Population is a difficult issue to discuss. You can tell it’s a difficult subject by simply looking at the expression on people’s faces when you bring up the subject, say, at a party. They walk away if possible. They change the subject. Or if you’re lucky they laugh about it.
Nothing wrong with laughing. Sometimes the best way to deal with tragedy is through humor. But laughing is sometimes a way of changing the subject. Overpopulation isn’t really funny at all, so I tend to think the humor is meant to change the subject.

If you are persistent in talking about it, and they don’t walk away, and they can’t manage to change the subject, they steer the subject towards a population issue that is considered “safe”, such as demographics, or peripherally related, such as consumption. They won’t address it head-on. They won’t treat overpopulation as they would any other serious problem.

That is, they won’t try to resolve the problem. And that makes the problem difficult to solve, or even study.

As a scientist, when faced with a real problem that can’t be studied, it becomes necessary to study the reason that it can’t be studied. So bear with me while we discuss the nature of the population problem, and of problems in general.
I submit that unresolved scientific problems are analogous to dissonant music. I can define dissonance in such a way that it satisfies both music theory and epistemology (the philosophy of science) as “Data or observations that exist, temporarily or permanently, outside of the current established model.”

So like music, problems are a phenomenon that cause a sensation in the mind. We can further recognize that dissonance resolves when a new model is established that explains the observations that were temporarily outside the model. Bach was a master at resolving dissonance. He wrote violin sonatas in such a way that they explored the extremes of tonality, then resolved back into the primary tonality without ever taking a logical misstep. When the piece is done you have the sense that everything was resolved, everything fits in your mental model. But if you took any one phrase out of context it would sound very dissonant indeed.

If we could do science the way Bach did violin sonatas, no scientific problem would be too big or too dissonant to resolve.
Our reactions to dissonance

<table>
<thead>
<tr>
<th>Level of Dissonance</th>
<th>Music</th>
<th>Science</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>low</td>
<td>twinkle, twinkle</td>
<td>solve 1+1</td>
<td>get bored</td>
</tr>
<tr>
<td>medium</td>
<td>Bach</td>
<td>solve cancer</td>
<td>pay attention</td>
</tr>
<tr>
<td>high</td>
<td>Schönberg</td>
<td>solve overpopulation</td>
<td>flee!</td>
</tr>
</tbody>
</table>

But in fact there are problems that are so dissonant that we can’t build a mental model around them, we can’t resolve them. The musical analogy is music that sounds like random noise. Shoenberg’s twelve-tone row music does it for me. I simply cannot build a mental model of the tonality he uses, which according to some music historians is “intentionally inaccessible”, a rebellion against the perceived triviality of the romantic era of orchestral music. If you are trapped in a concert hall listening to 12-tone row music, unable to change the channel back to Bach, you might experience the urge to flee the room. This is natural. In fact it is probably programmed into our genes.

Likewise, we can’t bring overpopulation home and park it nicely into our mental model. We can’t resolve it with our understanding of the human condition.
To explain, let me build a simple model but one that is sufficient for us to see the dissonance. Humans tend to assign a “good” value to new life, and a “bad” value to death.

If you are not sure whether this is true, think about the last time you expressed condolences on the birth of a new baby. Even unplanned children are congratulated, and we would not have it any other way.

Likewise, how often do you hear “congratulations on the death of your uncle John!”. Even if uncle John was 95 years old, we take his death with a note of sadness, not happiness.

Now, expressed here on a completely separate chalkboard is how we feel about sustainability. We think it’s good. We do not look forward to the extinction of all commercial fisheries, and we do not condemn organic farming for being nice to the soil. We might condemn it for high prices but not for its sustainability.
But Math tells us that population change is sustainable only when it is zero, and that population change equals births minus deaths. So we can draw this graph and label it. The trouble is, we can’t easily assign “Good” and “Bad” labels, since moving toward sustainable also means going down in birth or up in death.

