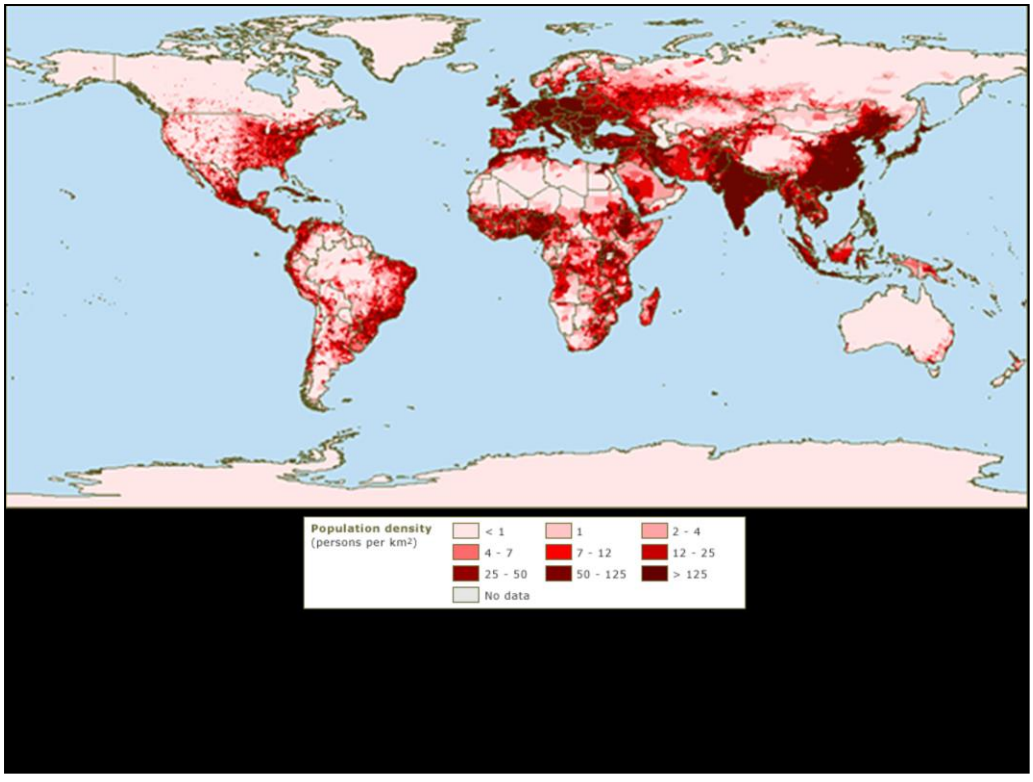
Population growth results in human populations

has generally been a result of death rates falling without birth rates falling as rapidly. In many (most?) cases, birth rates follow death rates and, eventually, decline to a new equilibrium, so population stabilizes after a period of growth. This is called the “demographic transition” by demographers, but naming it does not explain it. We understand the declines in death rate pretty well (medicine, sanitation, secure food supply, all increasing over recent centuries). So the big question is: what causes declines in birth rates/fertility observed?



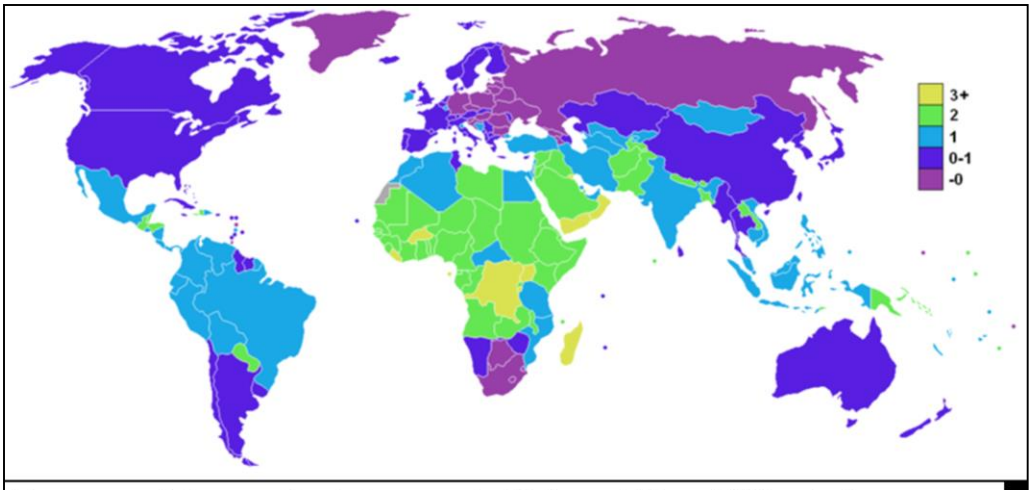
Some data on fertility rate changes in the U.S.

Hypotheses for causes for the various bumps and dips?



To sum things up a bit:

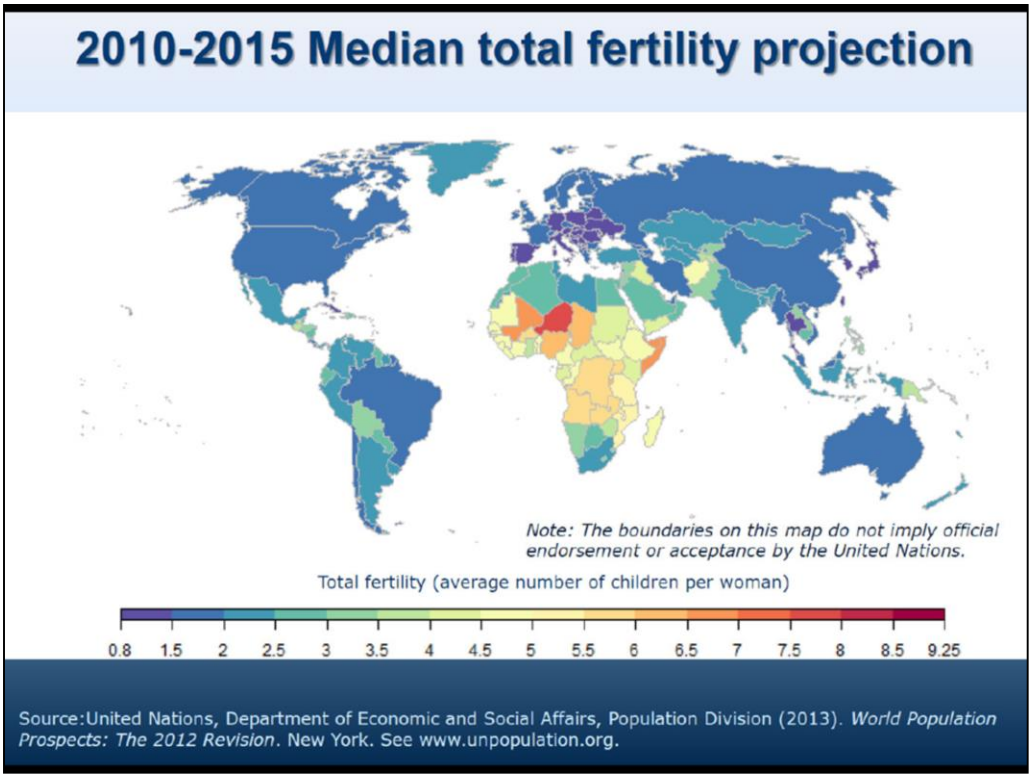
1. Human population is not evenly distributed around the globe. Population *densities* are highest in east and southeast Asia and parts of Europe – areas that differ dramatically in economic, environmental, and other variables.



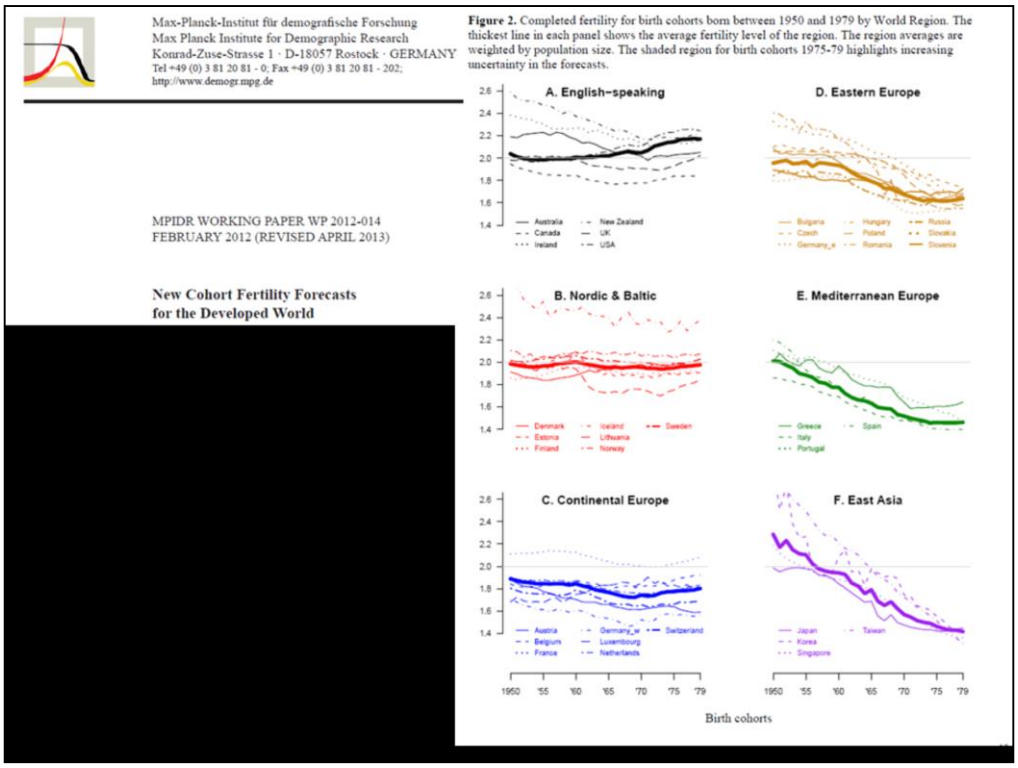
Human population growth rate in percent, with the variables of births, deaths, immigration, and emigration, as listed on CIA factbook (2006 estimate).

