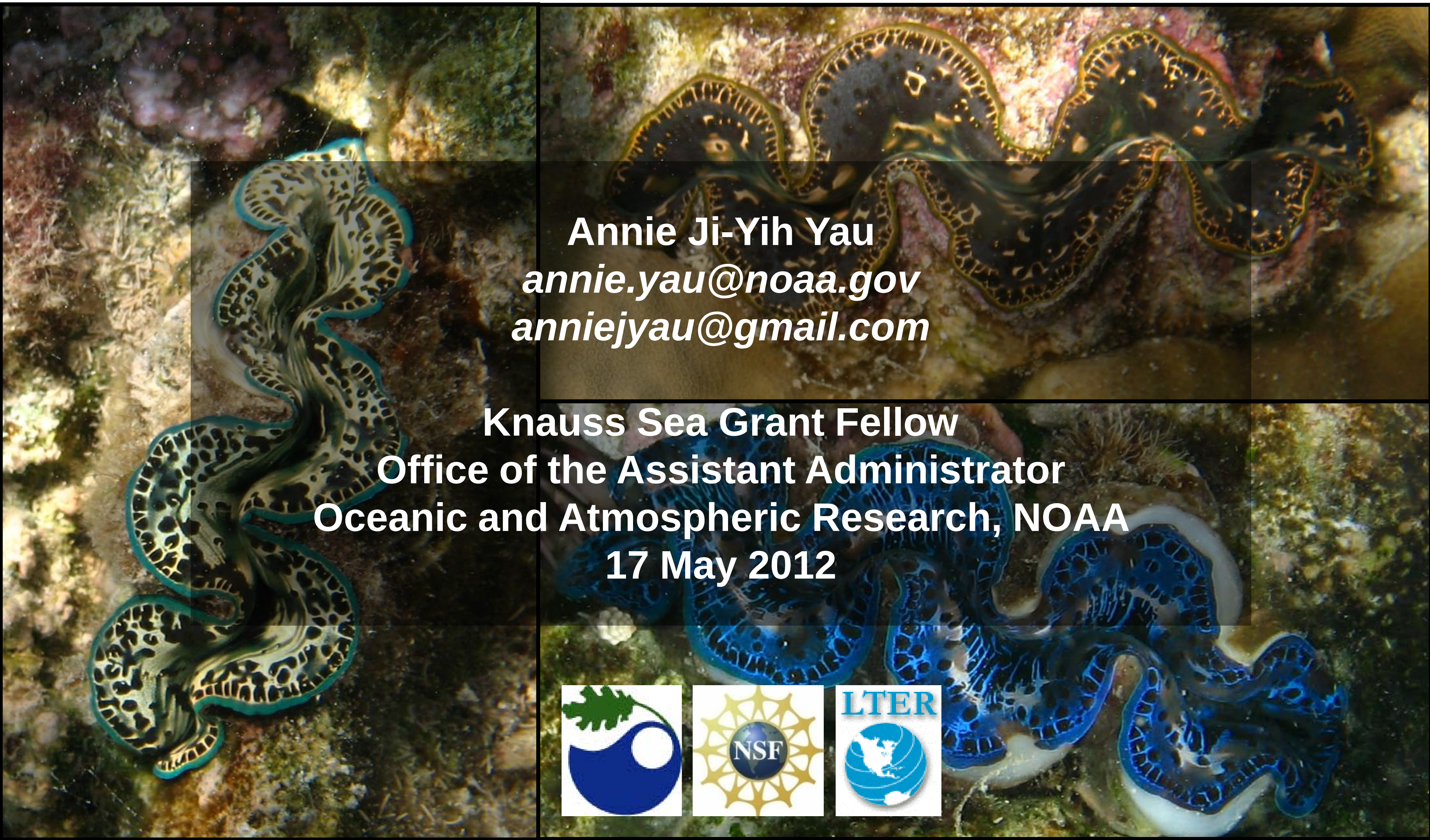
Managing & Modeling Fisheries at Small Spatial Scales:
A Case Study Using Giant Clams



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Small-scale, artisanal fisheries

Lack of funding, institutions, personnel, central organization, biological information

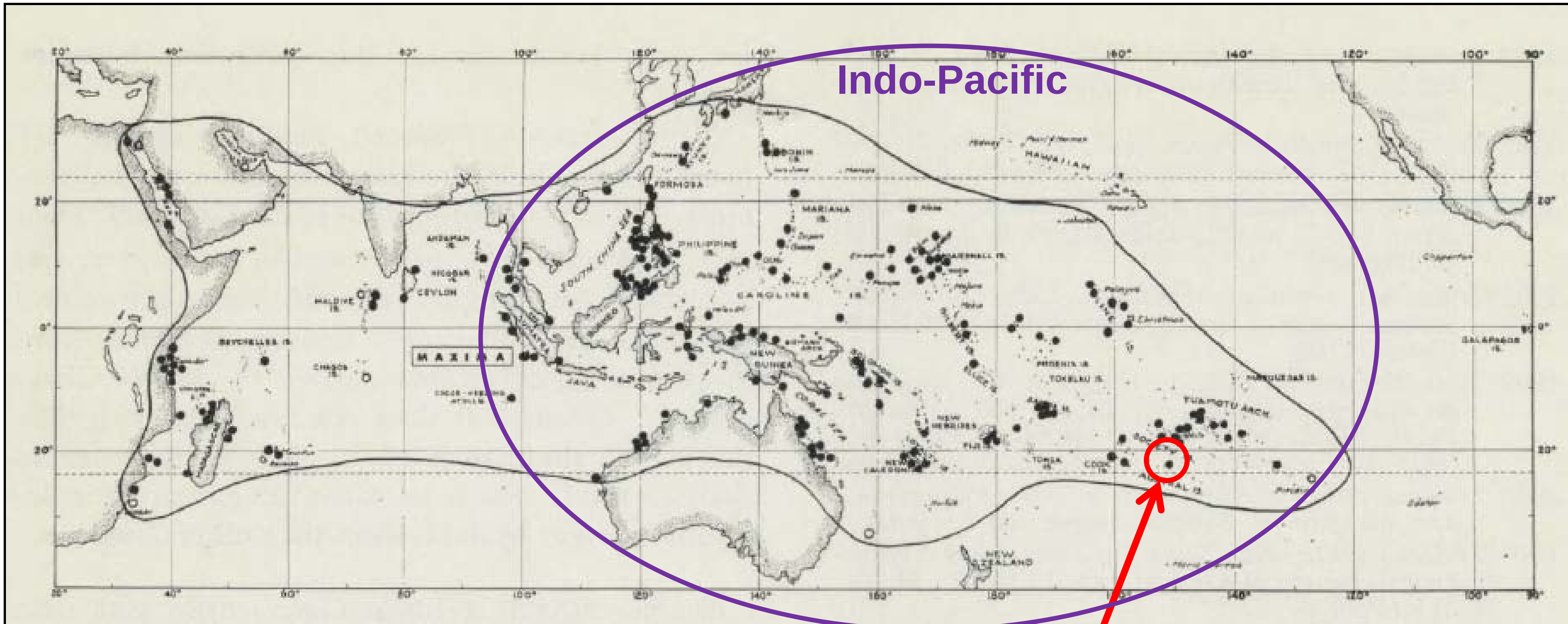
Small-scale in terms of:

- **Spatial scale of harvest**
- **Capital**
- **Technology and manpower**
- **Consumption and sale**

Giant clam fisheries

- Tropical/sub-tropical
- Sessile
- Hermaphrodites
- Pelagic larval duration ~7-11 days
- Form a symbiosis with photosynthesizing *Symbiodinium*

Giant clam fisheries exist throughout the Indo-Pacific



Range of *Tridacna maxima*, the small giant clam.