So we tend to flee in one of the ways I have just mentioned. If you are so brave as to bring up the subject, I have some advice. Offer a solution! This you will do instinctively anyway, since it is bad manners to leave an unresolved problem hanging in the air, like an unfinished symphony. Your instinct tells you not to start the sonata if you aren’t going to finish it.
So, you guessed it. I am going to offer what I think is the most logical scientific/political approach to the overpopulation problem. Please don’t leave the room early. If you do I have a very real fear of being labeled an “advocate for nuclear war.” I’m not. But this is perhaps the most obvious unmentionable, so best to quickly move past it and think of other solutions.
I am not going to hold you in suspense. The answer I am going to promote is contraception, specifically immunocontraception (which is new and not listed on this slide). At the end of the talk I will discuss the biotechnological challenges and the possible socio-political repercussions of a contraceptive vaccine.
Since we are unable to avoid it. Let’s take a look at the population problem. I hope you agree this is an unsustainable curve. We have gone from less than one billion people in the long period from one million years ago when the species began to around the year 1830. We doubled to two billion over the subsequent 100 years, then doubled again to 4 billion in the next 35 years. Over the last 50 years we have grown at the rate of about 1 billion people every 12 years. Approximately linear.
As an aside, let’s look at the **real** problem.

Two days ago ago I searched Grants.gov for any program announcement that contained the word “overpopulation”. I found two grant opportunities, both from USAID. Nothing from the National Science Foundation, nothing from the National Institutes of Health. For contrast, the keyword “cancer” brings up 408 granting opportunities, “rivers” brings up 192. Encouragingly, “Contraception” brings up 46, most associated with HIV and other diseases rather than population control.
Population growth is exponential given ideal growth conditions, with an exponent that is the difference between birth rate and death rate. Note that when birth rate and death rate are equal we get exp(0) and the population is constant. If $r$ is positive we can calculate the doubling time $t_{1/2}$ by dividing log2 by the population increase. This is equivalent to dividing 69.3 years by the percentage growth, and rounding off to 70 years makes it easier to remember. So a 1% growth rate translates to a doubling time of 70 years, 2% 35 years, etc.
It is important to note that exponential growth is normal for any living thing. Under constant conditions, that is what organisms do. So the linear growth rate we are experiencing now, worldwide, is not a sign of increased stability, but instability. It means growth conditions are changing, not that they are somehow leveling off.

How they are changing is a matter of interpretation, but just looking at this graph on the left, log–population versus time, we see a decreasing slope. If we plot the derivative of the log–population plot, we can see a general downturn in growth conditions since the mid–1960’s worldwide. The US growth rate reflects relatively constant conditions over the last 40 years.
So if we want to understand this problem, we have to model it. The naive model assumes constant growth conditions. This assumes no changes in fertility and no changes in life expectancy. My exponential fit, although it is not perfect, predicts a population of 13B in 2050.
What do other models predict?
So I found this Nature paper, predicting the future population. First, I noticed it was published not by ecologists or even biologists, but by economists. But I rationalized that economists should be in touch with the food supply, so maybe they were just as qualified as I am to predict the population.

Note that they predicted a smooth transition from high birth rate to replacement value over 95 years, with really big error bars. A smooth transition would seem to imply nearly constant conditions, but really it implies gradual but constant change in growth conditions. This made me wonder what their unstated assumptions were.
Looking for a more authoritative view, I found this document published by the United Nations, which regularly publishes population predictions. 2004 was the first time they projected out to 2300. Here I notice again a gradual leveling off, and I noticed some amazingly large confidence limits and some pretty amazing numbers. The stated assumptions were hard to find, but clearly they assumed no upper limit to population, at least as far as 36B. I looked at how this projection was done, and it turns out they did it by projecting trends in birth rate and death rate into the future. That is, they did the projection by curve fitting and extrapolation, no assumptions at all, and no underlying physical limits or constraints. Interesting.
Types of science

<table>
<thead>
<tr>
<th>Who we are.</th>
<th>What we do first.</th>
<th>What we then do.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Scientists</td>
<td>Devise a hypothesis.</td>
<td>Test it against real data.</td>
</tr>
<tr>
<td>Social scientists</td>
<td>Devise a hypothesis.</td>
<td>Publish it.</td>
</tr>
</tbody>
</table>

This leads me to conclude that there are really two very different ways to do science. There is natural science and there is social science. That is, you can do science or you can choose to not do the science. It is unfortunate that this is the state of the art in such an important field as population, but it is also understandable given the dissonance this field creates.

