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

Small-scale, artisanal fisheries

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

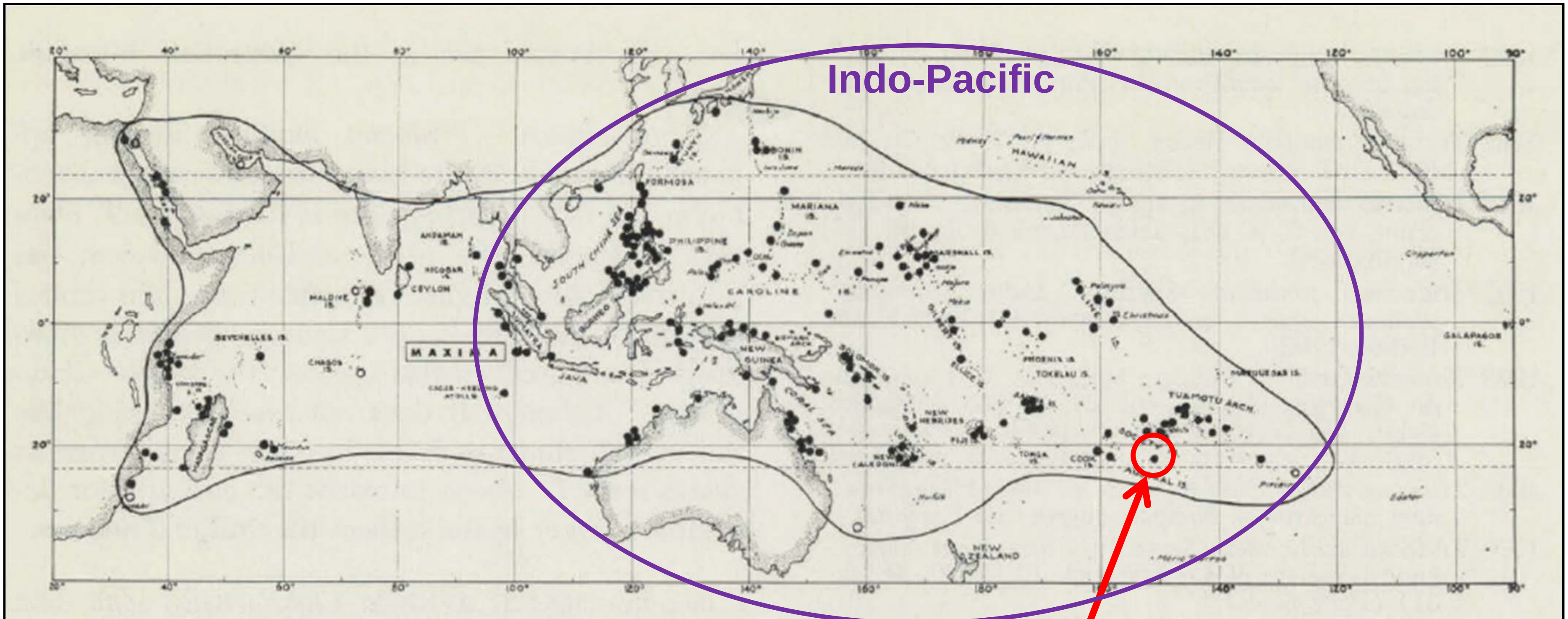
Small-scale in terms of:

- **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

Research Questions

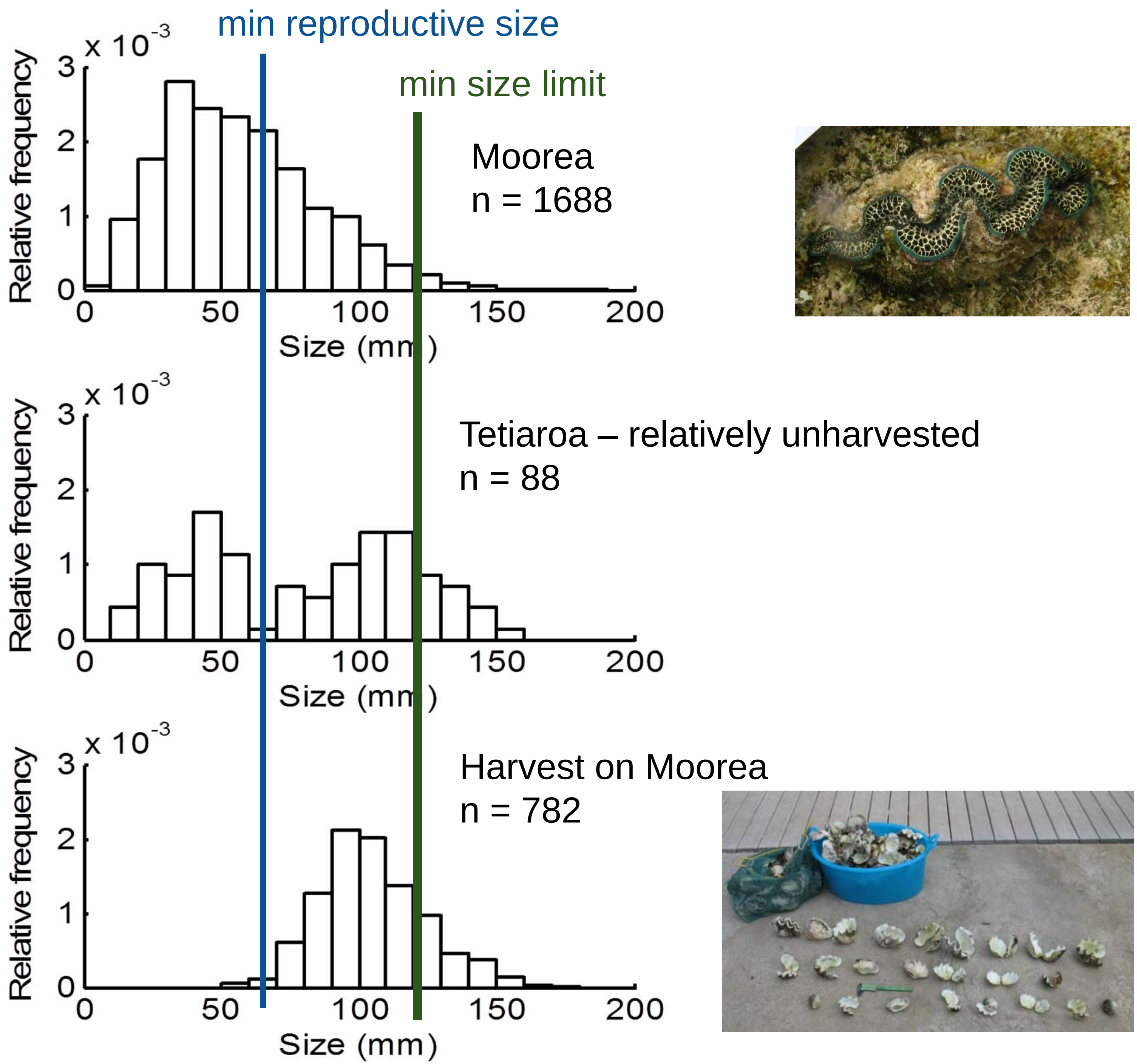
Under uncertainty in the level of self-recruitment,

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


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

Research Questions

Under uncertainty in the level of self-recruitment,

1. How do you model a population and its fishery?
   Approach:
   - Modify an Integral Projection to model local population abundance
   - Measure demographic data on growth, survival, recruitment, & reproduction
   - Use this data 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 why they're 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 size-specific sensitivities
- IPMs require less data to parameterize than matrix models
- All analyses that managers use from matrix models can be performed with IPMs

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, 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

