Directed Extinction of Exotic Fish Populations in the Wild Using a Fish Bearing Multiple Y Chromosomes

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Wild Sex and Drugs

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Approaches to the Eradication of Exotic Fish

Chemical

- **Rotenone**
  (nonspecific)

Biological

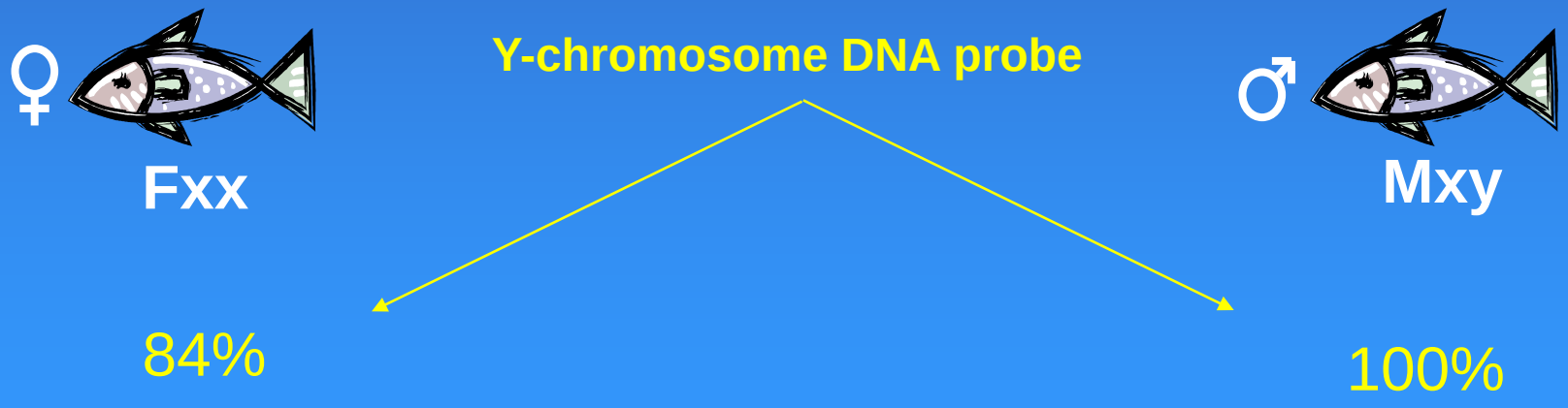
- **Specific disease or parasites**
  (unavailable)

- **Sterile males**
  (specific, but requires overwhelming numbers of sterile males to compete with normal males)

- **Altered sex ratio**
  (specific, requires that one sex is reduced to zero over time)

Coho Salmon
Sex-reversed females (Fxy) in the Columbia River

Nagler, J. J., Bouma, J., Thorgaard, G. H. and Dauble, D. D. (2001) High Incidence of a Male-Specific Genetic Marker in Phenotypic Female Chinook Salmon from the Columbia River, *Environmental Health Perspectives* 109, 67-69.



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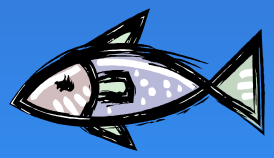
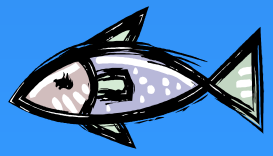
♀ 

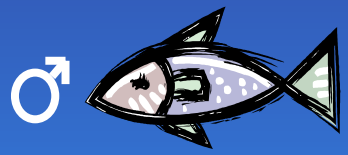
Fxx

♀ 

Fxy

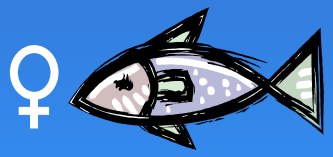
Some females containing a Y-chromosome are actually males which were sex-reversed

XY sex-determination



♂

XY



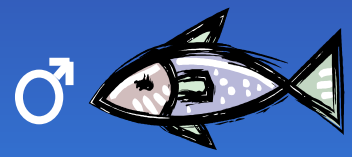
♀

XX

	X	Y
X	XX	XY
X	XX	XY

Males/Females
Ratio 1:1

Females with a Y chromosome produce more male progeny, some of which are Myy



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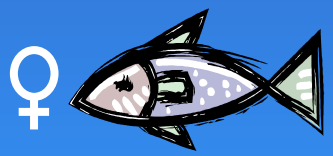
Mxy

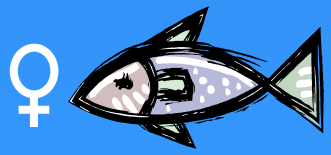


♀

Fxx

	X	Y
X	XX	XY
X	XX	XY

Males/Females
Ratio 1:1



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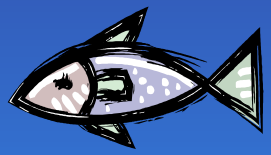
Fxy

