Large individuals: high fecundity, live a long time. Few enemies besides man, practically immortal...

Small individuals: high natural mortality rate, low or zero fecundity

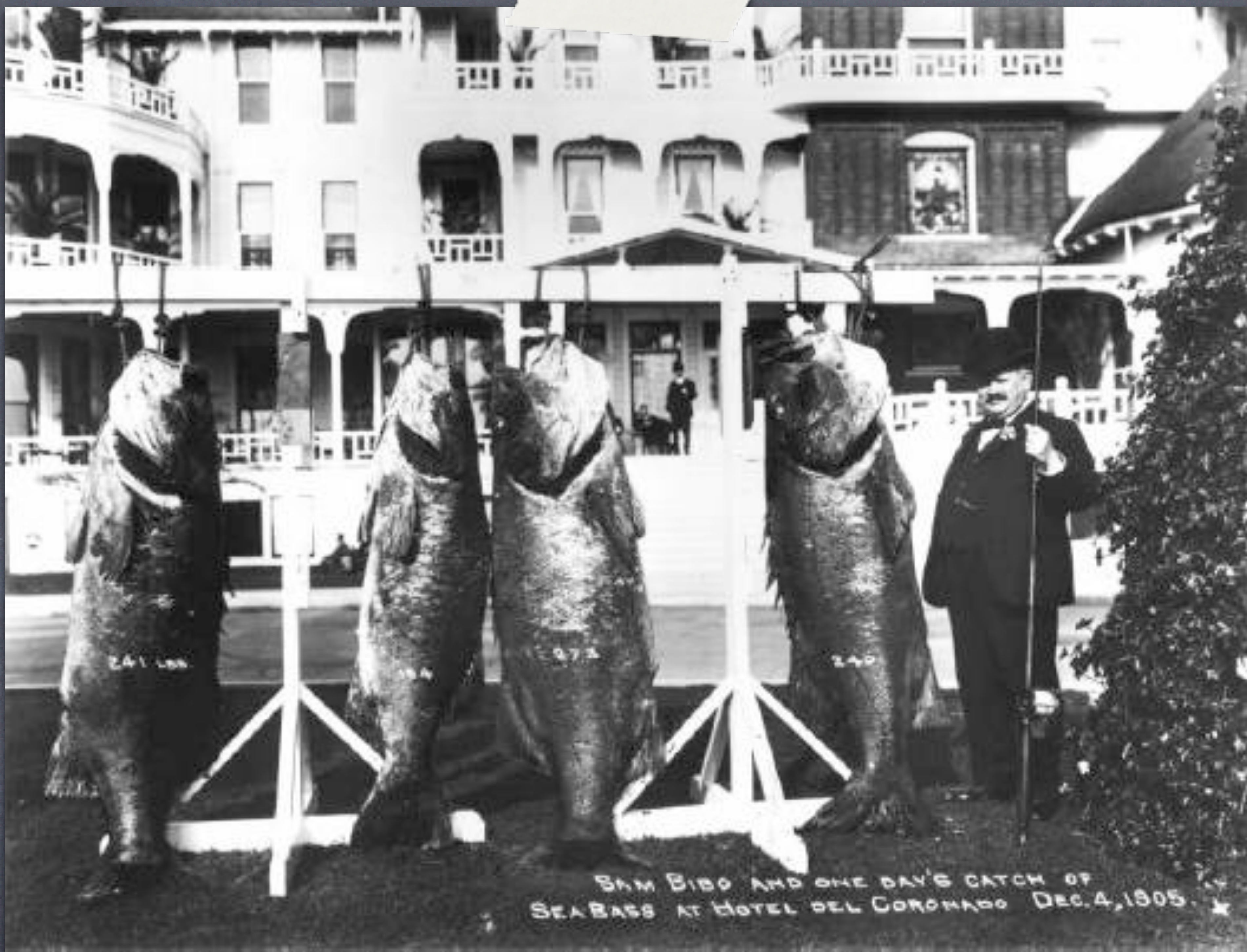
Size matters*...

But not in the way fisheries managers (or women) seem to think.

*Keep the small ones, throw out the big ones...

Now you may think that this might be a rather self-serving hypothesis, relative to which I may have a particularly biased interest, and a hidden agenda, but I can assure you that nothing could be further from the truth... This is a purely objective investigation and intellectual exercise.

My presentation here will be kept to a minimum, to leave time for discussion.



Nobody remembers what the place used to be like

About 8 years ago I started a book about conservation and how we need more than business as usual to save the world. Unfortunately, somebody offered me a job and the manuscript has been stuck in a drawer the last 7 years or so. One of my pet theses, for which I had designated a chapter in the book, is that one of the reasons people never rise up and take action against the injustices we perpetrate on the natural world, is that no one remembers what the place used to be like. I like to think that if people remembered more than 30 years back, and could remember how fabulous the world once was, that there would be a public outcry against the current state of the world and we might actually do something about it. This essay would recall some of the descriptions of natural phenomena in the past, and inkling of which you might get from this photo.

In Maine and throughout the Northeast, lobsters were once so plentiful that native people used them as fertilizer. Throughout New England and the Canadian Maritime Provinces settlers learned from this and used to put 3 lobsters on a potato plant as fertilizer. Lobster were referred to as “bugs” and as “poor man’s beef”. School children would be harassed if they had lobster in their lunch pails... The colonists served them to prisoners and indentured servants. Lobsters were originally caught by hand in tidal basins. Maine's lobster fishermen only began using traps some time in the 1850s.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Spiser du denne er du kriminell

Spiser du denne kan du bli dømt for miljøkriminalitet. Krepsen er mindre enn minstekravet, og dermed ulovlig å fiske.

Foto: Camilla Helena Wernersen/NRK

Fredag starter krepsefisket. Men det er strenge regler for fangsten av de små, hissige dyrene.