So at this point I would like to tell a little story about how I got interested in the field, what I did and how it leads to a different hypothesis.
First of all, after a little reading and a few simulation experiments, here is the hypothesis I came up with. To be honest it’s not new. I borrowed it from Garrett Hardin, Paul Ehrlich, and a few others. This is called boom bust behavior. The boom is exponential growth, the bust rate is difficult to predict but is usually faster than the boom, depending on “response functions” which I’ll explain in a minute. This model fits the behavior of an animal species that has no predators and is only limited by the availability of food, which itself reproduces at a decreasing rate as it is consumed. The downturns are simply starvation. The boom cycles assume constant growth conditions. This model assumes to learning, no corrective actions, no advance of technology, and in that sense it is a naive model. But at least it recognizes two things (1) that exponential growth is the norm, and (2) that there is a limit to population, known as the “carrying capacity”.
 Sharp overshoots have been observed in herbivores on islands without any predators. When the grass is overgrazed it grows back too slowly to support the herd, whose population then collapses.

This other example is yeast in grape juice. Yeast, like reindeer, don't save food for later, they just eat it up.

*Sometimes in these articles on population you get sardonic statements like this one.*
"It is an obvious truth, which has been taken notice of by many writers, that population must always be kept down to the level of the means of subsistence; but no writer that the Author recollects has inquired particularly into the means by which this level is effected..."

-- Thomas Malthus, 1798
An Essay on the Principle of Population

The idea that the food supply limits the population at the carrying capacity was first stated by the British scholar Thomas Malthus, and those who subscribe to this way of thinking today (the late Garret Hardin, Paul Ehrlich and others) are sometimes labeled “Malthusians” in disgust by other scholars (economists such as Julian Simon) who refuse to accept limits to growth.
This is not a worst case scenario, not yet! Worst case would be just one boom and bust. Since our species has not experienced such a boom before, it might not survive the bust! So it is not out of the question to propose it as a lower limit projection, which would be zero.

So it is not out of the question to propose it as a lower limit projection, which would be zero population.
We can also propose a best case scenario, where we converge on the carrying capacity and remain there. But I won’t propose an ever increasing population, even as a best case scenario, and if we did converge on the carrying capacity, I can’t reasonably assume we can converge quickly, since that would require dramatic cultural and technological changes to happen overnight, so I’ll say we spread those changes over a time, which will be a time of constant change. So if we are in the best case scenario, we may already be in that time of constant change.
The most likely scenario might be something in between. Some boom/bust and some adaptation, converging on the carrying capacity by overshooting and correcting. This assumes periods of constant conditions leading up to change conditions. Over time we may learn to anticipate the change conditions and minimize the bust period. This would have to happen through cultural evolution, not though speciation.
So here are four hypotheses, ranging from bad to good. One feature present here but missing in the projections from the UN is the idea that slower population growth may converge at a higher population.
The UN projections state the opposite, that faster growth today will converge on a higher population. You can weigh the arguments, but you can’t use experiments and there is no historical data to test our theory. Well, almost.
So every good hypothesis needs data to back it up. Jared Diamond is the author of Guns, Germs and Steel, the story of how geographical features can lead to historical outcomes. His latest book “Collapse” chronicles how populations have grown, outgrown their environments, and collapsed, sometimes dramatically. Easter Island for instance lost 97% of its population in 10 years. They continued to cut trees and make fishing boats out of them even down to the last tree, and in the end resorted to canabalism in the face of starvation. The Greenland Norse disappeared completely during the 15th century. They were isolated from Europe and never learned how to fish! Diamond suggests that the Rwanda genocide was a Malthusian collapse in its roots, and points out that the amount of cropland per person was down to a critical level just before the unrest broke out.

Diamond claims that societies make decisions that affect their fates and he devotes several chapters to societies that have succeeded in making dramatic cultural shifts affecting their survival, such as Iceland, China and Japan.
Upper limit to carrying capacity

- Maximum total production rate = Total sunlight hitting the Earth * Maximum efficiency in conversion to food
- Total consumption rate = total population * individual consumption rate
- Total consumption rate ≤ Total production rate (obviously!)
Limits to food production

- Arable land -- finite, decreasing yields
- Water -- surface, aquifer, fossil water irrigation
- Fisheries -- predicted to collapse by 2050 (R. Ellis, “Empty Ocean”)
- Climate change -- high temperatures lead to crop failure. (failed pollination, insect dependence)
Someone on a blog writes “how much food will we need to feed the growing population?” and another blogger answers “that’s like asking how much wood does it take to feed a bonfire!”

The same point is made by Pimentel of Cornell in this paper, where he argues based on historical records that we have always expanded the population to fit the food supply. That is, it isn’t a question of how much food it will take to feed 9B people but of how many people can be supported with the available food supply.

