The Cost of Avoiding Sea Cucumber stock depletion

Alvaro Hernández-Flores
Alfonso Cuevas-Jiménez
Javier Aranda-Nah

North American Association of Fisheries Economists
NAAFE 2015
Biennial Forum

Ketchikan, Alaska, May 22, 2015

Marist University of Merida

The Cost of Avoiding Sea Cucumber stock depletion

OUTLINE

1. An overview of the sea cucumber fishery in Yucatan
2. Research question
3. Geostatistical stock assessment
4. The Allee effect (Population density as limit reference)
5. The spatial bio-economic model
6. Results
7. Conclusion

The sea cucumber fishery in Yucatan, Mexico

2013

- In 2013 a stock of sea cucumber (*Isostichopus badionotus*) was discovered in northern shelf of Yucatan.
- A survey calculated a biomass of 17600 tons.
- The species has an attractive price for local fishers US$3.5 per kg.
- To avoid the "race for sea cucumbers" and the collapse of the stock, authorities established a total quota of 1278 tones
- Issued a limited number of permits: 250 boats
- Restricted the fishing season to six weeks.

Cervera, K. 2011

Isostichopus badionotus

Ex-vessel Price: US$3.5 per kg

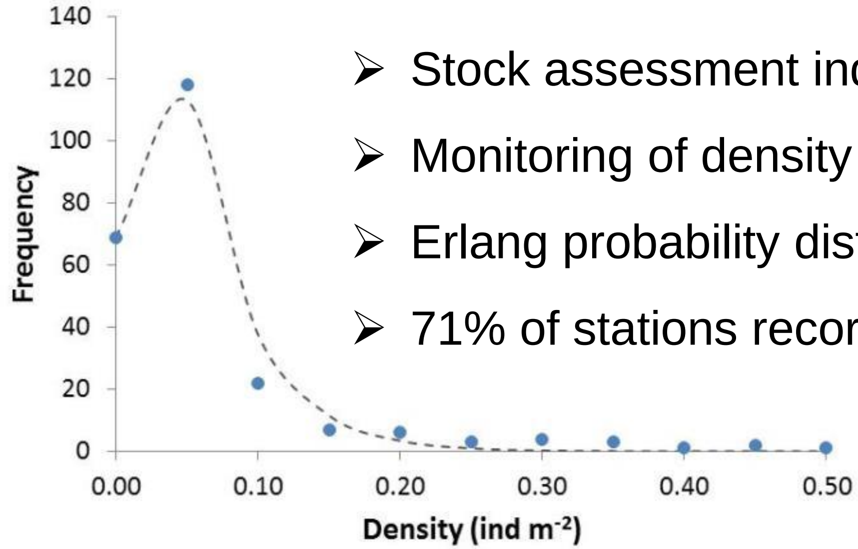
Poot, A., 2010

Research questions

1. What should be the spawning stock size to maintain a viable sea cucumber population?
2. What should be the minimum density to ensure the reproductive success?
3. What is the cost* of avoiding stock depletion?

