Reference points for vulnerable fish species based on bioeconomic age-structured models: an approach for *Totoaba macdonaldi*

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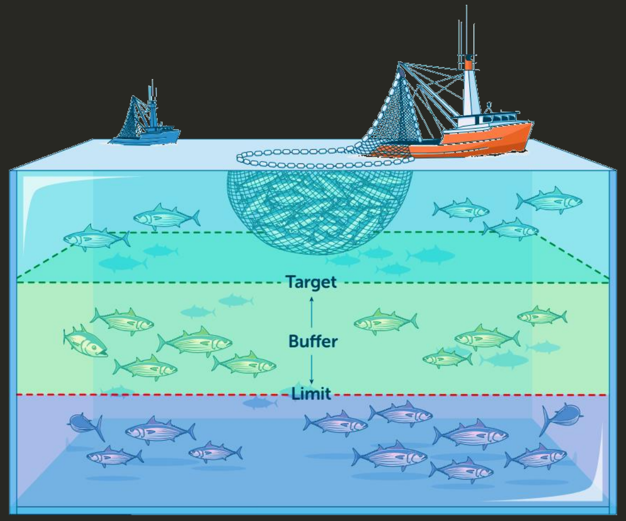
INTRODUCTION

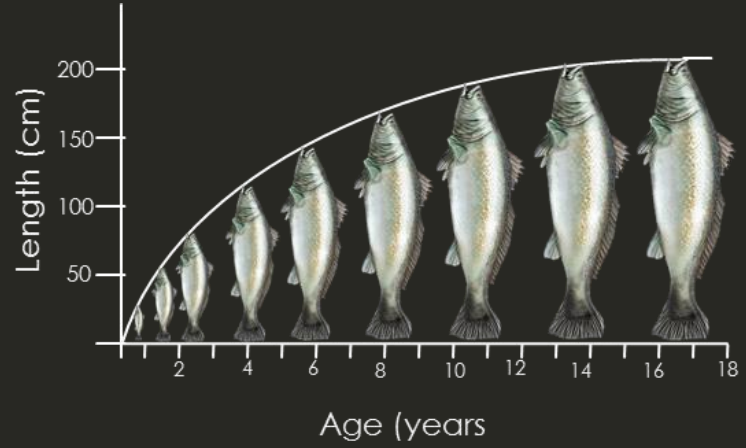
Reference points are one of the **main tools** for fishery managers **to make decisions about future catch** options.

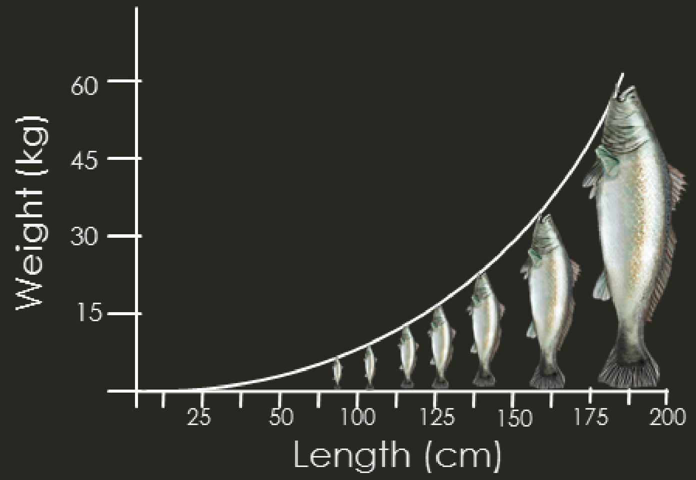
RP's should reflect:

- desired biological states of the stock (**TRP's**)
- safe biological harvesting levels (**LRP's**)



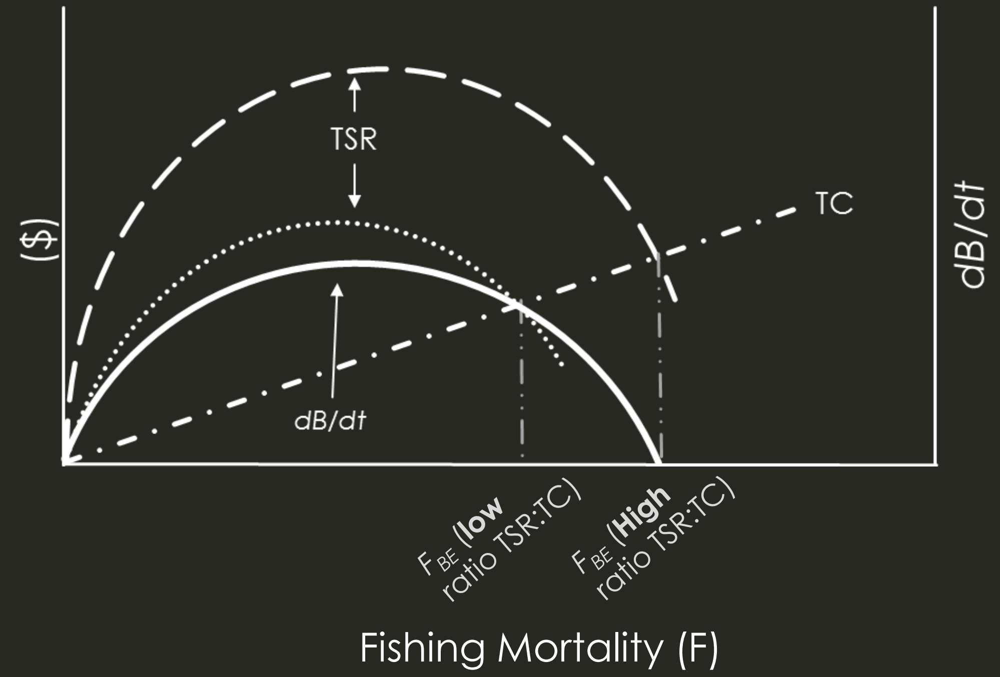
RP's based on size or age structured models are a good approach for "data-poor" stocks.