CAMILLA WERNERSEN

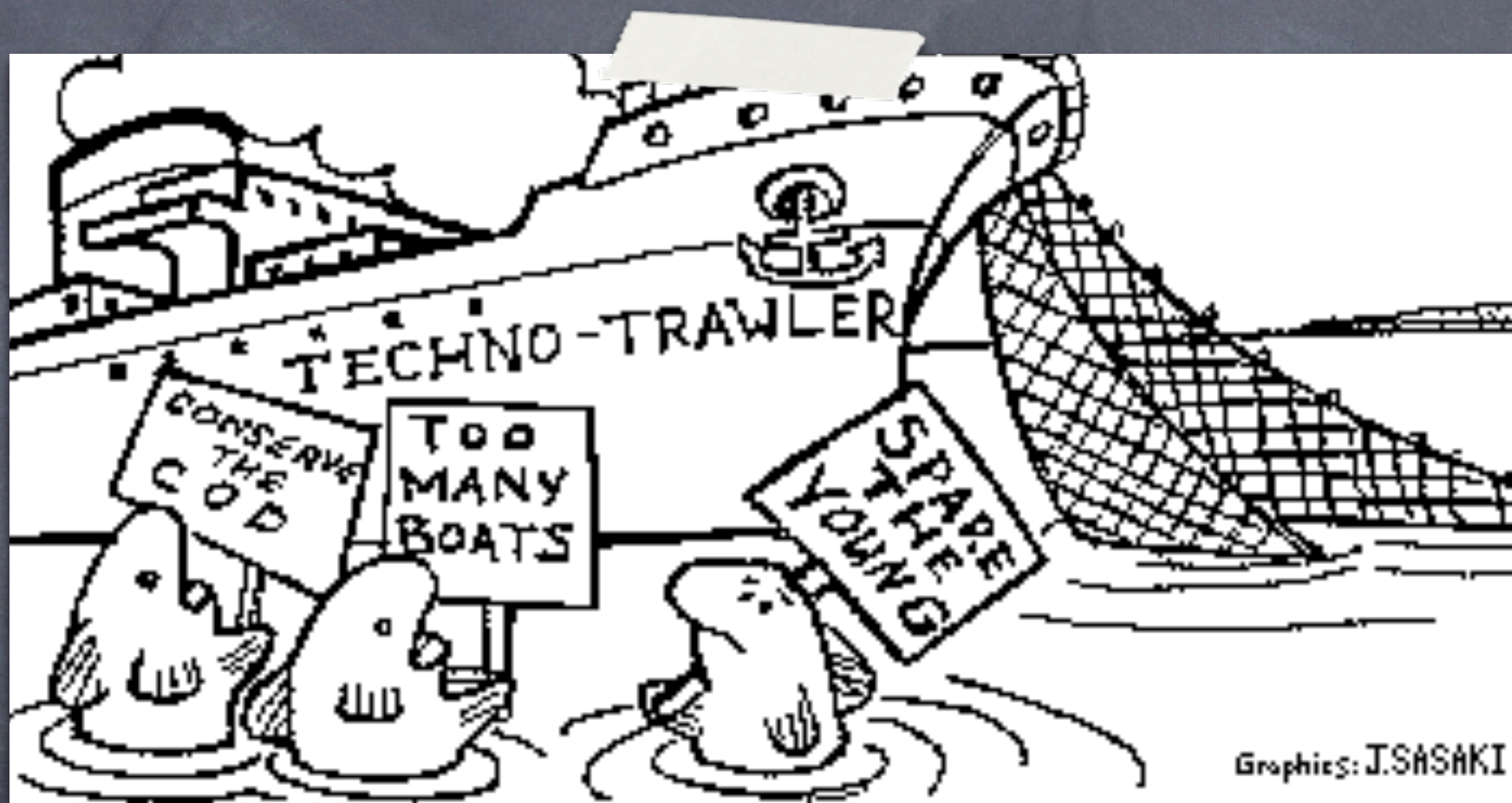
As you know, in many shellfisheries, like that on lobster or crayfish the authorities insist that one throw out individuals that are smaller than a certain minimum size limit.

In fisheries they say things like: “Small mesh dooms future fish populations by trapping the small and immature”, although it is not clear to me where this conviction comes from.

Perhaps it´s because there are so many of the small ones, that if not combined with a maximum number caught fishermen will overharvest?

We seem to be doing a lot of things wrong in fisheries however. Fishery after fishery around the world is overexploited. The richest fishery in the World, that off the Grand Banks east of New Foundland closed in 1992, and has shown no sign of recovery. A recent paper in Nature Communications showed that the UK fishing fleets today are working 17 times harder to make the same catch as they did with sailing vessels in 1890, or to put it a different way: that commercially harvested demersal fishes are down to below 4-2 percent of 1890 stocks. Haddock stocks and some other important species are below 1 percent of 1890 levels. Also in modern times a fishery on large fishes tend to diminish the stock biomass by 90% in the first 10 years of operations.

We have rules to protect small lobsters and crayfish, yet in Norway lobster is now an endangered species.



1. Spare the young or spare the old?

Many years ago when I was a graduate student at Princeton, Professor Andy Dobson held a seminar on harvesting models. The discussion got onto harvesting rules whereby a lot of fisheries have minimum size limits, that is, if a fish or a lobster or something is too small it has to be thrown back out. Offhand, I suggested that it might be better to throw out the big ones. I suggested that since a lot of the kinds of organisms that humans like to harvest: fish, shellfish, crustaceans, and not least trees, have the kind of age and fecundity schedules where old individuals churn out a disproportionate amount of propagules (seeds or eggs), and that they can live for a long time if not killed by us, then perhaps it would be better to harvest the smaller and younger individuals which have high natural mortality rates anyway. I did not think this particularly clever on my part, nor that it would be entirely original, so I was rather surprised when this idea was outright laughed at. I figured Andy ought to know all about harvesting models, so the fact that he ridiculed the idea made me wonder if the idea had in fact not been explored. People whom I feel ought to know, say things like “well, where are the old ones going to come from if we harvest them as young?”, and even suggest that such an idea violates the laws of thermodynamics.

Well, being an insolent graduate student and not overawed by Professor Dobson, I immediately went down to my office after the seminar and slapped together a quick and dirty model to show a proof of concept, that this idea might actually work and could make for a more robust fishery. It’s this model, and modifications of it, that I want to discuss with you today.

"Cod—A species of fish too well known to require any description. It is amazingly prolific. Leewenhoek counted 9,384,000 eggs in a cod-fish of middling size—a number that will baffle all the efforts of man to exterminate."

—J. Smith Homans and J. Smith Homans, Jr. eds, Cyclopedia of Commerce and Commercial Navigation , New York, 1858

One of the most important fisheries, in the world, historically is the north Atlantic cod fishery. Traditionally it was held that it was impossible for man to overharvest life in the ocean. Unfortunately, this belief has proven woefully erroneous. In this slide I wanna draw your attention to the extreme fecundity of many of the species we harvest.

A cod 1 meter long can put out 6 million eggs, while one measuring 1.2 can put out 9 million.

(Our own great hero, Thomas H. Huxley, Darwin's Bulldog, did untold damage to life in the seas as member of three British Fishing Commissions. At the 1883 International Fisheries Exhibition in London he declared: "Any tendency to over-fishing will meet with its natural check in the diminution of the supply... this check will always come into operation long before anything like permanent exhaustion has occurred." Unfortunately, his proclamations have been influential nearly ever since, and sadly not just in Britain.)

Large individuals: high fecundity, no enemies except man, practically immortal

I bet that for none of you, this is what you think of when you think of a cod.

This is a rather typical life-history in the kinds of species humans like to harvest. Think of the massive old cod, pike, groupers, tuna, lobster, oysters and other shellfish, as well as trees: they can live a very long time, and pour out absolutely massive amounts of eggs or seeds year after year after year. Giant clams, canopy trees, lobster and cod may be the quintessential examples.

Today we hardly know what such species used to be. Of course fishermen are notorious exaggerators but some pictures don't lie.

In the days of the New Amsterdam colony which is present day New York, the Governor reported lobster 6 feet long, and oysters were commonly a foot long even into semi-modern times despite oysters being a main staple of New Yorkers.

