

# Approaches to Modeling, Types of uncertainty

Ecological Forecasting, Jan 26th

First, checking in on lab from  
Tuesday.

Any questions, or issues?

# Revisiting logistic growth

$$N_{t+1} = N_t + rN_t(1 - N_t/K)$$

The diagram illustrates the components of the logistic growth equation. Two blue arrows point from labels below the equation to specific terms: one arrow points from 'Low density growth rate' to the term  $rN_t$ , and another arrow points from 'Carrying Capacity' to the term  $K$ .

Low density growth rate

Carrying Capacity

# Forward Modeling

$$N_{t+1} = N_t + rN_t(1 - N_t/K)$$



Estimated



Data

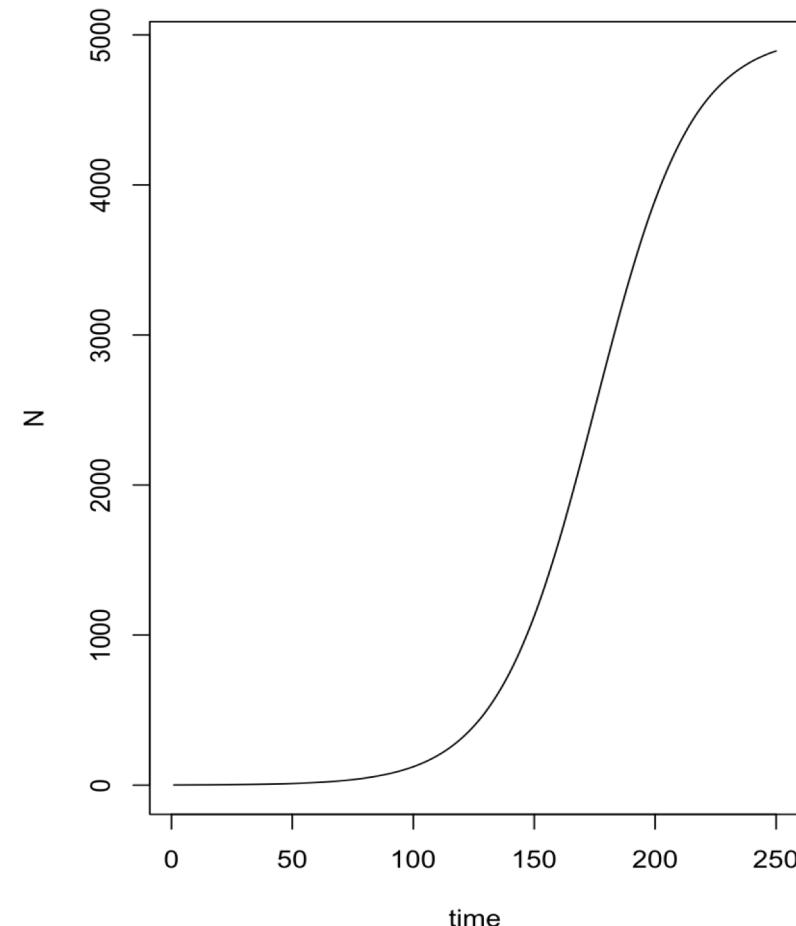


Data

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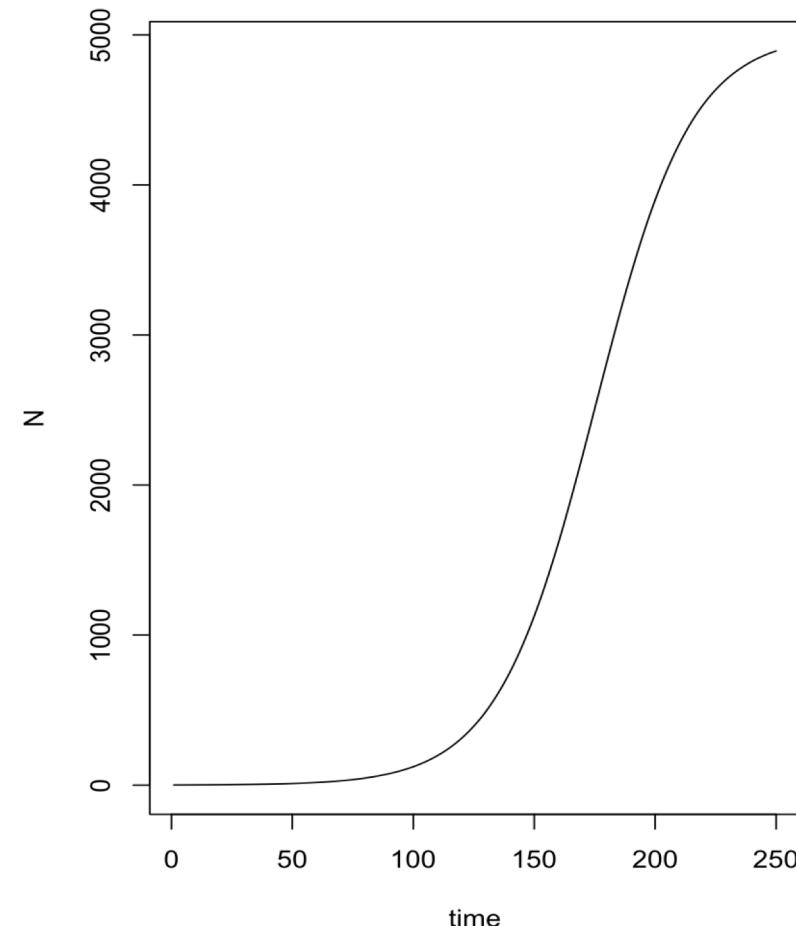
Model is purely deterministic,  
stochasticity can be added in some forms