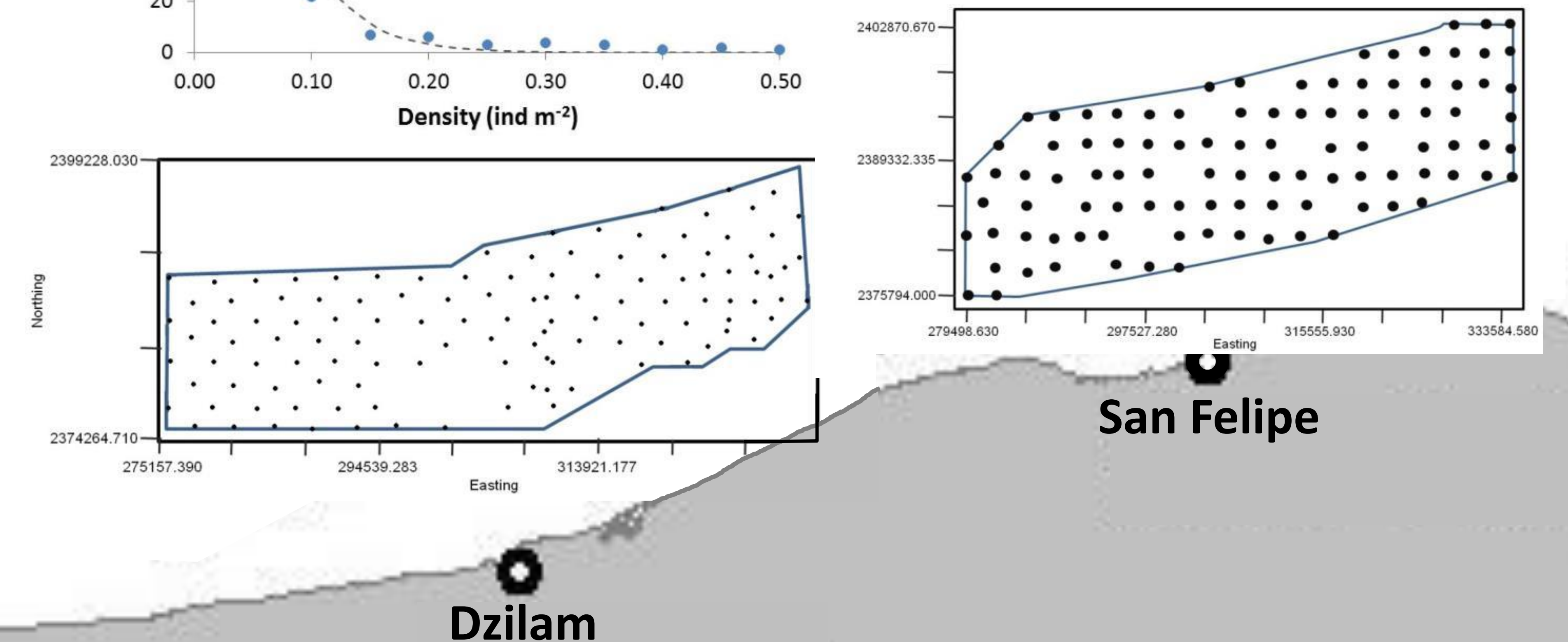
**** social opportunity cost***

Geostatistical stock assessment



- Stock assessment independent of the fishery
- Monitoring of density in 236 points
- Erlang probability distribution
- 71% of stations recorded sea cucumber

Cervera, K. 2011



March, 2013

Geostatistical stock assessment

- Ordinary Kriging Interpolation Method
- Spatial models of population density

$$N_i = \rho_i s_i$$

$$B_i = w \rho_i a_i$$

Area	Density (ind m^{-2})	Surfaced (m^2)	Percentage of Surface
1	≥ 0.30	15,634,500	7 %
2	≥ 0.20	77,110,000	35 %
3	≥ 0.10	126,990,000	58 %

Total Biomass
16,406 tons

The Allee effect:

Population density as limit reference point

Cervera, K. 2011

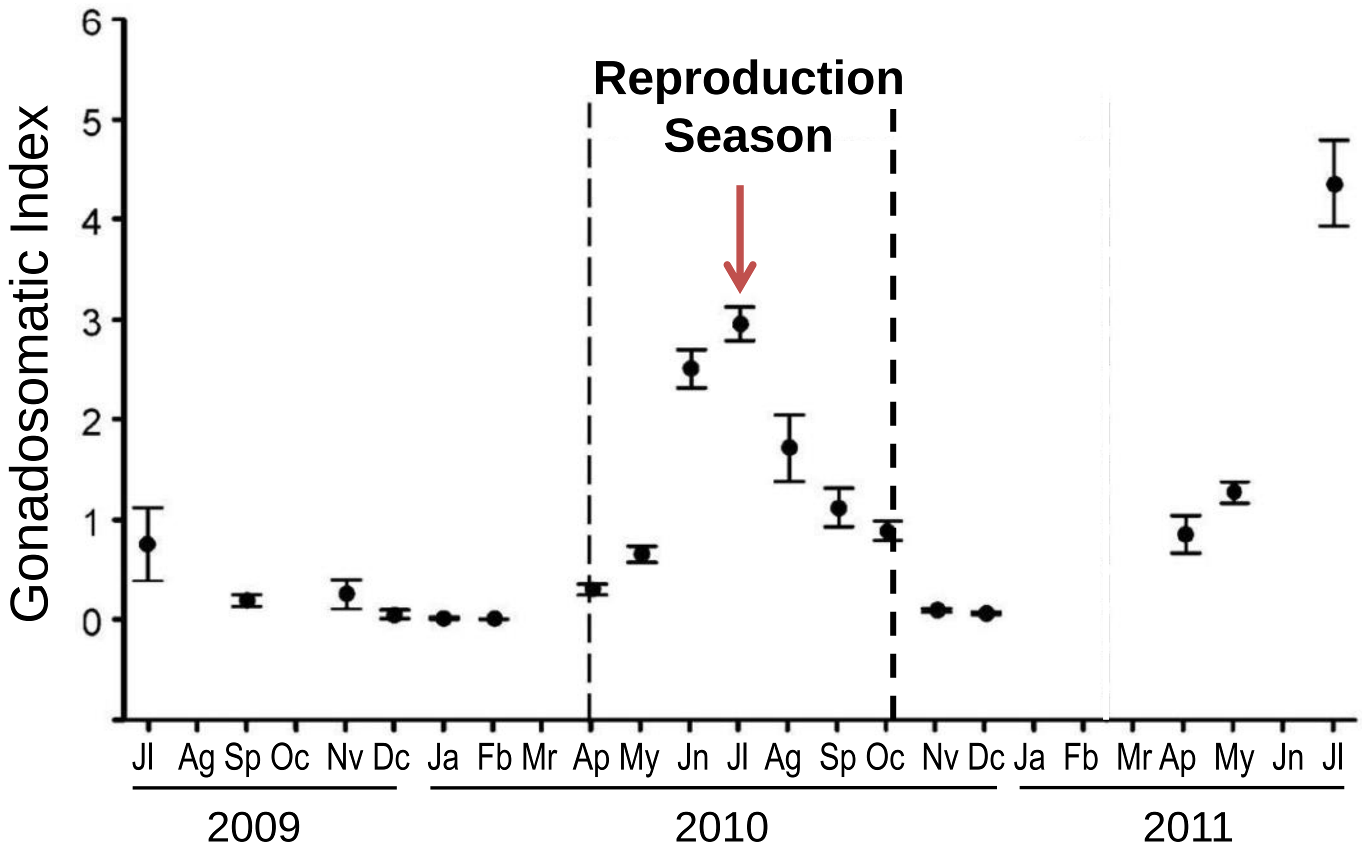
- Sea cucumbers are dioecious
- Present external fecundity
- Their reproductive behavior and success determined by hormones and biochemical communication
- Males and females require a minimum distance to start courtship, expel gametes and fertilize eggs.
- Form large patches as a reproductive strategy

Cervera, K. 2011

The Allee effect:

Reproductive Season

Poot, A., 2010



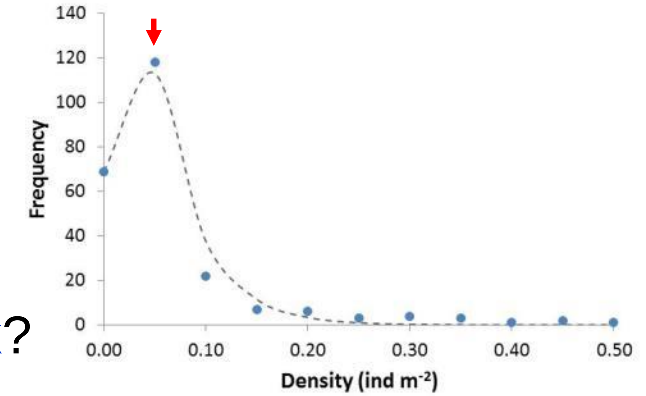
Source: Poot, A., et al., 2012.

The Allee effect:

Population density as limit reference point

Erlang distribution function fitted to population density approaches an

30 % with no sea cucumbers (0.0 ind m^{-2})
50 % of stations with low density (0.05 ind m^{-2})
20 % with higher concentration (≥ 0.1 ind m^{-2})



1. What should be the remaining spawning stock?
2. What should be the minimum density to ensure the reproductive success?