	X	Y
X	XX	XY
Y	XY	YY

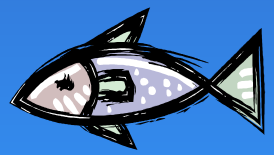
Males/Females
Ratio 3:1

Myy males are viable and produce only male offspring

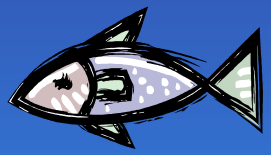
♂ 

Mxy

	X	Y
X	XX	XY
X	XX	XY

♀ 

Fxx

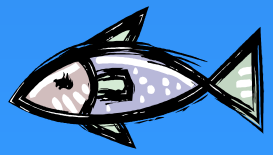
♂ 

Myy

	Y	Y
X	XY	XY
X	XY	XY

Males/Females
Ratio 1:0

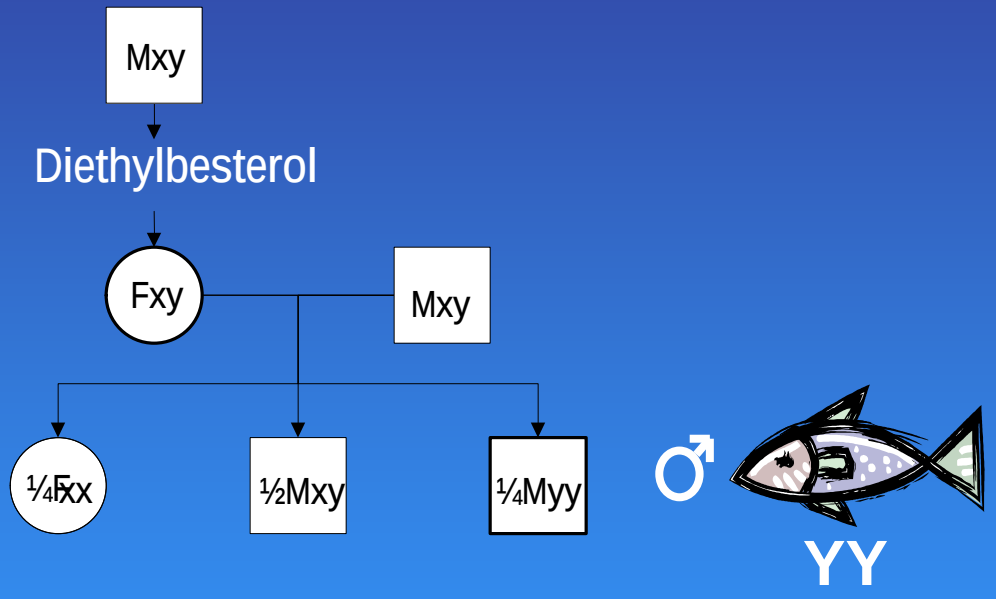
	X	Y
X	XX	XY
Y	XY	YY

♀ 

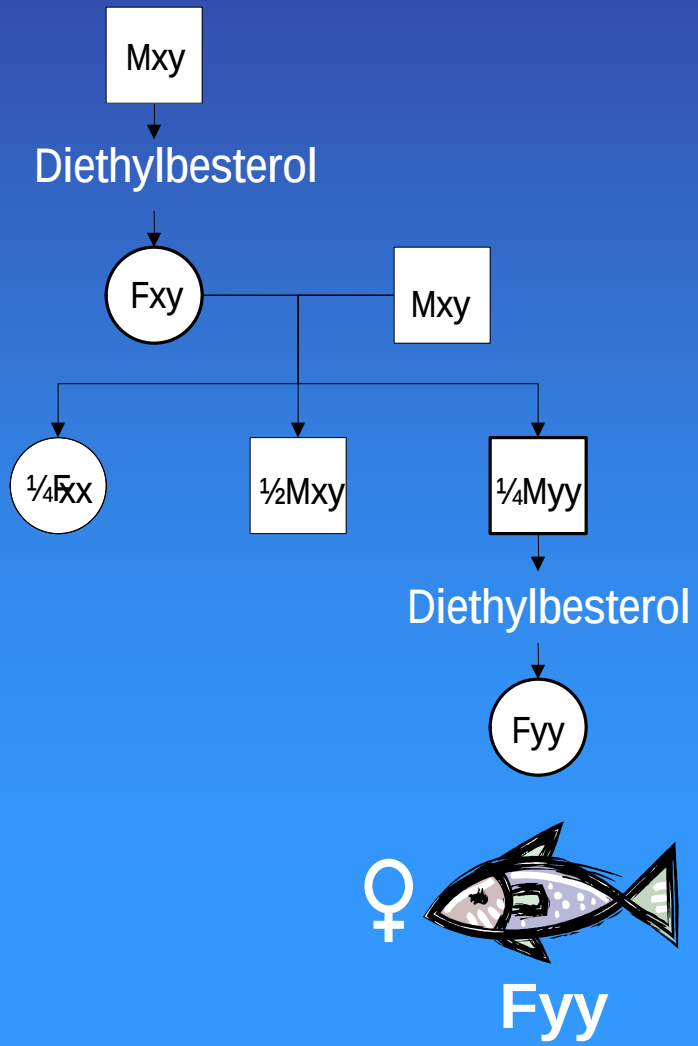
Fxy

If sufficient numbers of YY fish are added to a normal population, will normal females (Fxx) ultimately decline to zero?

Hormone manipulation can be used to generate male fish with two Y chromosomes.

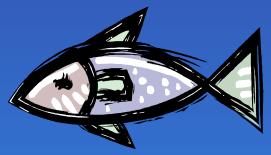


Hormone manipulation can also be used to generate female fish with two Y chromosomes (Fyy).