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Parameter	Quantity	Units
<i>Aboveground state variables</i>		
$n(\mathbf{z}, \mathbf{x}, a, t)$	density† of size $\mathbf{z}$ type $\mathbf{x}$ plants in gaps of age $a$ at time $t$	$\text{m}^{-2}$
$p(a, t)$	distribution of gap ages $a$ at time $t$	dimensionless
<i>State dimensions</i>		
$\mathbf{z}$	plant size $\mathbf{z} = [z_x, z_a] = [B_s, B_g]$	$\text{kg C}, \text{kg C}$
$\mathbf{x}$	plant type $[x_1, x_2] \cdot x_1 = 0$ if $C_s$ , 1 if $C_d$ , $x_2 = \text{leaf longevity}$	dimensionless, yr
$a$	gap age	yr
$t$	time	yr
<i>Plant resource environment</i>		
$\mathbf{r}$	resource vector $\mathbf{r} = [\phi, W, N]$	$\text{J}\cdot\text{m}^{-2}\cdot\text{s}^{-1}, \text{m}^3 \text{H}_2\text{O}/\text{m}^2, \text{kg N}/\text{m}^2$
$\phi$	photosynthetically active radiation (PAR)	$\text{J}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$
$W$	soil water content	$\text{m}^3 \text{H}_2\text{O}/\text{m}^2$
$N$	plant available soil nitrogen content	$\text{kg N}/\text{m}^2$
<i>Transition rates</i>		
$g_s$	structural biomass growth rate	$\text{kg C}/\text{yr}$
$g_a$	living biomass tissue growth rate	$\text{kg C}/\text{yr}$
$\mu$	mortality rate	$\text{yr}^{-1}$
$f$	fecundity	$\text{yr}^{-1}$
$\lambda$	total disturbance rate $\lambda = \lambda_F + \lambda_{DI}$	$\text{yr}^{-1}$
$\lambda_F$	fire frequency	$\text{yr}^{-1}$
$\lambda_{DI}$	rate of canopy gap formation	$\text{yr}^{-1}$
$s$	survivorship of plants following disturbance	dimensionless
<i>Plant size characteristics</i>		
$h$	height	m
$B_s$	living biomass ( $B_l + B_r + B_{sw}$ )	$\text{kg C}$
$B_s$	structural stem biomass	$\text{kg C}$
$B_l$	leaf biomass	$\text{kg C}$
$B_r$	root biomass	$\text{kg C}$
$B_{sw}$	sapwood biomass	$\text{kg C}$
<i>Leaf-level carbon and water fluxes</i>		
$\dot{A}_n$	net rate of carbon gain per unit leaf area	$\mu\text{mol C}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$
$\Psi$	evapotranspiration rate per unit leaf area	$\mu\text{mol H}_2\text{O}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$
<i>Decomposition model state variables and coefficients</i>		
$C_1$	fast soil carbon pool	$\text{kg C}/\text{m}^2$
$C_2$	structural soil carbon pool	$\text{kg C}/\text{m}^2$
$N_1$	fast soil nitrogen pool	$\text{kg N}/\text{m}^2$
$N_2$	structural soil nitrogen pool	$\text{kg N}/\text{m}^2$
<i>Miscellaneous</i>		
$n_0(\mathbf{z}, \mathbf{x}, a)$	initial plant density $n(\mathbf{z}, \mathbf{x}, a, 0)$ †	$\text{m}^{-2}$
$p_0(a)$	initial gap age distribution	dimensionless
$\mathbf{z}_0$	seedling size	$\text{kg C}, \text{kg C}$
$y$	integer gap number ( $1 \dots Q$ )	dimensionless
$h^*$	height above which mortality is treated as disturbance	m
$c_s$	stomatal conductance	$\mu\text{mol H}_2\text{O}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$
$T_L$	leaf temperature	°C
$T_A$	atmospheric air temperature	°C
$C_i$	interstitial concentration of $\text{CO}_2$	mol/mol
$C_a$	atmospheric concentration of $\text{CO}_2$	mol/mol

†  $n(\mathbf{z}, \mathbf{x}, a, t)$  is technically a density distribution where  $n(\mathbf{z}, \mathbf{x}, a, t)dz_x dz_a da$  is the per  $\text{m}^{-2}$  density of type  $\mathbf{x}$  plants between size  $z_x$  and  $z_x + dz_x$ , and size  $z_a$  and  $z_a + dz_a$  in gaps aged between  $a$  and  $a + da$  at time  $t$ .