To ask whether we are approaching that limit, you can fly over the country and look down. You will see that a large fraction of all arable land is now already in use. So we have reason to believe food supply is maxing out.
Arable land area is one limiting factor, because plants need light to grow. But water is another. As we run into and over the limits of surface water, farmers in the midwest have adapted by mining the aquifers below them. In this satellite image of Kansas, each green circle is a center pivot irrigation system, watered from the Ogallala aquifer. The O. aquifer is being slowly depleted in many places as the water is being pulled out at a rate greater than the replenishment rate. Wheat farmers in Saudi Arabia and Nevada have been using “fossil” water to turn their deserts into farms, ancient aquifers no longer in circulation. Saudi Arabia plans to end wheat production by 2016 to conserve scarce water supplies.
Good news: Sustainable hydrocarbons

**Biodiesel, Biobutanol, Biogasoline**

Algal-oil production may be the *only viable method* by which to produce enough automotive fuel to replace current world diesel usage.

Microalgae have *much faster growth-rates than terrestrial crops*.

The per unit area yield of oil from algae is estimated to be from between 5,000 to 20,000 US gallons per acre per year (4,700 to 18,000 m³/km²·a), this is *7 to 30 times greater* than the next best crop,

Studies show that algae can produce up to *60% of their biomass in the form of oil*.

Regional production of microalgae and processing into biofuels will provide *economic benefits to rural communities*.

**Drawbacks:** Sterility. Algae farms require enclosures

See also: [http://www.oilgae.com/](http://www.oilgae.com/)

Global Green Solutions Inc,
El Paso TX

Good news for sustainability in the face of peak oil
The situation with seafood is even worse. Projections are that all commercial fisheries will collapse before 2050.
Fish farms require approx 5 kg of wild fish for each 1 kg of farmed fish. "Fishing down the food chain."

Fish farms
Another way to test whether a population booms and busts or just floats up and down is to assume we humans behave like any other animal and model a food web. I am a chemist by training, so I modeled a food web as a chemical reaction with oxidized carbon from the atmosphere going to reduced carbon and back to oxidized.
• Species are measured in units of reduced carbon “C” or “biomass”

log-biomass actually, for convenience
• Species can be plants (green) or animals (red)

for future reference
• Plants catalyze CO$_2$ $\rightarrow$ CH

Plants grow proportional to biomass.

from the atmosphere
Limiting factor may be anything or a combination of things, but this just recognizes that the size of the ecosystem is finite.

- The sun's maximum total input to the food web is fixed.

All plants stop growing when the sum total biomass ≥ sun limit
• Primary consumers (herbivores) get biomass from plants
Secondary consumers (carnivores) get biomass from other animals.
etc.

trophic levels
non-discrete
All species also catalyze $\text{CH} \rightarrow \text{CO}_2$.

i.e. All species lose biomass to respiration and natural death, at a constant rate.

note, death and respiration are chemically equivalent. Rarely are they perceived that way.
• Predator species collapse when prey is scarce.

No one is allowed to skip lunch.
In the initial model there is no compassion for endangered species. They get eaten. This is just to see what happens. Later we will modify this behavior.
The fraction of the population that is fed grows at the prescribed growth rate.
The fraction not fed starves. There are no CARE packages in the model.
• Unfed fraction starves (becomes CO$_2$).

...and their carbon becomes CO$_2$
On the next cycle, the endangered species goes extinct, followed closely by its predator.
Hollings functions modify predator/prey relationship. Predators can starve while prey still exists, but is scarce.

Now we can add compassion to the system. OK, not real compassion, more like frustration. These are called Hollings Response functions, in which the likelihood of finding prey is a function of the prey population. When a prey species becomes too scarce, a predator either dies off or stops finding a different prey, allowing the endangered prey to grow again. In ECOME we cut the link from predator to endangered prey. We tried experiments with and without Hollings response functions, because we aren’t sure they should apply to humans.
• Species evolve by splitting unevenly.
New species lose predators and/or gain prey.
Speciation rate is user-variable.