2. Population growth rates (r; and remember that

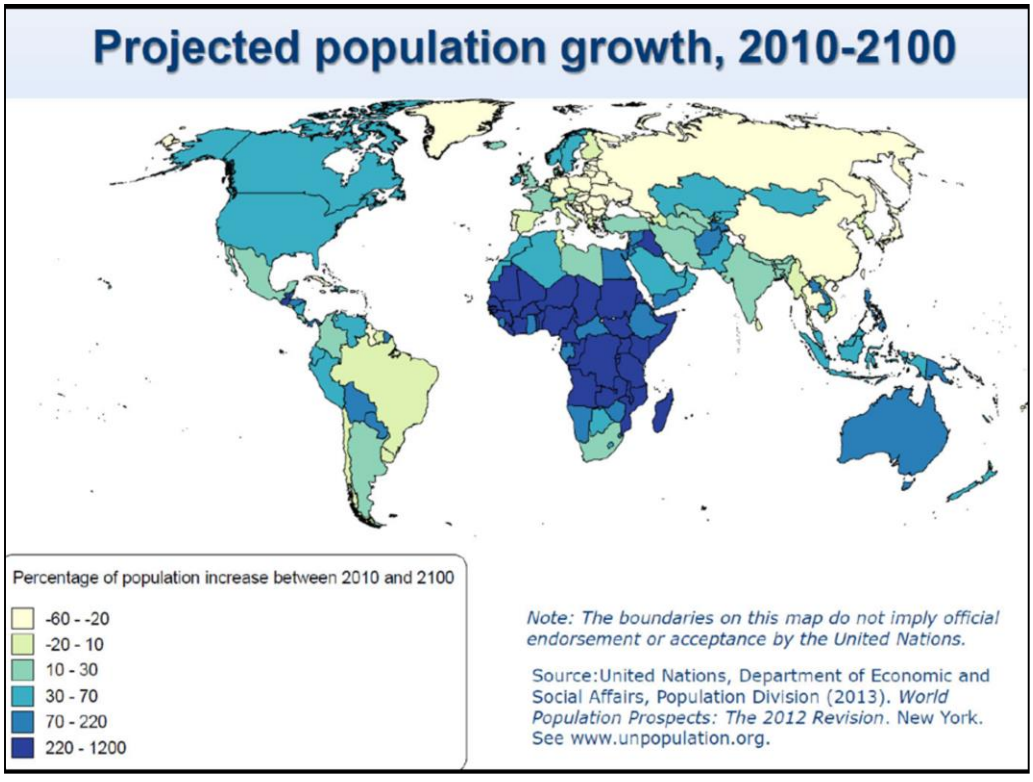
doubling time is roughly 70/r when r is given in percent, as here) also differ dramatically – and not consistently with density. Lowest growth rates are in eastern Europe, where populations are shrinking. Highest growth tends to be in the poorest countries.



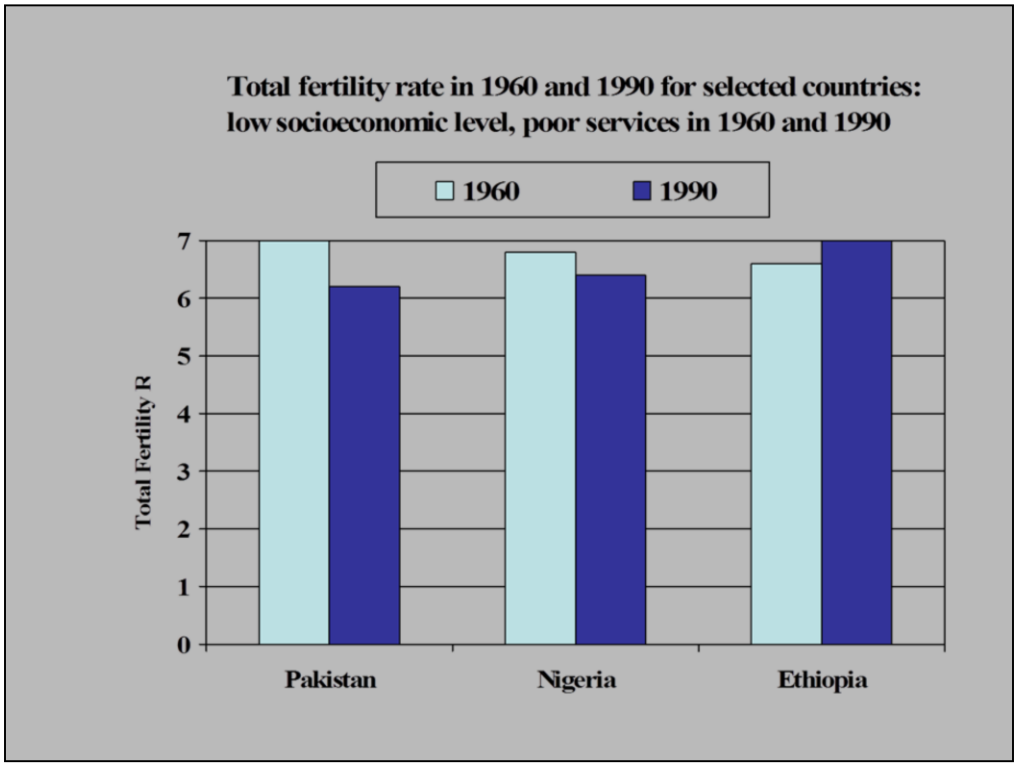
3. Fertility rates match ‘r’ closely



Trends that have led to this situation.

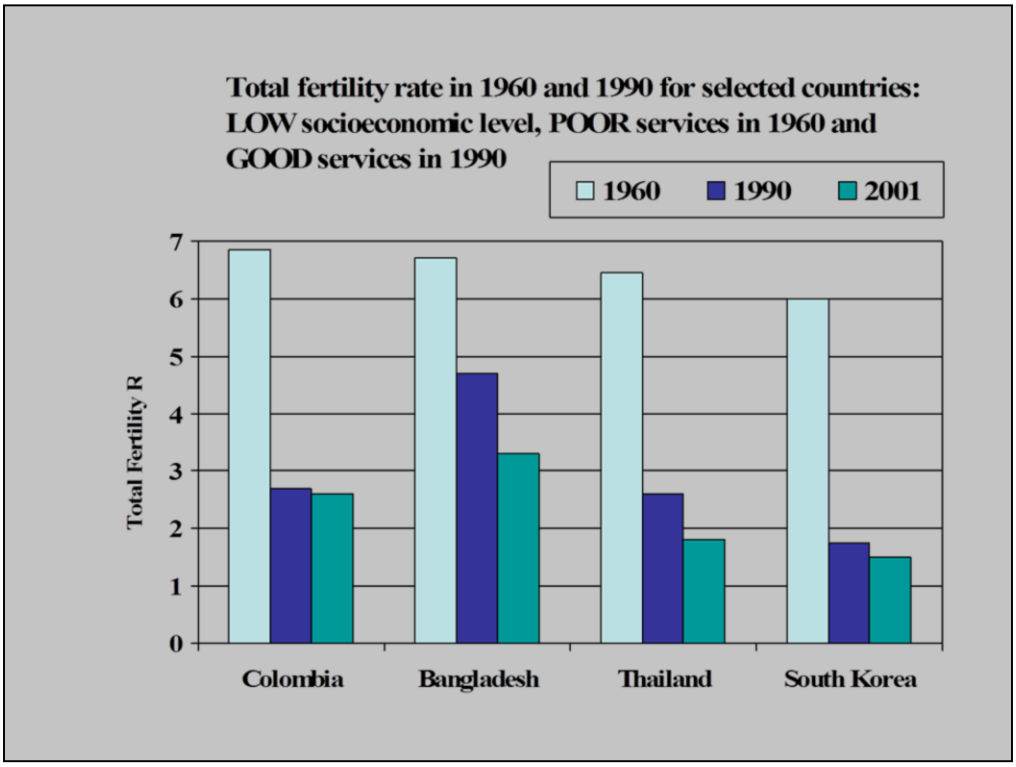


4. The result is that projected population growth varies dramatically, from significant shrinkage in eastern Europe and China (once the 'demographic inertia' of large cohorts in reproductive age classes passes) to projected increases of several-fold in much of Africa.



What explains these differences among

countries? Comparisons help test hypotheses. Here, countries with little change in socioeconomic conditions OR social services….



And, here, countries that are ALSO relatively

economically poor (although South Korea has become much richer since 2001), BUT with significant improvements in social services/security.