# Forward Modeling

Anyone know of any applications of forward modeling?

Forward modeling, historically, has been of the most common modeling approaches. Big push to make more and more complex forward models came in the 1970s, 1980s with increases in computing power.

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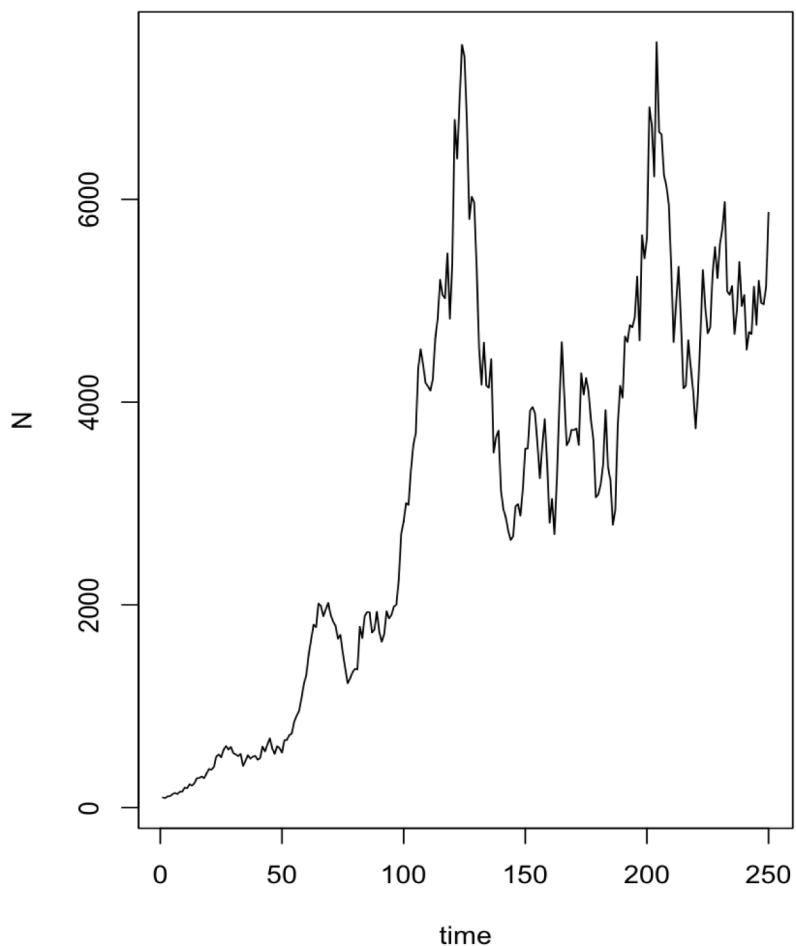
While computers are powerful and important tools, adding additional processes and complexity to models does not always yield better predictions.

# Inverse modeling

$$N_{t+1} = N_t + rN_t(1 - N_t/K)$$

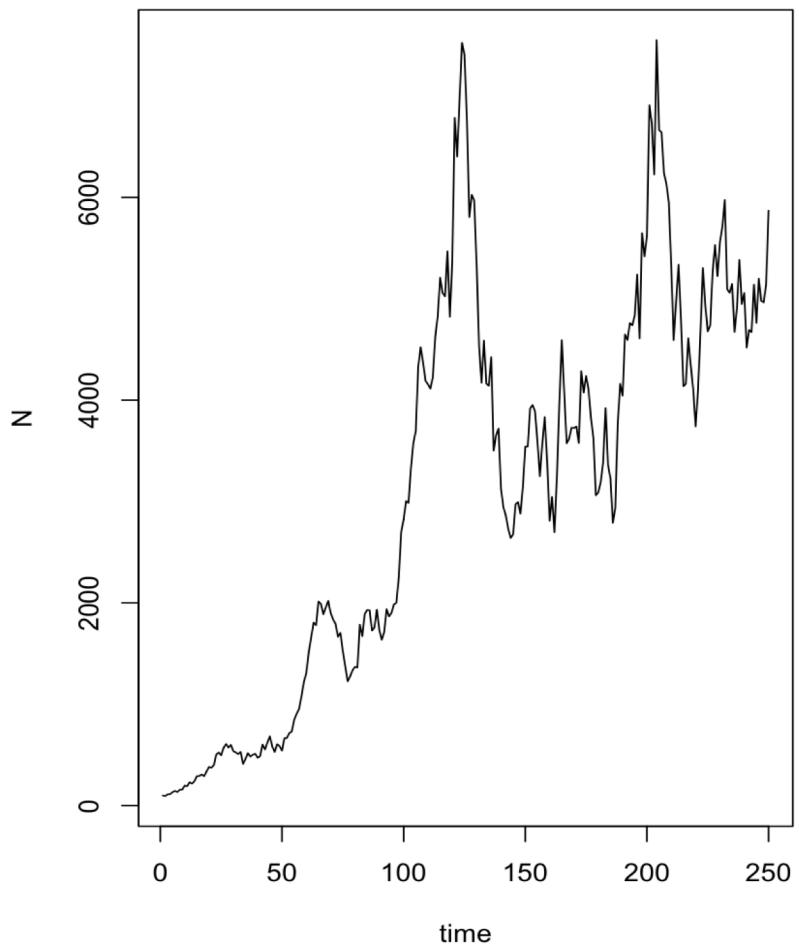
The diagram illustrates the components of the logistic growth equation. The term  $N_t$  is labeled 'Data'. The term  $rN_t$  is labeled 'Estimated'. The term  $N_t/K$  is also labeled 'Estimated'.