Females with two Y chromosomes produce only male progeny, half of which are Myy

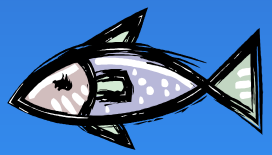
♂



Mxy

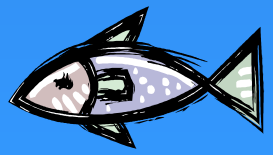
	X	Y
X	XX	XY
X	XX	XY

♀



Fxx

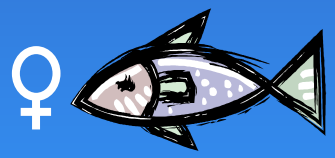
♀



Fyy

	X	Y
Y	XY	YY
Y	XY	YY

Four different matings are possible, leading to increased male production



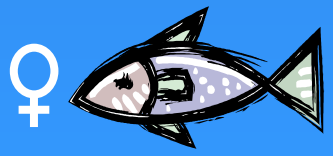
♀ **Fxx**

♂ **Mxy**

	X	Y
X	XX	XY
X	XX	XY

♂ **Myy**

	Y	Y
X	XY	XY
X	XY	XY



♀ **Fyy**

	X	Y
Y	XY	YY
Y	XY	YY

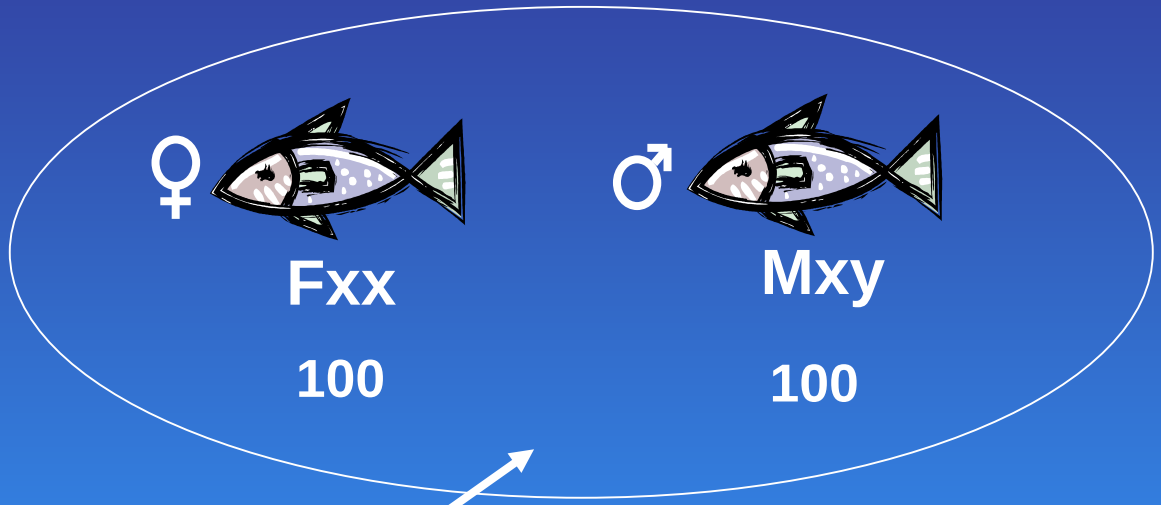
	Y	Y
Y	YY	YY
Y	YY	YY

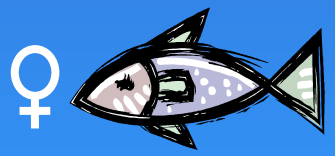
Males/Females Ratio 7:1

Male/Female ratio will increase over time if Fyy added.

Will Fxx go to zero over time?

Model Population





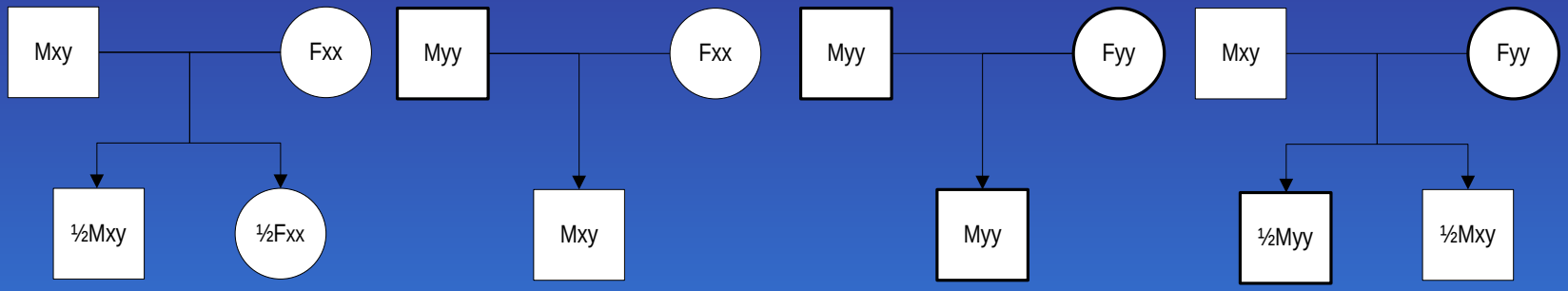
Fyy

?

Does extinction of Fxx ever occur?

If so, how many Fyy must be added before extinction occurs?

Four types of matings pairs will occur



Assumptions:

◊ **Mating Advantage**: A recent review found that large body size conferred mating advantage in 40% of the 186 animal taxa surveyed (Anderson, 1994); however here we will assume that transgenic individuals don't have mating advantage.

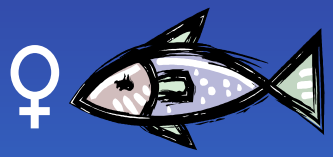
◊ **Viability**: Offspring survival to sexual maturity is the same for wild-type and transgenic individuals.

◊ **Fecundity**: Clutch size is the same for wild-type and transgenic individuals.

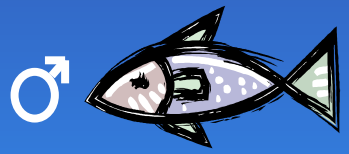
◊ **Sex Distribution**: In every clutch that produces males and females, their proportion is the same (50%).

◊ **Life Span**: We will assume that transgenic and wild-type individuals have the same life span and death rates.