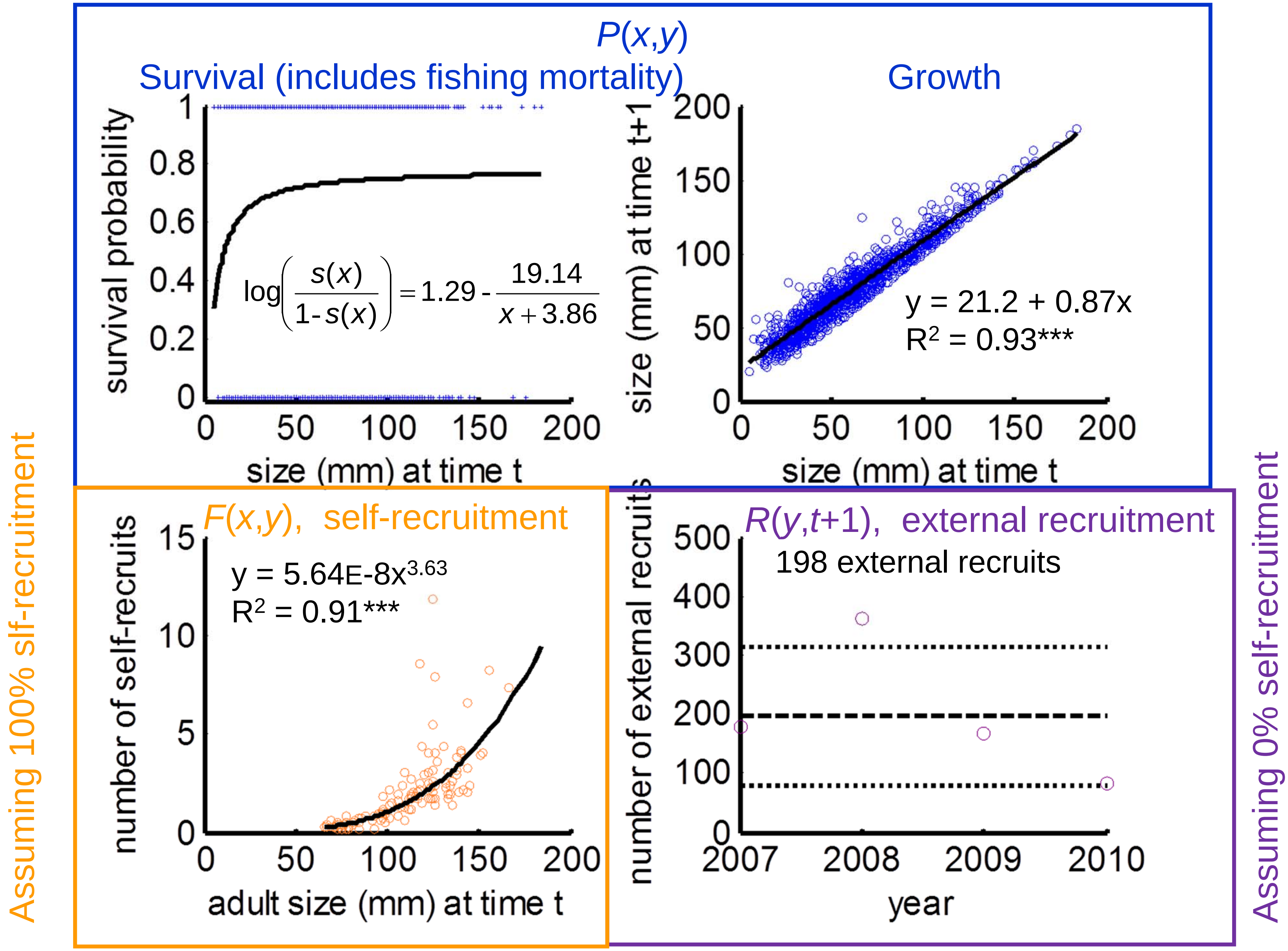
growth

survival:
includes fishing and natural mortality

fecundity

recruitment

RESULTS: Size-dependent functions for giant clam IPM

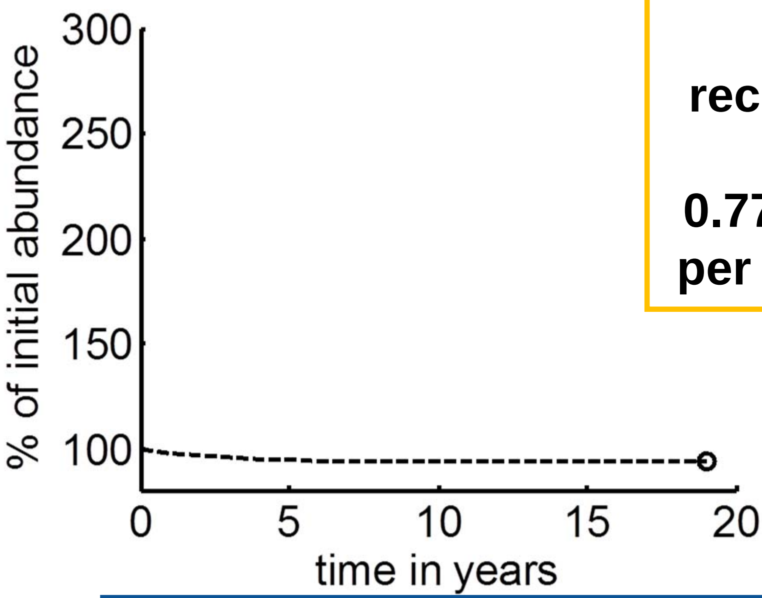


RESULTS: Integral Projection Model

open | closed

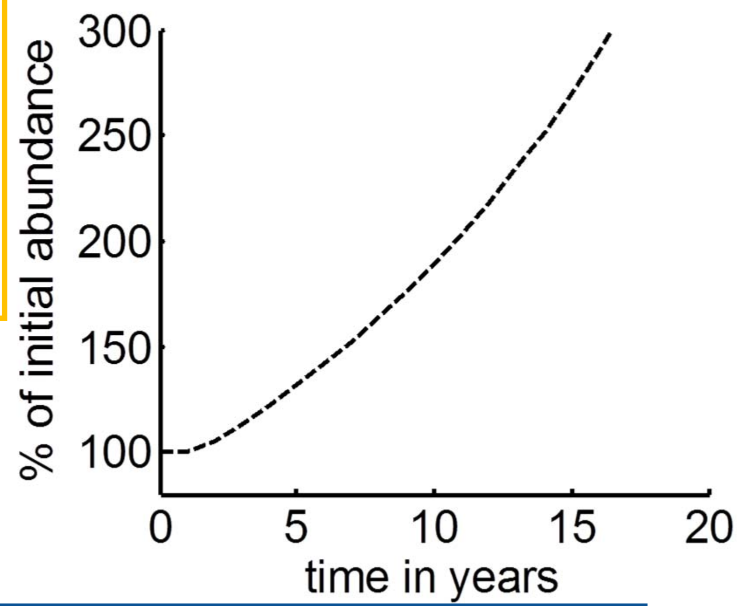
0% | self-recruitment / total recruitment | 100%