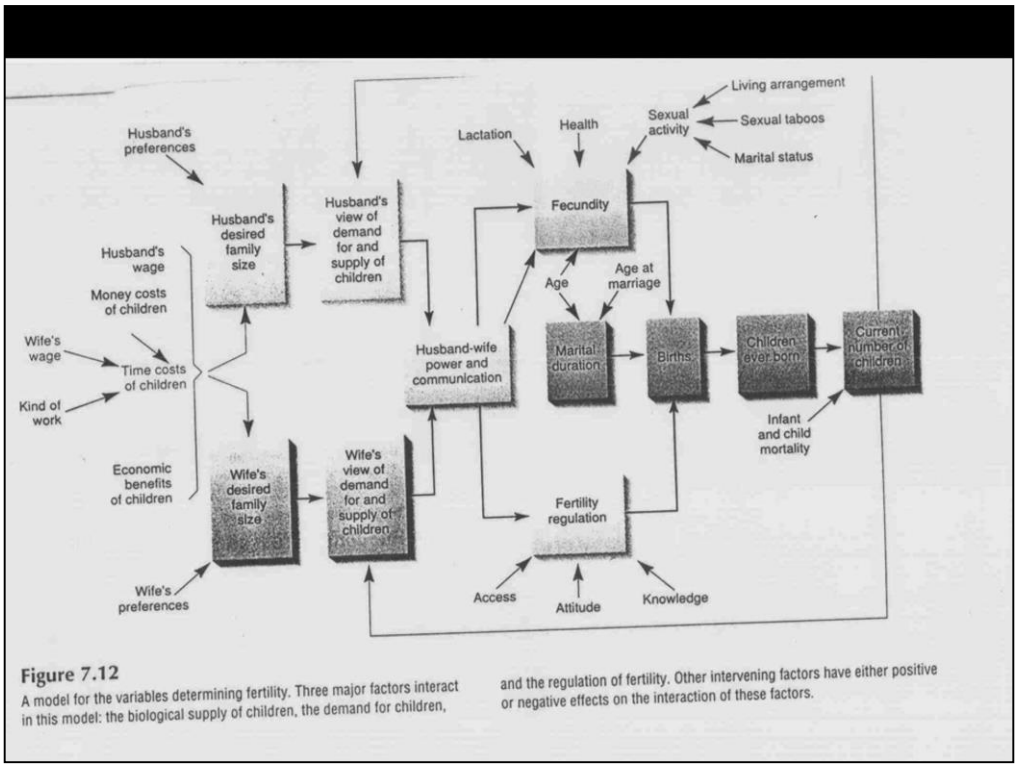
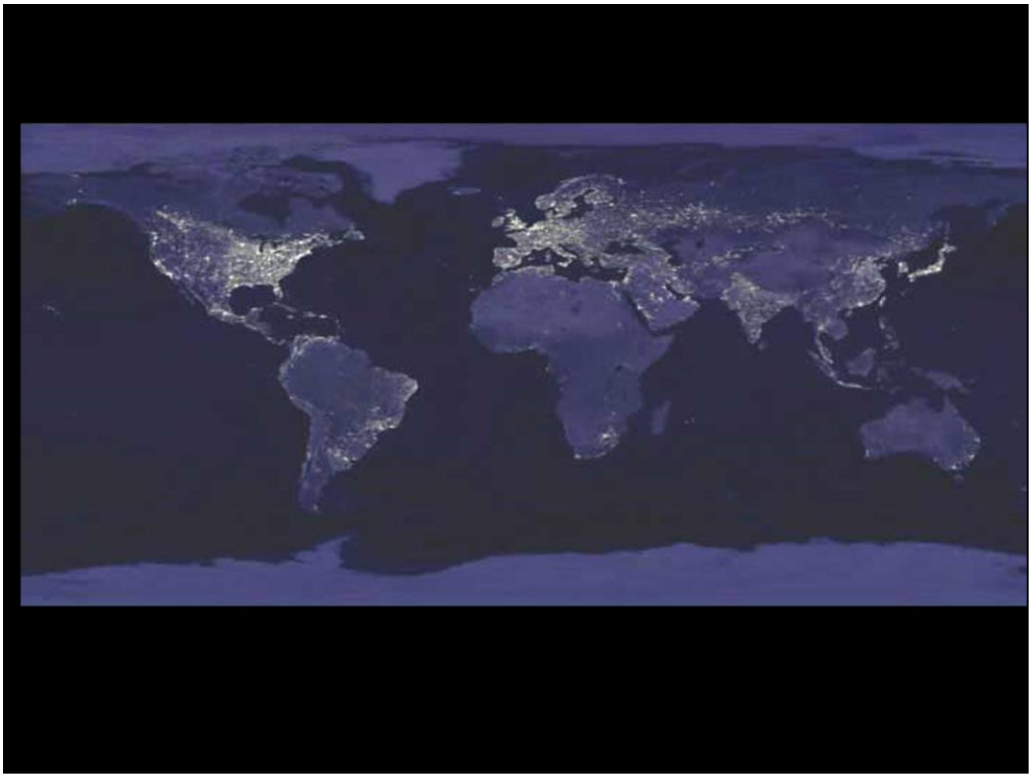


Figure 7.12
A model for the variables determining fertility. Three major factors interact in this model: the biological supply of children, the demand for children, and the regulation of fertility. Other intervening factors have either positive or negative effects on the interaction of these factors.

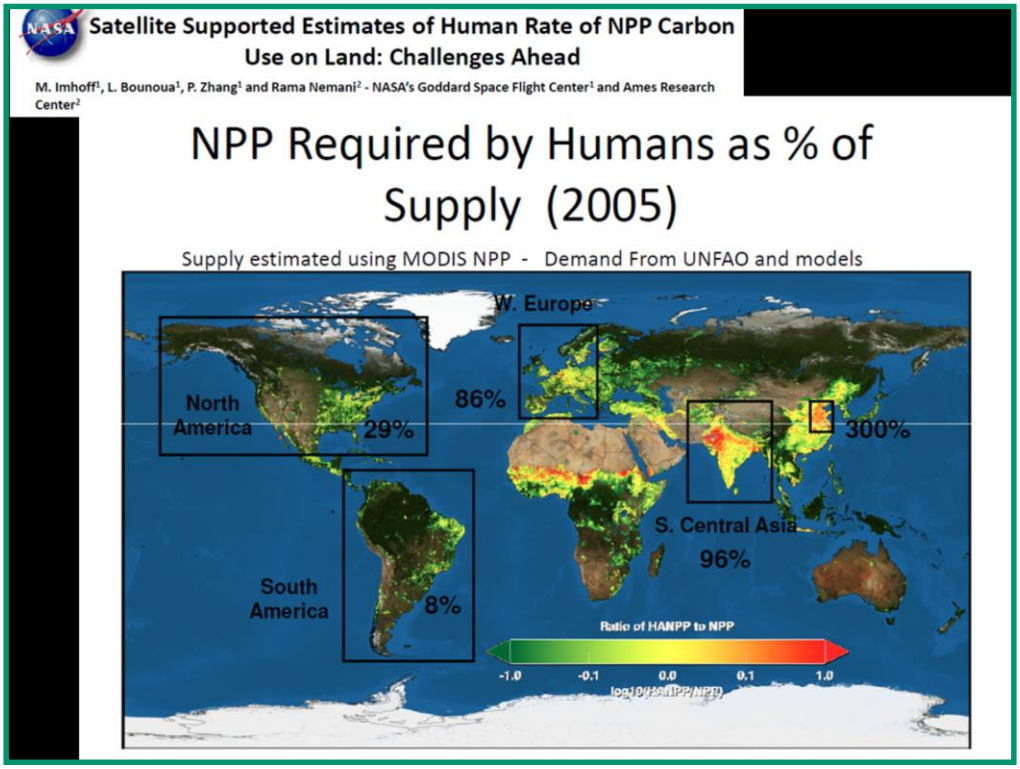
Many factors influence decisions about fertility, and there are complex feedback loops that make it impossible to point to one single dominant cause. However, most demographers point to interactions between a) economic consequences of childbirth (are children an economic benefit or cost?), b) women's contribution to family decision-making AND to family economies (closely tied to educational opportunities), and c) security (whether individuals can reasonably expect children to

survive to adulthood and to have support for themselves in old age).

TO EXPLORE THESE LINKAGES, visit https://www.gapminder.org/world/



The world from space at night.



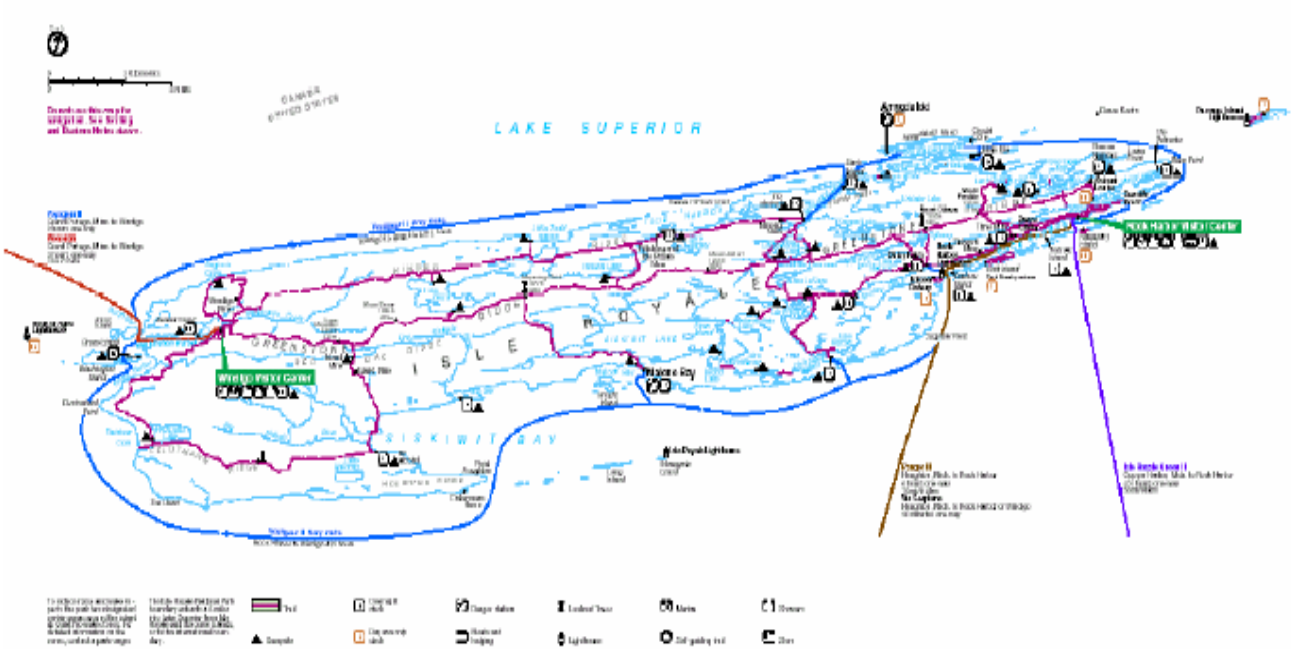
WHAT IS THE GLOBAL CARRYING CAPACITY FOR HUMANS? We'll revisit

this later, when we talk about ecosystem function, but "NPP" (net primary production) is a measure of biomass production by photosynthesis. All life, including humans, depends on this process, and