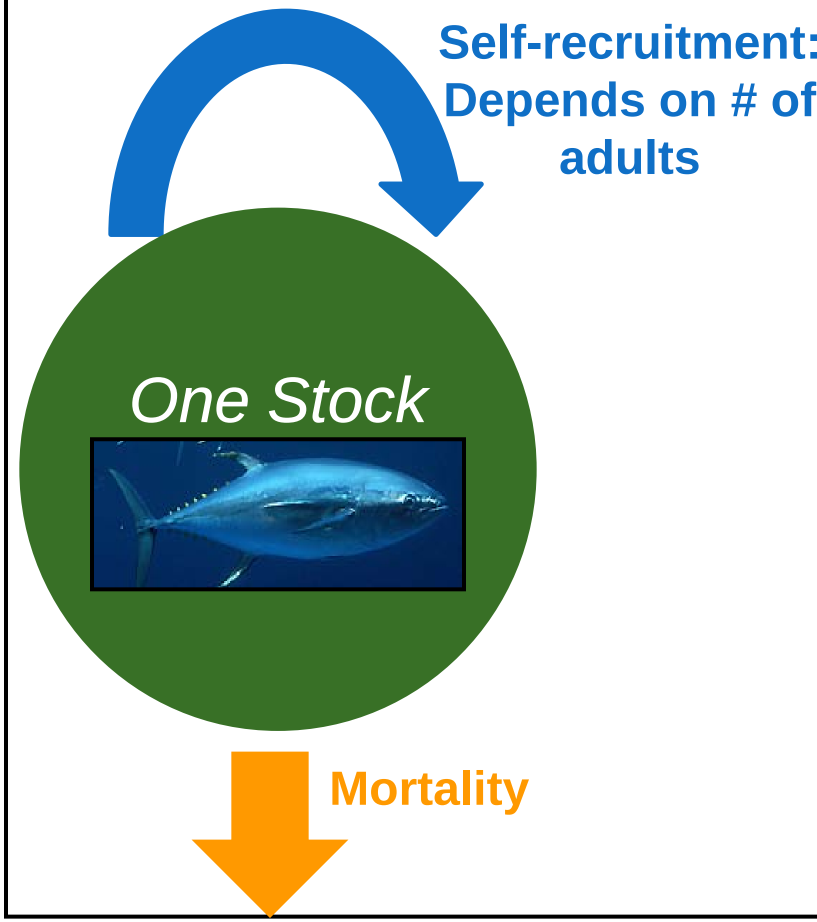
Managing at small-scales:

- Spatial scale of ~10s – 100s of km
- Island or reef scale
- A mix of self-recruitment and external recruitment

Recruitment is critical to managing fisheries

Recruitment: The addition of new individuals to a population

Conventional fisheries management often assumes a single stock, 100% self-recruitment



Small-scale artisanal fisheries: <100% self-recruitment.

- Only self-recruitment depends on the # of adults

Research Questions

Under uncertainty in the level of self-recruitment,

1. How do you model a population and its fishery, to determine trends in abundance?

2. How do you set a size limit that maximizes harvest while sustaining population abundance?

Mo’orea, French Polynesia

Research Questions

Under uncertainty in the level of self-recruitment,

1. How do you model a population and its fishery, to determine trends in abundance?

   Approach:
   - Modify an Integral Projection Model to account for uncertainty in self-recruitment
   - Measure demographic data on giant clams and use it to create an IPM for giant clams

2. How do you set a size limit that maximizes harvest while sustaining population abundance?



Integral Projection Models
(and ways they are better than matrix models)

(Easterling et al. 2000, Ellner & Rees 2006)

- IPMs describe individuals as continuous in size (or age), instead of binning them into size (or age) classes
  - This eliminates the need to artificially define size classes, and eliminates size-specific sensitivities

- IPMs require less data than matrix models
  - IPMs use regression methods

- IPMs can be used to calculate all analyses used by managers from matrix models – e.g. population growth rate, sensitivity and elasticity analyses

General model of population at small spatial scales

(with a mix of self-recruitment and external recruitment)

$$Abundance_{t+1} = Growth\ Rate * Abundance_t + External\ Recruitment$$

Where *Growth Rate* combines survival (from natural and fishing sources of mortality), growth, and self-recruitment

Integral Projection Model modified to account for a mix of recruitment:

$$n(y,t+1) = \int_L^U (P(x,y) + F(x,y))n(x,t)dx + R(y,t+1)$$

METHODS: Gather data on demographic processes

Mark and recapture study: 99% recapture rate

- 12 sites, 44 permanent transects
- Surveyed Jun-Aug 2006-2010 (5 years)
- Clams tagged with unique 3-letter code
- n = 1,949 clams surveyed
- 2,340 m^2 covered

~4000 hours or 168 days underwater

growth

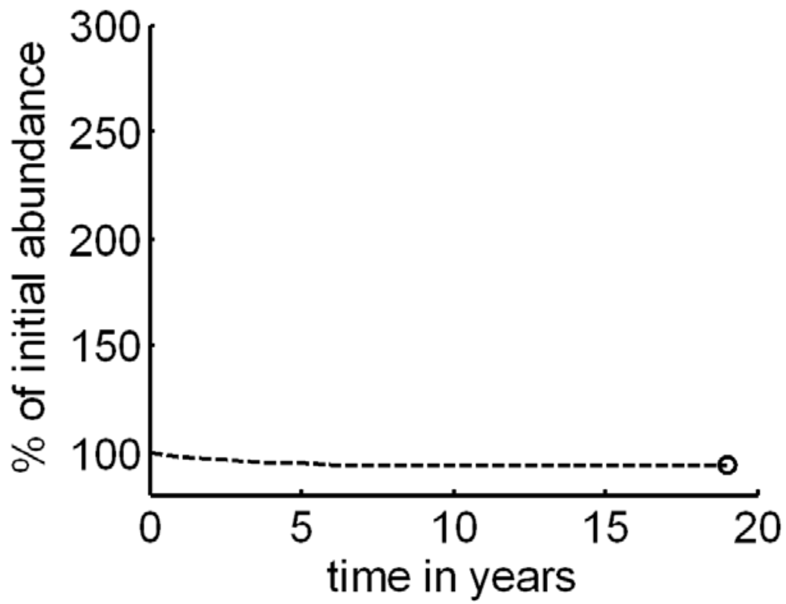
survival:
includes fishing and natural mortality