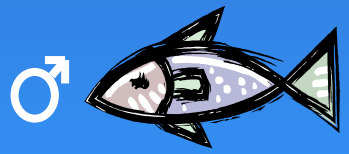
In the mathematical model each fish is represented by a differential equation



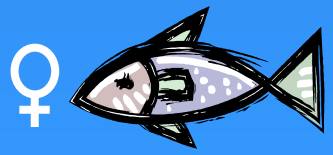
Fxx



Mxy



Myy



Fyy

$$\frac{d}{dt}Fxx = 0.5BFxxMxyL - DFxx$$

$$\frac{d}{dt}Mxy = (0.5BFxxMxy + 0.5BFyyMxy + BFxxMyy)L - DMxy$$

$$\frac{d}{dt}Myy = (0.5BFyyMxy + BFyyMyy)L - DMyy$$

$$\frac{d}{dt}Fyy = \mu - DFyy$$

$$L = \left(1 - \frac{Fxx + Fyy + Mxy + Myy}{K}\right)$$

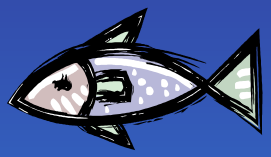
B = Rate of births. Is proportional to the fecundity.

D = Rate of deaths. Takes into account the life span.

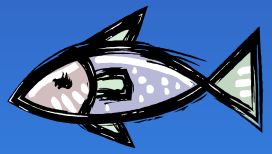
K = Carrying capacity of the ecosystem.

μ = Constant influx of Fyy.

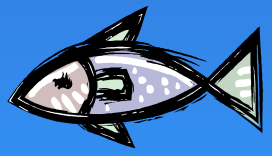
Initial Conditions



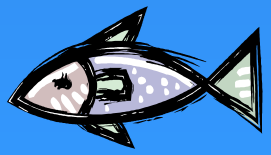
100 Fxx



100 Mxy



0 Myy



10 Fyy

$$\frac{d}{dt}Fxx = 0.5BFxxMxyL - DFxx$$

$$\frac{d}{dt}Mxy = (0.5BFxxMxy + 0.5BFyyMxy + BFxxMyy)L - DMxy$$

$$\frac{d}{dt}Myy = (0.5BFyyMxy + BFyyMyy)L - DMyy$$

$$\frac{d}{dt}Fyy = \mu - DFyy$$

$$L = \left(1 - \frac{Fxx + Fyy + Mxy + Myy}{K}\right)$$

B = Rate of births. Is proportional to the fecundity.

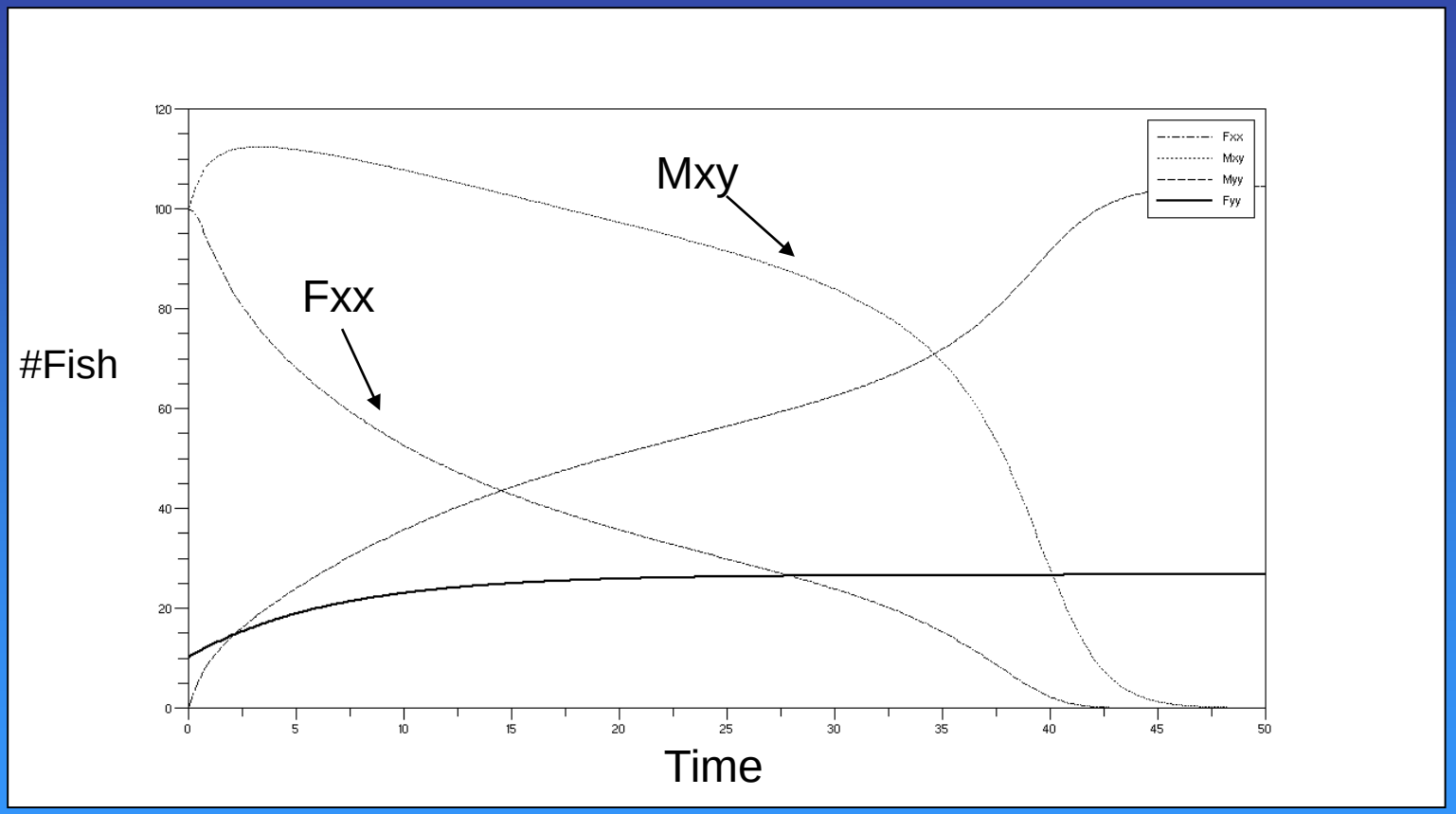
D = Rate of deaths. Takes into account the life span.