Models like this are unstable and collapse immediately. But if we introduce speciation, we get dynamic stability. Speciation is the uneven splitting of the species biomass. Giving new “edges” to the daughter node. Note that this could be genetic speciation or migration, or even behavioral changes.
Here is a small ECOME consumption web just before and just after two speciation events. The daughter plant node has lost a predator, and the daughter animal node has gained prey. That is, only advantageous speciations are modeled, as it seemed pointless to model the ones that would just die faster. Now we'll run a simulation.
In this simulation you see plants speciating slowly and animals speciating quickly, randomly choosing nearby nodes as prey, consuming prey and going extinct when the prey runs out. But life goes on because some animals evolve to eat different plants and plants keep speciating to avoid predation. Triangles indicate autopredation or cannabilism, which can be viewed as competition within a species, and I’ll get back to that.
In this simple model, the system is dynamically stable over long periods as long as there are enough nodes. With a small number of species it always collapses down to only plants, as in this case. The system is dynamically stable if the speciation rate equals the extinction rate. Except in rare cases where the predator prey relationships balance exactly, a species will grow exponentially or shrink exponentially or superexponentially. This is why you see lots of straight lines in a log plot.
If we were to zoom in on any one of those animal peaks, we would see an animal’s population shoot up for as long as prey is available, then reach a population called the carrying capacity where predation begins to have an effect on the prey population. The slope of the degradation depends on the degree of the overshoot. If the overshoot is large, then the decline due to starvation is more severe. If the overshoot is shallow, then the predator population goes back below the carrying capacity and the carrying capacity goes back up again to where it is limited by something else in the system (such as space).
Surprisingly, I didn’t see simple pairwise predator prey relationships like the lynx and the hare, where the population of the lynx looks like the integral of the population of the hare. I suspect these are cases where evolution has carefully tuned the growth rates so that overshoot is never severe and both population survive.
So now the next thing to do was to recognize the ways that humans are exceptional and try to model those differences to see if it changes the boom/bust behavior. One things humans can do that other animals can’t is pass on cultural traits by writing and story-telling. Here is an example of cultural traits being passed through the act of reading.
To a first approximation, animals don’t have Culture. They only inherit traits from their immediate ancestors with few changes. Real genetic changes take place on the scale of millions of years. Natural selection determines which genes persist in the gene pool.
Cultural changes can take place on the order of decades or less, and the traits can come from any ancestral source, as long as they recorded their ideas in a book or a story or some other persistent record. This is Lamarckian evolution, an evolutionary theory that predated Darwin.
In Lamarckian evolution, traits are gained by usage. For example, an animal that stretches its neck to eat then passes on that trait to its offspring. This is nonsensical of course, but there are other ways that Lamarckian evolution does take place.
Let me illustrate with an example closer to home. Students that choose not to use their brains don’t gain the selective advantage for jobs. The higher salaries they presumably make are then passed down to their teenage offspring, as fancy cell phones granting them a selective advantage in high school mating rituals.
So I tried running ecosystems with these new human capabilities.
The simulation starts off like the previous with species evolving and dying off. Then at some point, one of the animal species becomes human and gains the first 3 human traits. Humans quickly boom and bust. Slow motion shows they became cannibalistic towards the end. You can interpret that as either warring within the species, or actual cannibalism. Cannibalism and war are biochemically equivalent since both convert biomass into CO$_2$ in proportion to population.
In a nutshell, the first three human characteristics, coded into the simulation, do not save us. They do in fact make us reach a higher peak population, and they do succeed in wiping the ecosystem of the other slow-evolving species. However, exponential growth always overtakes other species that are directly or indirectly limited by the land area.
The only case study that led to a stable population was 4. Population Control, where we constantly correct our growth rate to match the carrying capacity. We should note that the first three cultural traits already exist, whereas this fourth one does not, at least not yet.

<table>
<thead>
<tr>
<th>New trait</th>
<th>ECOME simulation result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. EDUCATION: Humans evolve without speciating.</td>
<td>boom/bust</td>
</tr>
<tr>
<td>2. TRADE: Humans consume from anywhere in the ecosystem</td>
<td>boom/bust</td>
</tr>
<tr>
<td>3. DEFENSE: Humans consume their own predators.</td>
<td>boom/bust</td>
</tr>
<tr>
<td>4. POPULATION CONTROL: Humans control their growth rate.</td>
<td>stable</td>
</tr>
</tbody>
</table>
Eric Pianka, Denton A. Cooley Centennial Professor of Zoology, UT Austin.

The Ebola Solution

*Ebola zaire* with a 90% mortality rate in humans, is spread only by direct contact between people. *Ebola reston* infects only non-human primates but is airborne transmissible.

It is only a matter of time before the more pathogenic strain *E. zaire* gains the ability to be airborne transmissible, like its homolog *E. reston*.