fecundity

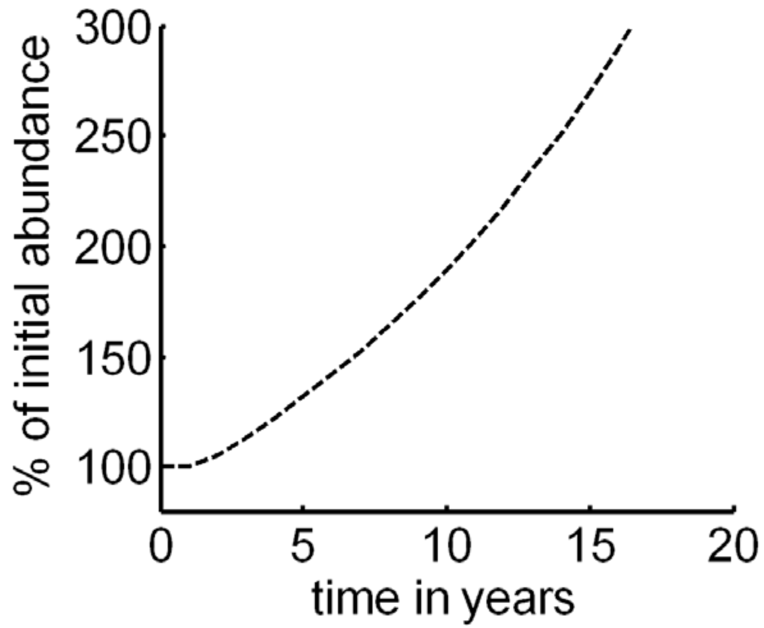
recruitment

RESULTS: Integral Projection Model

At 0% self-recruitment,
Equilibrium abundance = 93%
of present abundance



At 100% self-recruitment,
Exponential growth (rate = 1.07)



From 0% to 52.85% self-recruitment:	**Equilibrium abundance**
From 52.85% to 100% self-recruitment:	**Exponential growth**

Harvest of giant clams on Mo'orea is sustainable.
i.e. The population of giant clams can support the present-day fishing rate.

Research Questions

Under uncertainty in the level of self-recruitment,

1. How do you model a population and its fishery, to determine trends in abundance?

2. How do you set a size limit that maximizes harvest while sustaining population abundance?

   Approach:

   - Simulate future harvest of giant clams for a range of minimum size limits across the range of possible self-recruitment



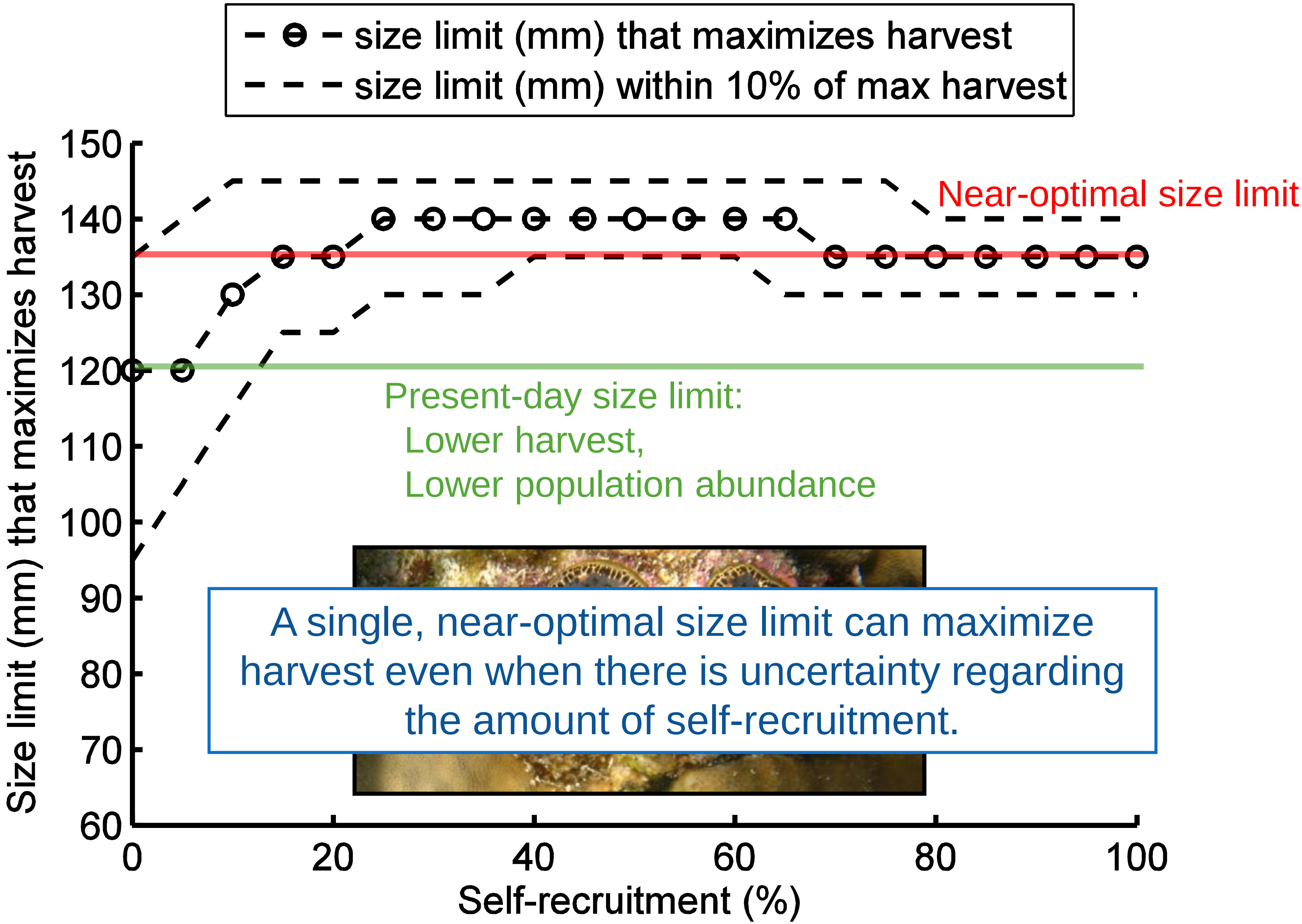
METHODS: Simulate future harvest

$$Abundance_{t+1} = Growth\ Rate * Abundance_t + External\ Recruitment$$

- For all combinations of:
  - Self-recruitment from 0-100% of total recruitment, in 5% increments
  - Minimum size limits from 60-180 mm, in 5 mm increments
- Simulate the harvest of 50% of the legal-sized clams each year, stopping the simulations at year 30
- Calculate biomass of harvest and population abundance at year 30