K = Carrying capacity of the ecosystem.

μ = Constant influx of Fyy.

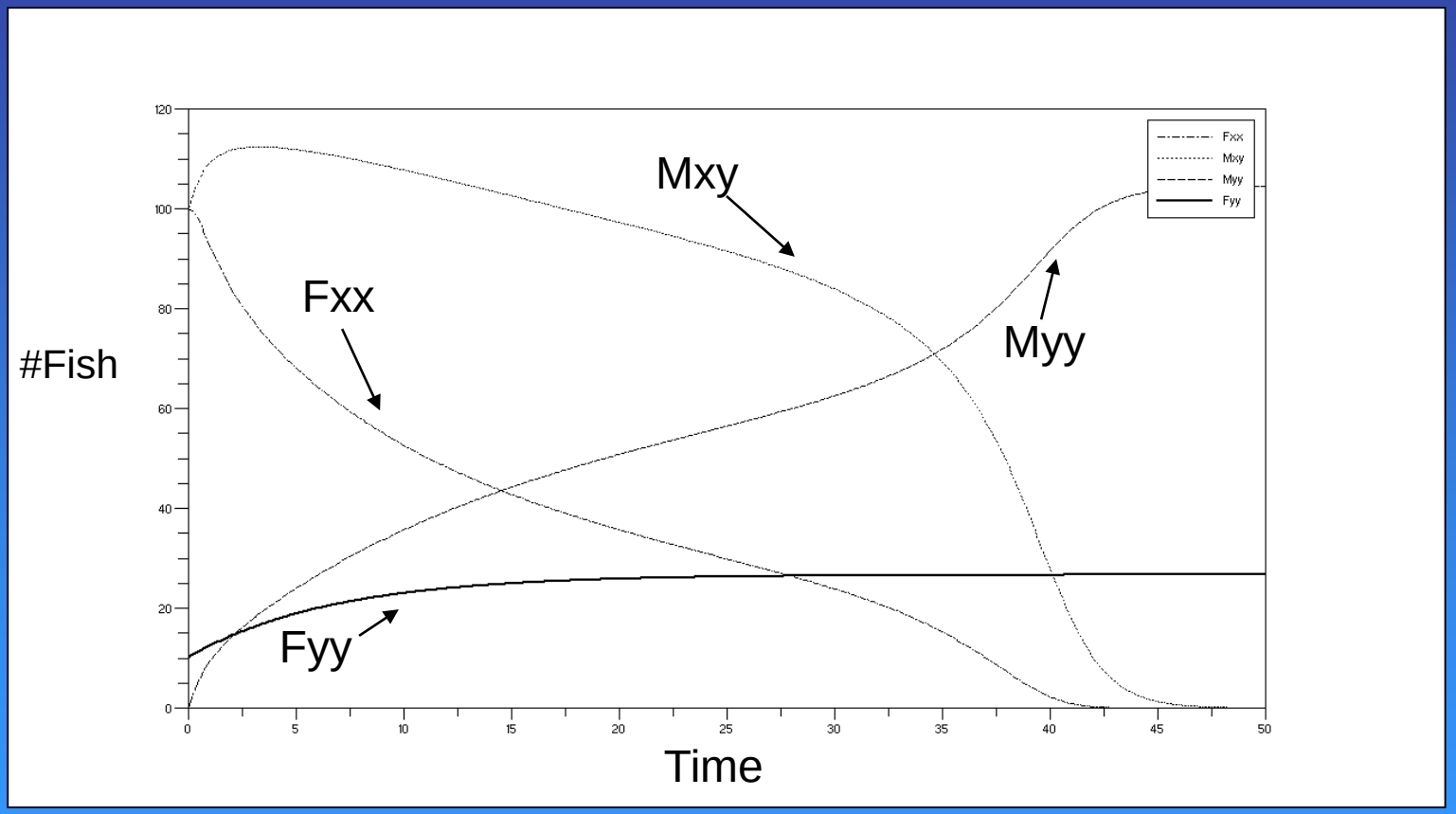
B=[0.01, 10]
D=[0.1, 3]
K= 300
μ= [0, 100]