Model description

Stocks, quotas, carrying capacity and harvests expressed in biomass; 1 egg: 0.001kg; juvenile: 1kg; adult: 10kg

$$\omega_{t+1} = M\omega_t;$$

$$\omega_t = \begin{pmatrix} \omega_e \\ \omega_j \\ \omega_a \end{pmatrix};$$

$$M = \begin{pmatrix} 0 & b_j & b_a \\ t_e & s_j & 0 \\ 0 & t_j & s_a \end{pmatrix};$$

$$t_e = s_e = c;$$
$$t_j = 1 - s_j - d_j;$$
$$s_a = f(\omega_{a,t});$$
$$b_j = 0;$$

Harvesting rule:
Quota=Min (1000kg, 0.9stock)

Following slides:
b_a=10000;
t_e=0.001; d_j=0.9;
s_j=0.8(1-d_j);
sa=0.9;
K_a=4000kg;
$\omega_{a,t+1}$=Min(K_a, $t_j\omega_{j,t}+s_a\omega_{a,t}$);

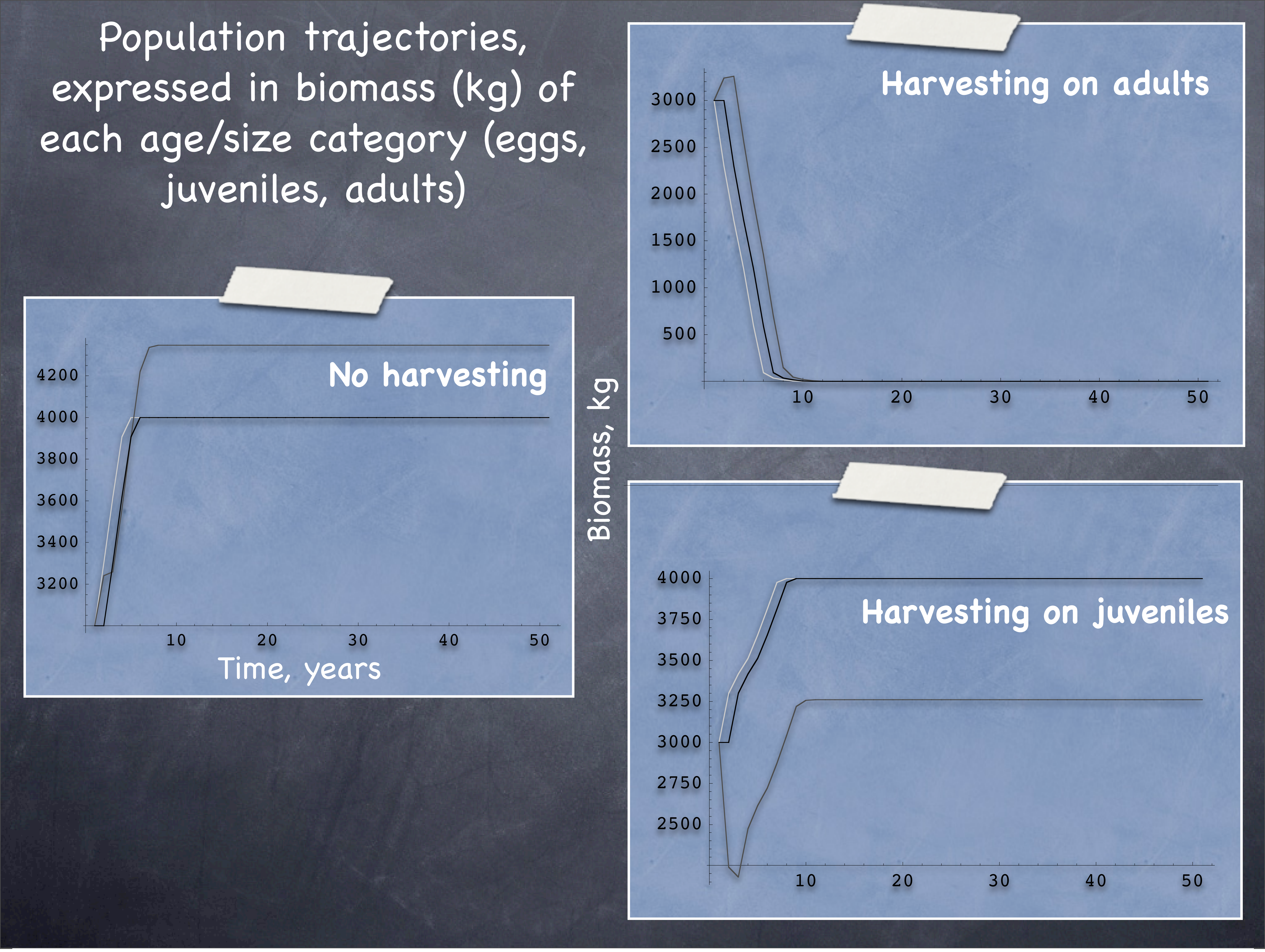
So here is a summary of the model. I want to emphasize that this is purely a demographic mechanism. I am aware of the recent literature on unfortunate evolutionary effects of harvesting large, mature individuals, but this mechanism is completely independent of that.

Here is the model; it is a very simple model as I wanted to first do simply a proof of concept. I include 3 stages: eggs, juveniles, adults. We could have inserted each age class, yearlings, 2-year-olds, 3-year-olds, and so on, but this is a simplification, allowing individuals to stay in each size class for a number of years, through “survival rates” sj and sa (the probability of staying another year as a juvenile or adult, respectively).

I imposed regulation on adults, as I thought this was the implementation that would most bias results in favor of the conventional wisdom that it is best to harvest large individuals (adults). Actually in the results you are about to see regulation is on tj+sa, as wa, t+1= Min (Ka and tjwt etc.). This density dependence precludes analytical treatment of the matrix itself, though it may be possible to discuss sensitivities to different kinds of harvesting/disturbances.

This is not an extreme model in favor of my thesis. Adult only have a 90% chance of survival per year, and juveniles only have a 90% mortality per year, they don’t have a prolonged juvenile period, and adults only produce 10,000 eggs—as opposed to a mature cod which may produce 10 million. On the other hand, only one in a thousand eggs die, and perhaps this is low. Each adult produces 10 eggs that make it to the juvenile stage and perhaps this is high... (?) The scale of this calculation is relatively small, Ka of 4000 kg means there is only room for 400 adults and about 4300 juveniles in the harvested area, but there is no reason to think that this does not scale up.

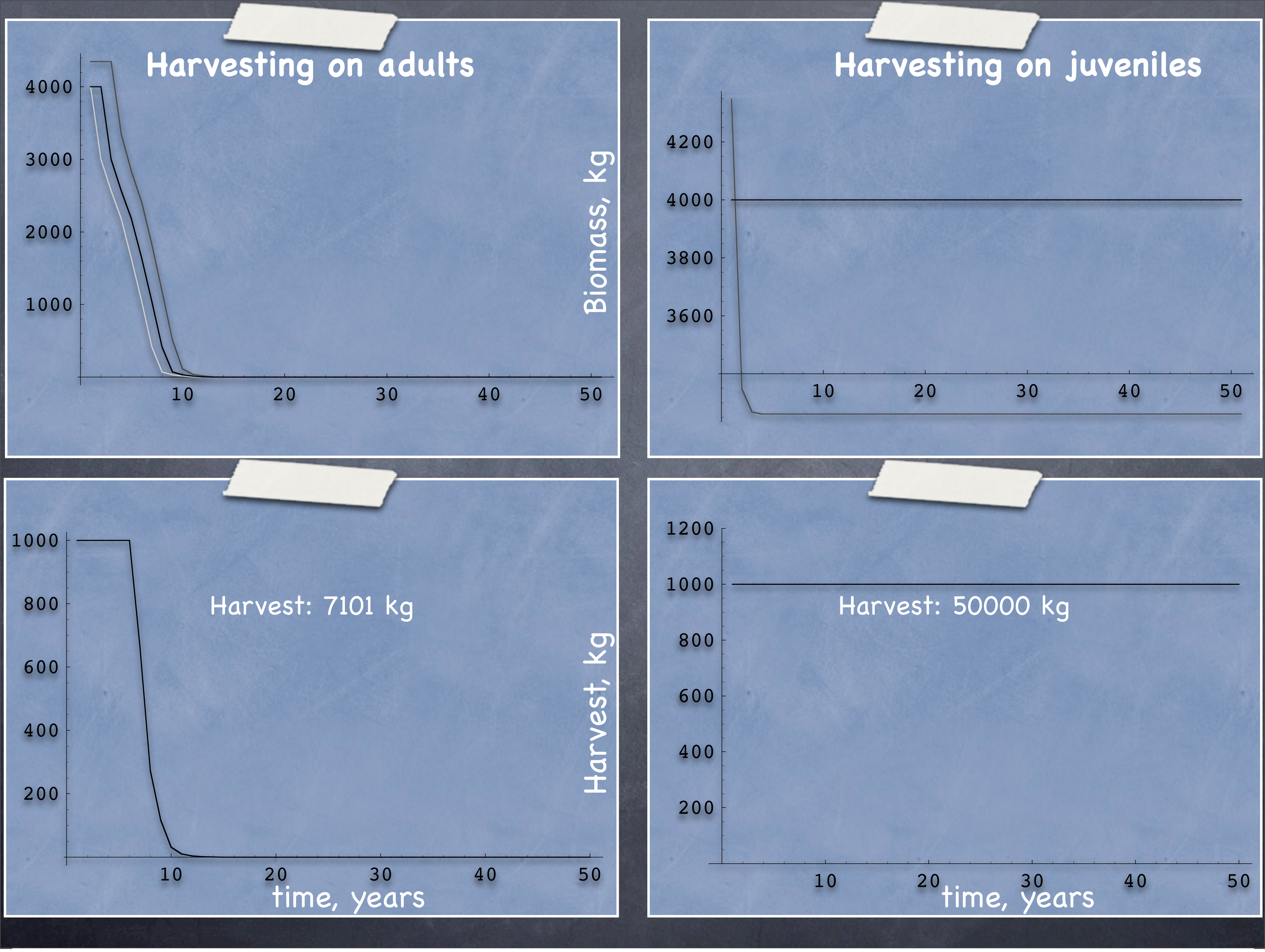
I have chosen a simple and relatively sustainable harvesting rule compared to actual fisheries: you take the set quota, or a proportion of the stock, whichever is smaller.