To return to more general thinking about population regulation:

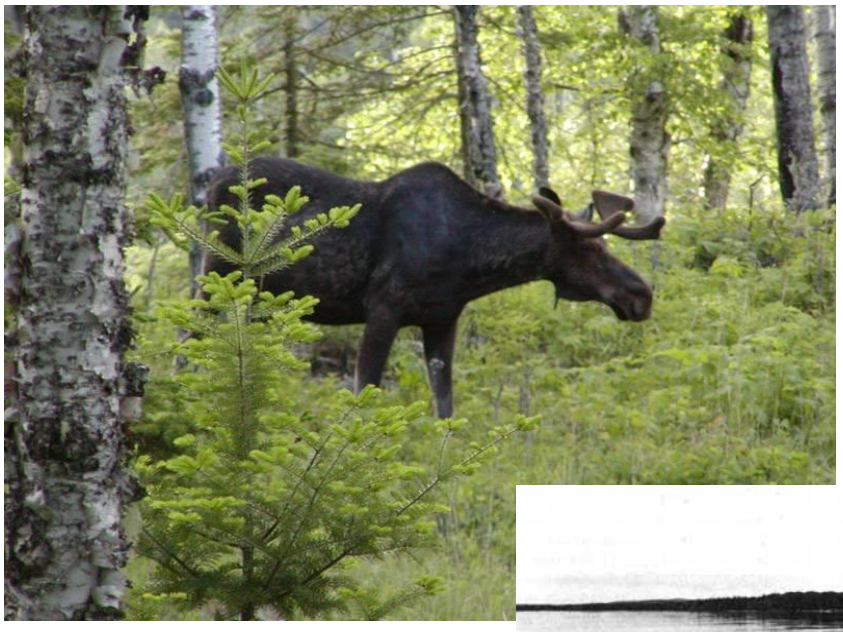
Populations in the wild are affected by much more complex interactions than simple competition for resources. Birth and death rates are affected by many interactions with shifting ecological factors. Here is a story to illustrate some of this complexity; we will not explore all of these types of interactions in detail in this class (there's too much!) Populations of moose and wolves on Isle Royale, in Lake Superior, are a particularly dramatic and uniquely well-studied example (almost no other wild populations of large mammals have been studied in such intimate detail for this long). Go to www.isleroyalewolf.org for a lot of information about this study.

Isle Royale is 544 km^2 in area



http://www.nps.gov/isro/home.htm

It's a big island, primarily wilderness. There has never been significant human habitation on the islan



Moose arrived in early 20th century by swimming (they probably displaced woodland caribou previously present).

Moose populations grew exponentially and depleted primary winter food sources (they browse on twigs and conifer needles)

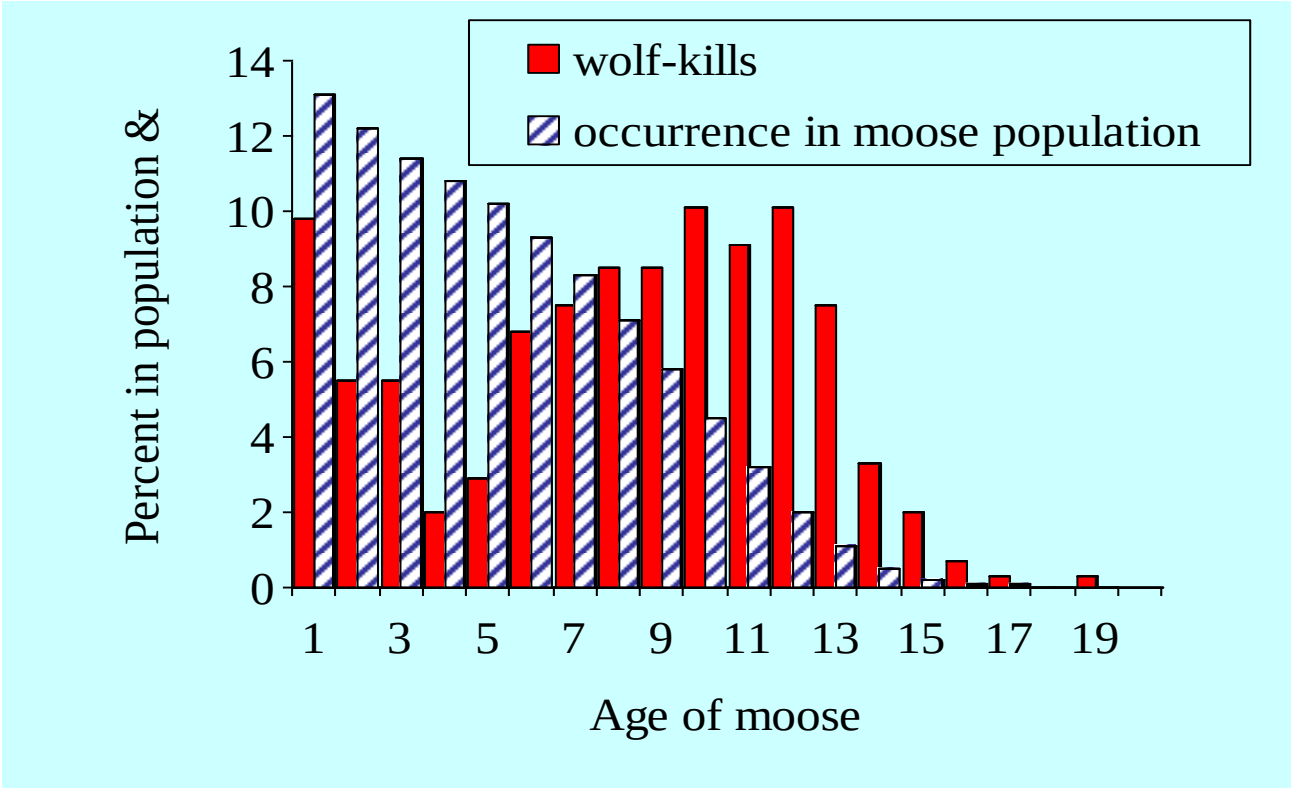
Habitat differences. Moose eat a lot of aquatic vegetation for sodium. Some trees provide more nutritious browse. So not all habitats had equal moose impact

Soon, managers began to speculate that moose populations could only be regulated by large predators, and there were none on the island. They attempted to introduce wolves in the 1940s, but the introduction effort failed (better understanding of reintroduction approaches has allowed more recent attempts, elsewhere, to be successful). Wolves arrived on their own in mid-20th century by crossing ice. Until recently, ice bridges formed between the mainland and Isle Royale every 3-4 years. They've become quite unusual in the last 20 years, and climate predictions suggest they're going to become a thing of the past within the next decade or two.

And they starting eating moose. Note that wolves are extremely social; hunting success depends on pack dynamics. Reproduction is in packs only and usually involving only one pair of wolves in the pack.

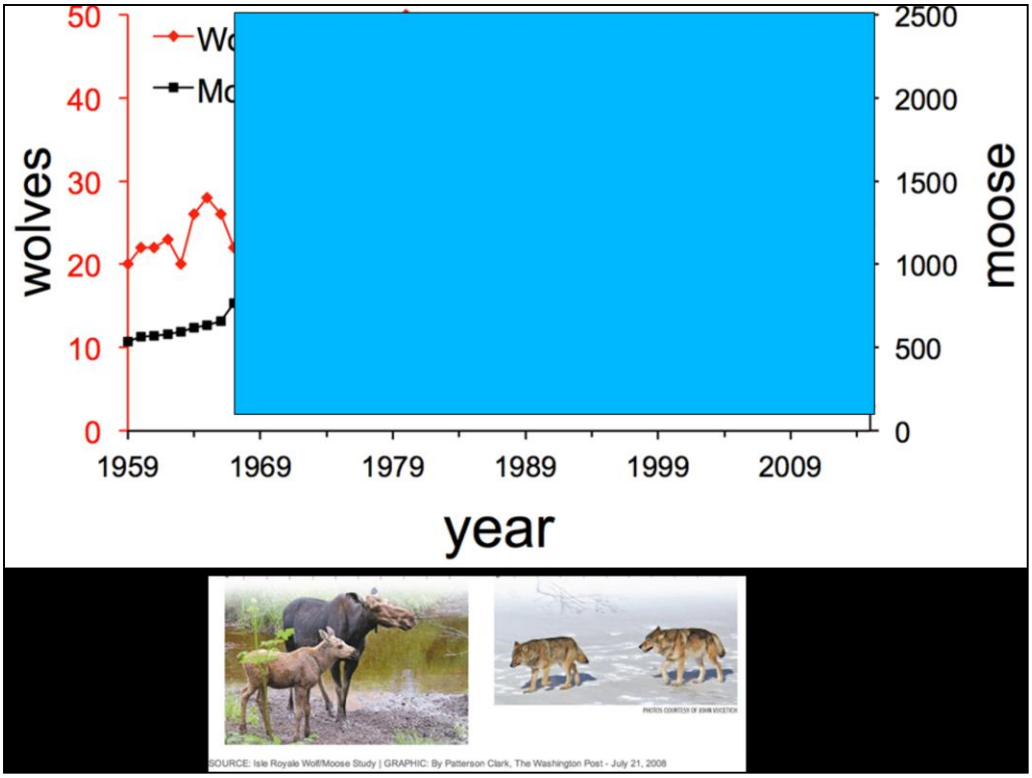
In 1996 carcasses of 175 dead moose were examined, and skulls and other specimens accumulated at the summer research cabin on Rock Harbor.