As the constant influx of Fyy (μ) increases, normal females (Fxx) decline



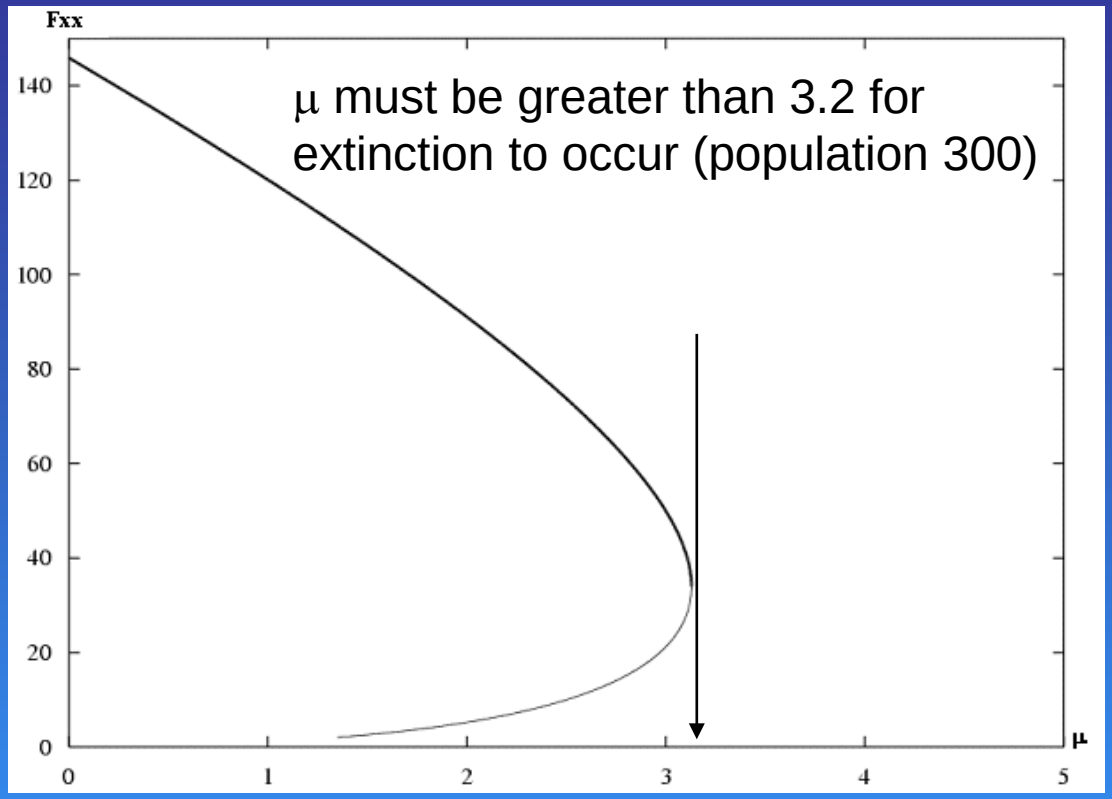
Normal females go to extinction at μ =4 or greater

As the constant influx of Fyy (μ) increases, normal females (Fxx) decline



Normal females go to extinction at μ =4 or greater

Bifurcation Diagram



***Fyy* should be at least 1.07% of the population, which are added at regular time intervals *t* (the average time period required for fish to become competent to mate).**

Gutierrez JB, Teem JL., *J Theor Biol.* 2006 Jan 6; [Epub ahead of print]

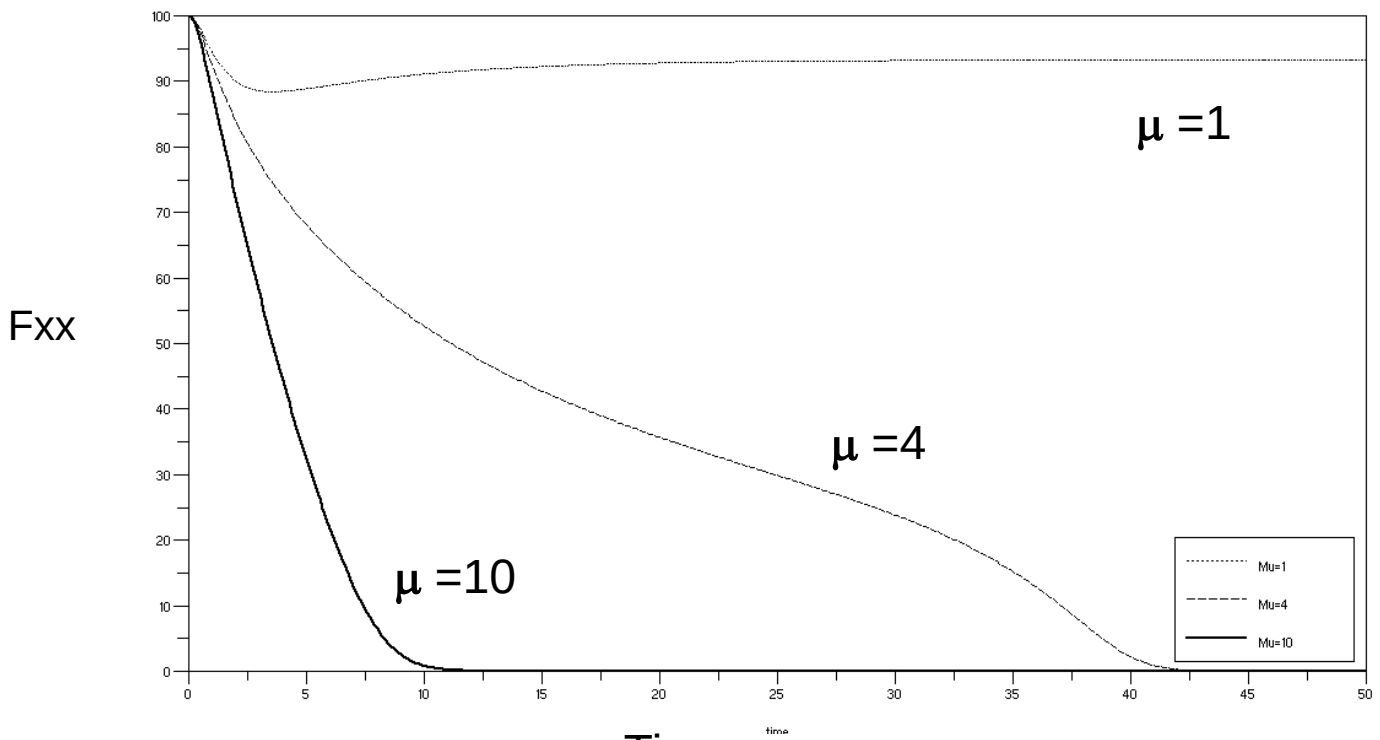
Conclusions

For a target fish utilizing a simple XY sex-determination system, the addition of YY female sex-reversed fish (Fyy) to a normal population of exotic fish can cause extinction by reducing the numbers of normal females Fxx to zero over time.