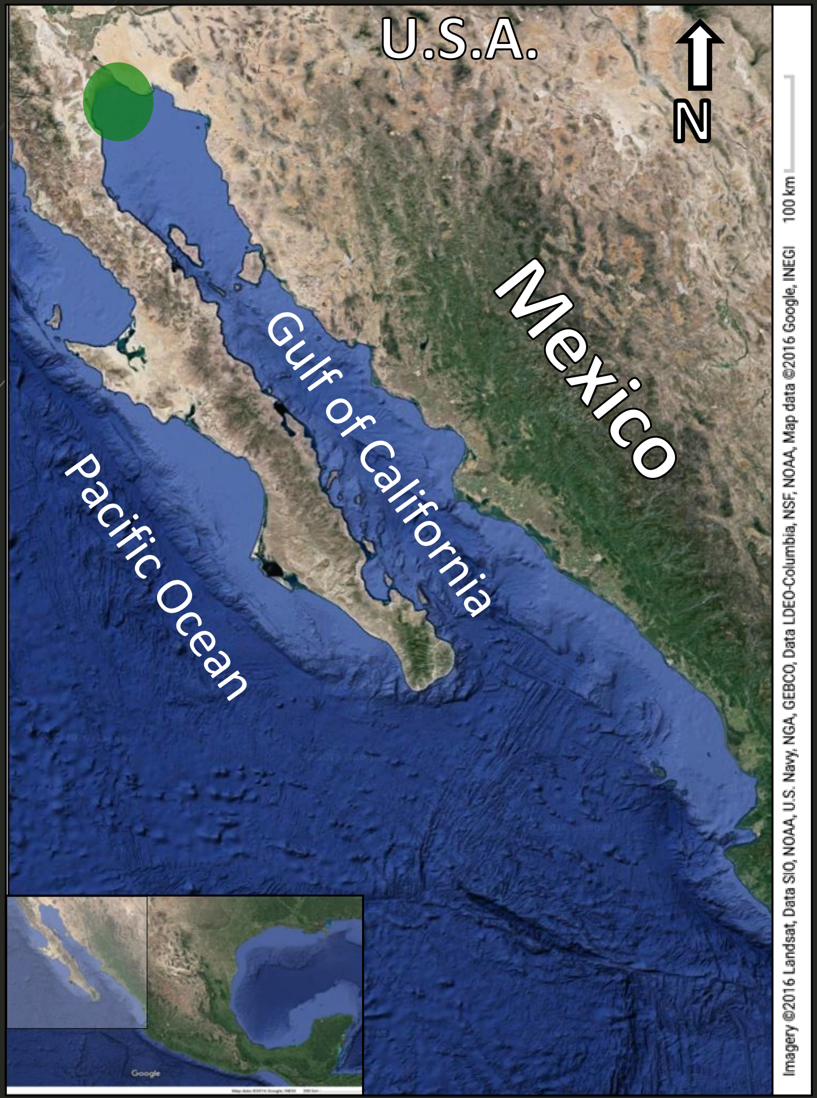
Vulnerable fish species

Big size
Long-lived
Late maturity size
Low reproductive rate
High value
Spawning aggregations



Totoaba macdonaldi biology (characteristics of vulnerability)

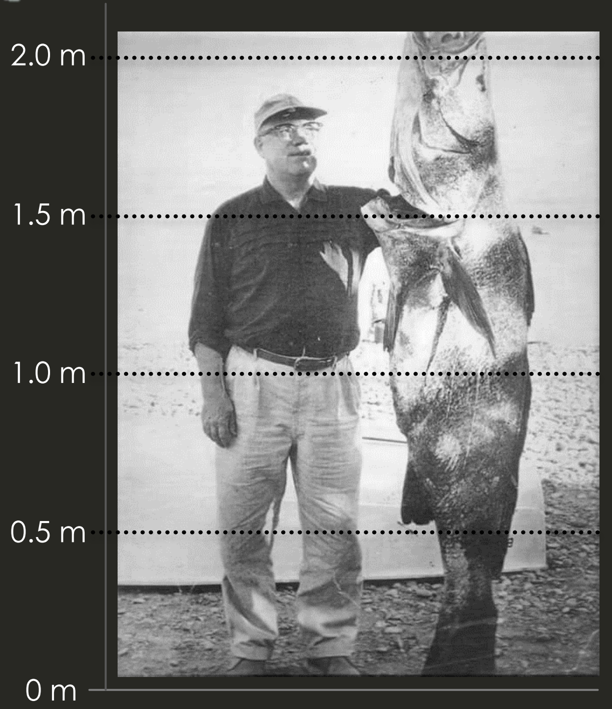
Sciaenid fish **endemic** to Gulf of California



Big sized: TL_{max} ≈ 2 m
Photo guy: ≈ 1.90 m.

Long-lived: 24 years.

Late maturity age: 7 years old.

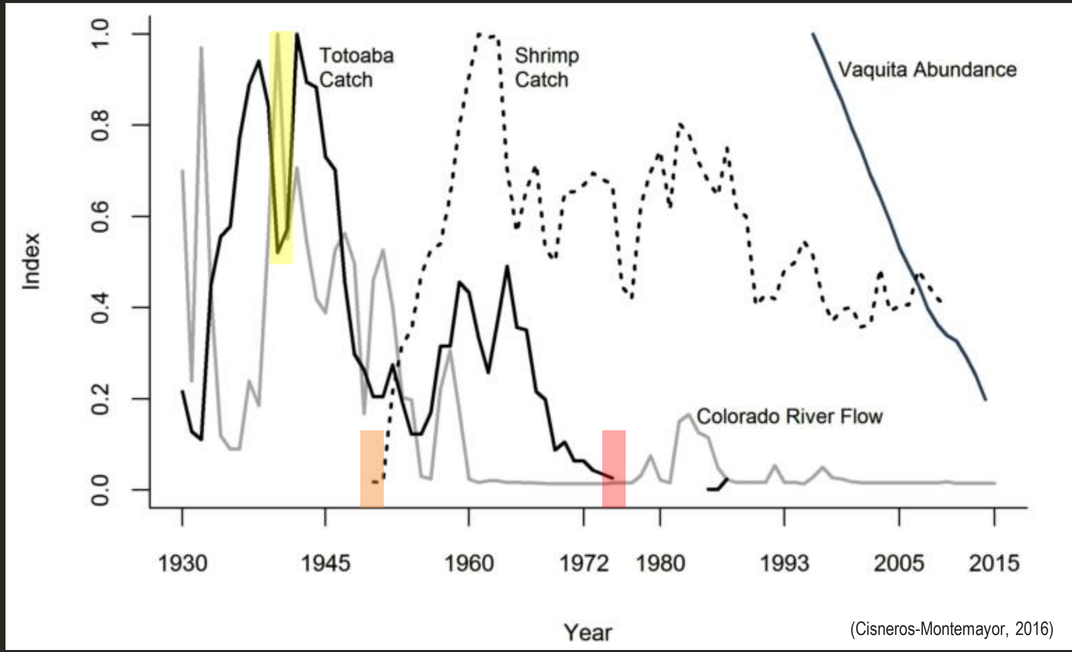


Spawning aggregations: spawning season from late winter to early spring in the Upper Gulf of California (main fishing area).