RESULTS: Annual harvest at year 30

RESULTS: A near-optimal size limit



RESULTS: Near-optimal size limits can be set for many different life histories

Life history characteristic	Values tested	Near-optimal size limit (mm)
asymptotic size	121.4 mm, 60.7 % of max size	N/A
	161.9 mm, 80.9 % of max size	135
	178.1 mm, 89.0 % of max size	150
time to asymptotic size	10 years	160
	38 years	135
	50 years	130
asymptotic size and time to asymptotic size[‡]	121.4 mm, 60.7 % of max size, 28 years	115
	161.9 mm, 80.9 % of max size, 38 years	135
	178.1 mm, 89.0 % of max size, 42 years	145
magnitude of variation in growth	51.3 mm	135
	68.5 mm	135
	85.6 mm	140
minimum reproductive size	33.1 mm, 16.5 % of max size	115
	66.1 mm, 33.1 % of max size	135
	99.2 mm, 49.6 % of max size	N/A
fecundity at asymptotic size	3.0 self-recruits	140
	4.0 self-recruits	135
	5.0 self-recruits	135
survival rate at asymptotic size	66.7 %	N/A
	88.6 %	135
	96.9 %	140

[‡]asymptotic size changed, time to asymptotic size re-calculated accordingly

CONCLUSIONS

- The population of giant clams on Mo'orea can support the present-day level of fishing mortality,
  - The population would decline by 7% in the worst case scenario (if the population has 0% self-recruitment).

- A single, near-optimal size limit will maximize (or nearly maximize) annual harvest of giant clams on Mo'orea across all levels of self-recruitment.

- This near-optimal size limit is 135 mm, which is larger than the current minimum size limit of 120 mm.

- A near-optimal size limit can be applied to organisms with a wide variety of life history characteristics under uncertainty in the level of self-recruitment at small spatial scales.

Policy Implications

- Integral Projection Models are a good alternative to matrix population models
  - Require less data to parameterize
  - Eliminate model sensitivities to size classes, and arbitrary size classes
  - Provide the same outputs and analyses as matrix models

- Even though we don’t know how much self-recruitment is occurring at a small spatial scale, we can still:
  - Model populations (using IPMs)
  - Set a single minimize size limit to maximize (or nearly maximize) harvest

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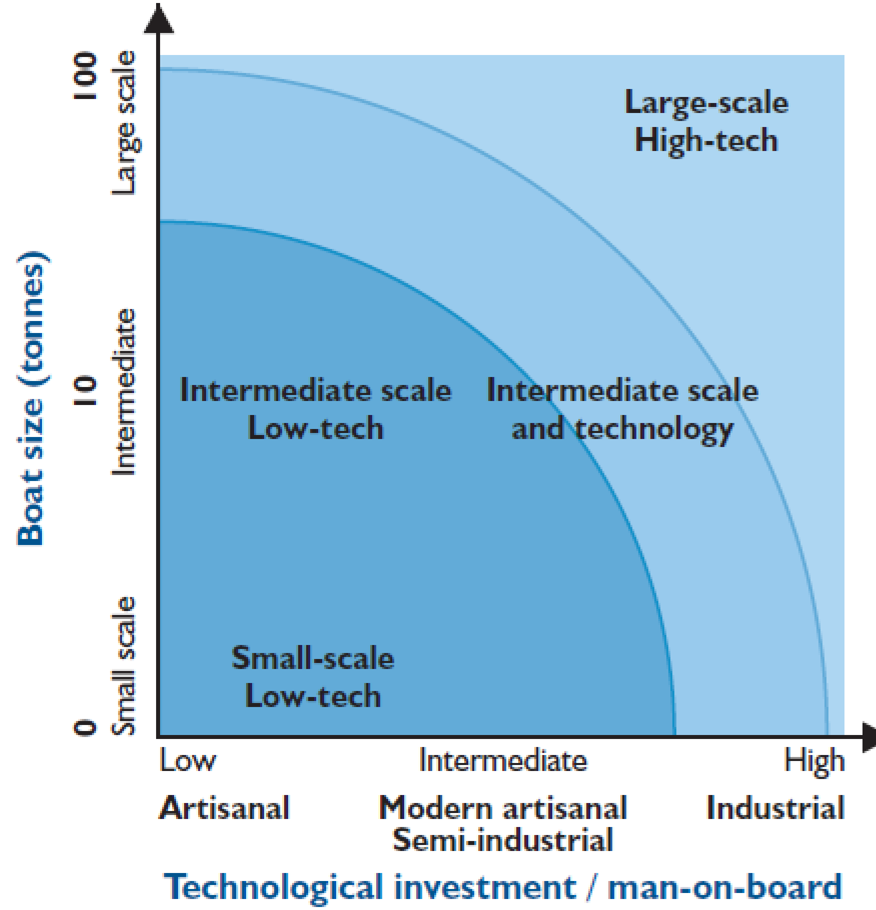
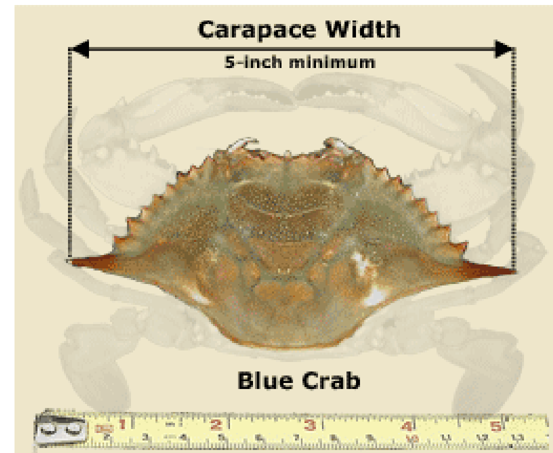


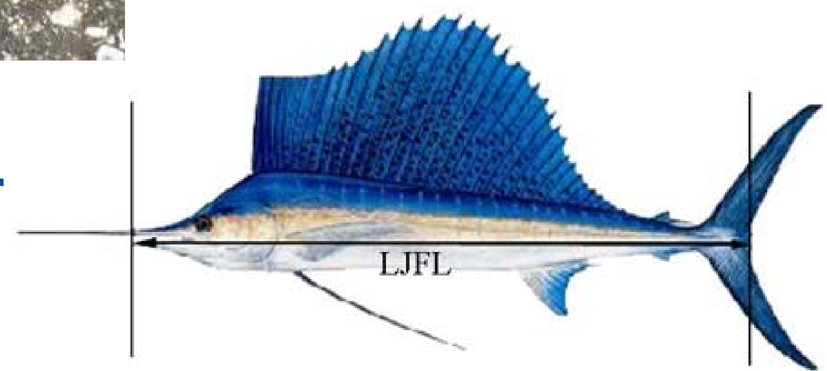
Unusually high densities in Tatakoto (Photo Y. Chancerelle) (Gilbert et al 2006)

Minimum size limits & giant clam fisheries

- Sets a minimum size for harvest
- A commonly used fisheries management tool
- Designed to allow individuals to reproduce before being harvested
- Result in sustainable fisheries when the limit is set correctly!