You see here the kind of density dependence I have imposed. This is nearly a sigmoid density dependence, but it is really exponential growth below carrying capacity and an abrupt cut-off at carrying capacity. Eggs and juveniles are not regulated at all, but they flatten out when the adult population flattens out.

As you can see, this model, which is equivalent to a pure contest competition, is very stable, and goes rapidly to an equilibrium state at Ka adults.

Harvesting on adults on top, harvesting on juveniles in the bottom right. In these trajectories, eggs are in the solid black, juveniles in a dark grey, and adults in a lighter grey.



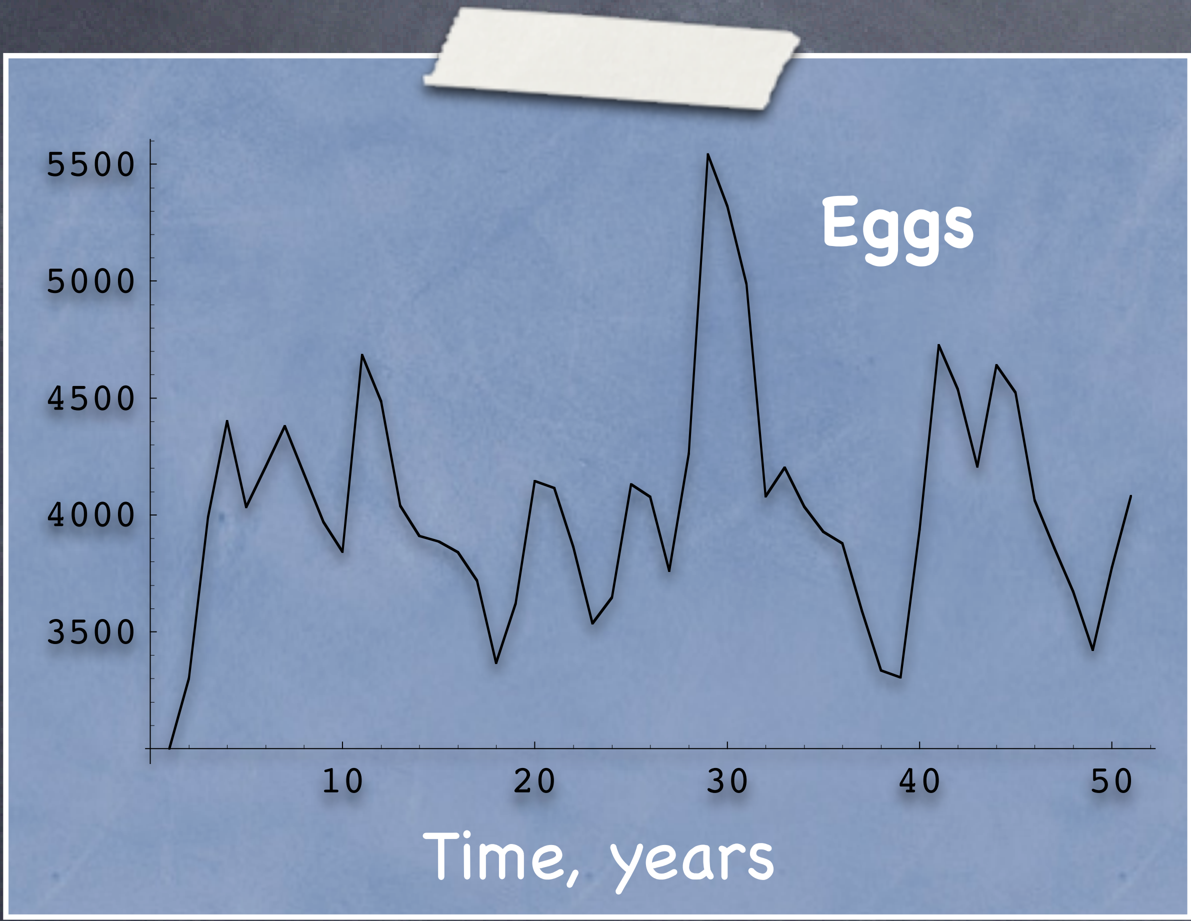
The model is somewhat stabilized by doing away with transients—letting model run to stable age-distribution before initiating harvesting, which is what I have done here; otherwise this is the same calculation as in the previous slide. Starting from a stable distribution, harvesting 1000kg or 90% of the stock biomass per year whichever is smaller. Left: harvesting on adults, right: harvesting on juveniles.