# Inverse Modeling



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# Inverse Modeling

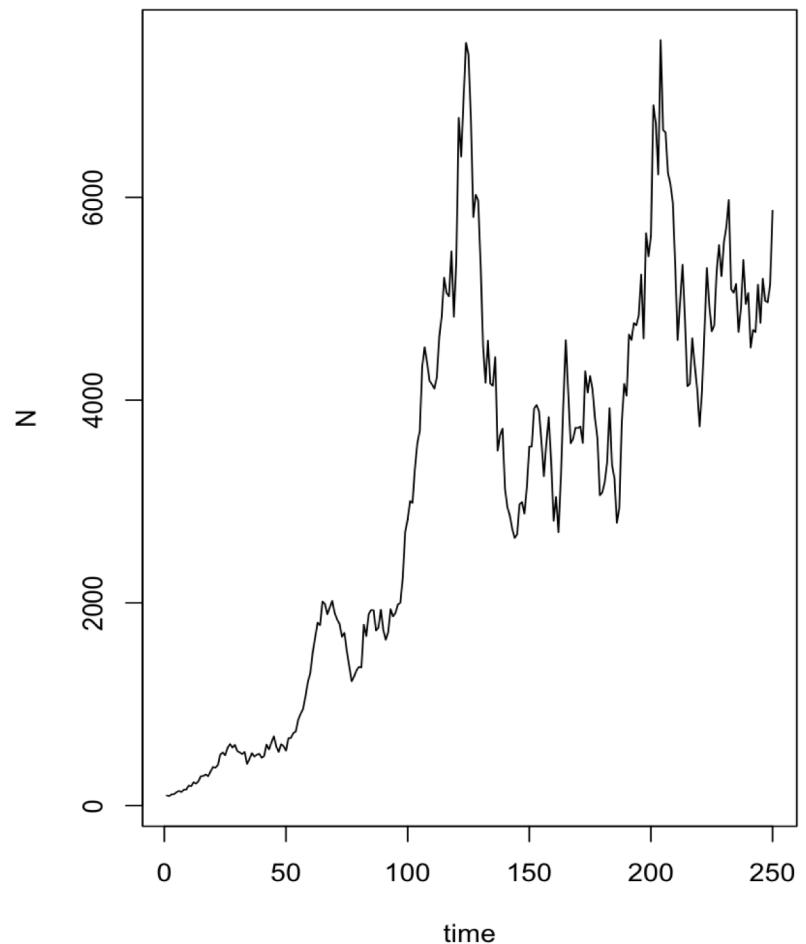


Probability distributions describes  
connection between data and model