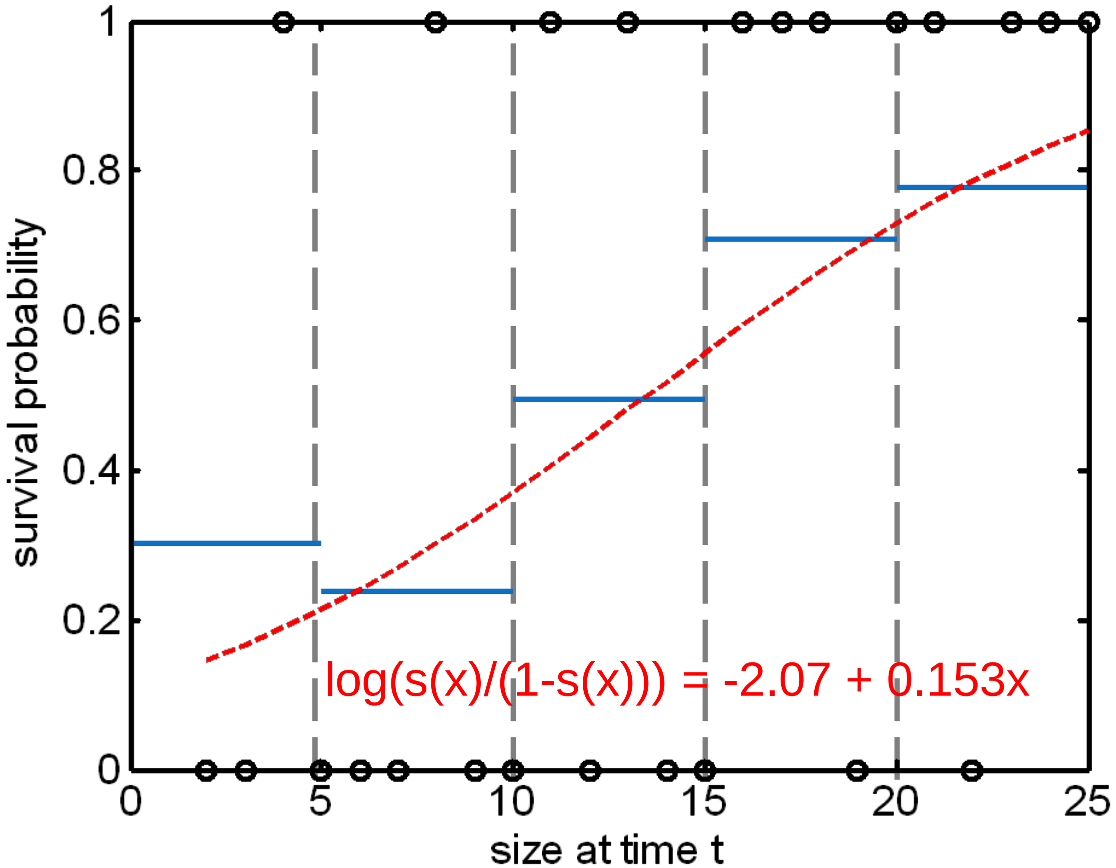
How do you set a size limit under self-recruitment uncertainty?



Integral Projection Models
(and ways they're better than matrix models)

(Easterling et al. 2000, Ellner & Rees 2006)

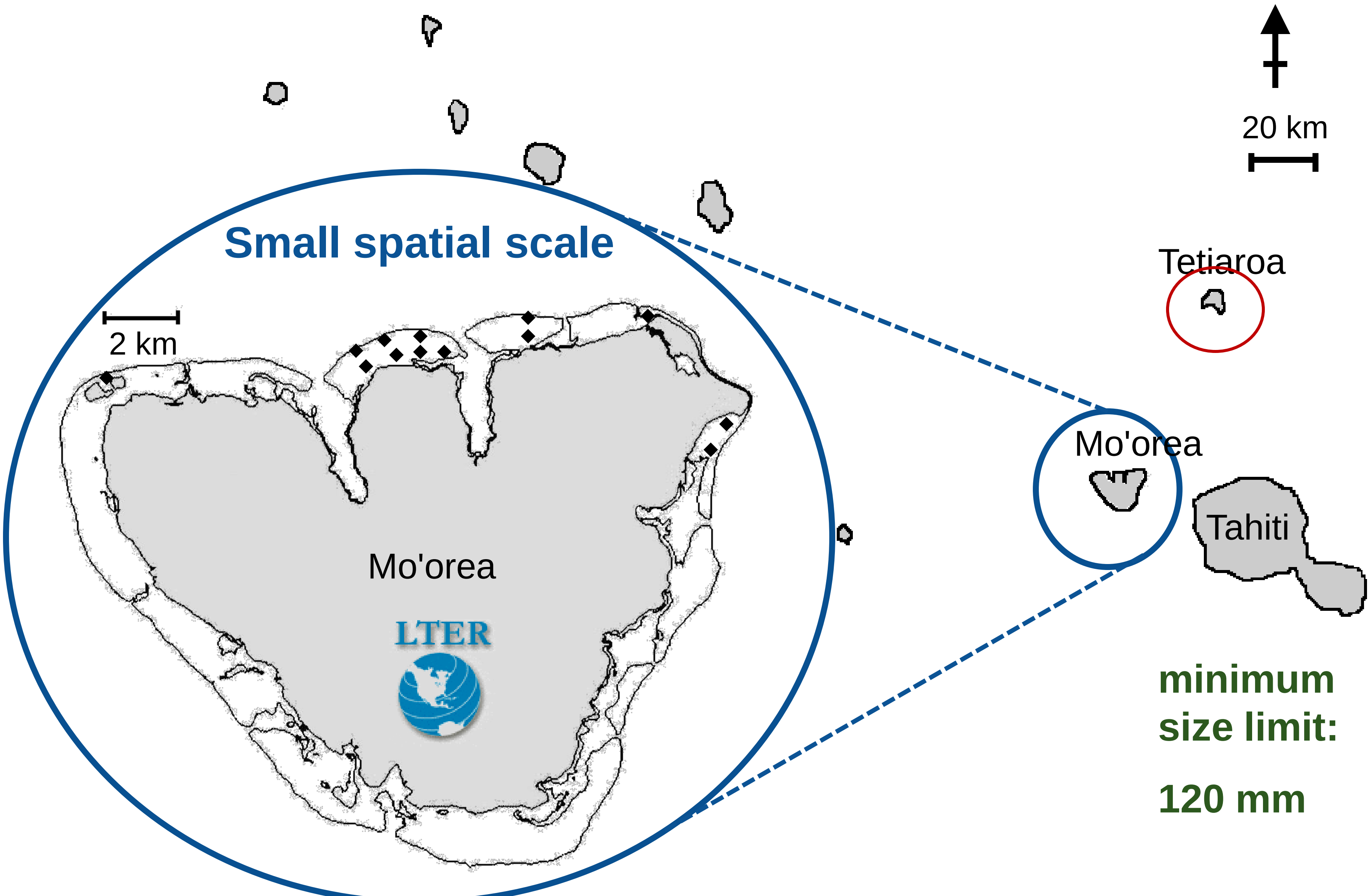
- IPMs require less data to parameterize