BRIEF TOTOTABA HISTORY

1920s - fishery beginning: communities were established

Habitat degradation, totoaba bycatch, catches reduction and recovery measures failed → 1975 permanent ban



CRITICALLY ENDANGERED
IUCN RED LIST

1996

U.S. FISH & WILDLIFE SERVICE

1979

CITES
Apenddix I

1976

(UNEP-WCMC, 2013;)

ACTUAL SITUATION

ILLEGAL FISHERY

- High demand of swim bladder by Asian black market.
- Chinese culture attributes medicinal properties to swim bladder soup; also is seen as a luxury meal.
- *T. macdonaldi* swim bladder can reach US$8,000/kg ex-vessel.
- Vaquita marina bycatch.

(Bobadilla *et al.*, 2011; Valenzuela-Quiñonez *et al.*, 2011)

ACTUAL SITUATION

- Sport fishermen arguments:
  - Recovered species,
  - Sport fishing does not damage vaquita (*Phocoena sinus*) population and has minimal effect on totoaba population.

- Scientific community insights:
  - Information available was inadequate when were banned.
  - Permanence spite of population depletion, habitat alteration, illegal fishing and bycatch.
  - Future conservation measures must focus on illegal fishing elimination.

(Flanagan & Hendrickson, 1976; Cisneros-Mata *et al.*, 1995; Valenzuela-Quiñonez *et al.*, 2011)

ACTUAL MANAGEMENT SITUATION

Not effective protection measures for totoaba:

- Reserve creation process lacked of characteristics from others succeed MPAs.
- There’s not consistency between conservation and fishery objectives.
- Is not clear how to achieve the objectives.
- Inspection and surveillance are few honest.

(Bobadilla *et al*., 2011; Valenzuela-Quiñonez *et al*., 2015; Cisneros-Montemayor *et al*., 2016)

ACTUAL POPULATION SITUATION

Population parameters:

- TL: 0.25 – 1.90 m;
- Gillnet captures the biggest individuals;
- Maximum age: 24 years;
- Distribution still being throughout Gulf of California;
- Spawning area still being at Colorado River Delta;
- Migration patterns have not changed.

(De Anda-Montañez *et al.*, 2013; Valenzuela-Quiñonez *et al.*, 2011; 2014; 2015)

ACTUAL POPULATION SITUATION

Population parameters:

- Have not suffered genetic diversity loss;
- Enough population size for conservation;
- At genetic level is not endangered

(De Anda-Montañez *et al.*, 2013; Valenzuela-Quiñonez *et al.*, 2011; 2014; 2015)

RESEARCH QUESTIONS

Which is the fishing mortality that maximizes yield per recruit (F_{max}) for both fishing gears and how does population age structure and spawning stock biomass (*SSB*) are affected?

How do Yields, *F* and *SSB* paths will performance using fishing rod under different scenarios and what is the NPV for each of them?

OBJECTIVES

Assess bioeconomic reference points of totoaba (*Totoaba macdonaldi*) for the two main fishing gears: gillnet and fishing rod.

Simulate paths of F, yields and SSB for fishing rod under different states of the nature.

Estimate NPV for each simulation.

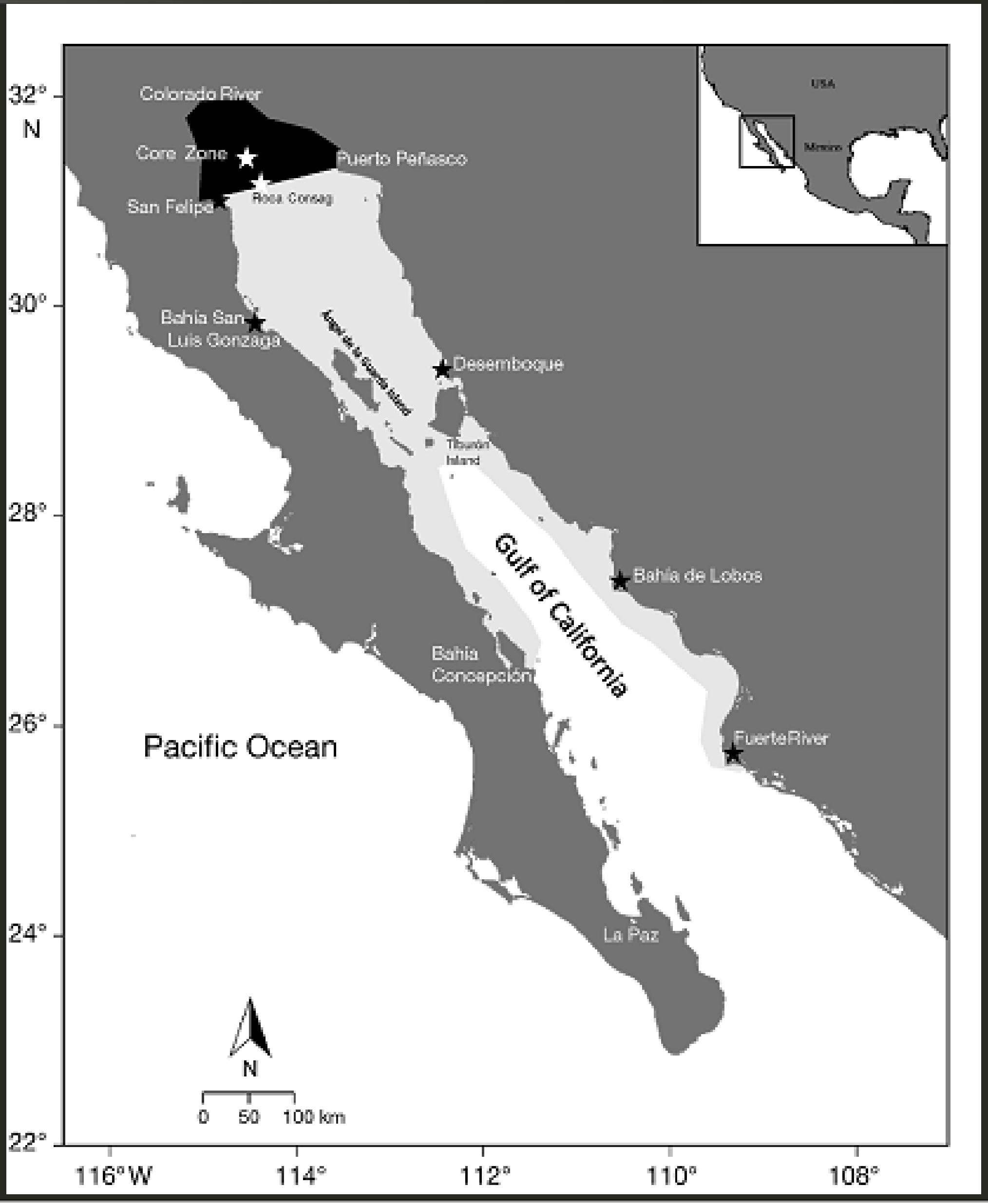
STUDY AREA

Gulf of California:

- Lat.: 23 - 32 °N; Long.: 107 -115 °W

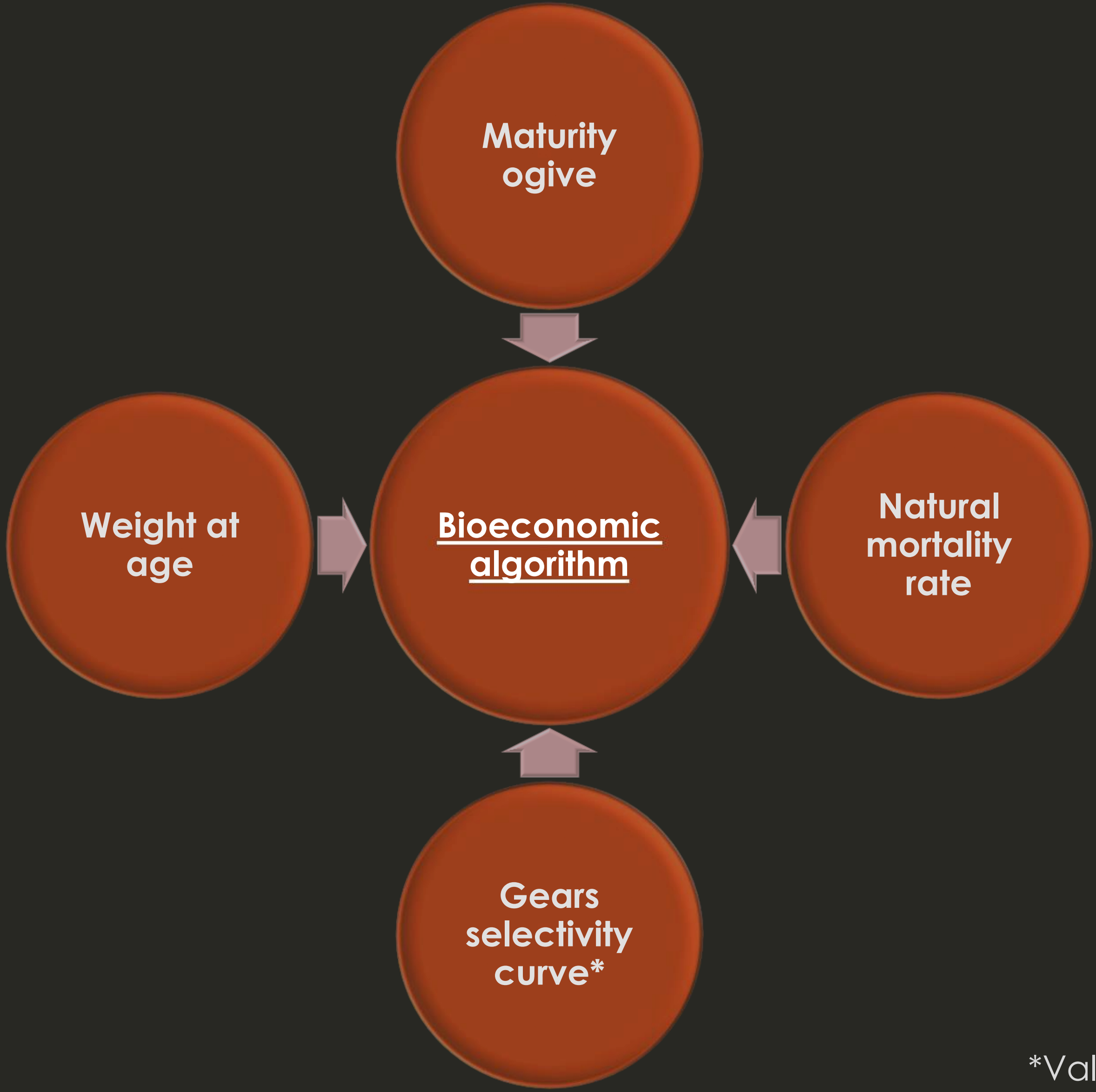
- Limits:
  - North: Colorado River Delta
  - East: States of: Sonora, Sinaloa and Nayarit
  - West: Baja California Peninsula
  - South: Pacific Ocean

- Extension:
  - Long: 1,400 km
  - Wide: 48 – 241 km



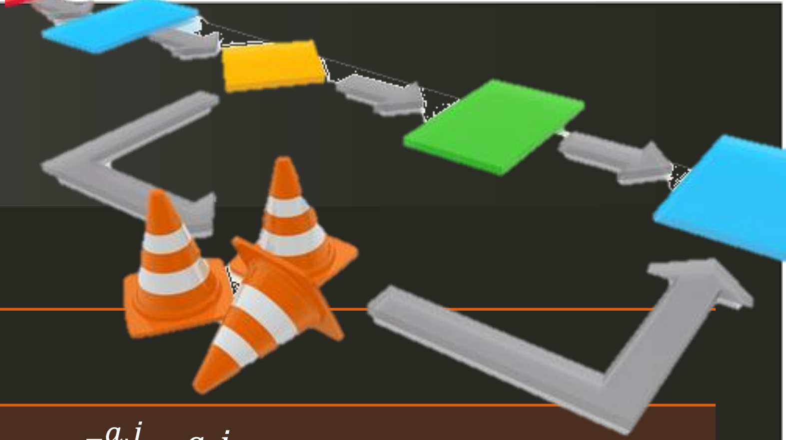
METHODOLOGY

Parameters



*Valenzuela-Quiñonez 2014

Hannesson (1975) model, optimized by Da-Rocha *et al.* (2015) algorithm

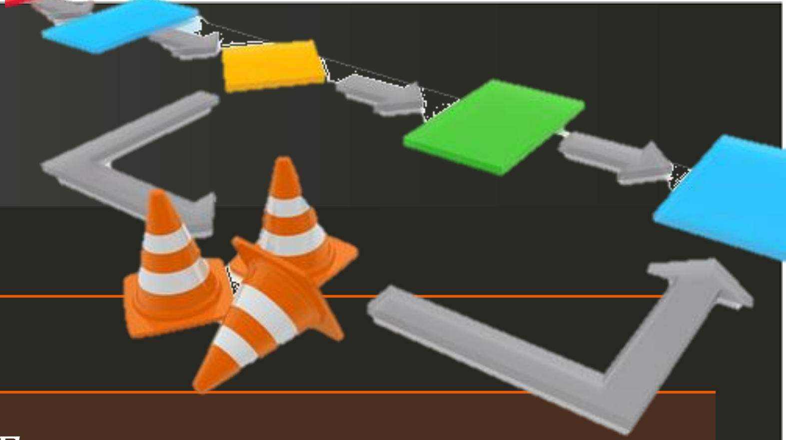


Stock Dynamics

Parameter	**Eq.**
Stock dynamics	$N_{t+1}^{a+1,j} = e^{-Z_t^{a,j}} N_t^{a,j}$
Total mortality rate	$Z_t^{a,j} = m^a + (p^{a,j}) F_t^j$
Natural mortality at age	$ln(m^a) = 0.55 - 1.61 ln(LT^a) + 1.44 ln(L_\infty) + ln(K)$
Population dynamics	$N_t^{a,j} = \varphi_t^{a,j} N_{t-(a-1)}^{1,j} \qquad \forall a = 1, \dots, A(j)$
Survival function *	$\forall j = 1, \dots, n \qquad \varphi_t^{a,j} = \begin{cases} \prod_{i=1}^{a-1} \exp(-Z_{t-i}^{a-1}) & \text{if } a > 1 \\ 1 & \text{if } a = 1 \end{cases}$

* For each period the survival depends on *a* – 2 previous mortality rates.