Fyy fish must be added in an amount that represents at least 1.07 % of the total population, and the addition must be continuous over time.

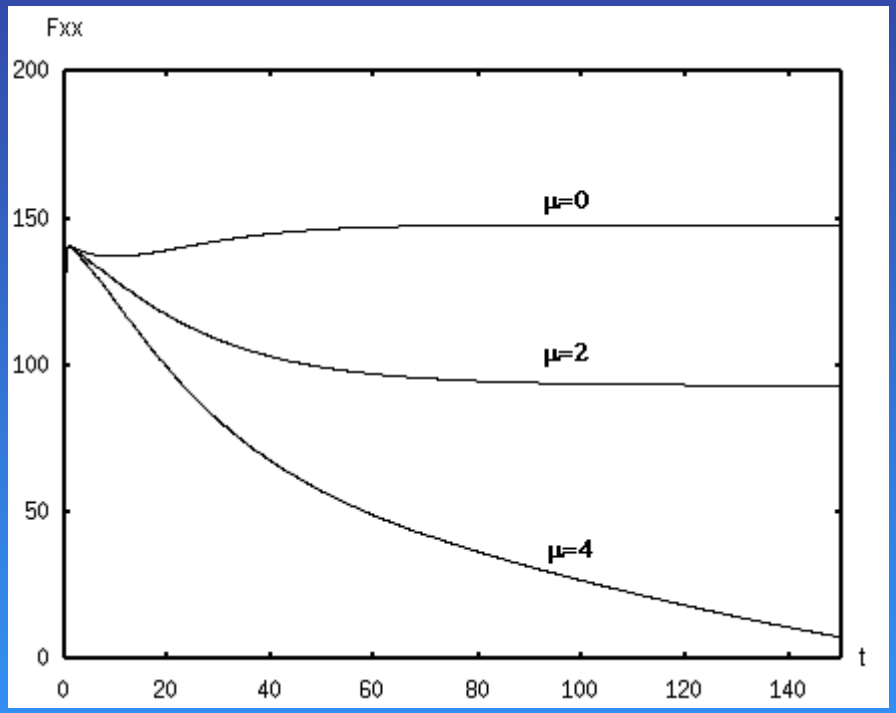
The shift in the sex ratio of the population requires many generations, thus extinction may require decades. However, the time required to attain extinction can be shortened by increasing the influx of Fyy fish (μ).

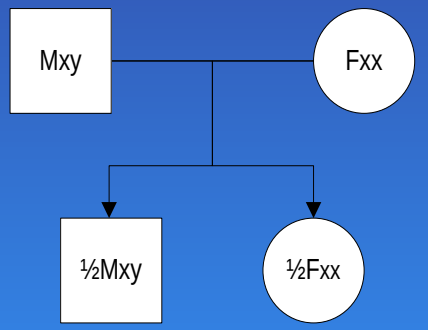
As the constant influx of Fyy (μ) increases, normal females (Fxx) decline