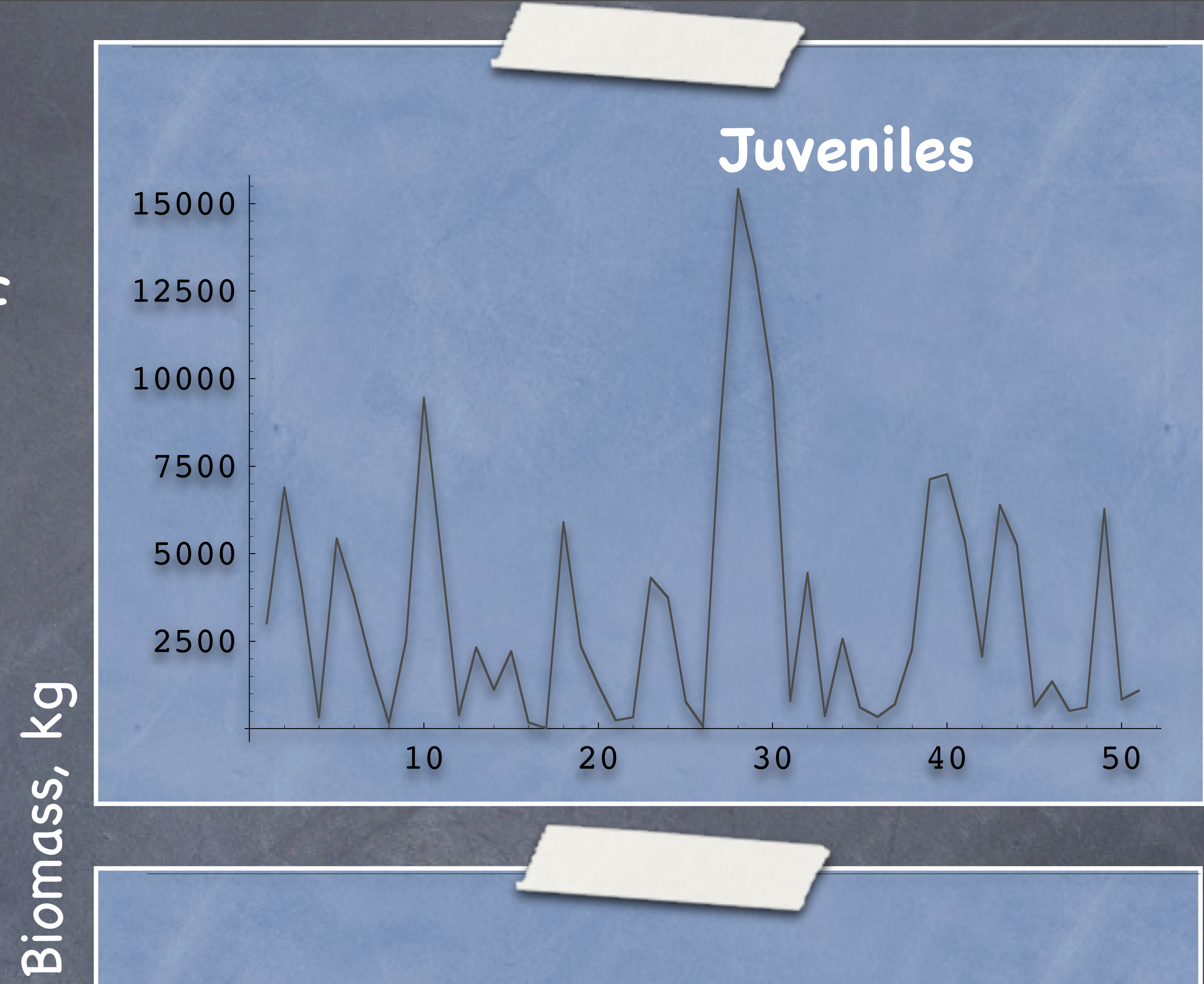
I have run a number of different simulations and never got a result clearly different from this. I either get this, or I get a situation where harvesting is not so high that it over-exploits the resource and a stable regime results no matter which age class you harvest on. Presumably it's possible to harvest so intensively that the population is driven to commercial extinction even if you do harvest only juveniles, though I have not seen that in any of my sets of parameter choices.

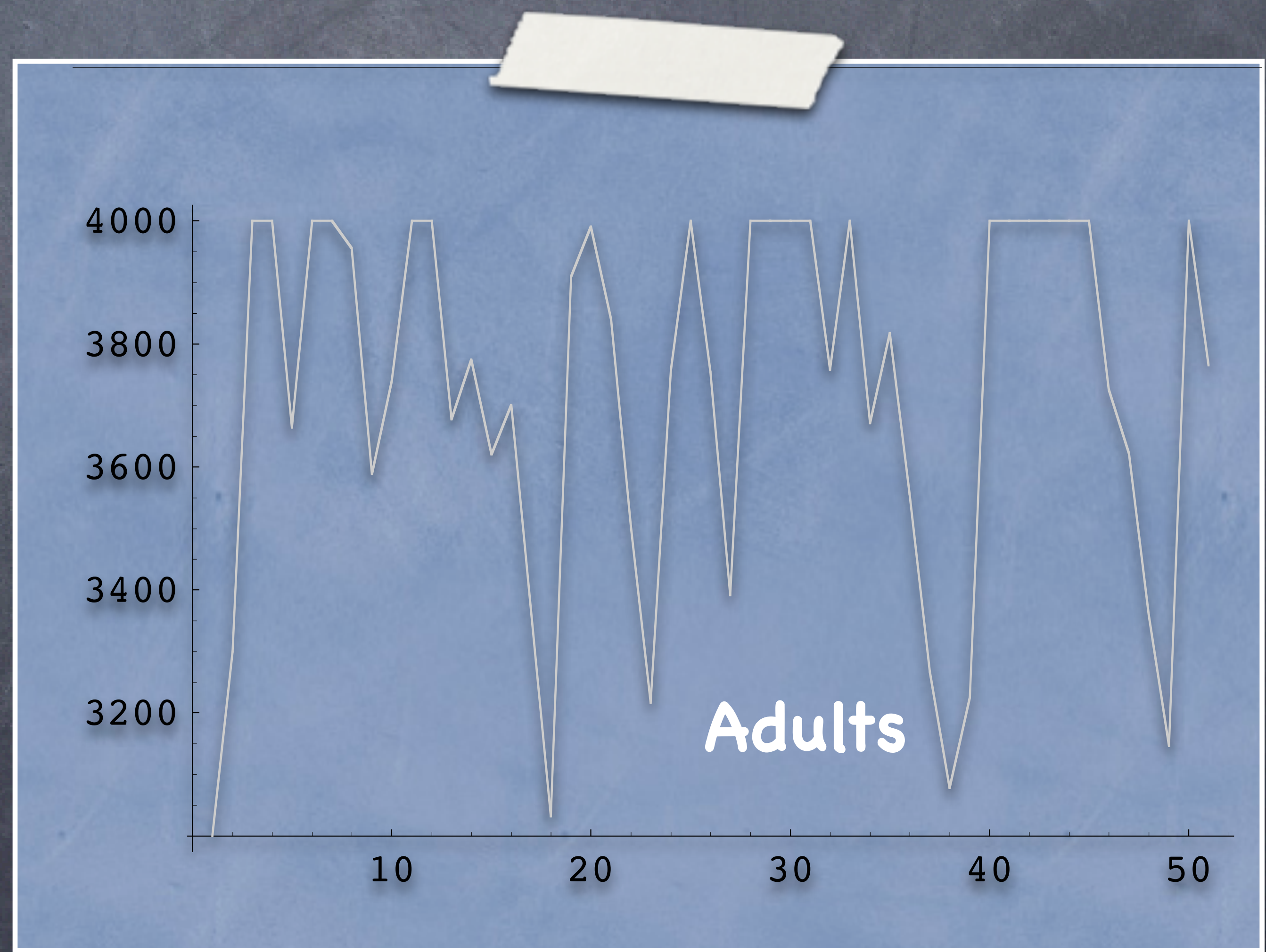
The way I look at these results is that since a certain harvesting pressure leads to overexploitation when you harvest on adults but not when you harvest on the juveniles, that means you can take out more biomass of the juveniles and still have a more robust and commercially viable fishery.