Cervera, K. 2011

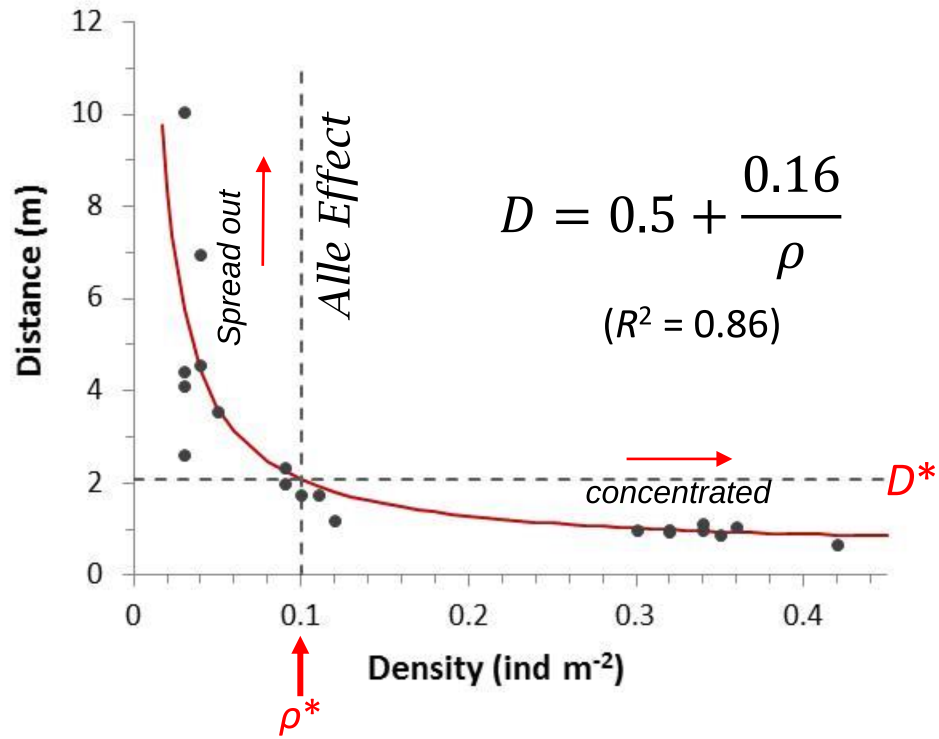
Density (ρ) vs. Distance (D)

The Allee effect:

Density (ρ) vs. Distance (D)

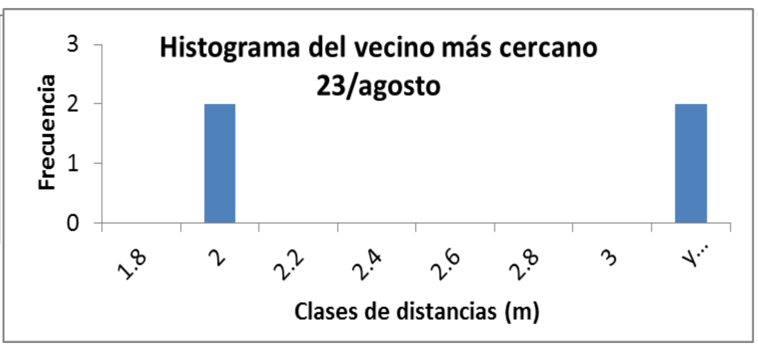
A relationship between ρ and D gave a hyperbola model, with asymptote (minimum distance between organisms): $a = 0.5$ (meters)

From May to August 2013
21 samplings
n = 383 distances



$$D = 0.5 + \frac{0.16}{\rho}$$

(R^2 = 0.86)



Cervera, K. 2011

The spatial bio-economic model

Characteristics

- Short run (time unit in days) dynamic model
- Depletion model (no natural mortality, no recruitment and no individual growth)
- Biomass is calculated from population size (*N*) multiplied by individual average weight (*w*) at areas with densities > 0.1 ind m^{-2}
- Vulnerable biomass is set for patches with densities > 0.1 ind m^{-2}
- The patch is divided into three sub-areas (s_i), according to their density
- Catch is calculated as: $Y = EqB$
- Catchability (q) is density-dependent since the fishing technique is by means of collecting with Scuba diving