From *The Vanishing Book of Life on Earth*

As you read in the assignment I gave, Eric Pianka is passionate about the future of the planet. He is not a terrorist. Neither is Paul Ehrlich. Neither was Garrett Hardin. His students attest to his love of life. Nonetheless, he crossed the line with some people when he publicly discussed ways that the population might be reduced. In the Vanishing Book he points out that HIV could not be an effective population control agent, but other viruses could, and he named two strains of Ebola, which if crossed could produce a strain that was both 90% fatal and airborne transmissible. He was investigated by the FBI at the instigation of his colleague, Forest Mims, who essentially called Pianka a terrorist.

Is he a terrorist? Did he mean to imply someone should do this thing? Or did he (as he later told the FBI) only mean to imply that such a mutant strain was possible. It is one of those statements that you can interpret with the best or most evil of intentions. I prefer to think Pianka is passionate about saving humanity and that it is clear to him (but not to Forest Mims or the FBI, or most of the rest of us) that passing through a disaster that could take the lives of 90% of humanity might be a blessing in disguise that saves the species from complete annihilation at its own hands. But I can see him believing that the longterm survival of the species, and of its culture, is far more important than the shortterm survival of any number of individual specimens. If so, it is a belief that comes from a lifetime of study and thought, and I would not be so presumptuous as to dismiss it, even if accepting such a belief raises my personal level of dissonance to that of amplified acordion playing twelve-tone row music with cowbell accompaniment.
Eric Pianka, Denton A. Cooley Centennial Professor of Zoology, UT Austin.

The Johnny Anti-Appleseed Solution

“First...bless everyone with infertility.” --E.P.
1. Design a molecule that could bind DNA to make people sterile.
2. Design another molecule that would unmask the first and make the person fertile, just for a short time.
3. Make people work for the second pill*. You’d get responsible parenthood. No more unwanted children, no juvenile delinquents...

*Married couples only?

One thing we have to accept is that there are an infinite number of possible futures, and out of all of them there is certainly one that is the least painful.

The one solution that I have heard that is not pure fantasy and may be the most politically salable was stated by Pianka in 2006 as the Johnny Anti-Appleseed Solution. Instead of being blessed with fertility as we are, he would have us be blessed with infertility. How this would be done is a technicality. He imagines a molecule that binds the DNA and prevents fertility somehow. Then, so that we can continue the species, we would invent a second drug that temporarily restores fertility. And, if we follow his suggestions, we make that second drug "hard to come by." In his words "make people work to get the second pill."

This intrigued me. By simply requiring an action, any action, to restore fertility, instead of an action to take it away, we would automatically eliminate all accidental pregnancies.

It has been estimated that half of all pregnancies are unintended, and about half of those end in abortion. There are about 750,000 teen pregnancies per year in the US alone. The downstream effects of unwanted children are well documented, crime, unemployment, drug use, gangs, and of course you have teen pregnancy continuing the vicious cycle. If this is not a social/environmental/economic cure-all, it is close.
In 1994,
49% of pregnancies were unintended
54% of these ended in abortion
48% of women have had ≥1 unplanned pregnancy
28% of women have had ≥1 unplanned birth
Highest unintended pregnancy rate among women 18-24, unmarried, low-income, minority.

## Effects of population decline

<table>
<thead>
<tr>
<th>“mechanism”</th>
<th>sociopolitical repercussions</th>
<th>environmental effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ebola (disease)</td>
<td>panic, unrest, refugees</td>
<td>no significant effect</td>
</tr>
<tr>
<td>Anti-Appleseed (contraception)</td>
<td>religious opposition*, aging populace</td>
<td>no significant effect</td>
</tr>
<tr>
<td>War</td>
<td>refugees</td>
<td>localized or widespread environmental destruction, possibly long-term.</td>
</tr>
</tbody>
</table>

* "THE ONLY way to solve the problem of contraception is to solve the problem of infallibility."  
-- Hans Küng; Catholic theologian; 1979
Fertility correlates with poverty

From the UN, Economic and Social Council Commission on Population and Development
3 April 2009

Does the solution have to be one of these draconian mechanisms?

It’s often stated that all we need to do is educate the world’s women. Then they will have fewer children voluntarily, and that has been demonstrated. I agree, but that is very much like the task of eradicating poverty, which is a honorable but monumental task. And we need to take into account that greater affluence means greater consumption, and this could actually push us over the carrying capacity faster.