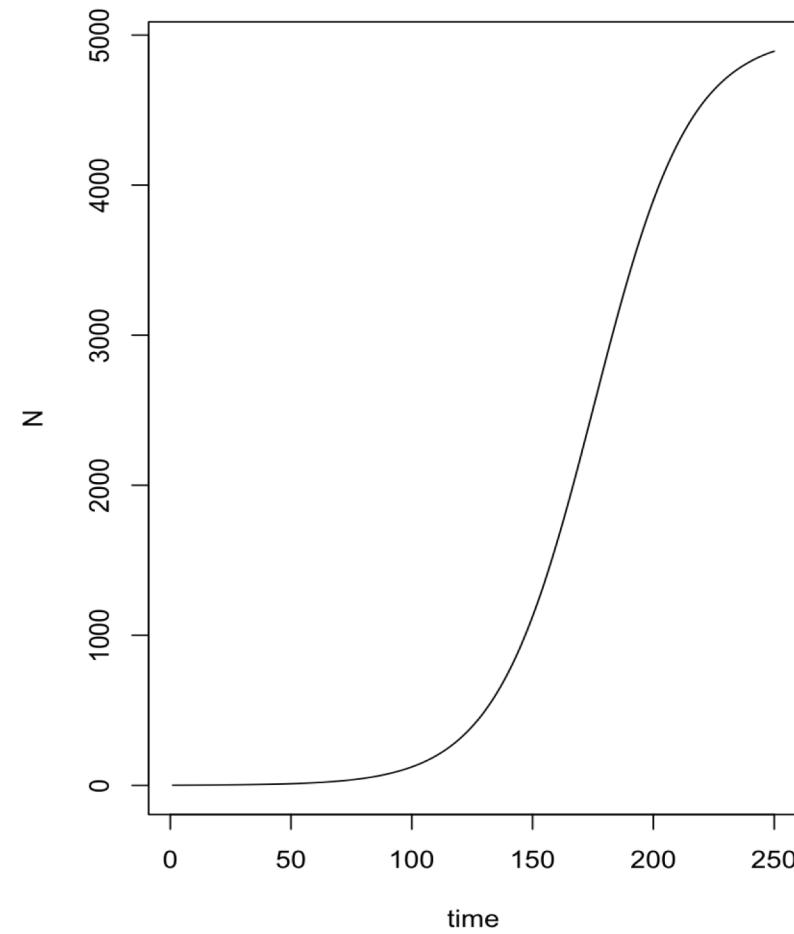
$$N_{t+1} = N_t + rN_t(1 - N_t/K)$$

# Forward and Inverse don't match

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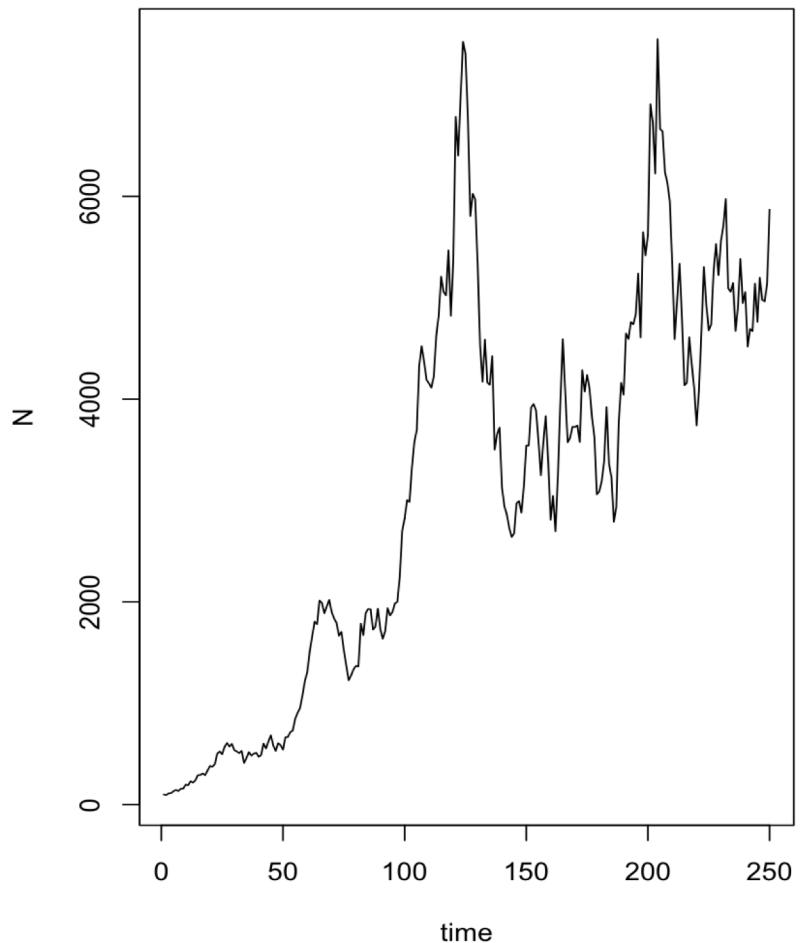