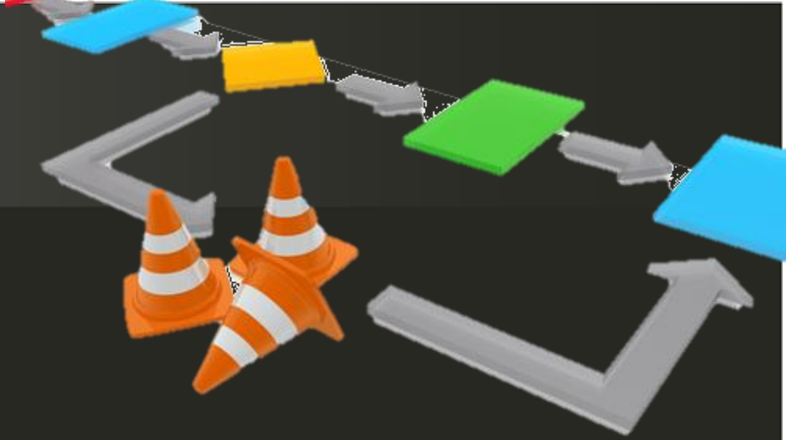
Hannesson (1975) model, optimized by Da-Rocha *et al.* (2015) algorithm



Reference Points

Reference Points	**Eq.**
Yields at steady state	$$Y_{ss}^{a,j} = \omega^{a,j} \frac{p^{a,j} F}{Z^{a,j}} \left[1 - \exp\left(-Z^{a,j}\right)\right]$$
F that maximize yields (F_{max})	$$\max_{F^j} \sum_{a=0}^{A} Y_a$$
Spawning stock biomass at steady state	$$SSB_{ss}^{a,j} = \sum_{a=1}^{A,j} \mu^{a,j} \omega^{a,j} N_{ss}^{a,j}$$
Total Yields	$$\sum_{a=1}^{A} Y_{ss}^{a,j}$$
Total population	$$\sum_{a=1}^{A} N_{ss}^{a,j}$$
Total SSB	$$\sum_{a=1}^{A} SSB_{ss}^{a,j}$$

Hannesson (1975) model, optimized by Da-Rocha *et al*. (2016) algorithm



Trajectories

Fishing mortality path $\{F_t\}_{t=0}^{\infty}$ that maximizes NPV considering stock dynamics into an age structured population and a discount factor β.

$$\sum_{t=0}^{\infty} \beta_t \frac{\prod_t^{1-\sigma} - 1}{1-\sigma}$$

where: $\prod_t = \sum_{a=1}^{A} pr_a y_{a,t}$ represents the incomes associated with the capture in the year t with a price pr_a and yield $y_{a,t}$ for age $a = 1, \ldots A$

Application to *T. macdonaldi*

Reference points for each gear were estimated in rates.

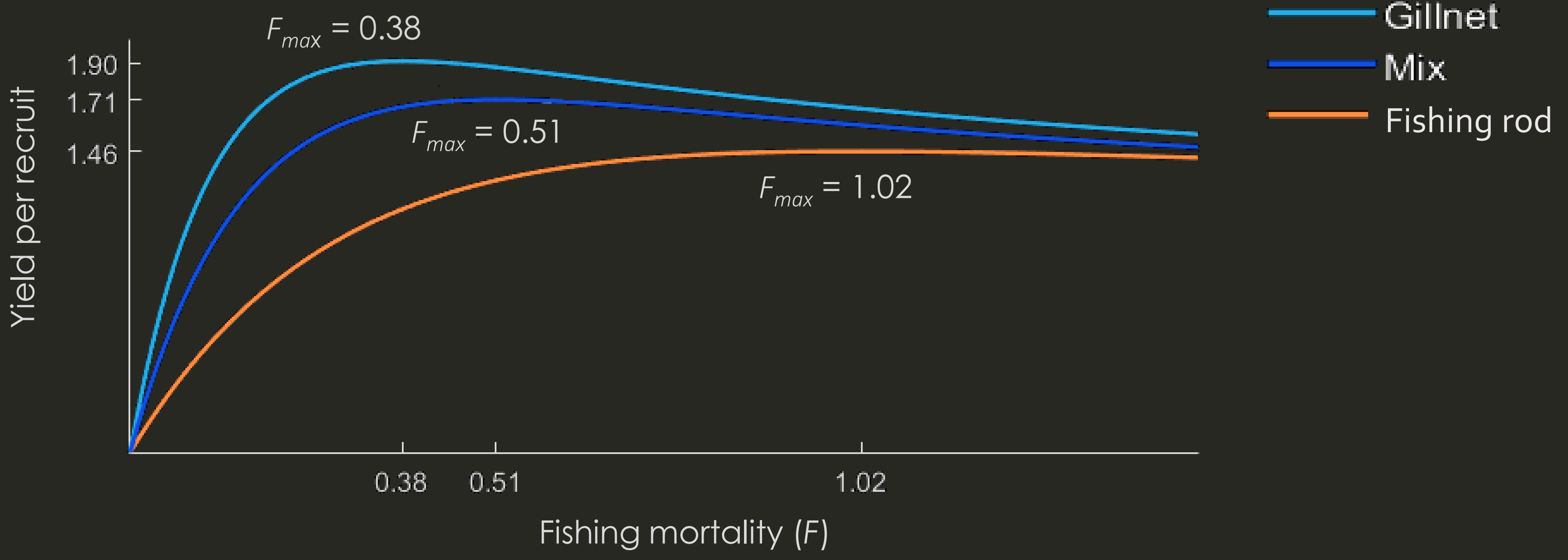
Optimal levels estimated with discount factor $\beta = 0.95$

Management trajectories constrained to fishing rod.

Trajectories modeled under 12 different scenarios. Considering three different population status and four different years for regulation beginning (3x4= 12).