Matrix model:
1 parameter for
each size class

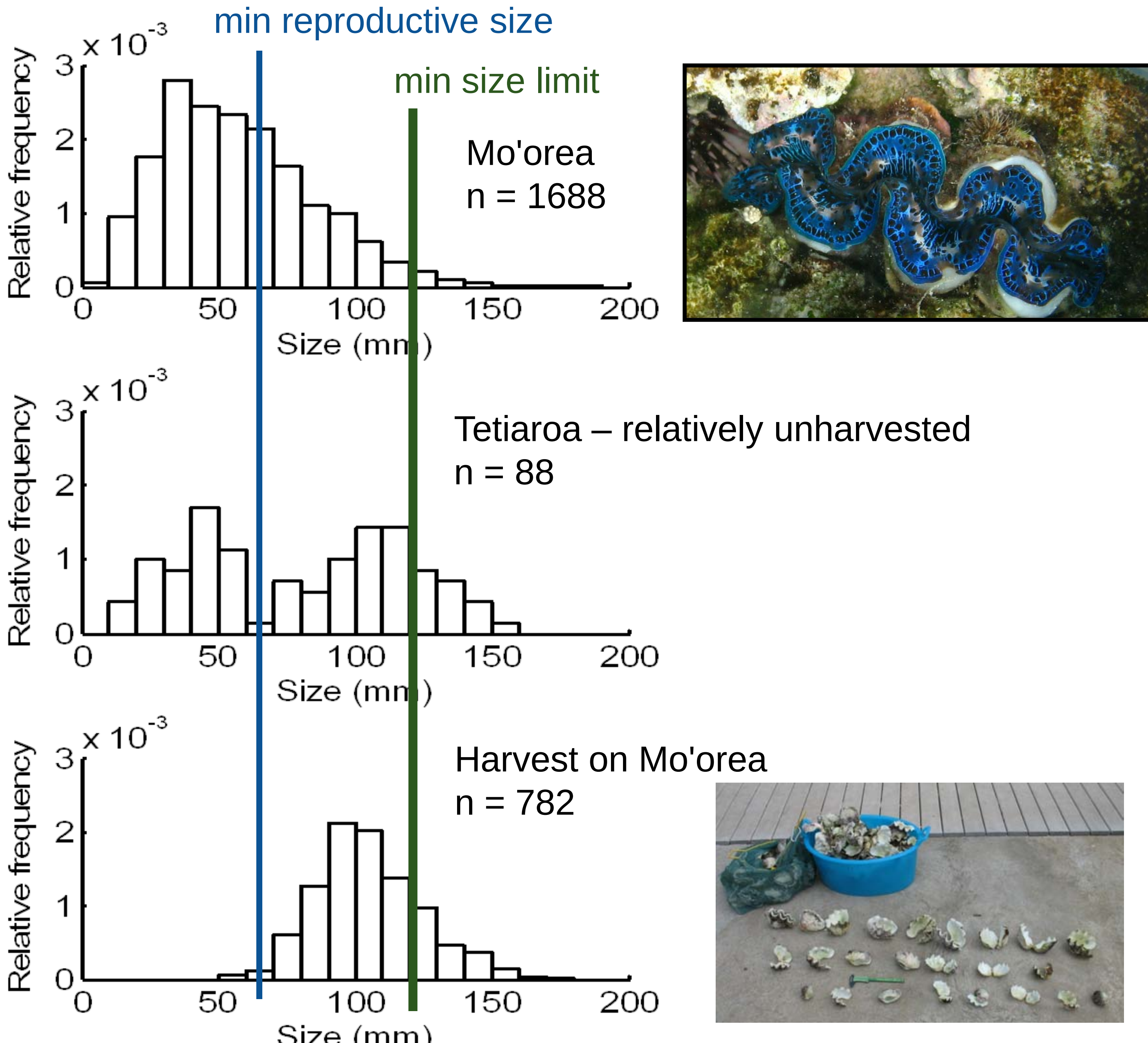
IPM:
2 parameters,
no size classes,
N = 24