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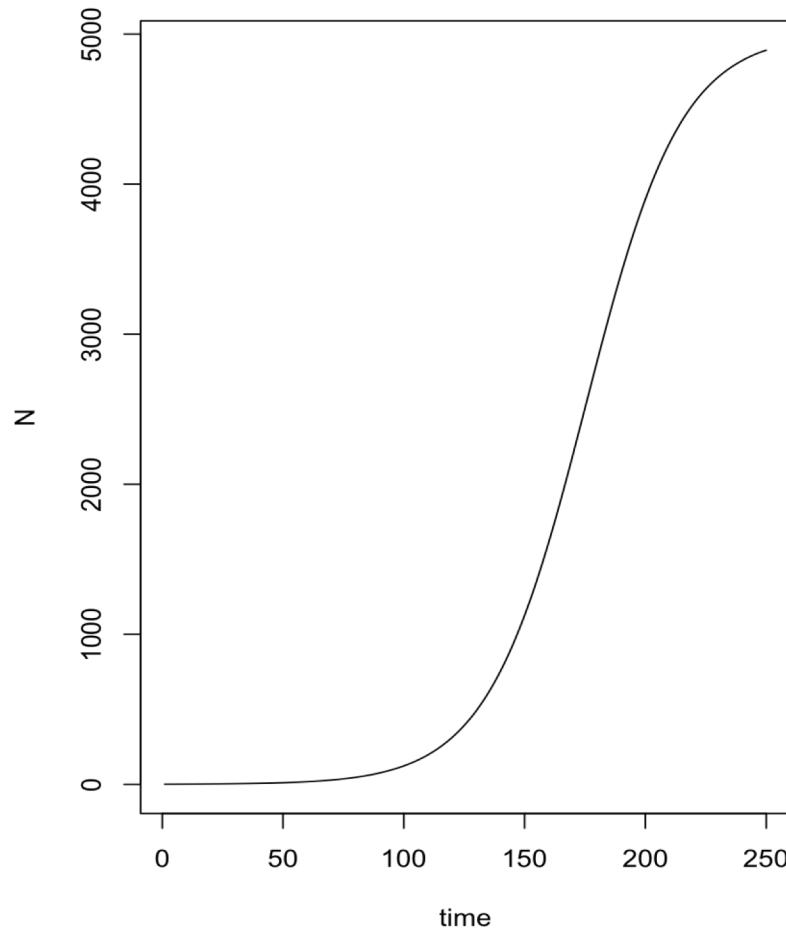


# What accounts for this?

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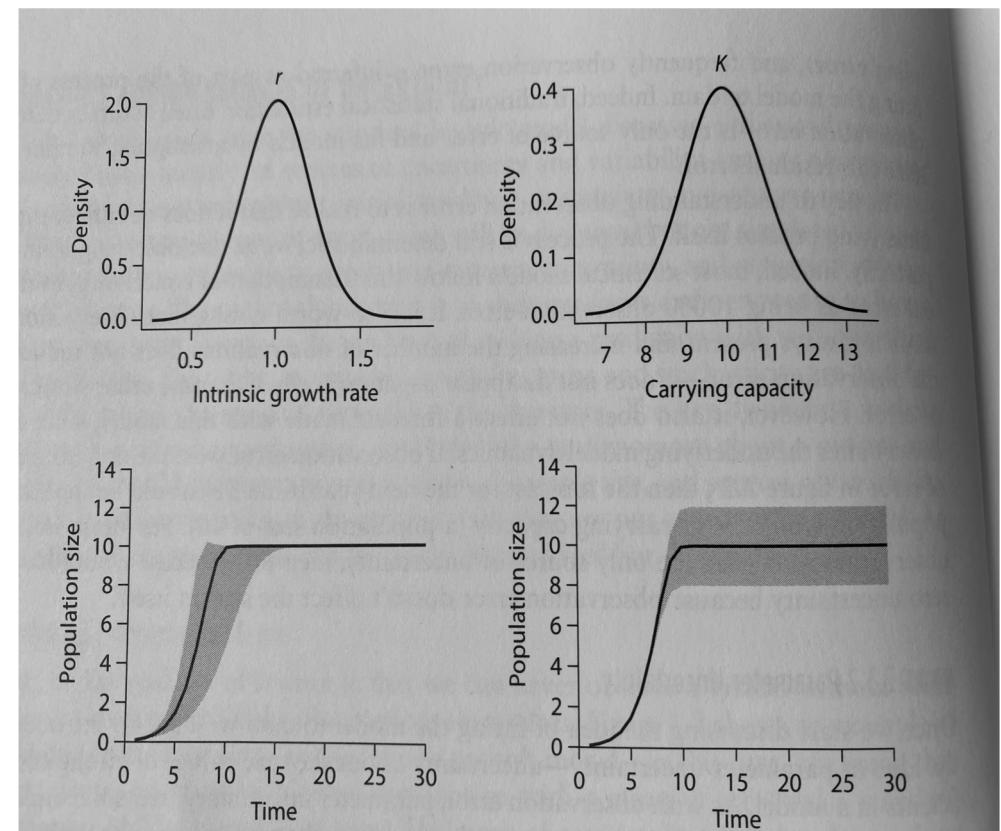
Variability and uncertainty

# Types of variability and uncertainty

Parameter uncertainty: The true values of the parameter in the models are unknown

This type of uncertainty can be accounted for by both forward and inverse modeling approaches