Researchers from Michigan Technological University initiated long-term studies of wolf predation, moose mortality, etc. over 50 years ago. It is now the longest study of large mammal population interactions in the world. Check out http://www.isleroyalewolf.org/wolfhome/home.html

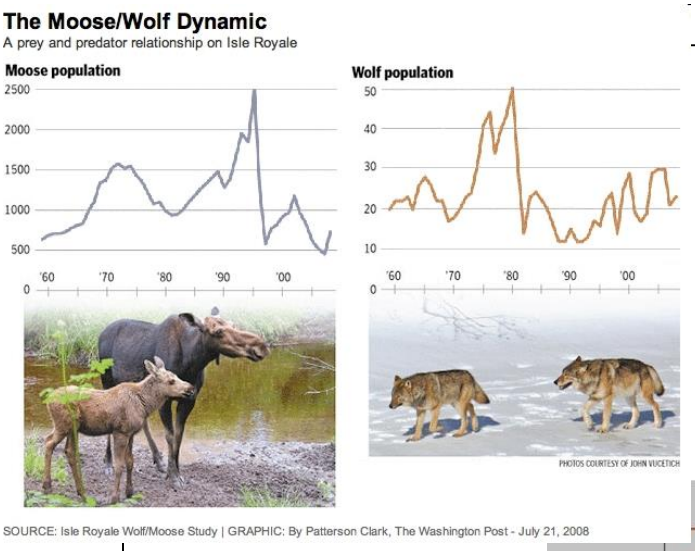


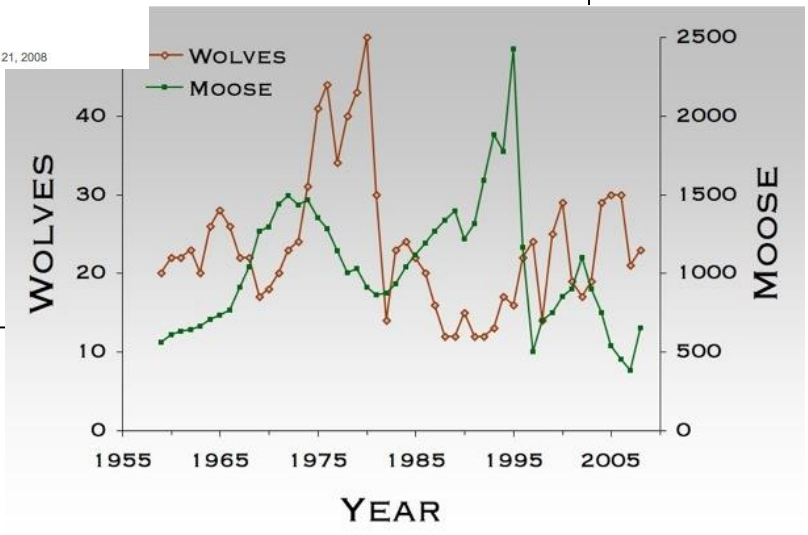
A wide range of findings:

First, note that nNot all moose are equally vulnerable to wolves; they prey disproportionately on young and old moose. (THINK ABOUT how to read this graph!)

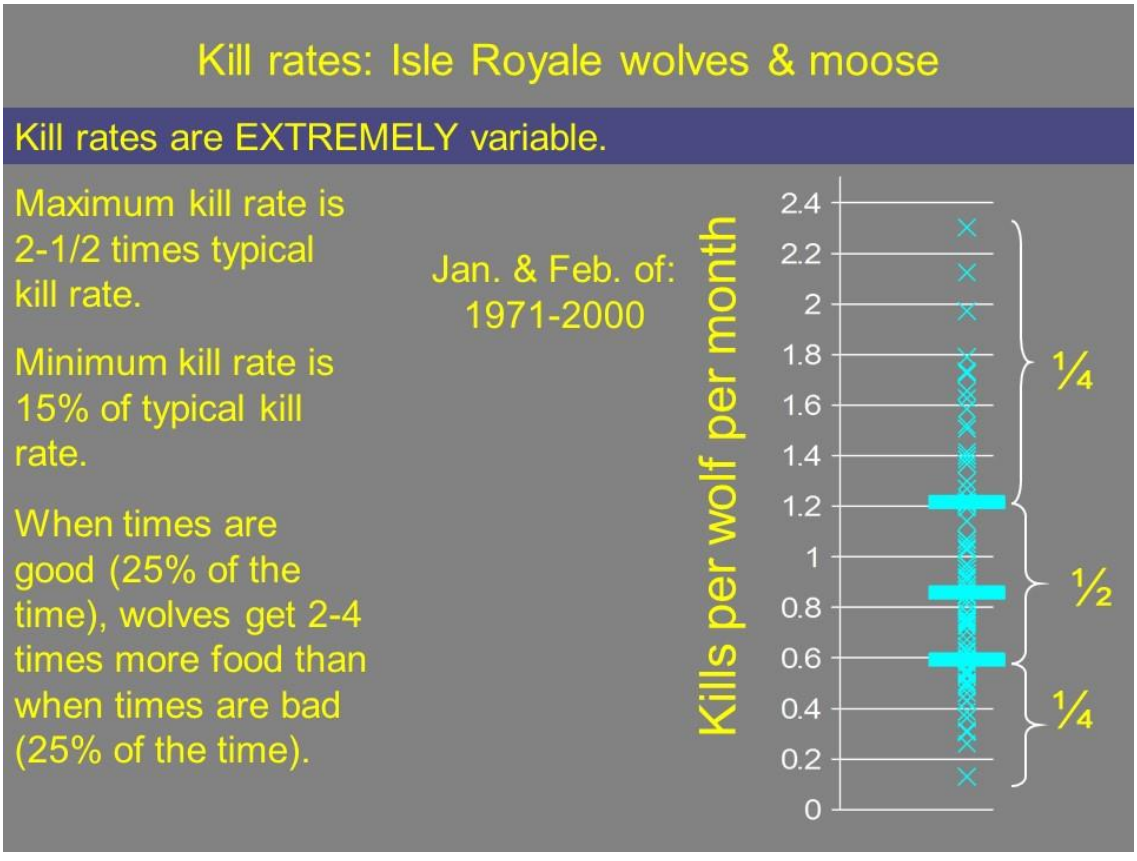


Conventional ecological theory at the time held that predator-prey systems would reach a kind of equilibrium; that was the reasoning behind the initial attempt at wolf introduction. This thinking is deeply rooted in traditional notions of nature as self-regulating and 'balanced'. During the first years of the study, this seemed like it might be the case; by 1959, when the study began, moose population on the island had dropped to N of about 500 (black line and right-hand vertical axis), and the wolf population stabilized at about 24 (red line, left vertical axis) animals organized into, usually 1 or 2 large packs (packs maintained exclusive territories, conducting 'border wars' to defend against neighboring packs).





But, subsequently, populations of both have fluctuated dramatically since long-term studies began. While short-term observations might (depending on time period) have suggested some degree of population stability, it is hard to see long-term dynamics suggesting any such pattern. Are moose populations regulated by predation or food? Wolves by food or disease (or inbreeding)? Or both, indirectly by climate? The big drop in wolf population about 1980 was due to the introduction of a disease (canine distemper) when visitors to the park (illegally) brought a dog that carried the disease). The increases from 1990 to about 2000 may be related to the arrival on the island of a single male wolf from the mainland who became a very productive breeder, and is thought to have helped counteract detrimental effects of past inbreeding (this is referred to population geneticists as a 'genetic rescue' effect. MORE RECENTLY, since this graph was produced, the wolf population has collapsed, due largely to reproductive failure related to inbreeding. As of the beginning of 2015, there were only three wolves on the island; a breeding pair and their year-old offspring. The young wolf appears to have significant health issues (spinal deformation and other things). Most experts expect the population to disappear very soon.



Wolves don't always hunt 'efficiently'; sometimes they kill lots more than they eat. (graphic didn't translate well; but When times are good (25% of the time), wolves get 2-4 times more food than when times are bad (25% of the time). Maximum kill rate is 2-1/2 times typical kill rate.

Minimum kill rate is 15% of typical kill rate.