FINDINGS

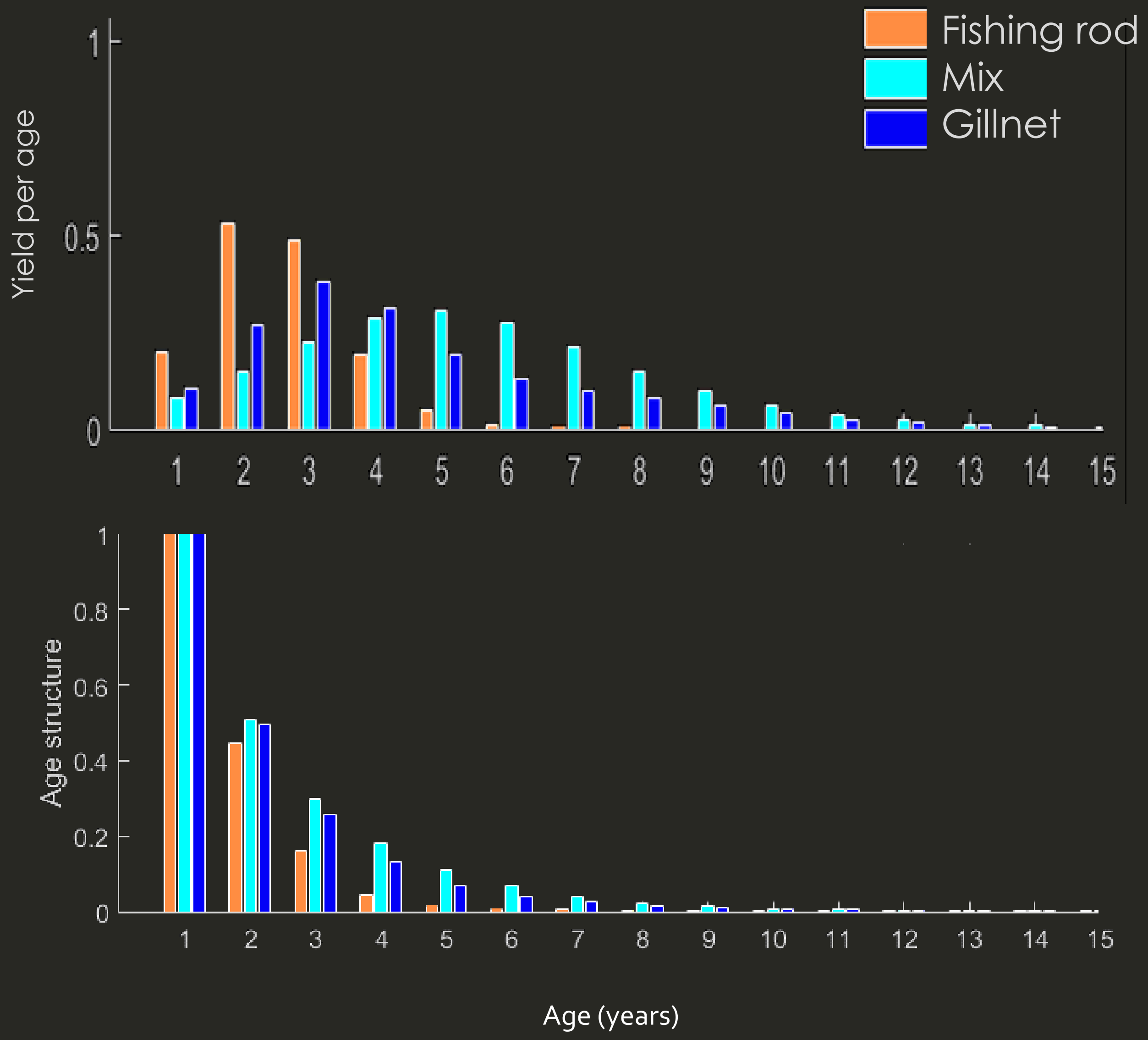
Reference points



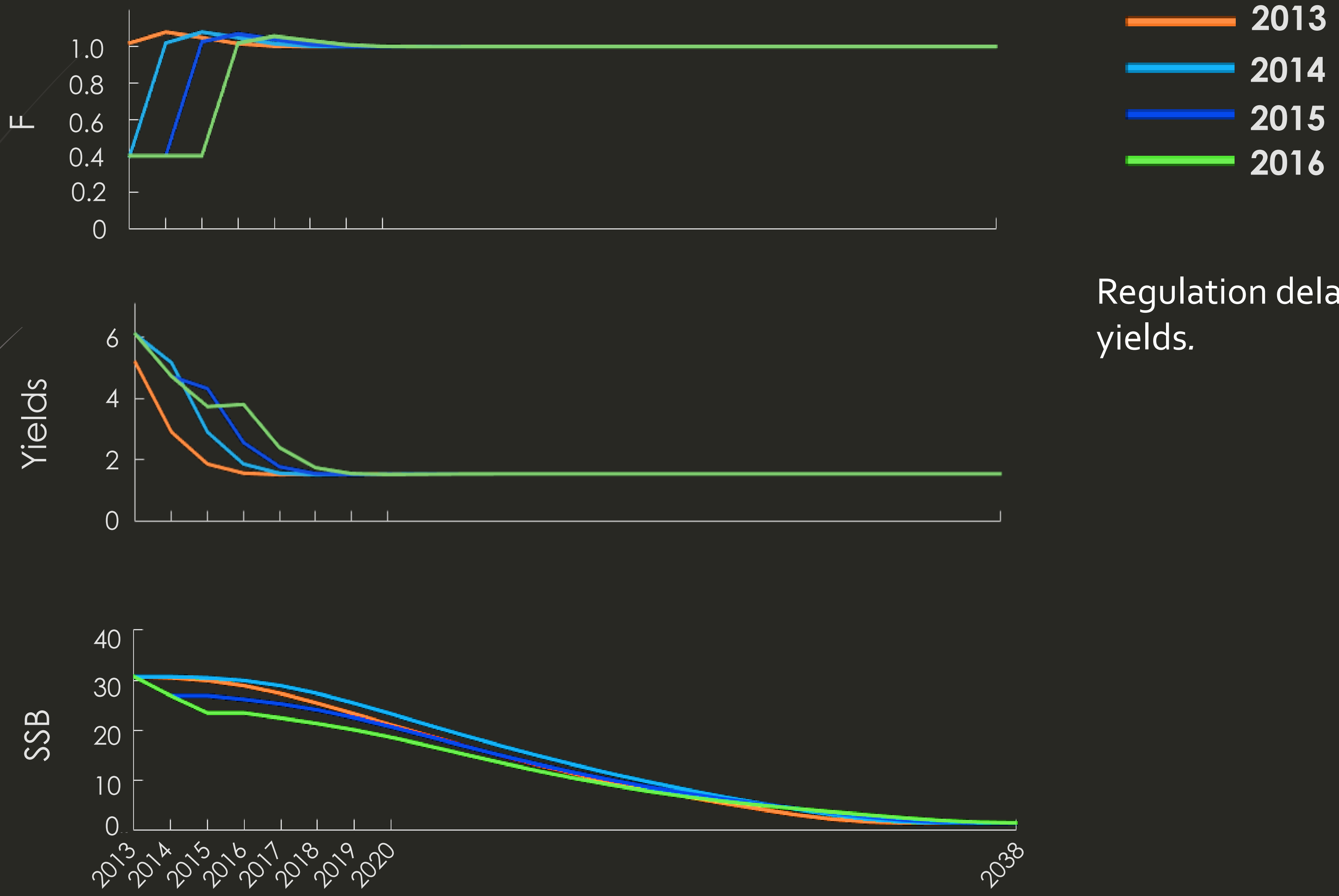
- **Gillnet** *higher YR with lower F.*
- **Fishing Rod** *lower YR with higher F.*