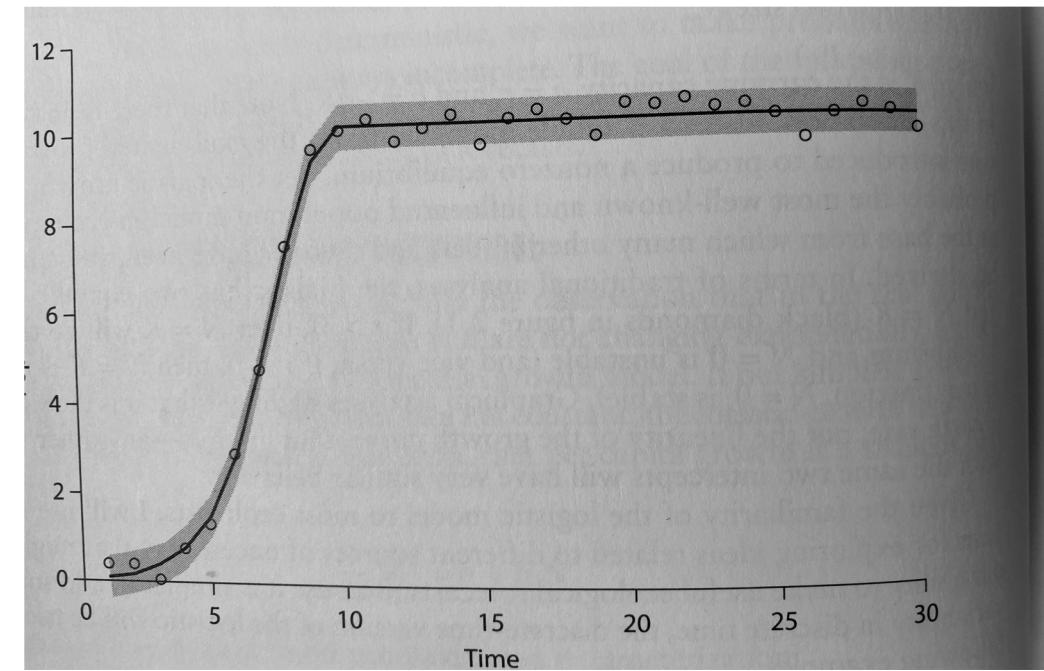
Parameter uncertainty will be reduced with more data collection.



# Types of variability and uncertainty

Observation uncertainty: The true state of the system can not be observed without error.

If observation error is the only source of error then the underlying forecast is deterministic.



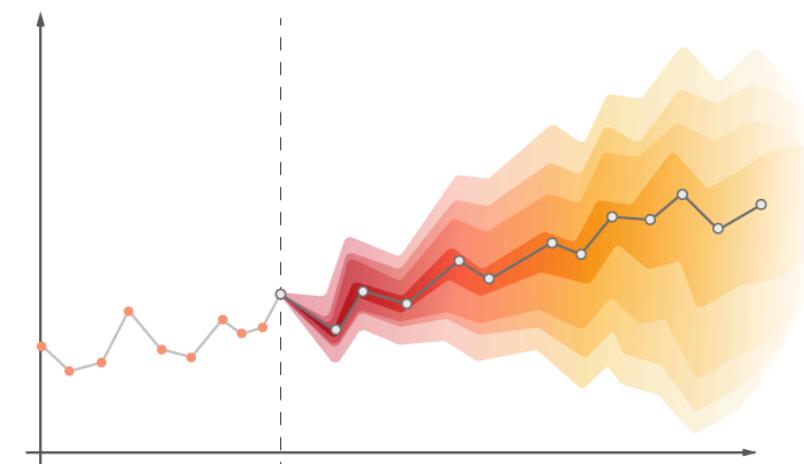
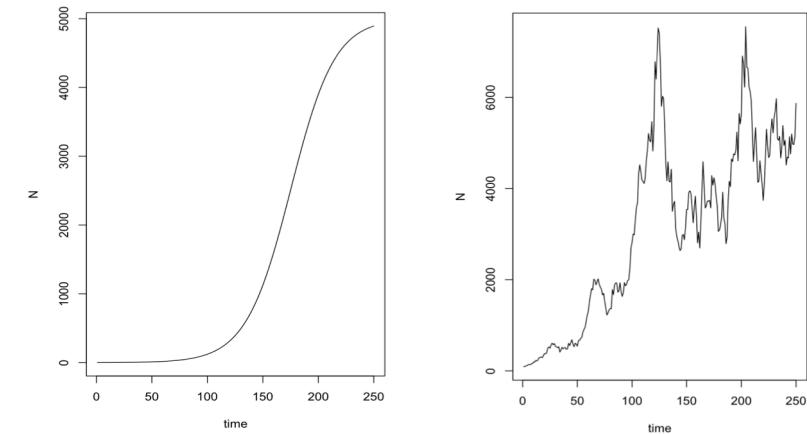
# Types of variability and uncertainty

**Process error/variability:** Our models do not include all of the relevant processes.

This source of error is very common in ecology and environmental sciences, but hard to include/describe with forward modeling approaches.

One way is using a model ensembling.