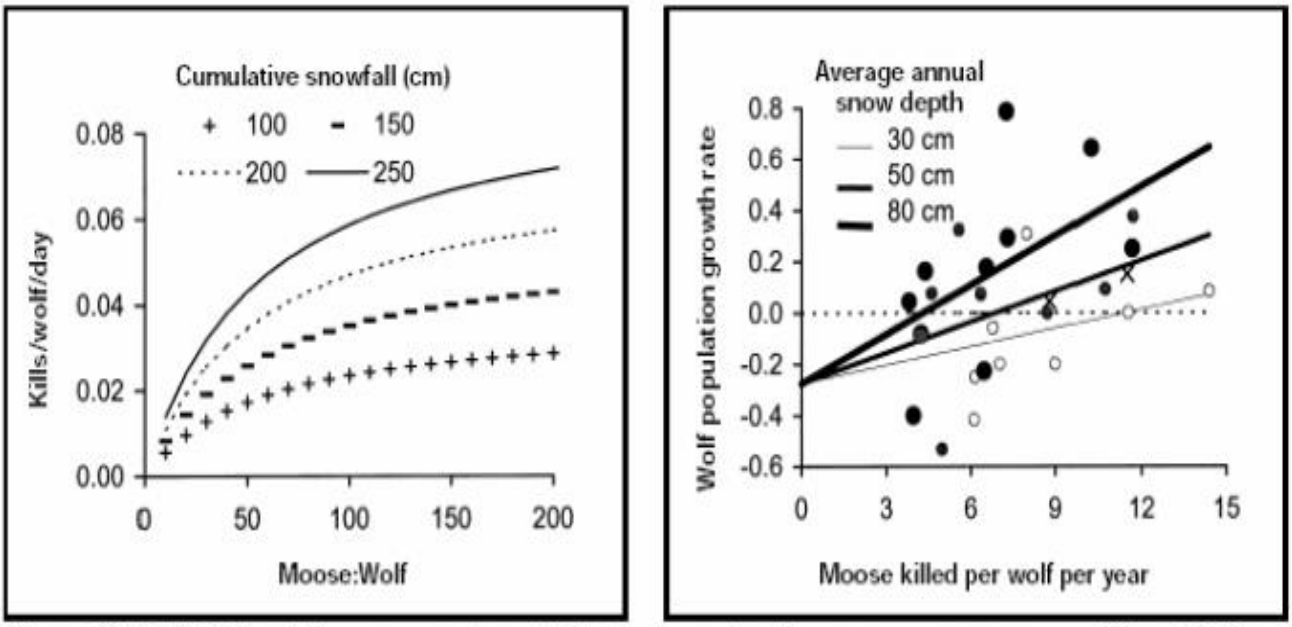


Figure 10. (Left) Wolves kill more moose (y-axis) during years when there are more moose per wolf (x-axis). These relationships, called functional response and numerical response, together determine the nature of predator-prey dynamics. Winter climate has an important impact on both relationships. In years with more snow, wolves not only kill more moose (left), they are also more efficient at converting moose killed into wolf population growth (right), possibly because moose are less fit.

This seems to be related to climate – particularly snowfall; moose are easier to kill in high-snowfall years because they are hungrier and can't move around as easily

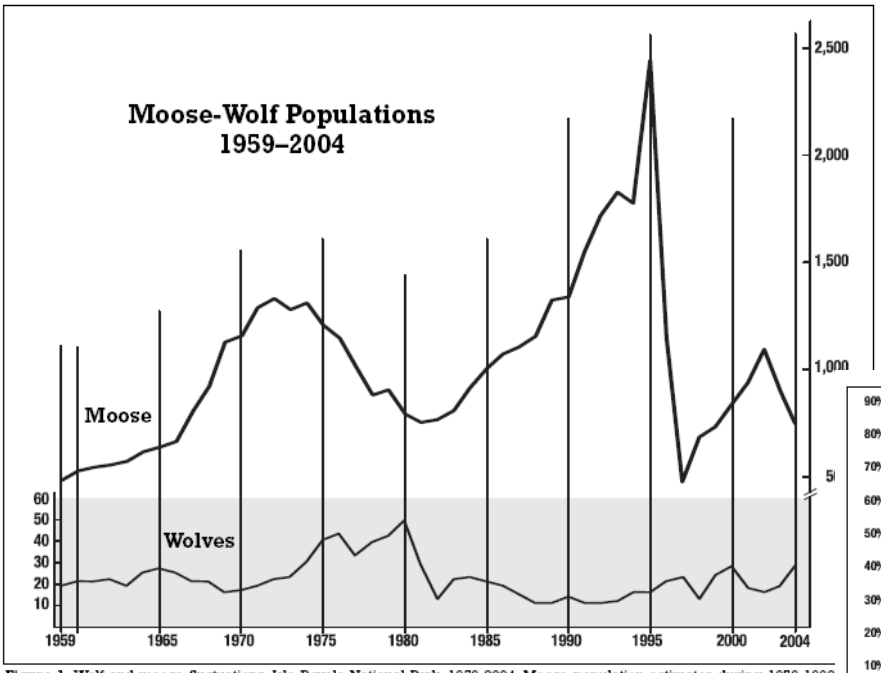


Figure 1. Wolf and moose fluctuations, Isle Royale National Park, 1959-2004. Moose population estimates during 1959-1993 based on population reconstruction from recoveries of dead moose, whereas estimates from 1994-2004 were based on aerial sur

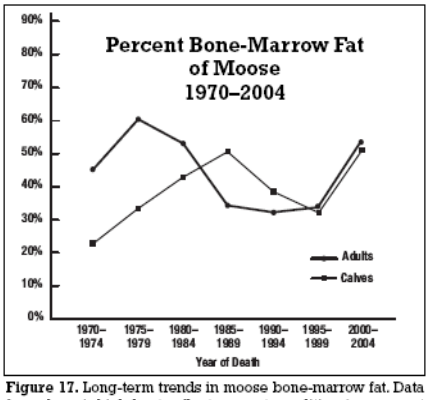
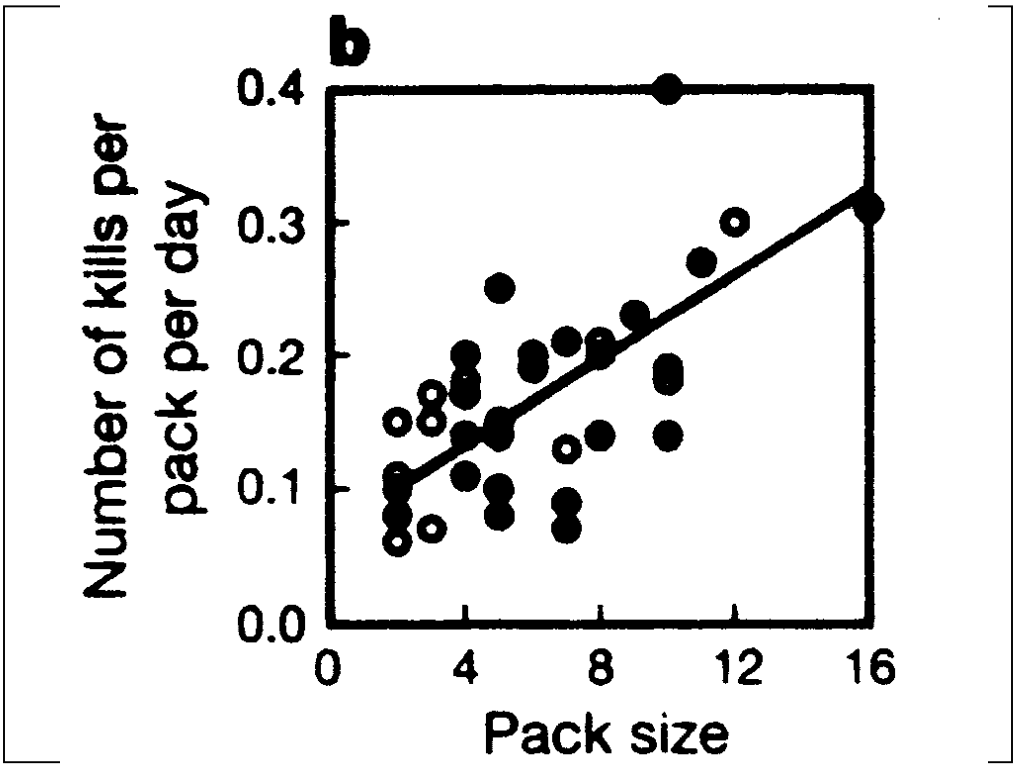


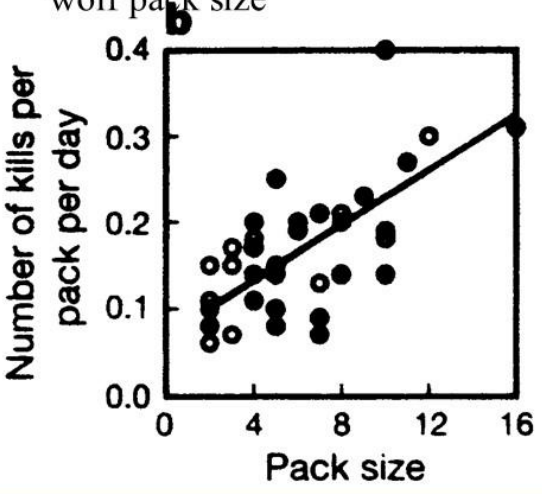
Figure 17. Long-term trends in moose bone-marrow fat. Data for calves (which best reflect current conditions) represent mean levels, whereas data for adults is the proportion with greater than 70 percent marrow fat. Over the past five years, marrow fat levels have been relatively high.

High moose populations are correlated with low bone-marrow fat (an indication of malnutrition), suggesting competition for food – density-dependent processes – at work. But, when moose populations are low, evidence of resource competition is not as strong.