On the other hand, improving the health of children influences decisions on family size towards smaller families. Women who see the survival rates climbing will choose to have smaller families. (no citation!) Thus less expensive measures may be possible to influence fertility.
Up till now we have discussed population as a global issue, but there are regional issues. They tie in with poverty and education. In fact, overpopulation could be viewed as practically solved in the developed world, but still exploding in the third world. This does not mean we in the developed world can sit back and wait for it to blow over. The UN projects (using simple trend analysis) that developed countries will be overrun with immigrants and refugees from less developed countries.
Africa has highest fertility. Europe, China, Japan, Brazil are lowest.

Regional differences in fertility.
Africa has youngest population. Europe and Japan are oldest.

The age of a population correlates inversely with fertility.
Demographic pyramids show changes in growth conditions in a given region. Here is a website where you can enter the number of cpw, the life expectancy and the average age at childbirth and it will simulate the demographic pyramid. Note that this ignores carrying capacity and immigration.
Environmental impact

\[ I = P \times A \]

\[ \frac{dI}{dt} = A \frac{dP}{dt} + P \frac{dA}{dt} \]

where \( \frac{dA}{dt} \) = change in affluence
\( \frac{dP}{dt} \) = change in population

If A is not changing much, then most of the change in I is due to change in P.

It has often been stated that half of the problem is the waste by the affluent societies. It is not straightforward how you would assign half the problem to one of two related indices. If instead you consider the change in impact, we can see that the equation, \( I = P \times A \) breaks down, using the chain rule, into two terms, a change of A term and a change of P term.
Affluence can be measured using Ecological Footprint analysis, which assigns an amount of the planet to the consumption of each person. Estimated differences between how the average person in an affluent country consumes and how much a person in a poor country consumes are about 8-fold.
If we look at the distribution of fertility with affluence, eliminating only the unintended and underage pregnancies, would reduce fertility to at or below replacement level in most countries. This would be a culture shift.
The coming market boom in male contraception

<table>
<thead>
<tr>
<th>Today</th>
<th>Tomorrow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condoms</td>
<td>short term</td>
</tr>
<tr>
<td>Hormonal</td>
<td>medium term</td>
</tr>
<tr>
<td>Vasectomy</td>
<td>permanent</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Today</th>
<th>Tomorrow</th>
</tr>
</thead>
<tbody>
<tr>
<td>short term</td>
<td>oral, no hormonal effect</td>
</tr>
<tr>
<td>medium term</td>
<td>easy, reversible</td>
</tr>
<tr>
<td>permanent</td>
<td>non-surgical</td>
</tr>
</tbody>
</table>

The biotech industry has an opportunity to be ready when the culture shift happens.
Contraceptive vaccines

Besides the availability of the present methods of birth control, the population explosion and unintended pregnancies continue to pose major public health issues worldwide. The world population has exceeded $6.43 \times 10^9$ (World POPClock projection, 2005) and increasing by $1 \times 10^9$ every 12 years. Ninety-five percent of this growth is in the developing nations. In the USA, half of all pregnancies are unintended, which result in $>1 \times 10^6$ elective abortions annually (Henshaw, 1998; Grow and Ahmed, 2000). This calls for a better method of contraception that is acceptable, effective and available both in the developed and developing nations. An ideal contraceptive method should be highly effective and safe, inexpensive, have a prolonged duration of action, be rapidly reversible and easily accessible, require infrequent administration, and be capable of private use (Contraception Online, 2004). A contraceptive vaccine (CV) has been proposed as a valuable alternative that can fulfill most, if not all, of the properties of an ideal contraceptive. Since the developed and most of the developing nations have an infrastructure for mass immunization, the development of vaccines for contraception is an exciting proposition.
Sperm capacitation as a target for contraception

Maturation

Ejaculation

Capacitation

Fertilization

Mature sperm are incapable of swimming and penetration of the egg without first being exposed to factors in the female reproductive tract that capacitate the sperm.

Capacitation is marked by changes in the membrane.