Reference points

- **Gillnet** higher *YPR is due captures wider range of ages and older (bigger). Also enables wider population age structure.*
- **Fishing rod** *lower YPR is due captures lower and limited range of ages (smaller). Also limits population age structure.*



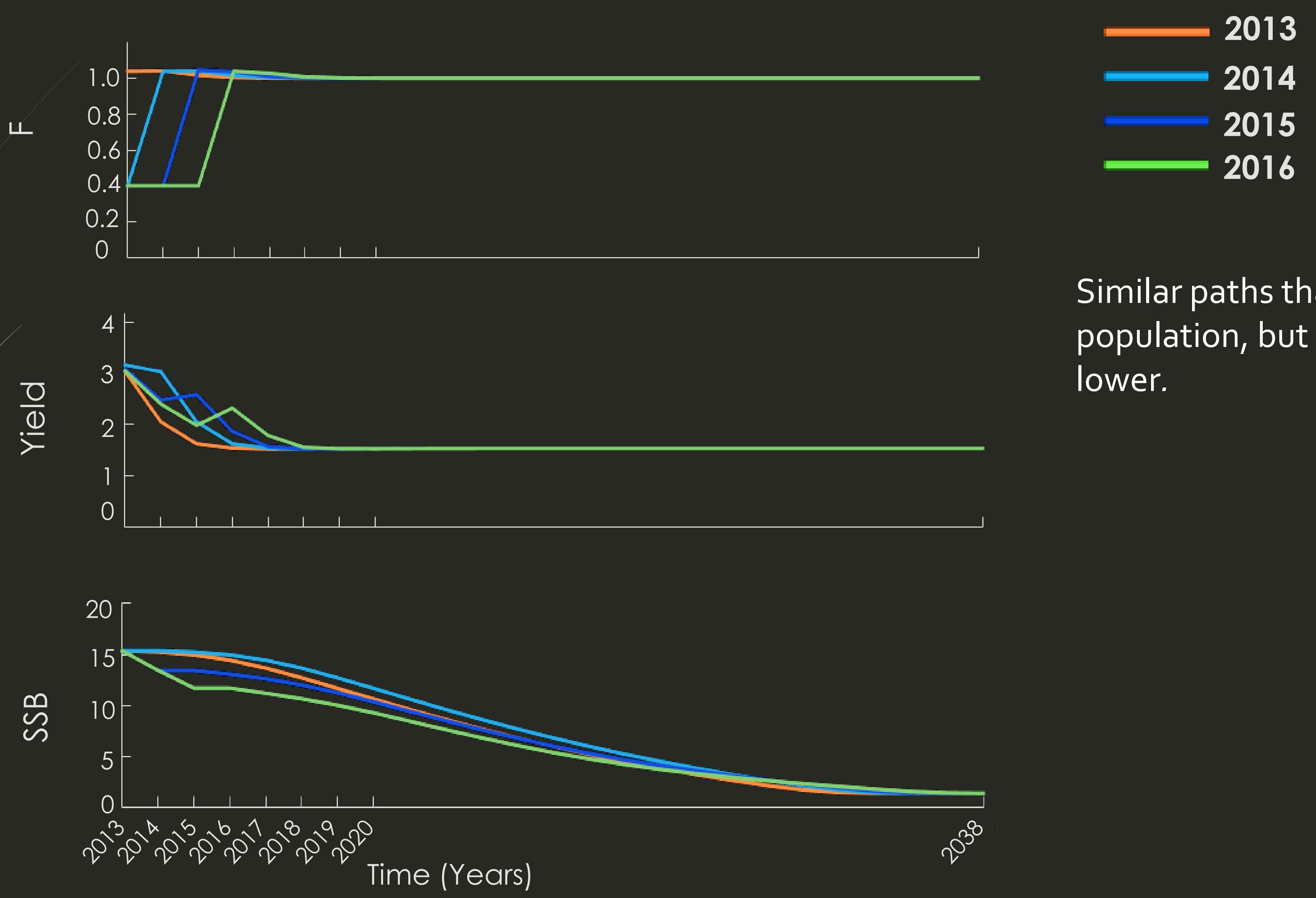
Recovered population fishing rod optimal paths



Regulation delay results in better yields.