Lower NAO index = greater snow depth correlates with larger wolf packs

Kill rate per pack (and per individual wolf) increases with wolf pack size



Well-used remains of a bull moose killed and consumed by the East Pack in 1997 illustrated that vulnerable prey were not readily located by wolves.

Kill rate per pack (and per individual wolf) increases with wolf pack size. The "NAO" – North Atlantic Oscillation – is a climatic cycle.

In low-snow years, when prey harder to find and kill, wolves consume kills more fully; in deep-snow years, they tend to eat just the nicest bits. So climate interacts with moose vulnerability interacts with kill success interacts with pack size interacts with kill rate…

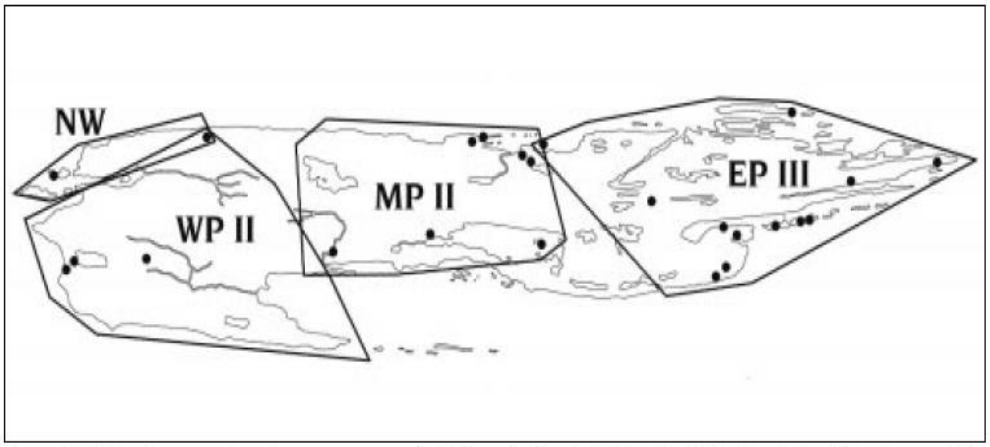


Figure 2. Wolf pack movements and moose carcasses (wolf-kills and otherwise) during the 1997 winter study. All packs except NW actively marked their territory.

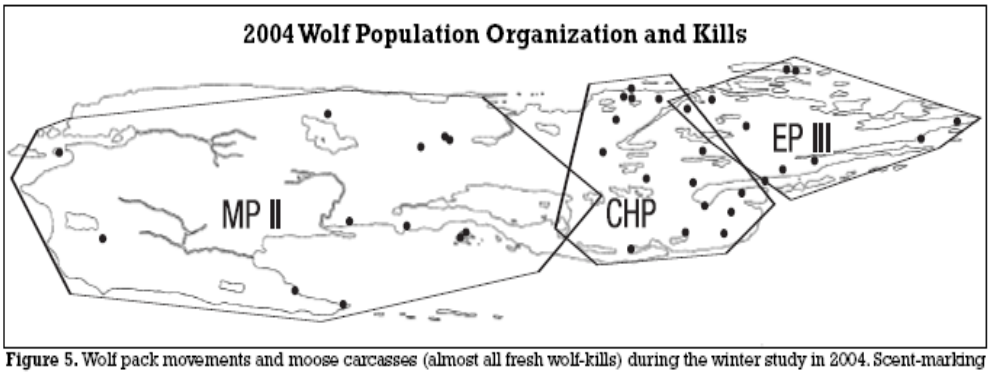
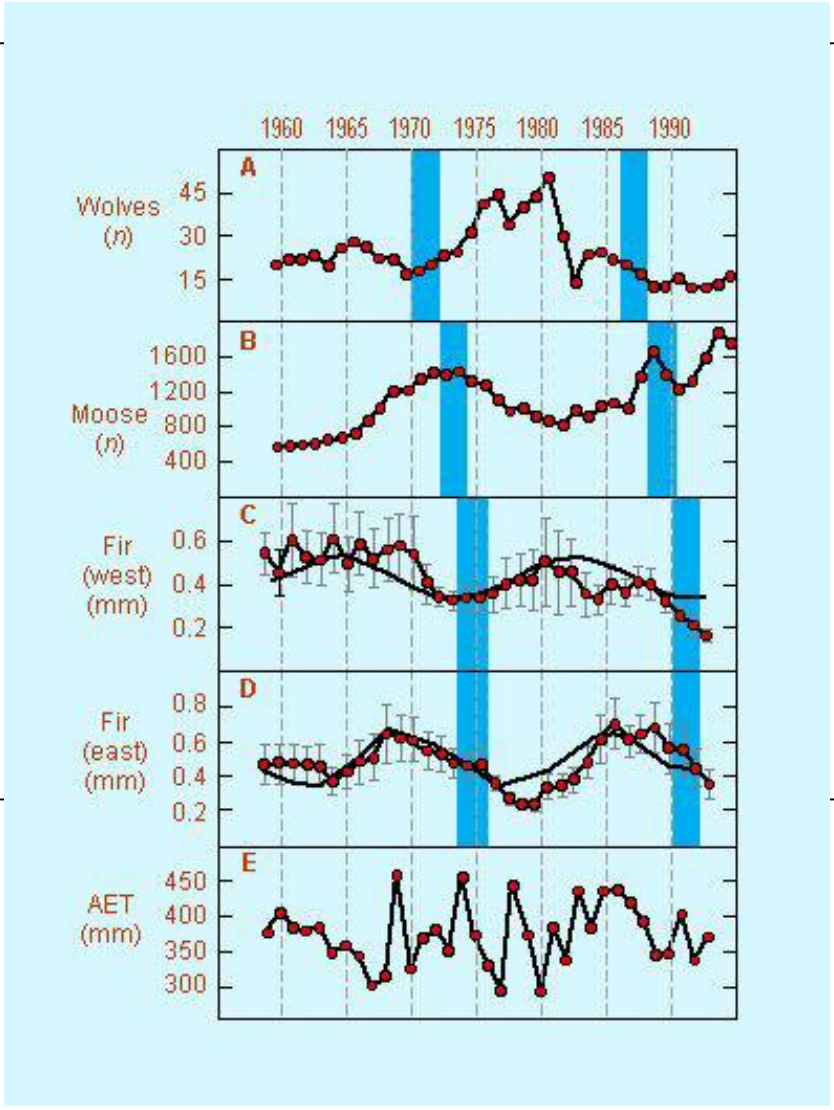


Figure 5. Wolf pack movements and moose carcasses (almost all fresh wolf-kills) during the winter study in 2004. Scent-marking was observed by all three of the packs.

Wolf pack interactions have varied greatly, with more packs, there can be more wolves – but packs fight for territory. Some packs are better hunters than others. Some years kills are concentrated along shore (where 'yarding' areas allow moose to overwinter in less deep snow); other years more widely scattered...



Some data suggest climate differences regulate plant productivity and drive everything from the 'bottom up'. Some suggest 'top down' regulation by wolves; when wolves depress moose populations, plant populations respond by increased growth…) "Fir" curves show measured growth rates (ring-widths) for fir trees in two areas. Note that "AET" is actual evapotranspiration - related to rate at which trees pump water through foliage -- but don't worry about that too much.