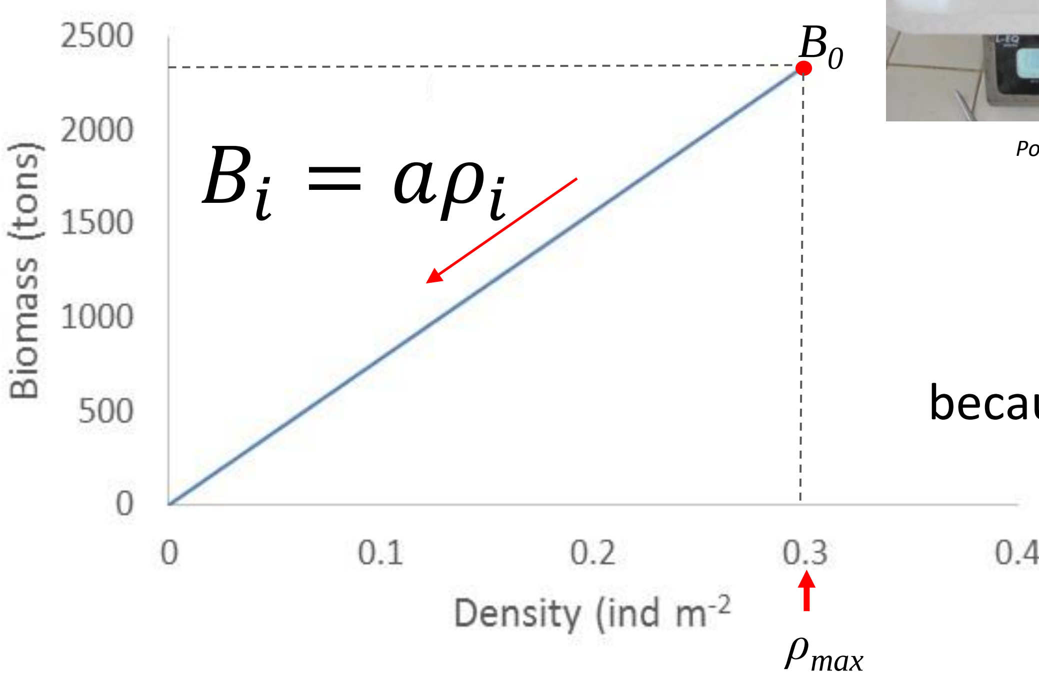
The spatial bio-economic model

Abundance and Biomass

$$N_i = s_i \rho_i \qquad\qquad B_i = w N_i$$

w weight

Poot, A., 2010



$$B_i = a \rho_i$$

$$B_i = \underbrace{w s_i}\rho_i$$

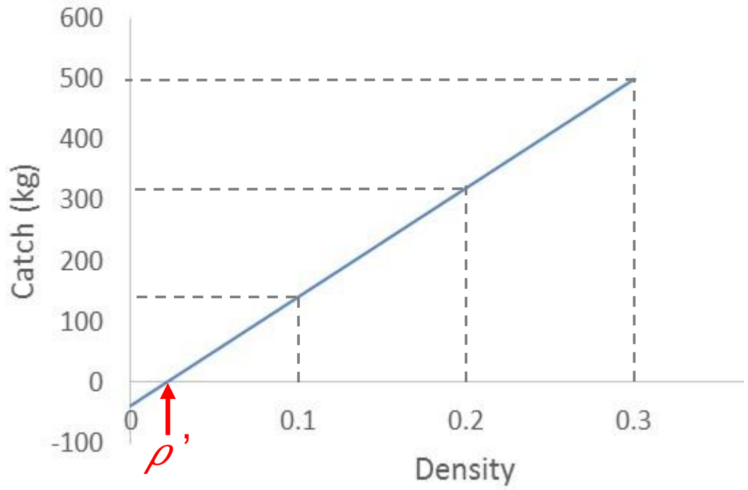
because w and s_i are constants,

$$a = w\, s_i$$

The spatial bio-economic model

Catch
(keeping effort constant)
E = 1 day-trip

$$Y_1 = b\rho_1 - c$$



Threshold density ρ = 0.02 ind m^{-2}

- Density determines fishing efficiency
- Catchability is highly dependent on density