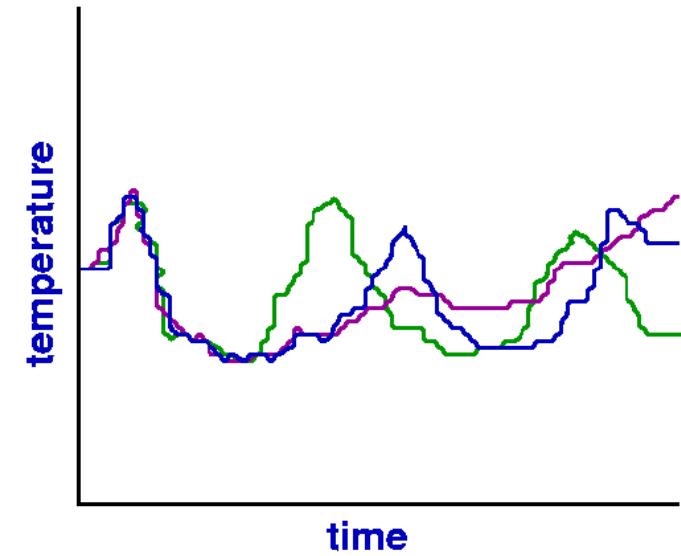
Because process error is uncertainty about the true state of a system, it propagates out in forecasts, often leading to greater uncertainty as time/space goes on.



# Types of variability and uncertainty

Initial condition uncertainty: Not knowing the current state of the system.

This is most important in chaotic systems like weather.



# Grab bag of other uncertainties

**Driver uncertainty:** If forecast includes “drivers” like temperature, than uncertainty in the forecast of that driver propagate through to forecasts. One of the reasons why the most ecologically realistic model may not be the best for forecasting.

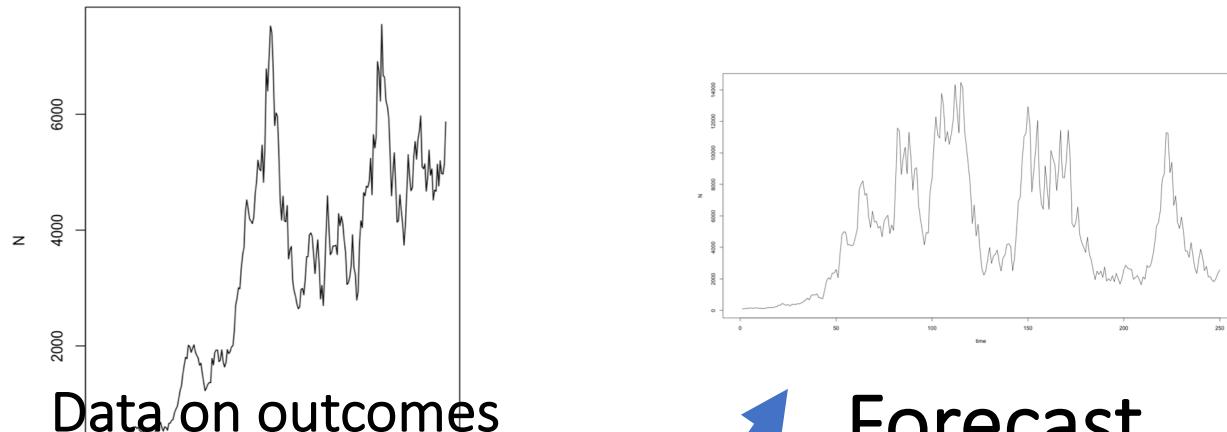
**Numerical approximation:** Computers make approximation errors. This rarely matters for most of our applications, but good to be aware of.

So how do we build models and forecasts  
in the face of all of these sources of  
uncertainty?

# Models as scaffolds

We use models to describe the relationship (or covariance) between different sources of data, and data yet to be observed.

# Models as scaffolds



Data on outcomes

Forecast

tip

$$N_{t+1} = N_t + rN_t(1 - N_t/K)$$

Data on parameters

# Soapbox

Models are sometimes described as process-based, mechanistic, statistical, phenomenological.

What does that mean?

# Soapbox

Any (or at least most) useful  
models contain some  
element of all of these.

# Readings- Clark et al.

What does “inherent uncertainty” mean and what are some examples?

What are some of the problems if a forecast doesn’t handle uncertainty properly?

What is the “bet-hedging” described in the paper and can you think of any examples?

What is your impression of how the “next steps” discussed here have been implemented in the last 20 years?

# Readings-Houlihan et al.

What is model transferability?

What is bias-variance tradeoff? How does it impact prediction?

Can we truly falsify forecast (in the NHT sense)?

# Next week!

Beginning some analysis of simple timeseries data.

Fitting and forecasting timeseries using R functions.

Feb 7<sup>th</sup>: No regular class. Please attend GPHS  
webinar (zoom) from 12-1.