Mo'orea, Society Islands, French Polynesia

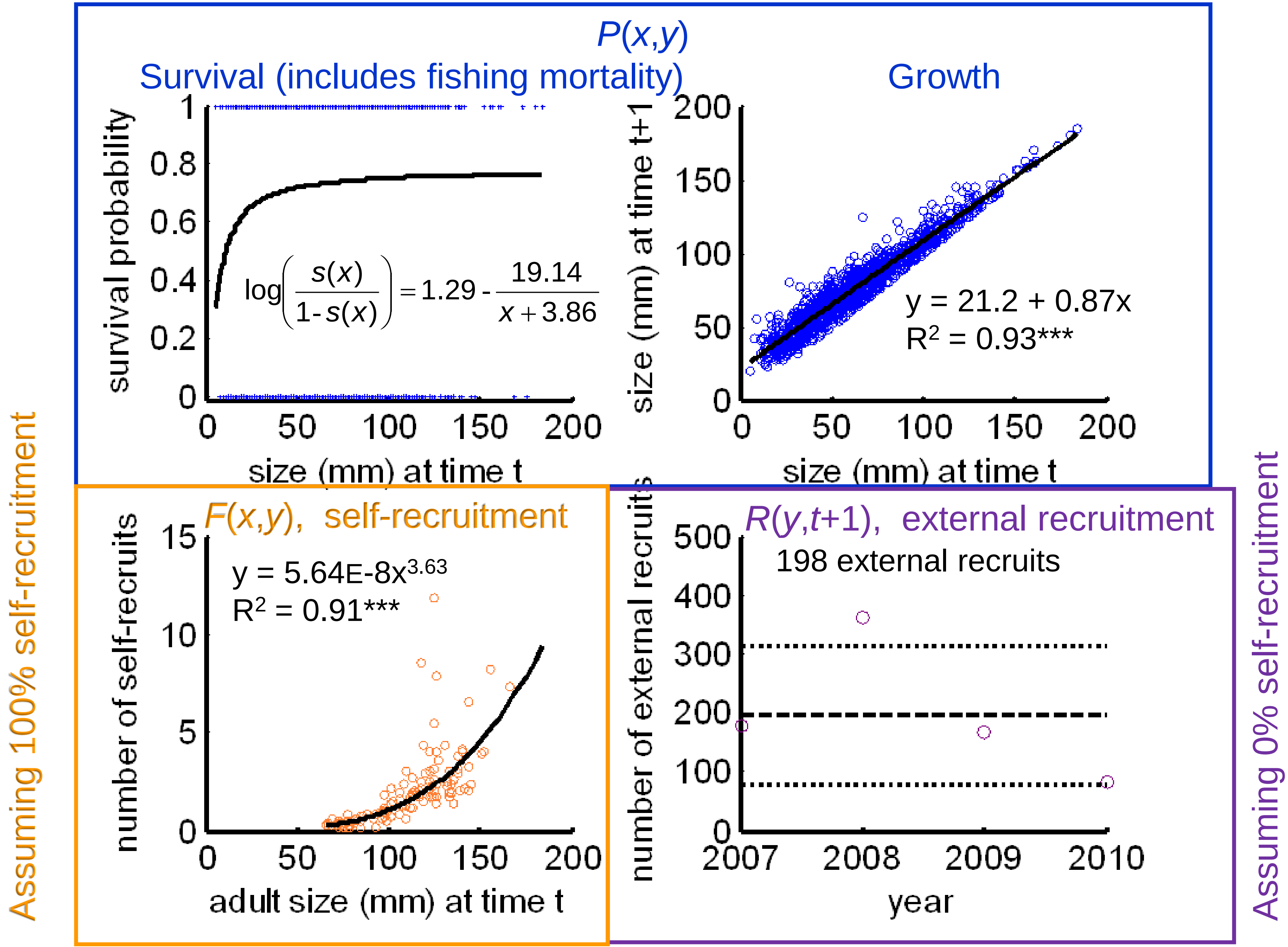


minimum size limit:

120 mm

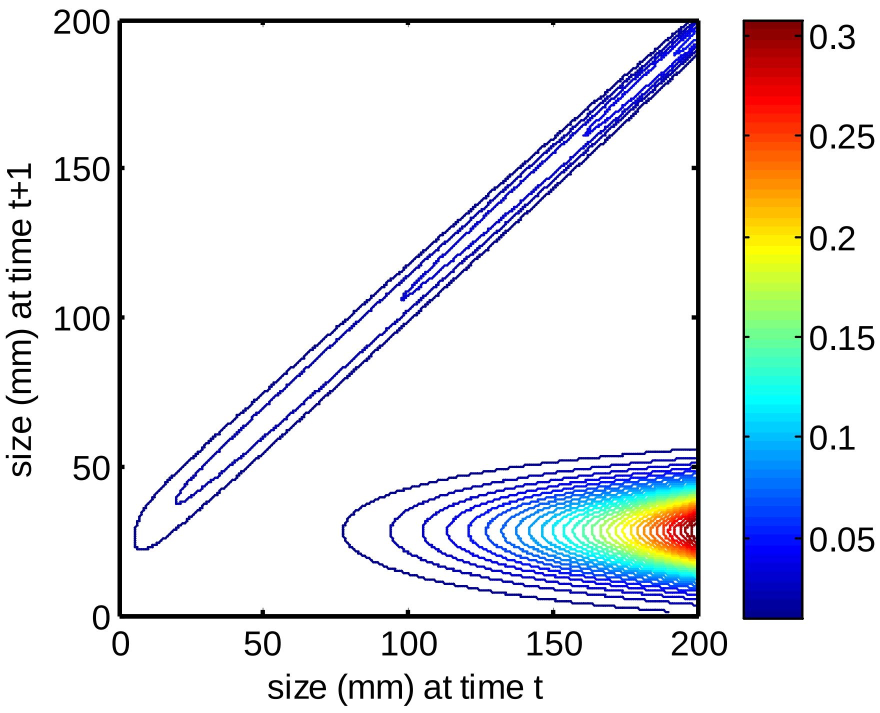

min reproductive size
min size limit
Mo'orea
n = 1688
Tetiaroa – relatively unharvested
n = 88
Harvest on Mo'orea
n = 782
Relative frequency
x 10^-3
Size (mm)
0
1
2
3
0
50
100
150
200

RESULTS: Size-dependent functions for giant clam IPM

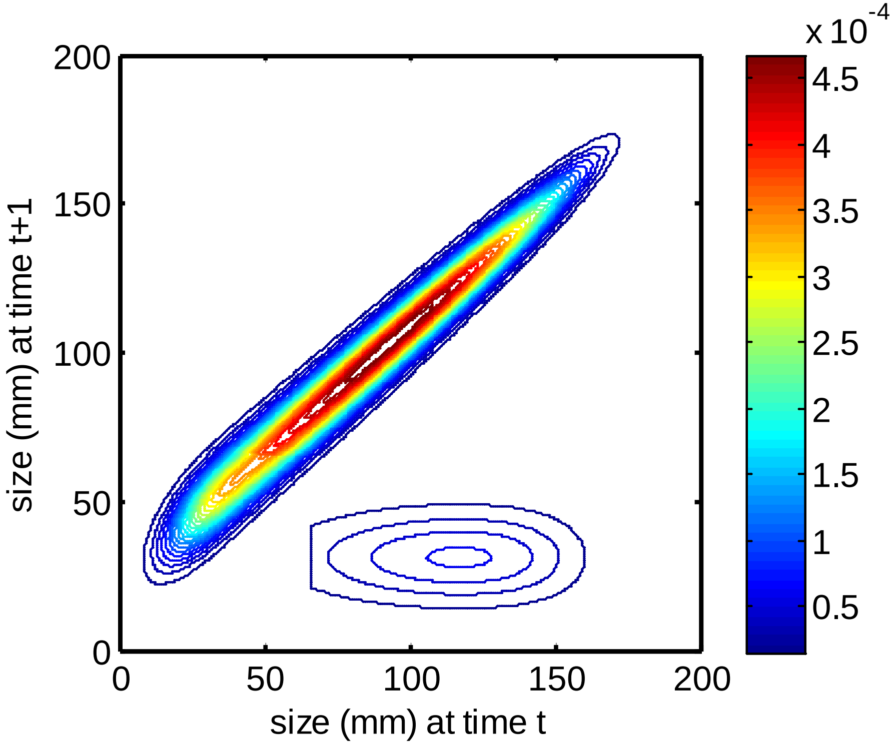


RESULTS: Transitions & Elasticities

Transition values: likelihood of transition from one size to another



Elasticities: Proportional changes in the population growth rate for a given change in a transition value



Model the extremes of self-recruitment for a local population

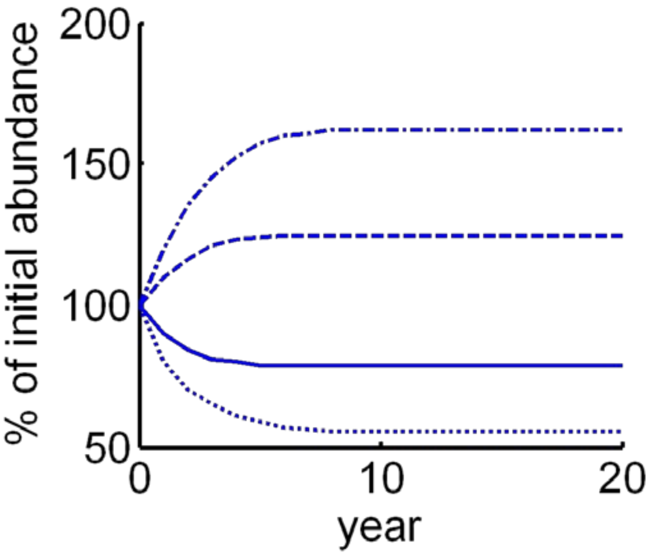
$$n(y,t+1) = \int_{L}^{U} \underbrace{(P(x,y)+F(x,y))}_{\lambda} n(x,t)\,dx + R(y,t+1)$$