The spatial bio-economic model

Catchability Density-dependent Function

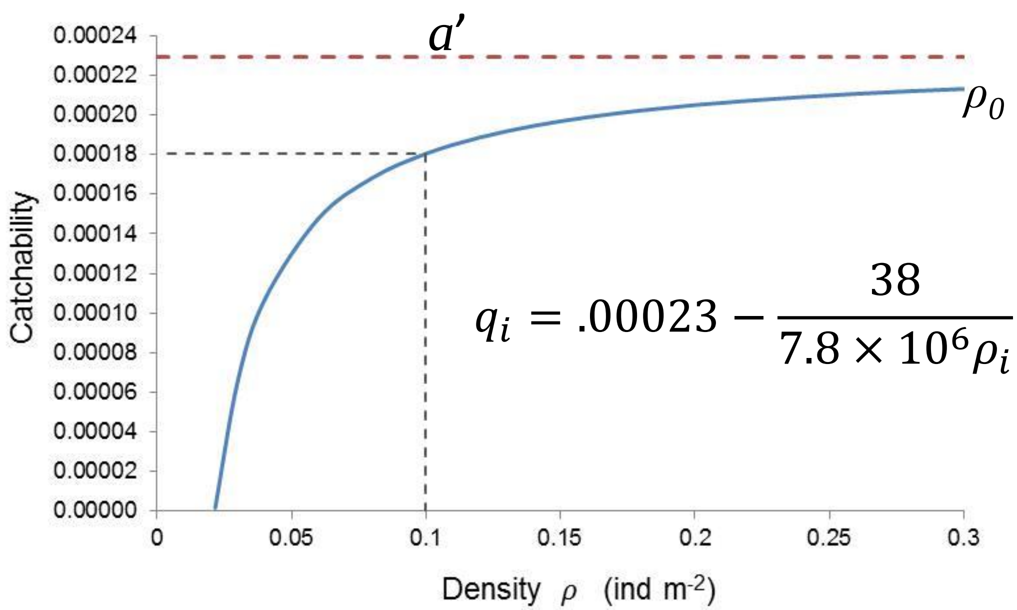
From catch equation

(effort constant)

E = 1

$$Y_i = qB_i$$

$$q_i = \frac{Y_i}{B_i}$$



$$q_i = .00023 - \frac{38}{7.8 \times 10^6 \rho_i}$$

By substituting catch and biomass density-dependent equations:

$$q_i = \frac{b\rho_i - c}{a\rho_i} = \frac{b}{a} - \frac{c}{a\rho_i}$$

$$a' = \frac{b}{a}$$

$$q_i = a' - \frac{c}{a\rho_i}$$

a’ is the asymptotic catchability coefficient

The spatial bio-economic model

Dynamics

(Unit time in days)

$$\rho_{i,t+1} = B_{i,t} - Y_{i,t}$$

$$q_{i,t+1} = a' - \frac{c}{a\rho_{i,t+1}}$$

$$Y_{i,t+1} = q_{i,t+1} E_{i,t+1} B_{i,t+1}$$

The spatial bio-economic model

Sea cucumber eviscerated ex-vessel price (USD/ton)	$3,300
Gas price (USD/liter)	$1.00
Weight loss (from total to eviscerated weight)	60%