No harvesting

Population trajectories, expressed in biomass (kg) of each age/size category





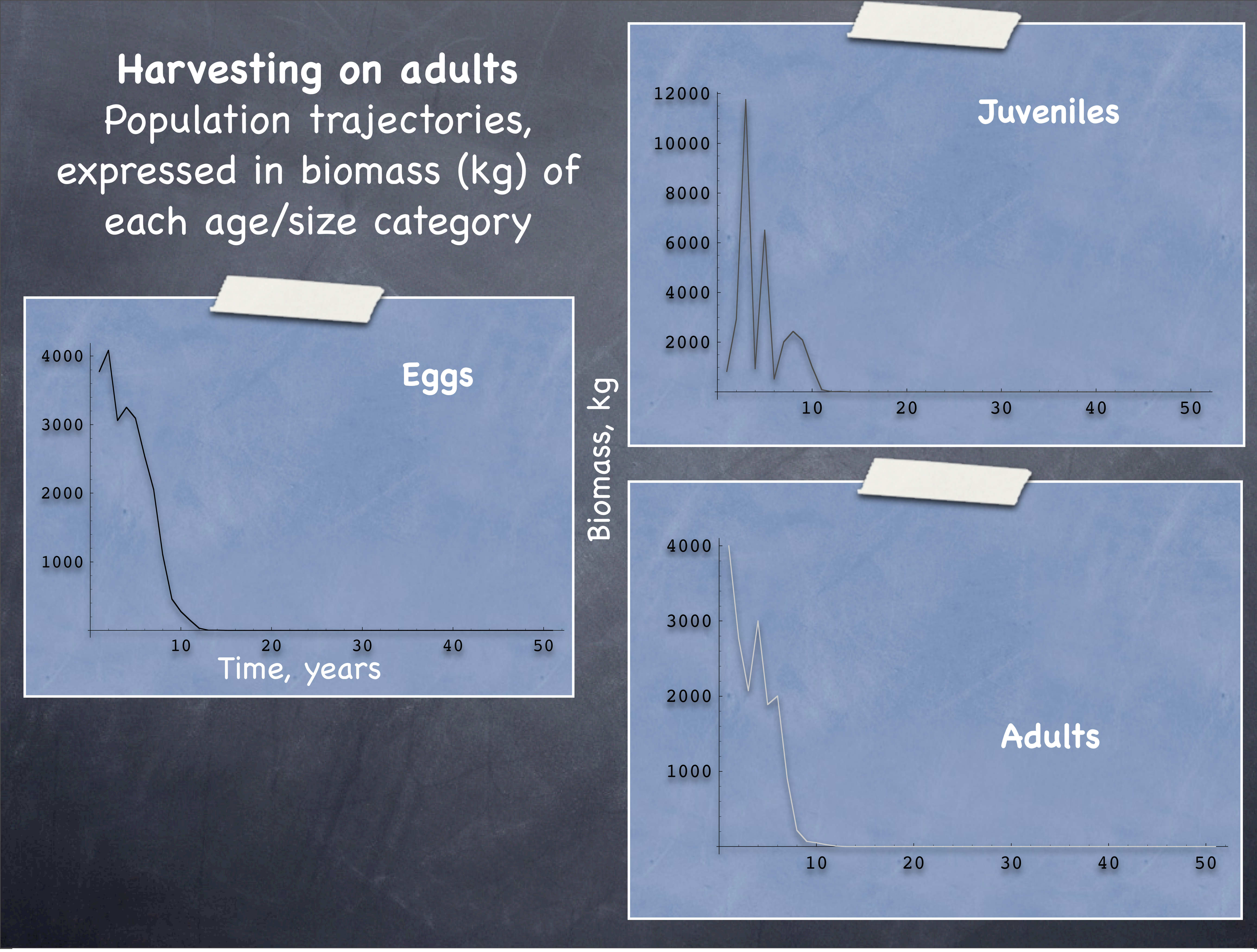


This is a model with some additional factors added in. I'm actually quite pleased with the perceived "realism" of the population trajectories. I have added some low fecundity for juveniles. I have added normally distributed environmental stochasticity on the survival of eggs (with mean=the expected survival in the absence of such stochasticity, and sd= 90% of the mean). I have also added occasionally very bad years in the survival of eggs (with probability per year of such an occurrence of 10% and an added mortality on eggs when it <u>does</u> occur uniformly distributed between 90% and 99%).

So this is now the case without harvesting: eggs, juveniles and adult trajectories.

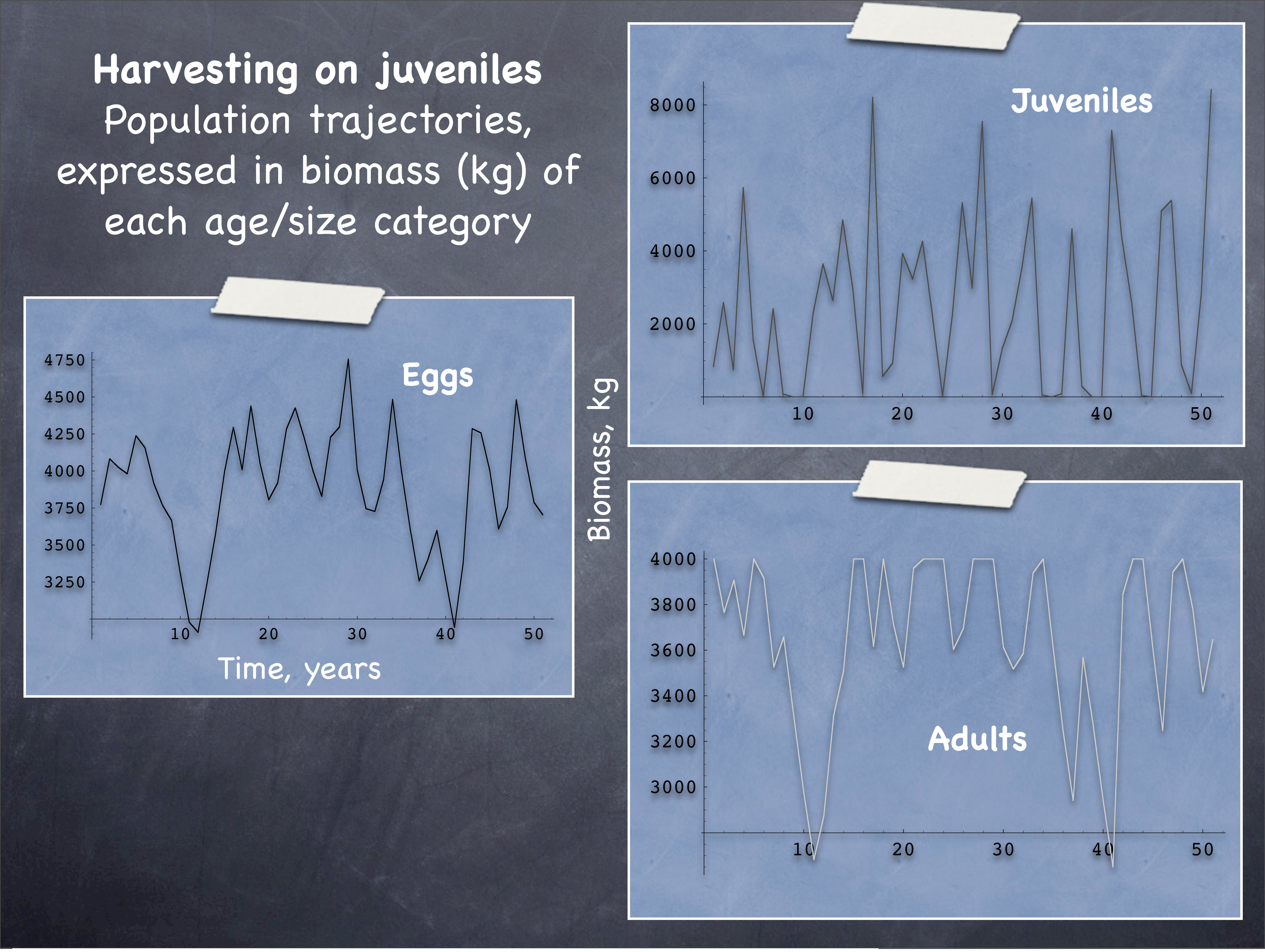
Please note that not all these figures have the x axis intersecting the y axis at zero. In the adults here, for instance, we see a fair amount of variation in population size, but only in the range between 3000 and 4000 kilos, or 300 and 400 individuals, as the x axis intersects at 3000 kilos.