Normal females go to extinction at μ =4 or greater

As the constant influx of Fyy (μ) increases, normal females (Fxx) decline

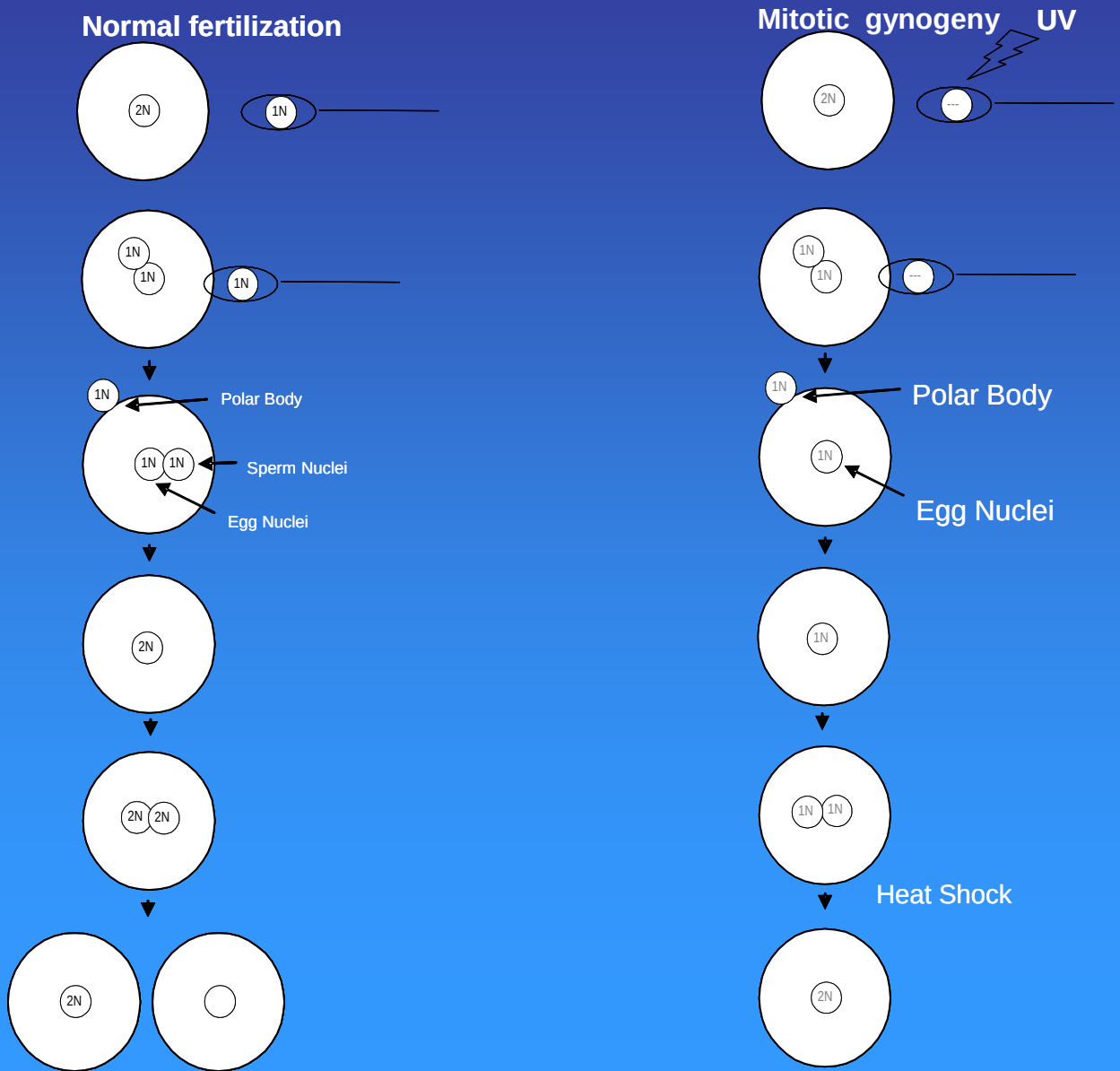




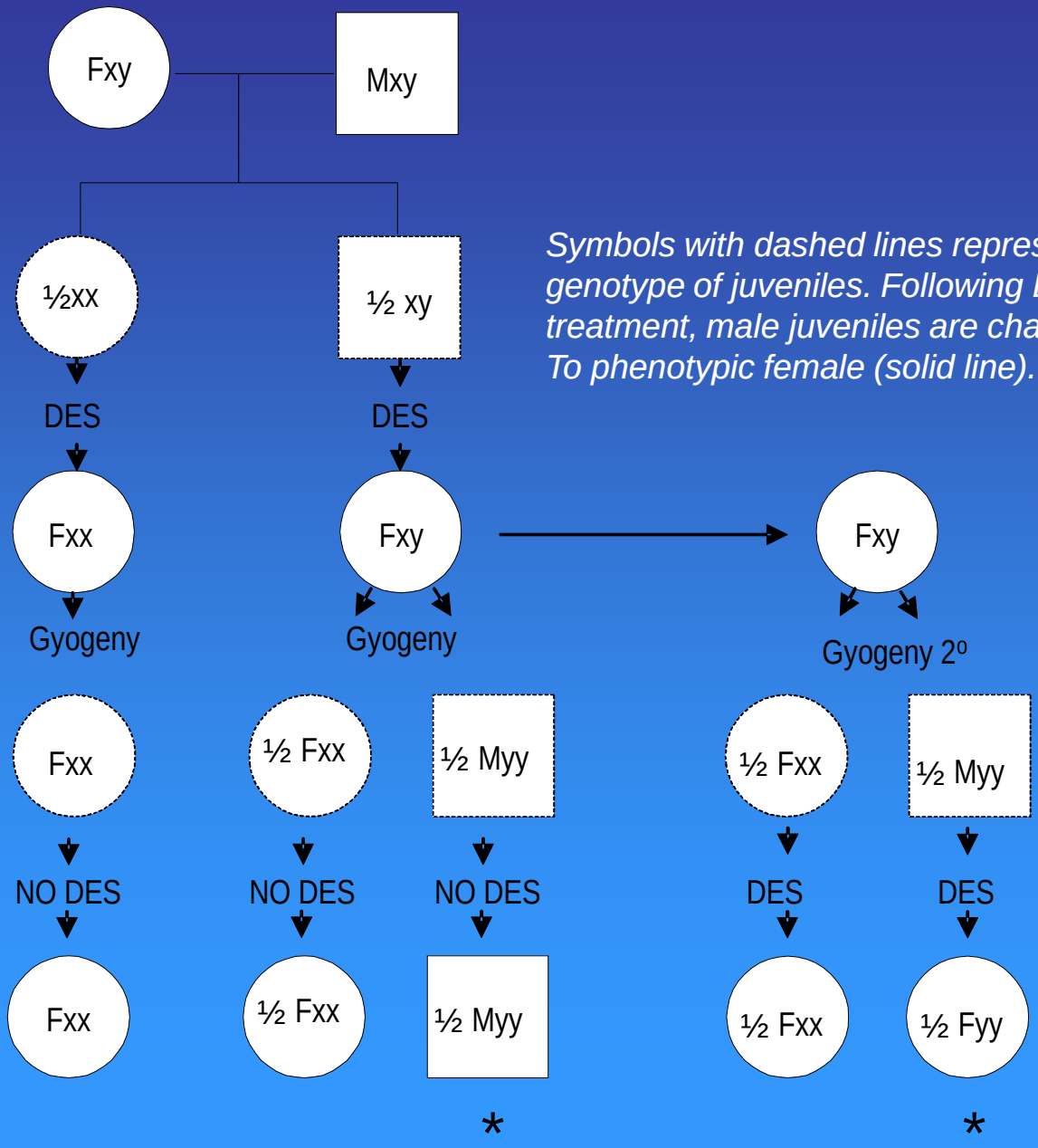
Fxx vs. t

Normal females go to extinction at μ =4 or greater

Myy produced by gynogeny using Fxy eggs



Strategy for production of YY Broodstock



Symbols with dashed lines represent genotype of juveniles. Following DES treatment, male juveniles are changed To phenotypic female (solid line).