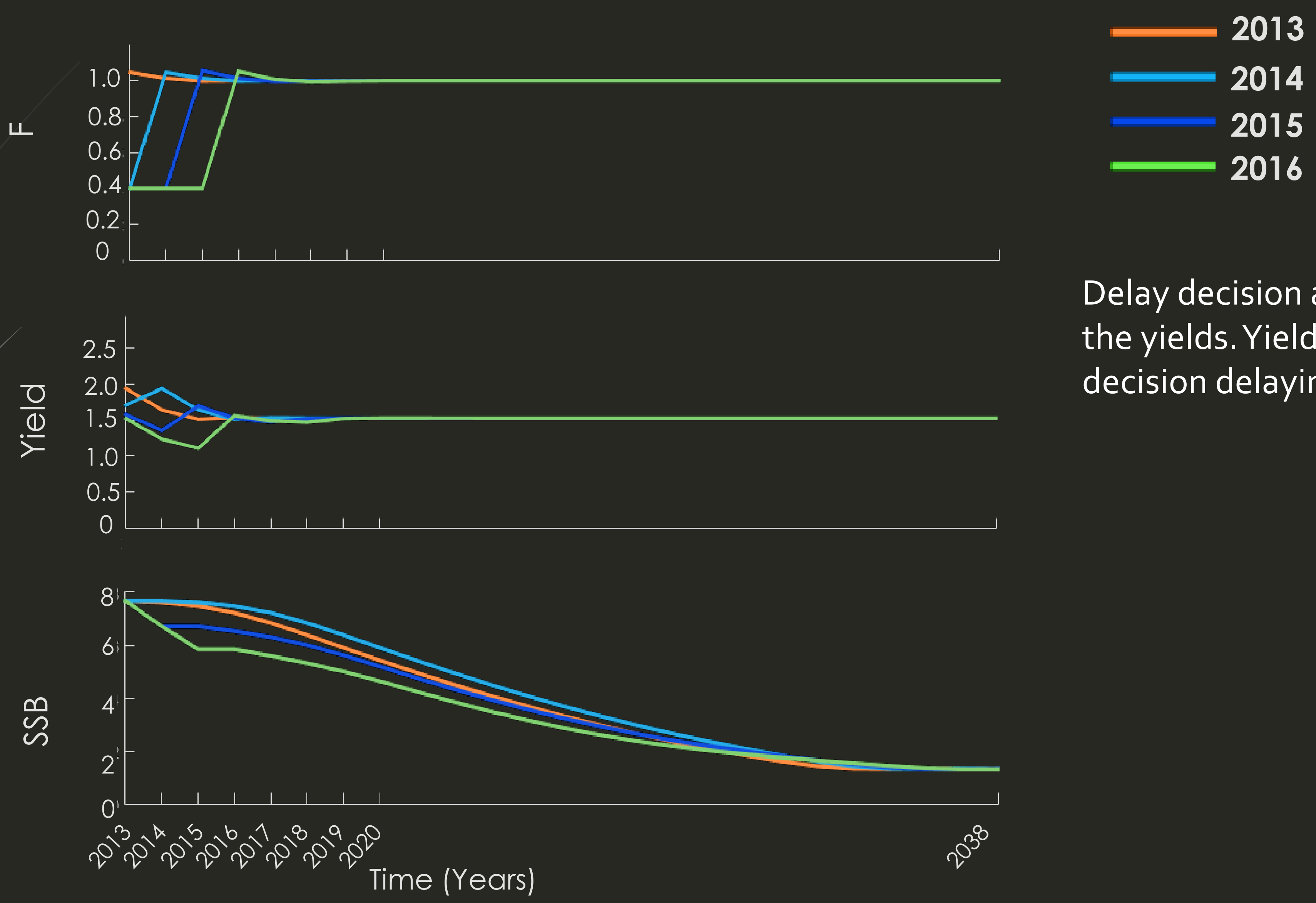
Findings

Mid-recovered population optimal paths



Similar paths that recovered population, but the yields are lower.

Depleted population optimal paths



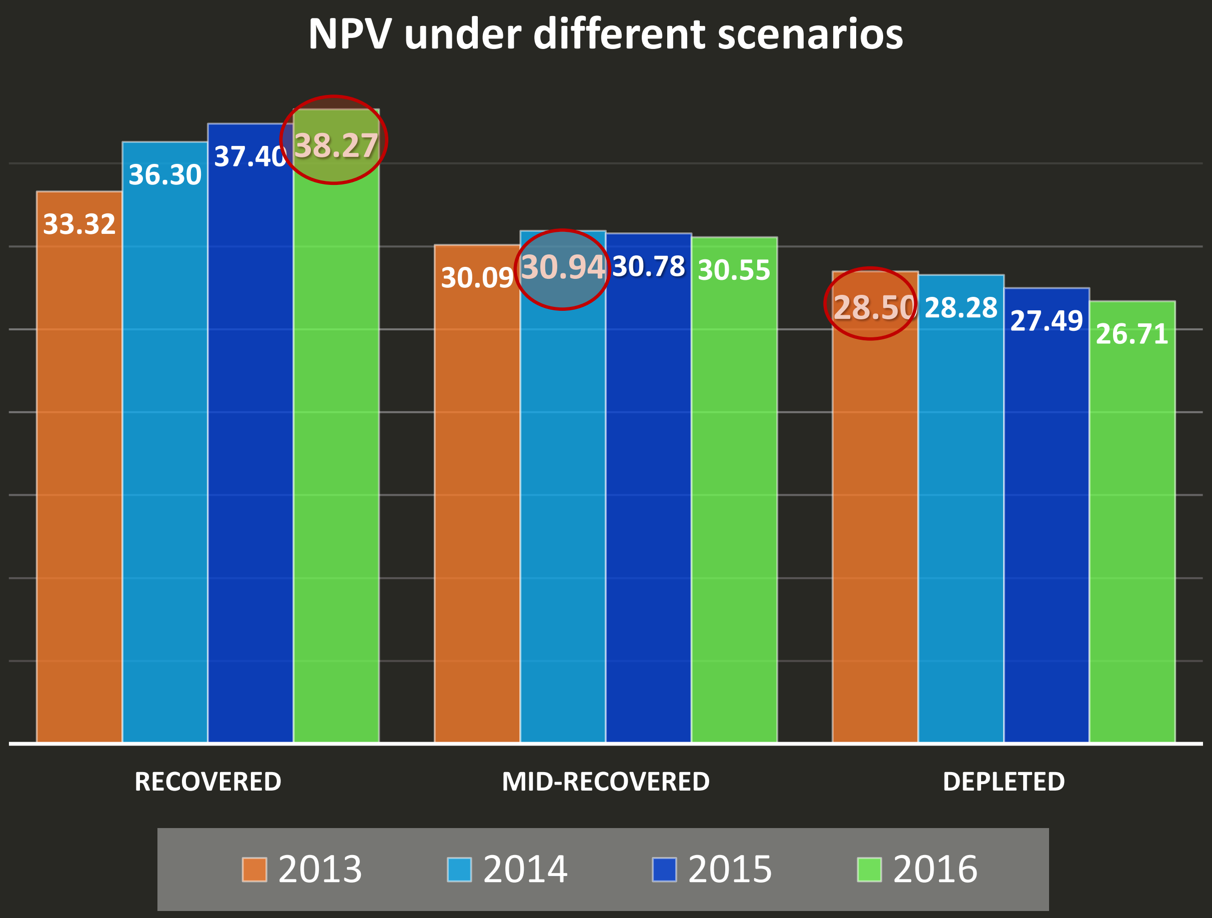
Delay decision affects strongly the yields. Yields are lower as decision delaying.

Net Present Value

- When population is **recovered**, **delay** the regulation **increase NPV**.

- In the case that is **mid-recovered maximum NPV** could be achieved if regulation were implemented **one year** after
- illegal fishery rised.

- If population still depleted **maximum NPV** could be achieved if regulation were implemented since illegal fishing started (2013).



CONCLUSIONS

Until 2014 *Totoaba macdonaldi* population had characteristics to develop sustainable fishery with good yields if this had been well regulated.

Although gillnet reach better yields is not recommendable since is highly depredatory for other species (e.g. marine mammals, sea turtles, elasmobranchs).

Absence of regulation results in income losses.

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