Also, while this model has an important element of stochasticity in it, and ordinarily it's not very informative to show a single iteration of a stochastic model, this model is still so strongly determined by the underlying deterministic dynamics that the overall pattern of each iteration is essentially the same for different simulations.



Same model and trajectories again, but this time with the same kind of harvesting on adults as in the first model.

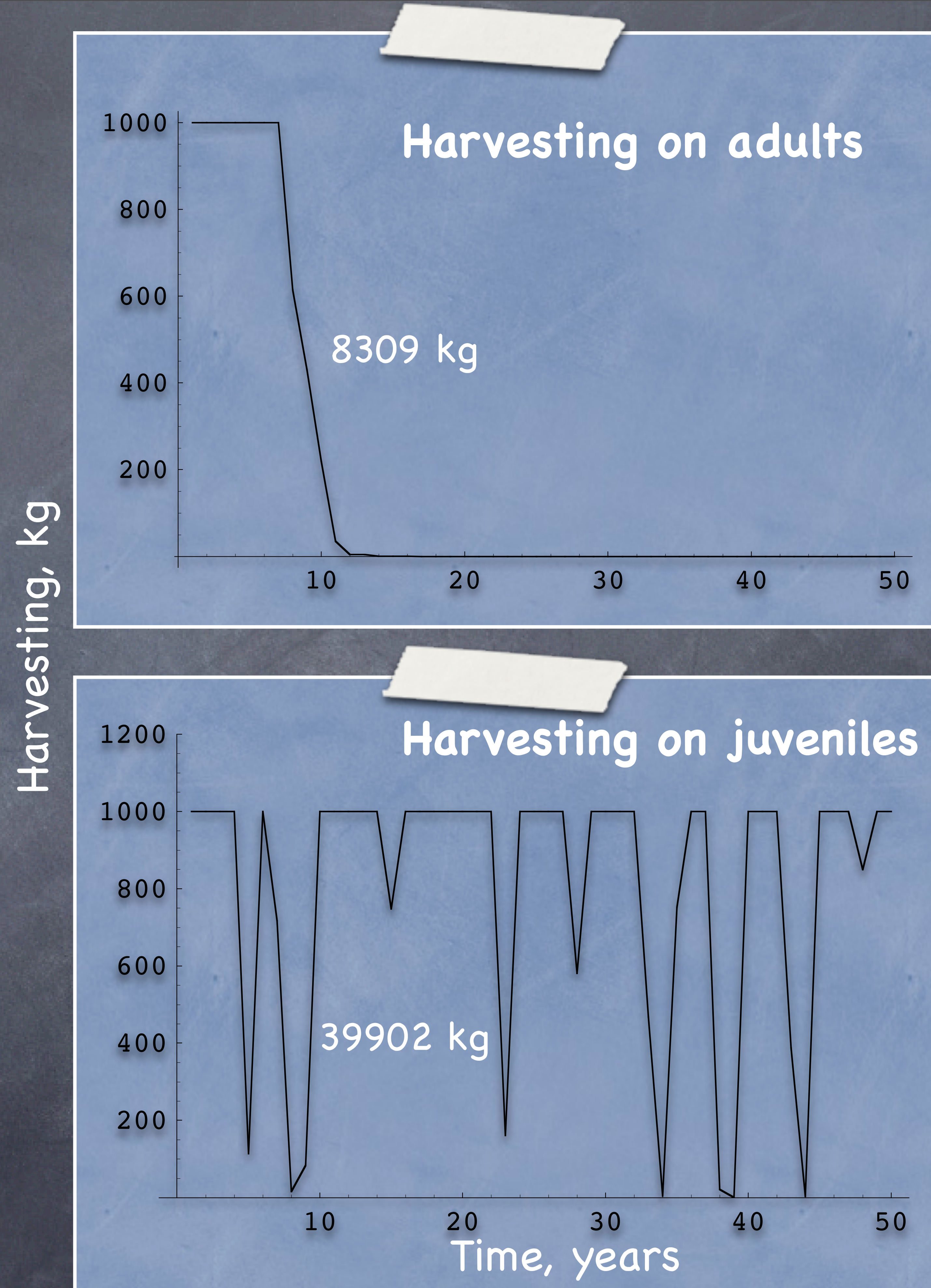
Harvesting on adults again leads to a very rapid decline of the stock: first adults, then eggs, then juveniles.



Harvesting on juveniles, however, still leads to persistent populations in a robust fishery.

Harvesting on adults or harvesting on juveniles

Simulations with regulation on the sum of adult survival and juveniles becoming adults. Occasional bad years, and normally distributed environmental stochasticity in egg survival.



Here we see the harvested biomass per year for the two alternative harvesting regimes. Harvesting on adults above, harvesting on juveniles below. Harvesting on juveniles, catches may vary with environmental stochasticity and occasional bad years in the survival of eggs, but the fishery continues and we get much larger catches over time, in this case about 40,000 as opposed to about 8,000 kilos over the 50 year period and the stock is still commercially viable.

Take-home message

- Can take out more biomass and yet get a more robust fishery by harvesting on juveniles rather than harvesting on adults

So my concludion is that you can actually take out more biomass and still get a more robust fishery if we harvest juveniles rather than adult (small individuals, rather than large individuals).

2. What's the worst thing you can do to someone: kill them or take their food away from them?

Besides the desire not to kill or mistreat animals, I feel the best reason to be a vegetarian is that one does not waste energy. As a rule of thumb, approximately 90% of the energy is used up at each trophic level (for temperature regulation, movement and so on) so that only 10% is passed on in the form of growth to be eaten by the next level up. So one thinks that feeding lower on the food chain is the more efficient way of foraging, and that one can feed more people at lower levels in the food web, or the same number of people on a smaller impact.