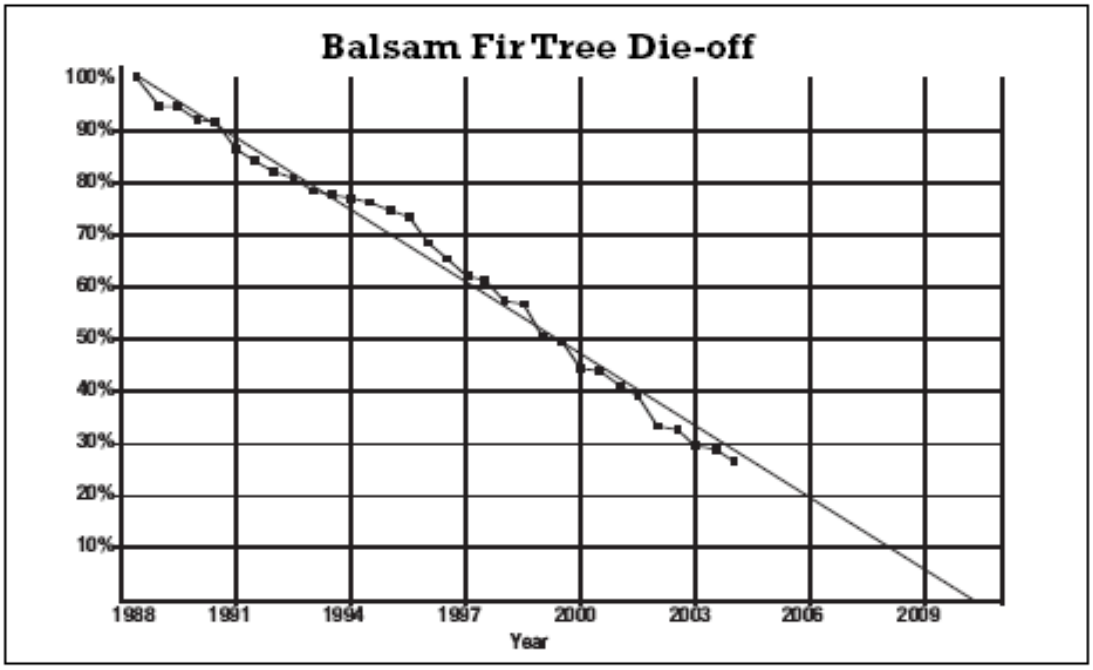
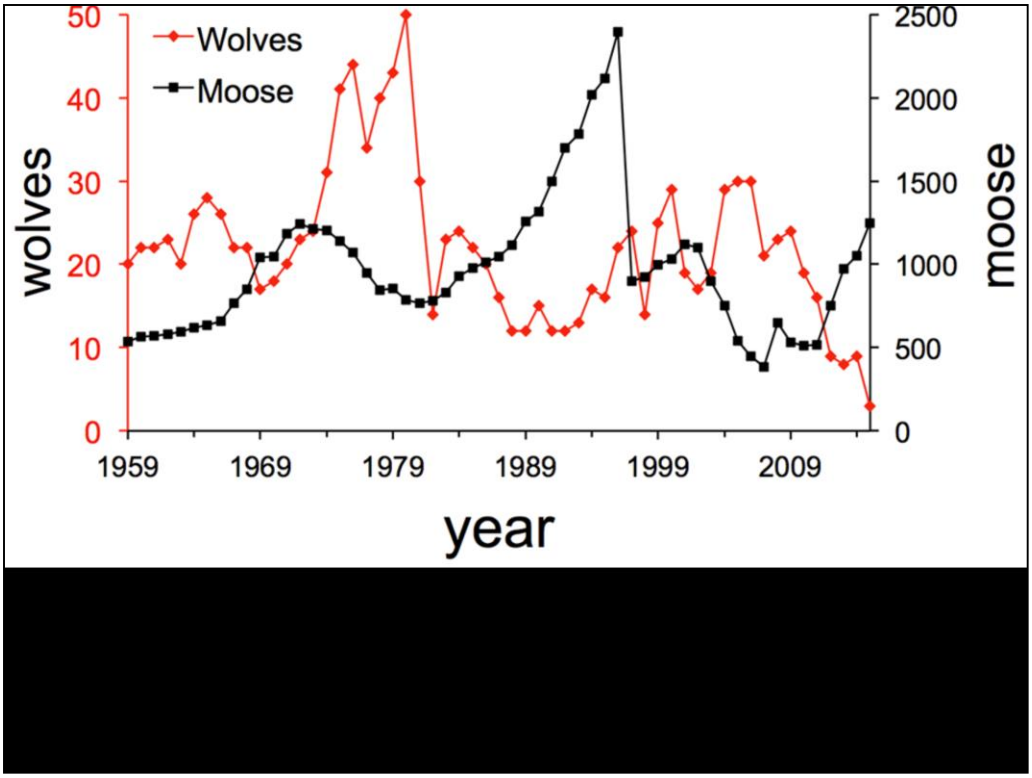
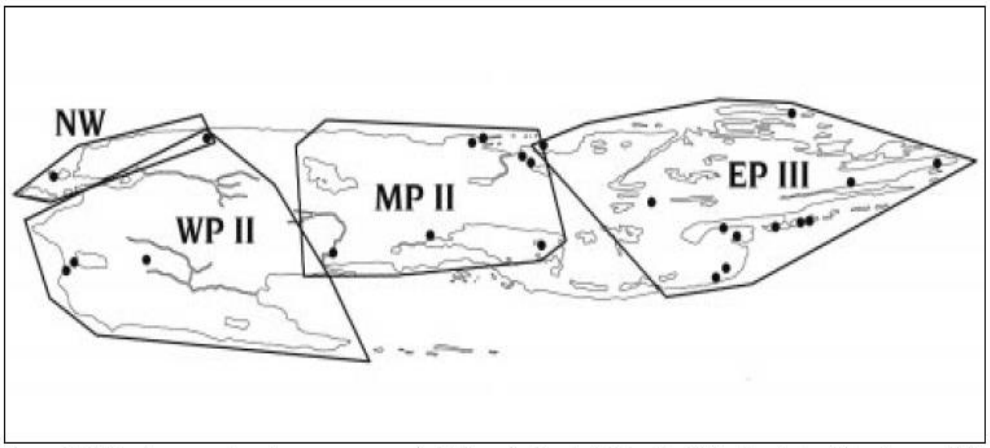


Figure 19. Balsam fir trees in the forest canopy that were tagged in 1988 have steadily died off without replacement. The remainder are expected to die by 2009-2010, and at that point a seed source for this species will be absent over 75 percent of Isle Royale. The demise of this species is ultimately caused by moose herbivory.

And food availability for moose may simply be changing due to long-term change in abundance of fir trees as they are competitively displaced by other species.



Following the distemper-caused crash in wolf populations, biologists began to note symptoms of inbreeding (high rates of skeletal malformation, early and severe arthritis, etc) in the wolf populations, and concerns were raised about the resulting fate of the population. Some suggested introducing new wolves from the mainland to reintroduce genetic diversity, but this was opposed by many as unwarranted human intrusion (and, in fact, it went against national park standard regs). Then the wolf population showed a substantial recovery. It wasn't clear at the time, but this appears to be due to a single male wolf introducing itself (by crossing the ice again) about 1997. This male became the alpha male in the main pack at that time, and fathered many offspring with two successive alpha females.



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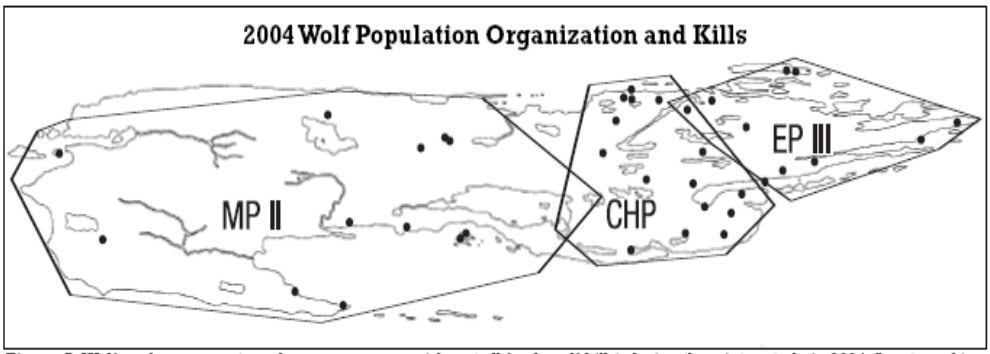
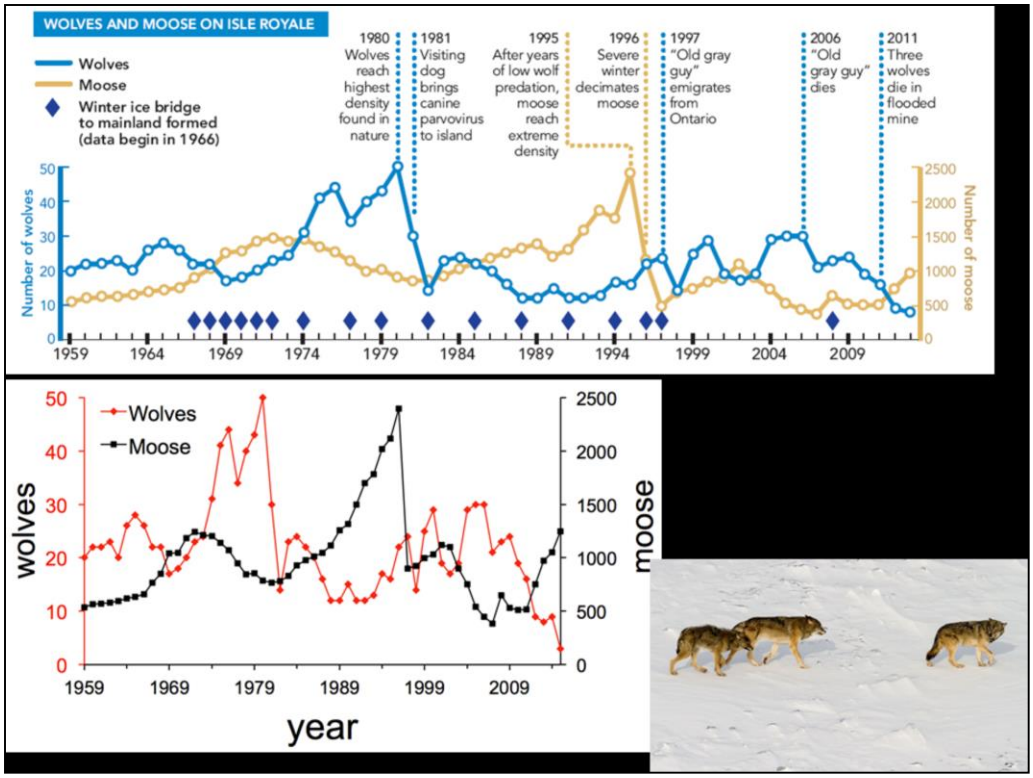


Figure 5. Wolf pack movements and moose carcasses (almost all fresh wolf-kills) during the winter study in 2004. Scent-marking was observed by all three of the packs.

His offspring then became alpha members of other packs (there were up to 4 for a while). A decade after his arrival, nearly ALL of the wolves on the island were his descendants, and there were multiple instances of alpha pairs being half siblings or parent-child. This is *extreme* inbreeding.



The wolf population has now crashed again – probably due in large part to inbreeding. Ice bridges have not occurred since the 'old gray guy's arrival, so there's been no opportunity for further 'genetic rescue'. An accidental drowning of three wolves in 2011 severely aggravated the situation. There only three wolves on the island in 2015; a breeding pair and their yearling offspring. The offspring (in rear of the photo) shows severe malformation and appears unhealthy in general. Expectations are that these last wolves will not survive long, and the wolf population will die out after about 65 years on the island. MEANWHILE, moose populations have been maintained, recently, at relatively low levels by changes in forest composition (and food source), very heavy infestations of winter ticks (due to milder winters?).