Capacitation is blocked in knock-outs of sperm specific cation channel protein (catsper).
Current best estimates are that the contraceptive vaccine will last only about 1 year before fertility returns and a booster shot is needed. Thus it may not stop all unintended pregnancies. It is worth noting that the immune response can be blocked for a short period at any time, such as for example when a could suddenly decides to have a child without waiting the full year. It is believed since sperm proteins are immunogenic, that no autoimmune problems should arise from a CV.
In recent study, they found that promoting contraception would be the cheapest way to reduce CO\textsubscript{2} emissions. The $7 cost of abating a tonne of CO\textsubscript{2} using family planning compares with $24 (£15) for wind power, $51 (£31) for solar, $57-83 (£35-51) for coal plants with carbon capture and storage, $92 (£56) for plug-in hybrid vehicles and $131 (£80) for electric vehicles. These projections assume an unchanged demand for contraception, but if resources become more scarce we may see a rapid increase in birth control, like Type 4 humanity in the ECOME simulations. Unlike these other technologies that only target energy production, targeting population also conserves not only energy but food supply and the environment. It’s been said that there is no long term viable solution that does not address population.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Cost per ton of CO\textsubscript{2} abatement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Family planning</td>
<td>$7</td>
</tr>
<tr>
<td>wind</td>
<td>$24</td>
</tr>
<tr>
<td>solar</td>
<td>$51</td>
</tr>
<tr>
<td>clean coal</td>
<td>$57 - 83</td>
</tr>
<tr>
<td>plug-in hybrids</td>
<td>$92</td>
</tr>
<tr>
<td>electric vehicles</td>
<td>$131</td>
</tr>
</tbody>
</table>
"global warming, the stunning rise of middle classes all over the world, and rapid population growth have converged in a way that could make our planet dangerously unstable."

Thomas Friedman, NY Times columnist, author of “Hot, Flat and Crowded”

To end, let me acknowledge that despite the strident nature of the population issue, a growing chorus of
a growing chorus

authors,...
"climate change and environmental degradation threaten the future of our planet. Growing populations and rising wealth place unprecedented stress on the earth’s resources. Malthus is back in vogue. Everything seems suddenly in short supply: energy, clean air and fresh water, all that nourishes us and supports our modern ways of life."

**U.N. Secretary General Ban Ki Moon:** "Global Action to Save Global Growth" -- Washington Post op-ed (July 3, 2008)
"the population of the world is supposed to go to nine billion by 2050. Nobody is going to talk about this in the election this year for either party, but I'm not running so I can say it. ...[I]t took us 150,000 years to go from one person to 6.5 billion, and we're going to nine billion in 43 years? Now just think about it. Think about the accelerating pace of change in the world. We're going to nine billion people. Almost all of those 2.5 billion people are going to be born in countries now unable to support the people who live there."

**Bill Clinton:** Speech at the Slate 60 Conference (October 22, 2007)
"In thinking about the future, one of the most important things that our analysts brought to--CIA analysts--brought to my attention was world demographics. Now I'm probably pointing at the obvious here, but let me point to some of the things that our analysts brought to my attention. Today, there are 6.7 billion people sharing the planet. By mid-century--by mid-century, the best estimates point to a world population of more than 9 billion. That's a 40 to 45 percent increase--striking enough--but most of that growth is almost certain to occur in countries least able to sustain it, and that will create a situation that will likely fuel instability and extremism--not just in those areas, but beyond them as well."

**CIA Director Michael Hayden**: Speech at Kansas State Univ. (April 30, 2008)
"We also know that over the next 20 years certain pressures - population, resource, energy, climate, economic, and environmental - could combine with rapid cultural, social, and technological change to produce new sources of deprivation, rage, and instability. We face now, and will inevitably face in the future, rising powers discontented with the international status quo, possessing new wealth and ambition, and seeking new and more powerful weapons. But, overall, looking ahead, I believe the most persistent and potentially dangerous threats will come less from emerging ambitious states, than from failing ones that cannot meet the basic needs - much less the aspirations - of their people."

**Secretary of Defense Robert Gates:** Speech at U.S. Global Leadership Campaign Tribute Dinner (July 15, 2008)

Interested? Go here for an in-depth look at climate and security:

http://www.cbc.ca/ideas/features/climate-wars/index.html

military leaders...
a growing chorus

"the stresses on woefully inadequate social services in many developing countries caused by high rates of population growth, which contribute to competition for limited resources, environmental degradation, malnutrition, poverty and conflict. Assisting countries in reducing rates of population growth to sustainable levels should be a priority of USAID."

United States Senate - July 18, 2008: FY 2009 Annual Foreign Assistance Bill
(Senate Report 110-425, p. 36)

and even senators are speaking openly and more frequently about the population problem. There is hope that the problem will now be carefully studied and a minimally painful and politically possible solution will be found.
ECOME: Carl McDaniel, Sam DeLuca
Catsper vaccine: Mark Platt, Pablo Visconti, Ana Maria Salicioni