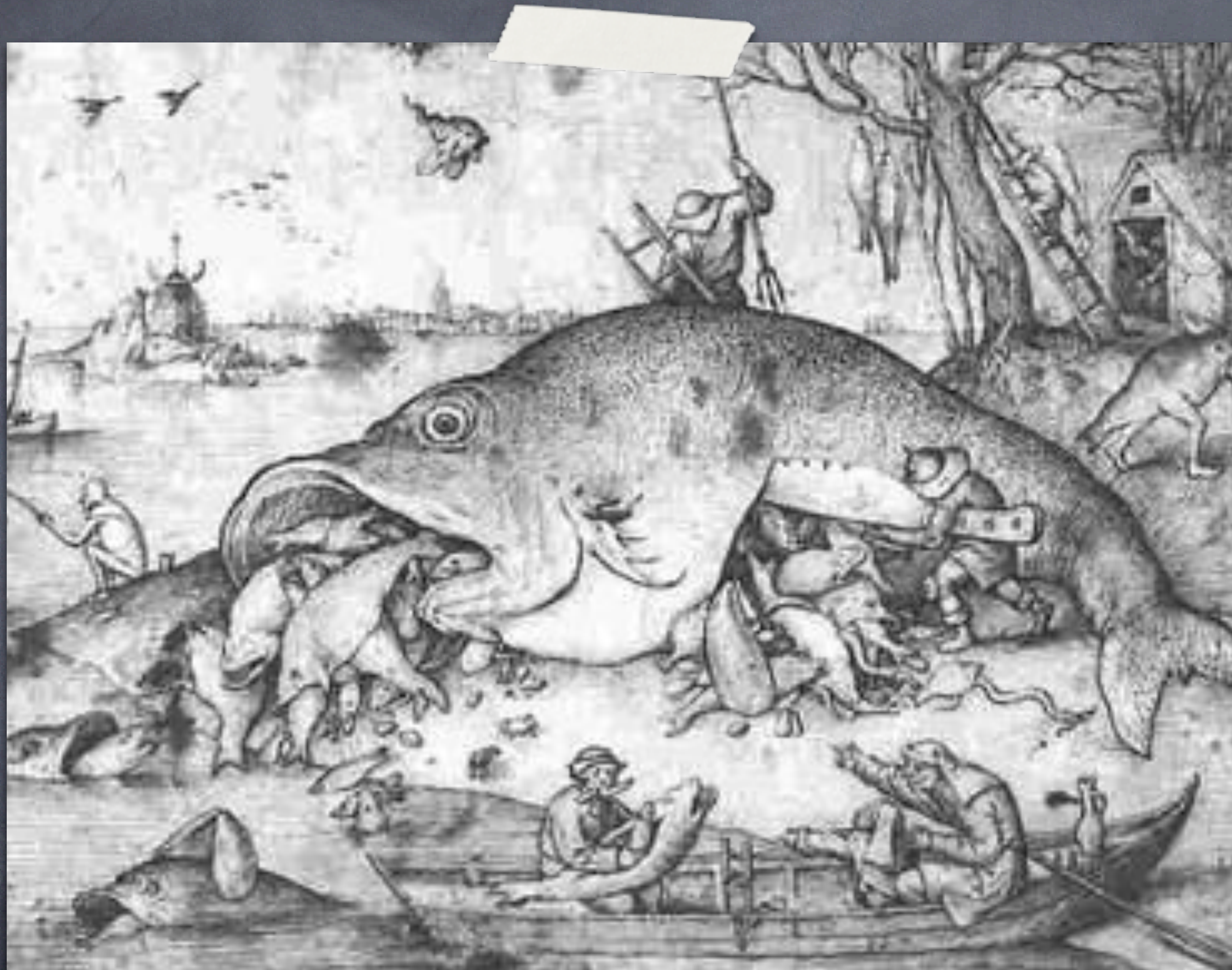
However, when you think about it, this clearly depends on whether you're taking food away from species higher up in the food chain and whether the system can stand humans harvesting at the lower trophic level.

What I'm afraid of, and one of the reasons I haven't developed this model any further yet, is that although the mechanism may be valid in a single species universe, in a multispecies universe the small fish that we would be harvesting may be food for numerous other species—whether or not we happen to be harvesting those other species.

Take krill for instance, what would happen to life in the sea if we humans took all our marine proteins from krill? Would we perhaps crash capelin, roughy, and cod populations even faster if we took their food away from them?

I wrote to Dan Pauly about this several years ago and he said that believe it or not this was a question he had not worked on, and did not know the answer to. He said intuitively one would think the best approach would be to harvest evenly on all trophic level.

But I tend to think that you'd be better off leaving the food alone so that there was a large amount of food available for the harvested population to rebound.



What is worse? Killing outright or taking food away?

This depends presumably on the shape of interactions in food chains and food webs. The shape of density dependence, whether food chains tend to be top down or bottom up regulated, and so on.

If we accept the conventional wisdom that most food chains are bottom up regulated, rather than top down, we might suppose that the lack of food is the most detrimental effect organisms face in nature.

This question is also linked to question 1 in the case of cannibalism. For instance, large cod are notorious cannibals. So by harvesting juvenile cod you may be taking food away from the adults which are supposed to form your “stable” core population.

The shape and cause of density dependence will presumably also be pivotal in many populations. I have no firm grasp of what density dependence might look like in many marine species, and if we are harvesting them they may be far from a population ceiling in any case.

3. Biomass vs interest rates; absolute mass vs growth rates

Standard economic thinking messes with us in some of these systems, and may have perverse effects when we are managing for something other than economic return. In a harvested system, interest rates and opportunity costs tend to drive resource "owners" to harvest at the point where the stock is no longer growing at a rate greater than the rate of return on alternative investments. This would mean that the forester for instance would cut "his" forest at the time when trees grow at a slower rate, for instance equal to the interest rate in the bank. So you cut the large trees and leave the small ones to continue growing, even though in absolute terms the large trees may still be putting on more mass than the little trees.

This economic mechanism, I propose, would be less important in the case of carbon trading, because carbon does not grow in the bank and there may be no equivalently effective means of capturing and storing carbon. Hence, the forestry regime for binding and holding on to carbon should be different from the usual forestry regime for economic return from selling timber.

If I am to keep on developing this idea, I hope to attract some people to work with me on these questions, as I am tired of working on things single handed. First one would like to know the extent to which any of these results are already known. I haven't yet conducted a thorough literature search, hoping that somebody in the biz could simply point out to me whether this was a known phenomenon or not. People I have mentioned this to say things like, well where are the adults going to come from if you kill the young, and this would violate the laws of thermodynamics. I have mentioned my thoughts on this to Andy Dobson, Si Levin, Don Ludwig, Dan Pauly, David Conover (on account of his evolutionary results of harvesting big fish), etc., but so far I've had no takers. I've also discussed with some of you in the audience, and so far I've had no one tell me outright that this is a known result and an accepted mechanism or harvesting strategy. Environmentalists I have brought this idea up with on the other hand have been very excited about it.

The importance of a core breeding population has been proposed in the matter of marine protected areas, so I was hoping that perhaps now people might be ready for a model with a kind of demographic protection as analog to a mere spatial protection.

I think, after a literature review, the next step ought to be to toy with the models and parameter choices a bit more, then try to look at real data from economically harvested species, like cod, lobster, trees, clams/oysters, tuna, groupers, and so on. Then perhaps one could enter into a dialog with harvesters to see if they might be amenable to changing some harvesting regimes accordingly.

I open the floor to questions and general discussion. We can also run the model in real time if anyone wants to try running it with different parameter values.

For discussion: Now there may be cases where prices mess with us. There may be cases where large individuals fetch a better price in the market. There may be more waste in filleting small fish than large fish. But I am equally sure that there are cases where the smaller and younger individuals actually taste better. In some cases there are technical difficulties in sparing the old and large individuals. Saw mills often prefer large trees because that is what they have been calibrated for. I am equally sure that a lot of these technical difficulties are surmountable if humans put their ingenuity to the task. With gill-nets tight meshed nets ought to let large fish bounce off as if on a wall, while small fish get entangled. With lobster, cray-fish, and bivalves catches are manually sorted and it is actually easier to throw out the large ones than to throw out the little ones.

Modifications

2x2 matrix	✔
Eliminate transient behavior	✔
Juveniles also reproduce	✔
Stay juvenile longer	
Density dependence on juveniles	
Differentiable density dependence	
Shape of density dependence	
Environmental stochasticity	✔
Scramble competition	
Leslie matrix with actual age levels directly	
"Real" data	
Time of harvesting (before, after, continuous)	
Other harvesting functions/rules	
Analytical results on sensitivity	
Multispecies/foodweb interactions	

Other steps: explore models with no density dependence
Explore models with density dependence on (reproducing) juveniles, etc.