Equilibrium abundance = 93% of present abundance



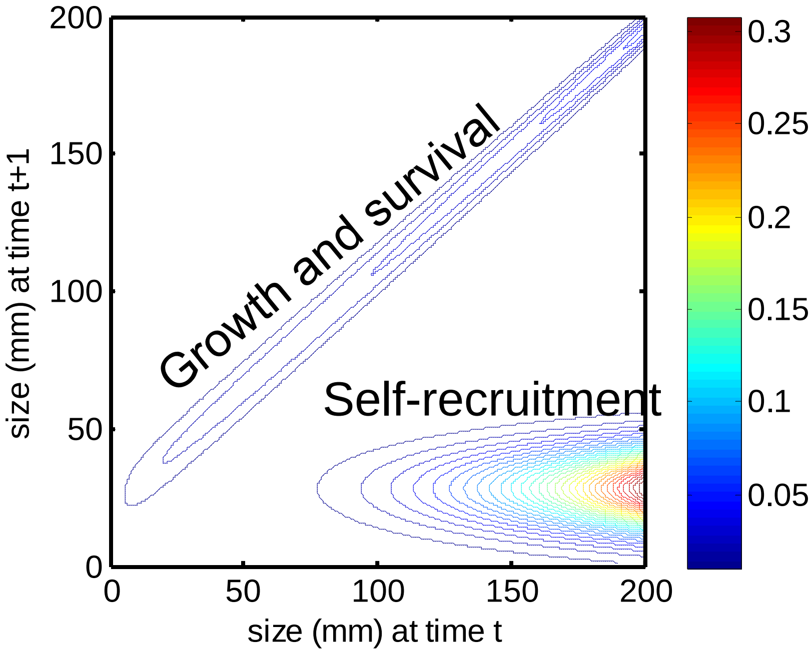
Transition point: 52.85% of the present recruitment level, *OR* 0.775 self-recruits per g of dry gonad

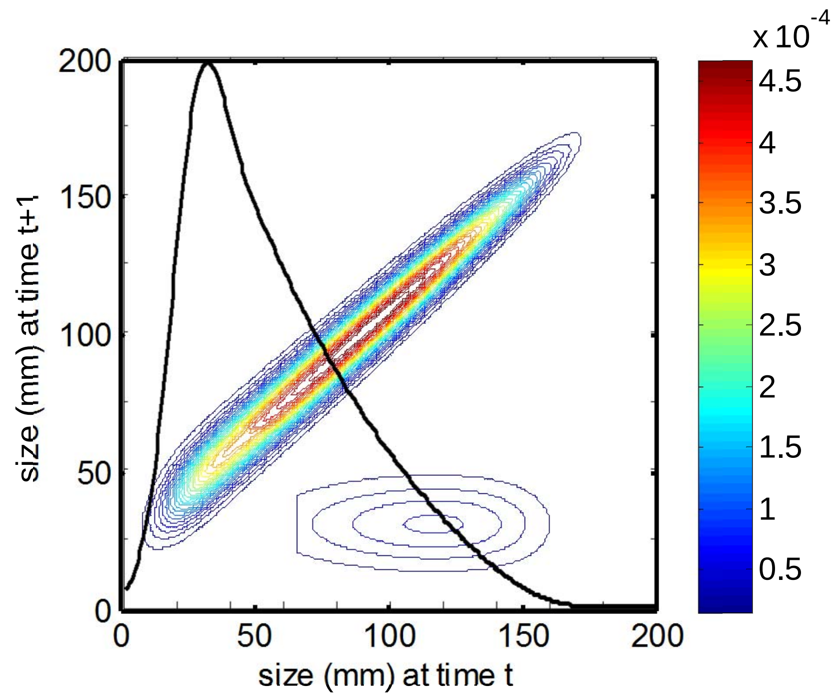
Exponential growth (rate = 1.07)



Harvest of giant clams on Moorea is sustainable.
i.e. The local population of giant clams can support the total measured mortality rate.

RESULTS: Sensitivity and Elasticity





Size-Based Approaches to Modeling & Managing Local Populations

Under uncertainty in the level of self-recruitment,

1. How do you model a population and its fishery?

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: Partition recruits in mixed recruitment model

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

- Model a population from 0-100% self-recruitment in 5% increments

- Mixed recruitment example:

Assuming there are 100 recruits annually,

At 20% self-recruitment,

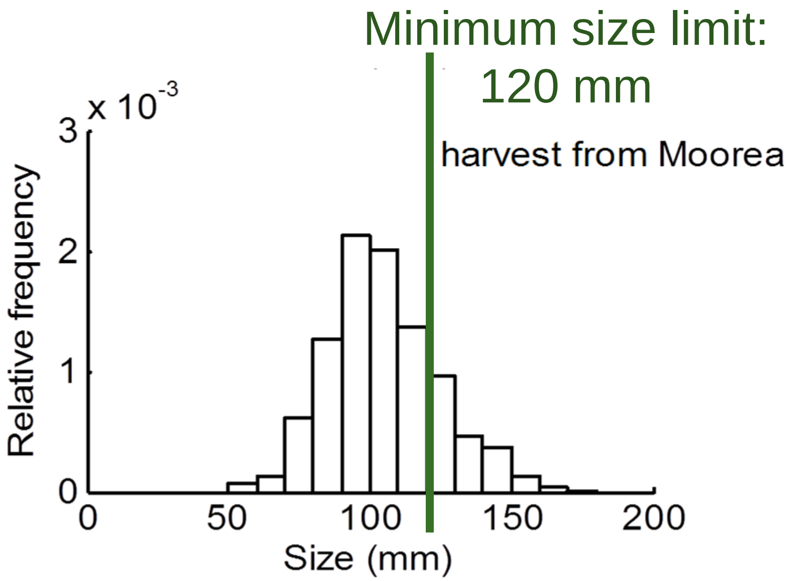
20 recruits are self-recruits: $F(x,y)$

and

80 recruits are external recruits: $R(y, t+1)$

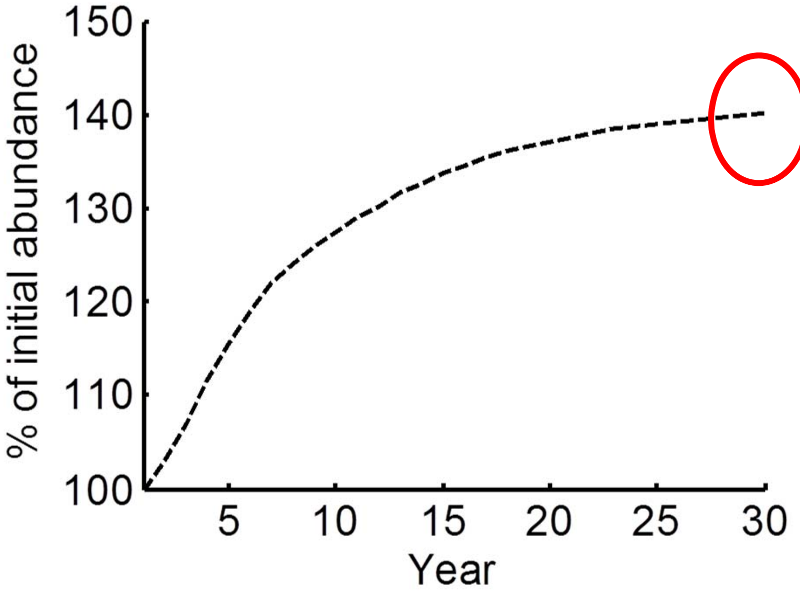
METHODS: Evaluate a range of minimum size limits

- Evaluate minimum size limits from 60-180 mm in 5 mm increments
- Assume enforcement of a given size limit
- For each combination of self-recruitment and size limit,
  - Run simulations for 30 years
  - Harvest = Remove 50% of the legal-sized clams each year
  - Calculate biomass of harvest at year 30