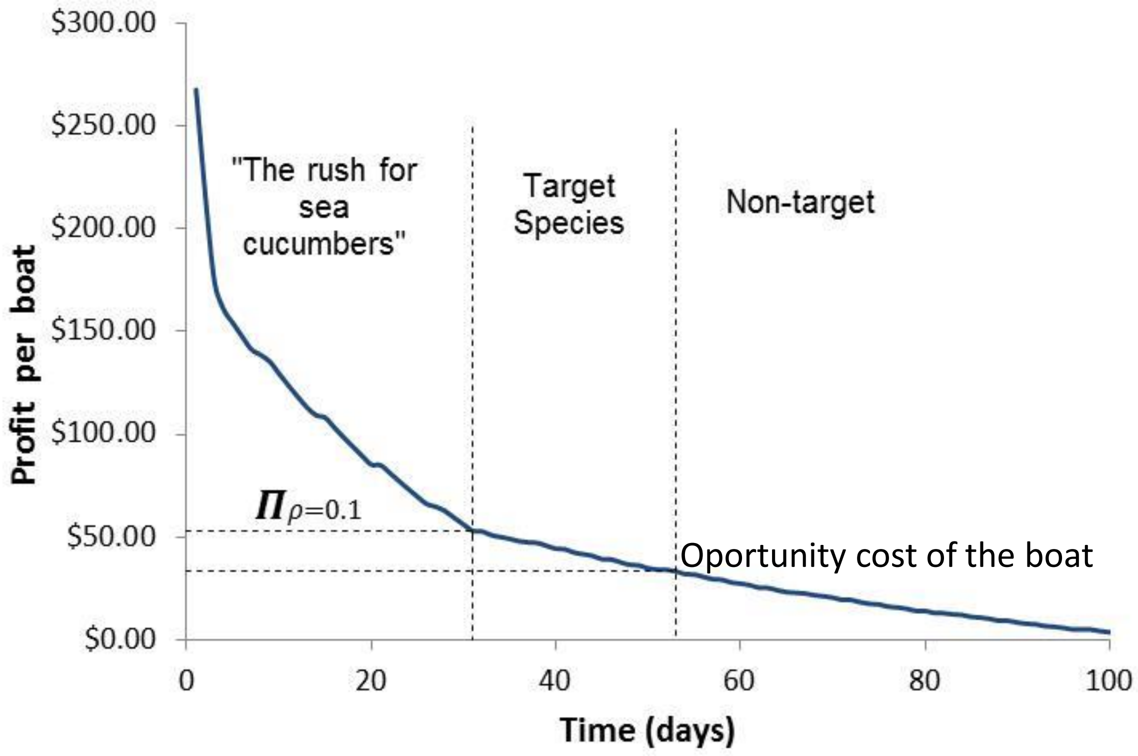
Cost density-distance transfer function

$$C_f = 121.7e^{-2.2\rho}$$

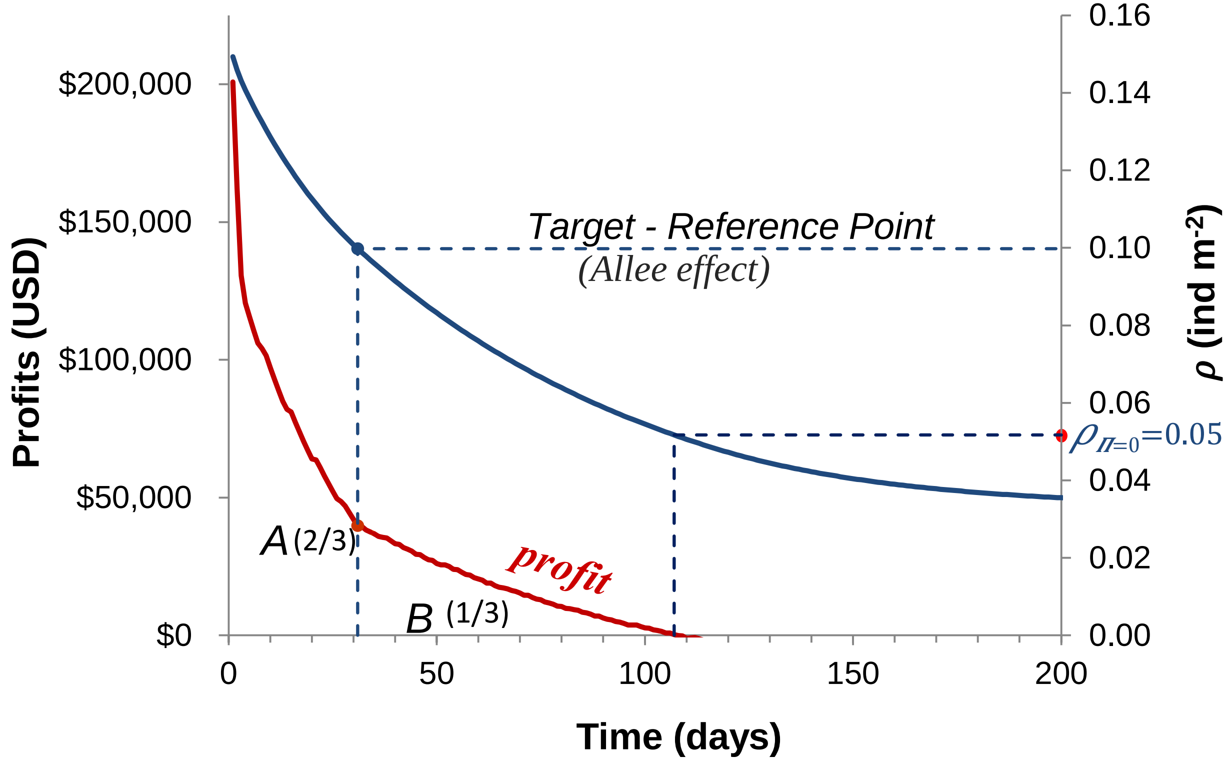
Catch per trip	Density	Gas
501 kg	$\rho \geq 0.3$ ind m^{-2}	40.4 l
≤106 kg	$\rho < 0.1$ ind m^{-2}	121.7 l