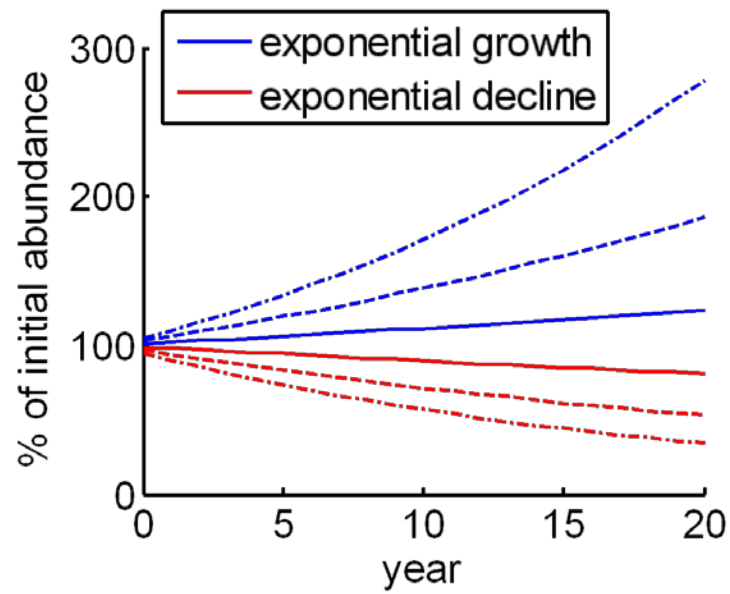
open | closed

0% **self-recruitment / total recruitment** **100%**

Equilibrium abundance
(remains constant through time)

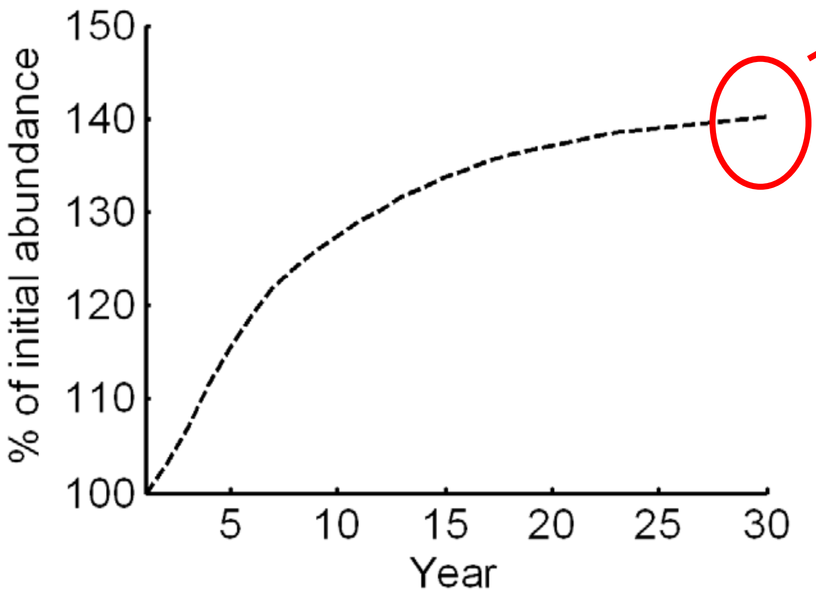
Exponential growth or decline
(from low initial abundance)



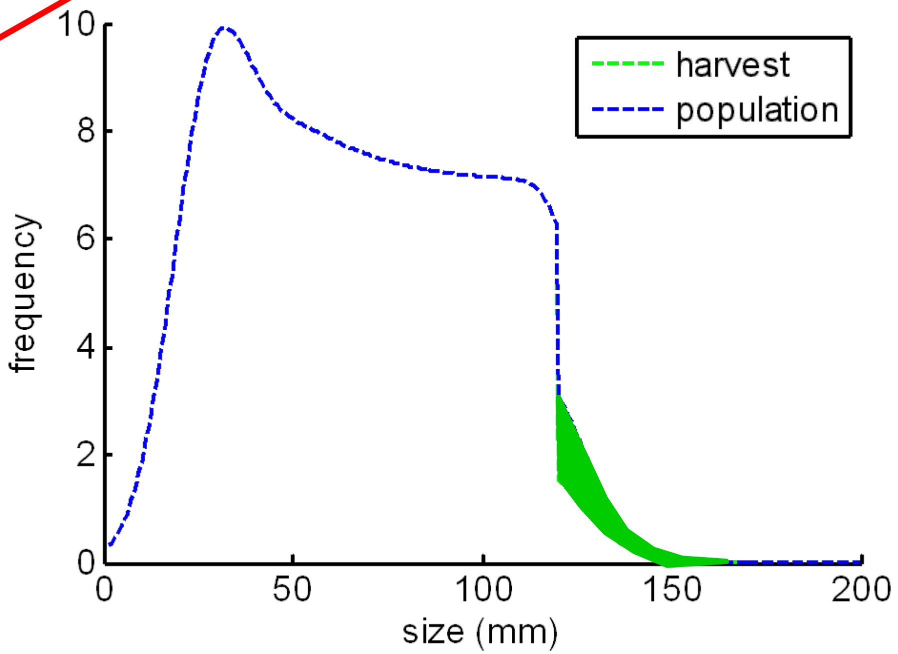


METHODS: Simulate annual harvest

Sample simulation:
20% self-recruitment, 120 mm size limit
population abundance over time



size distribution at year 30



	Tested values	Optimum size limit (mm)	Range of self-recruitment where setting optimum size limit results in harvest within 10% of max harvest	Maximum annual harvest (g)†	Maximum potential loss of harvest*
	25%	135	25 – 100 %	3,205	30.8 %
Current annual fishing mortality	**50%**	**135**	**0 – 100 %**	**15,151**	**8.7 %**
	75%	140	0 – 100 %	77,938	3.0 %
	25%	130	5 – 100 %	22,317	12.1 %
Future annual fishing mortality	**50%**	**135**	**0 – 100 %**	**15,151**	**8.7 %**
	75%	140	5 – 100 %	7,577	12.2 %
	20 years	130	0 – 100 %	3,965	3.9 %
Time horizon	**30 years**	**135**	**0 – 100 %**	**15,151**	**8.7 %**
	50 years	145	5 – 100 %	298,388	23.9 %

†occurs at 100% self-recruitment

*generally occurs at 0% self-recruitment