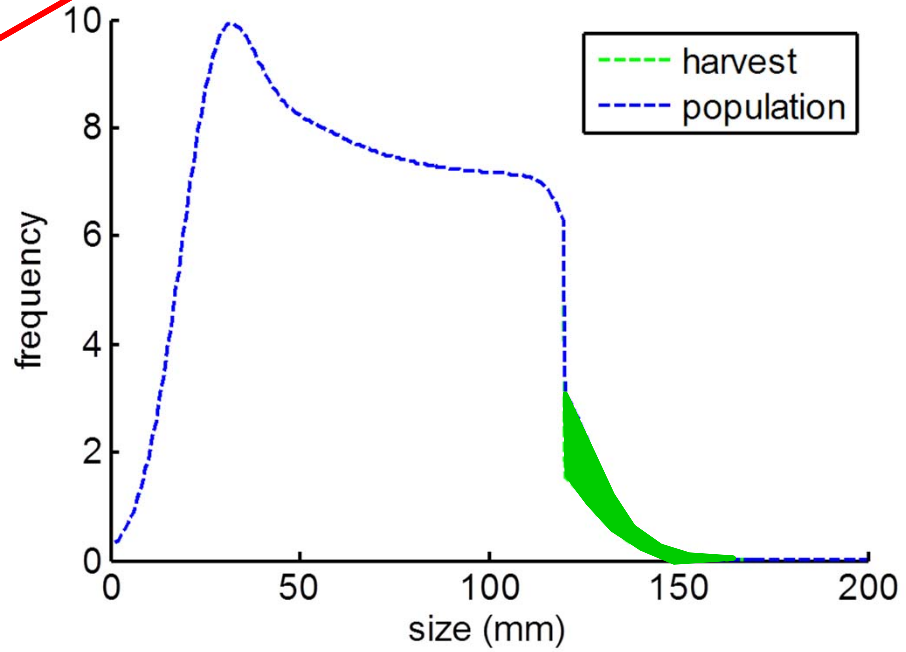


METHODS: Simulate annual harvest

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

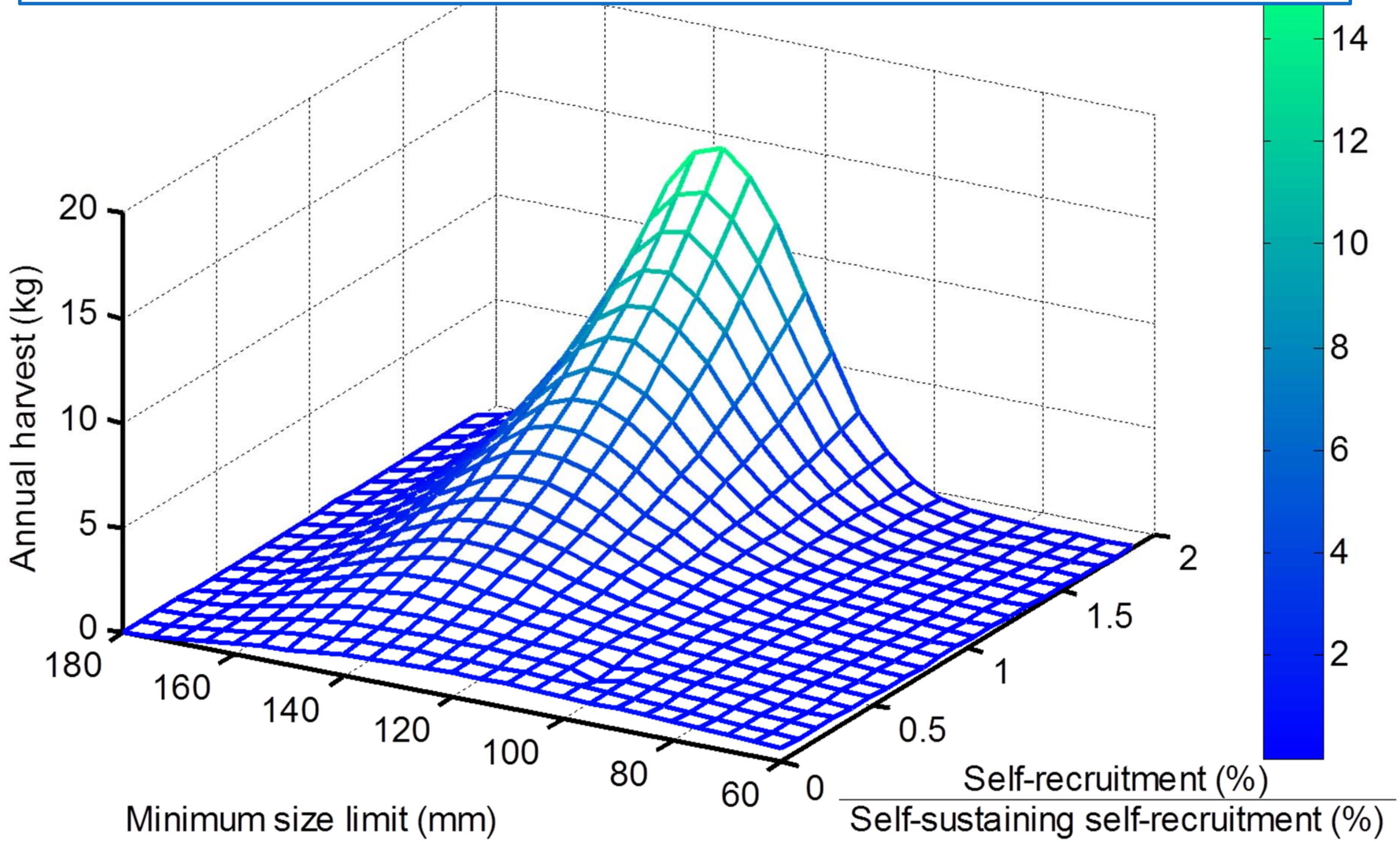


size distribution at year 30

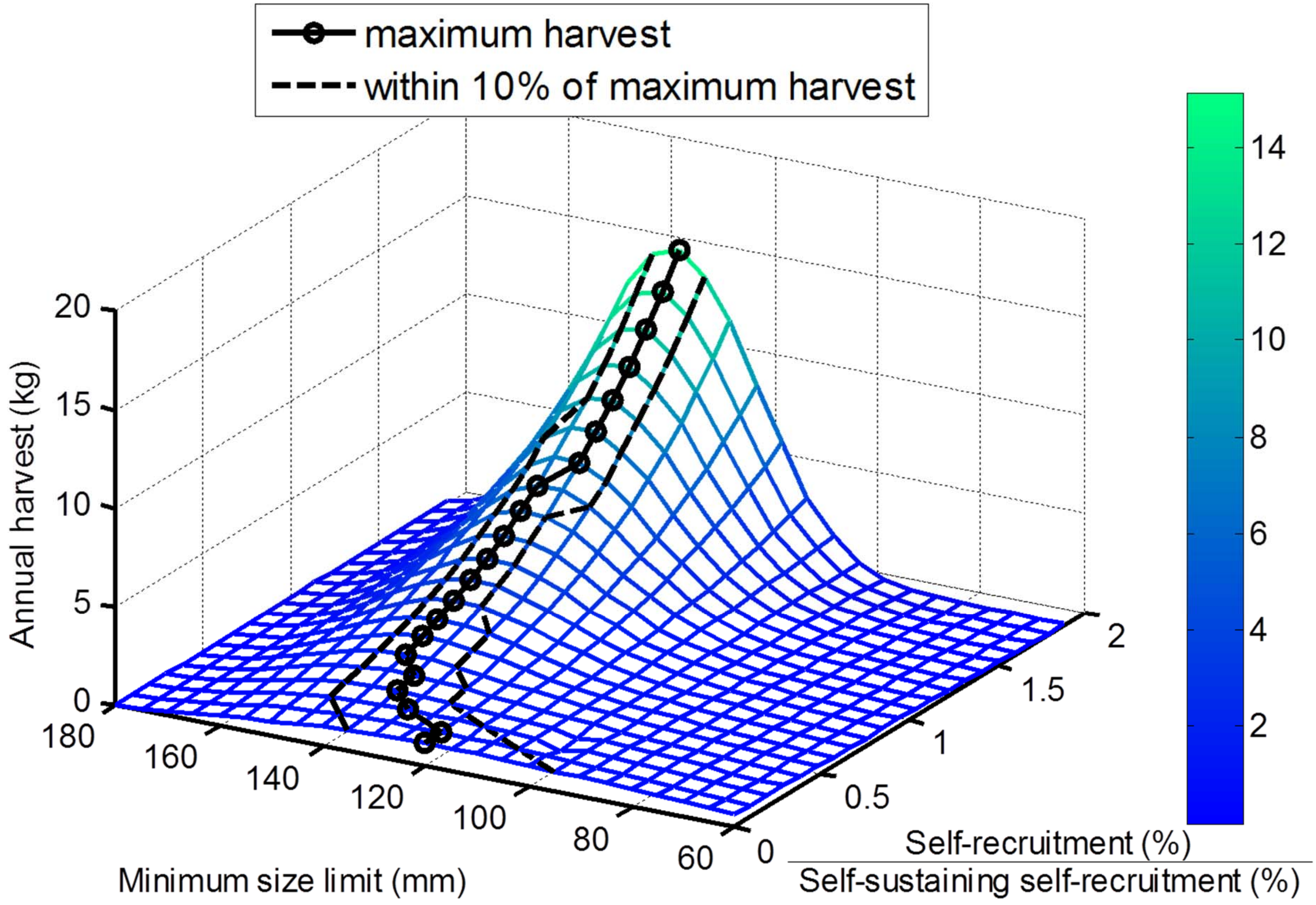


RESULTS: Annual harvest at year 30

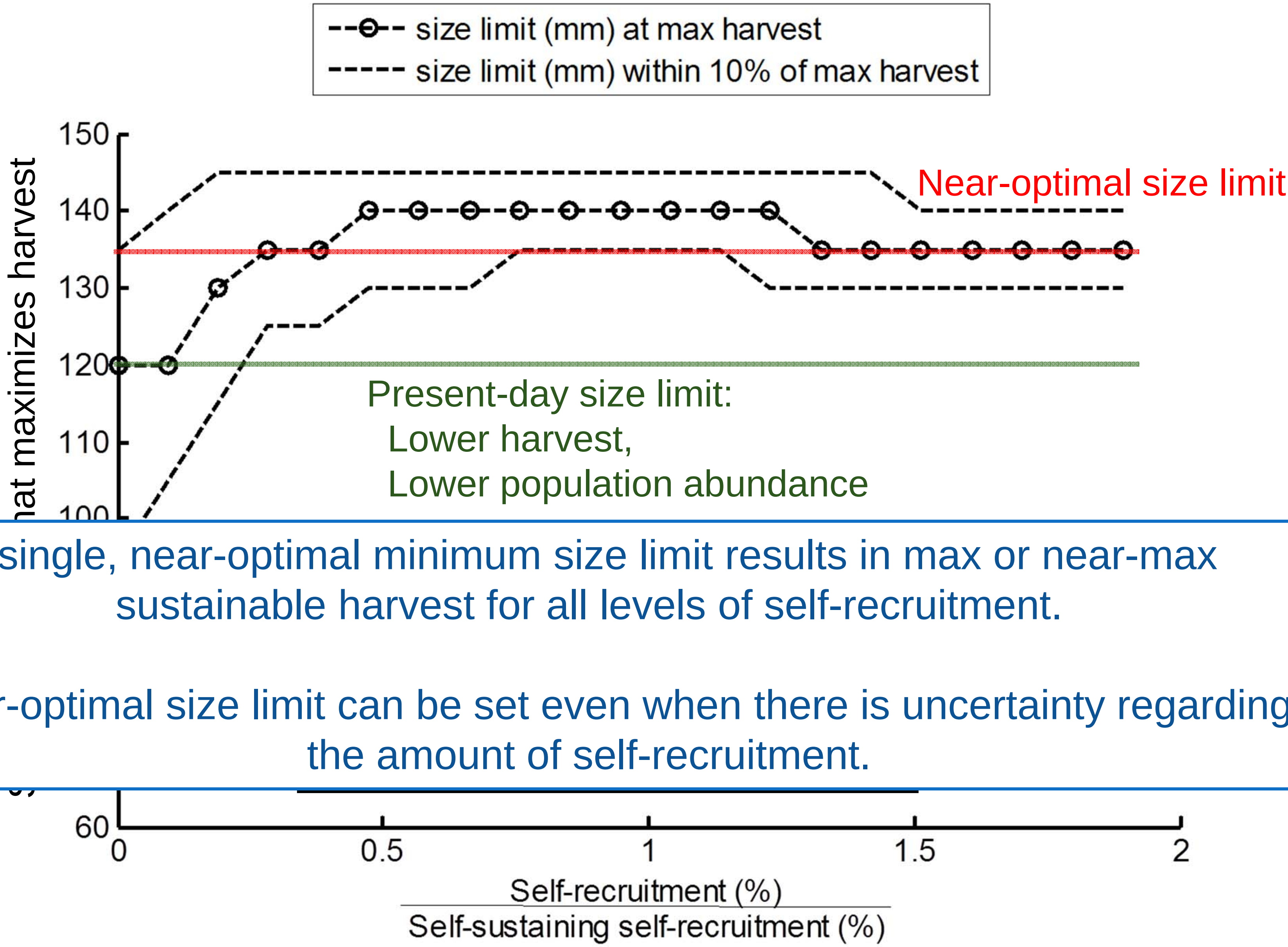
Maximum harvest = The maximum harvest possible (at year 30) for each self-recruitment level.



RESULTS: Annual harvest at year 30



RESULTS: A near-optimal size limit



A single, near-optimal minimum size limit results in max or near-max sustainable harvest for all levels of self-recruitment.