Results

The economics of the boat



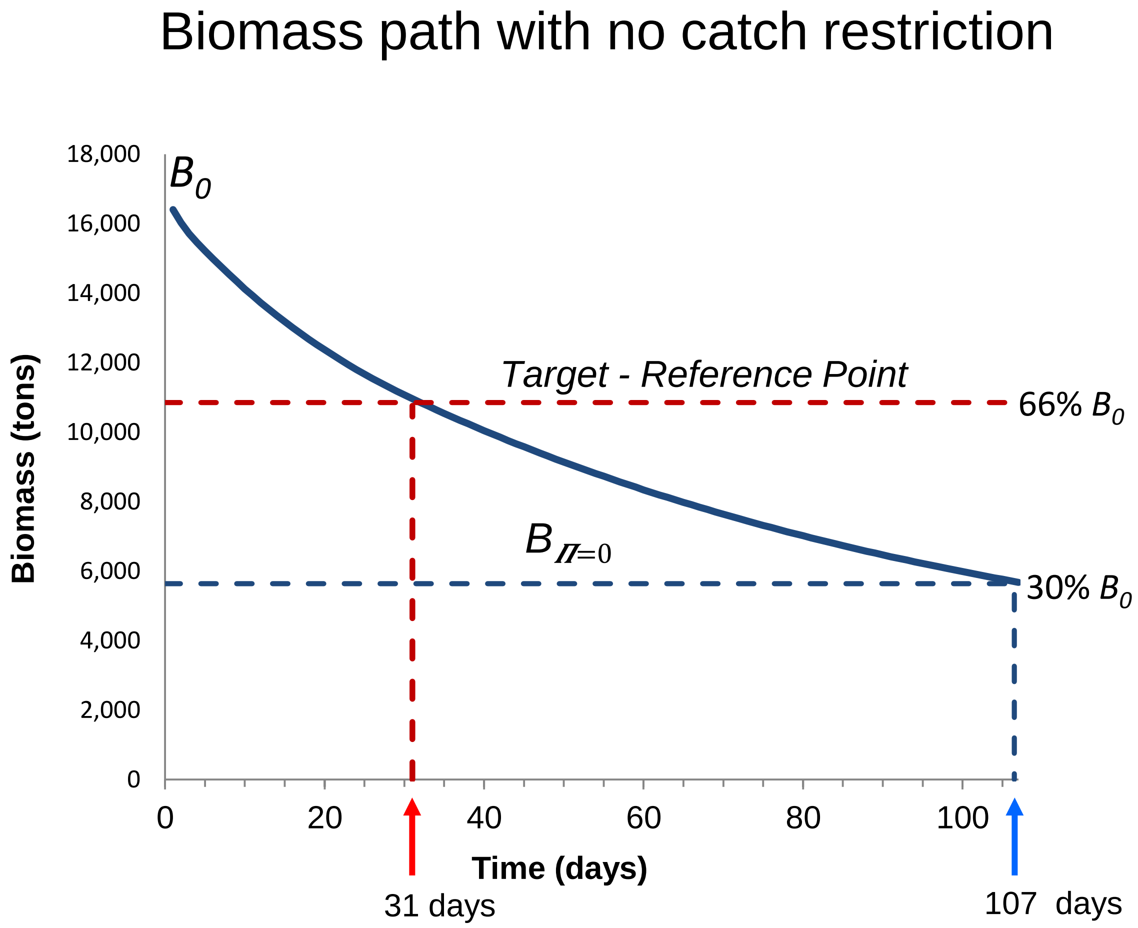
The Economics of the Fishery



Scenarios	Catch (t)	NPV Profits (USD)	Remaining Stock (t)	Density (ind m^{-2})	
1. Quota	5,550	*A* = $2.6 million	10,856	0.05	31 days
2. No catch limit	10,765	*A+B* = $3.8 million	5,641	0.10	107 days

Social Opportunity Cost: *B = $1,289,539*

Results



Biomass path with no catch restriction
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Biomass (tons)
B_0
Target - Reference Point
66% B_0
$B_{\Pi=0}$
30% B_0
0
20
40
60
80
100
Time (days)
31 days
107 days

Conclusions

- Without catch restrictions, the sea cucumber fishery would reach the bioeconomic equilibrium at a biomass 30% of B_0, a density ρ = 0.05 ind m^{-2}, a catch **Y = 10765 t**, and profits of **US$3.9 million**
- In order to avoid the Allee effect, the species requires a minimum density of 0.1 ind m^{-2}
- To avoid the Allee effect, it is necessary to establish a total quota of **5550 t** (34% of B_0)
- The quota would produce NPV of **US$2.6 million**, and biomass 0.66 B_0
- Society should renounce in the short run to **US$1.3 million** to maintain a renewable stock above the Alle effect threshold
- One reason that many sea cucumber fisheries worldwide are overexploited* could be that regulations do not take into account the Allee effect.

* 83% of sea cucumber fisheries in the world are over-exploited or fully exploited (*Purcell et al., 2013*),

Thank you

Alvaro Hernández-Flores

Alfonso Cuevas-Jiménez

Javier Aranda-Nah

ahernandez@marista.edu.mx

Marist University of Merida