A near-optimal size limit can be set even when there is uncertainty regarding the amount of self-recruitment.

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

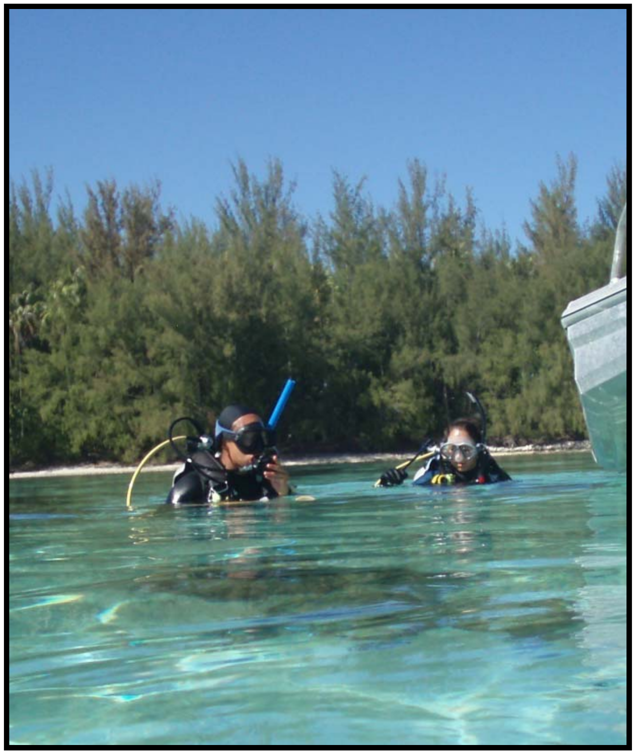
‡asymptotic size changed, time to asymptotic size re-calculated accordingly

CONCLUSIONS

- In the worst case scenario, the abundance of clams on Moorea would decline by 7% if the local population has 0% self-recruitment. The local population of giant clams on Moorea can support the total mortality rate, including present-day fishing mortality.
- A single near-optimal size limit will maximize(or nearly maximize) annual harvest of giant clams on Moorea 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 without knowing the level of self-recruitment.

Policy Implications

- Integral Projection Models are a good alternative to matrix population models
  - Require less data to parameterize
  - Eliminate model sensitivities to size classes
- Even though we don't know how much self-recruitment is occurring, we can still:
  - Model (using IPMs) and manage populations at small spatial scales
  - Set a single minimize size limit to optimize (or nearly optimize) harvest



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