

**Restoration of a Distressed Transboundary Fishery  
Subject to Climate Change—  
a Stochastic Dynamic Investment Game**

by

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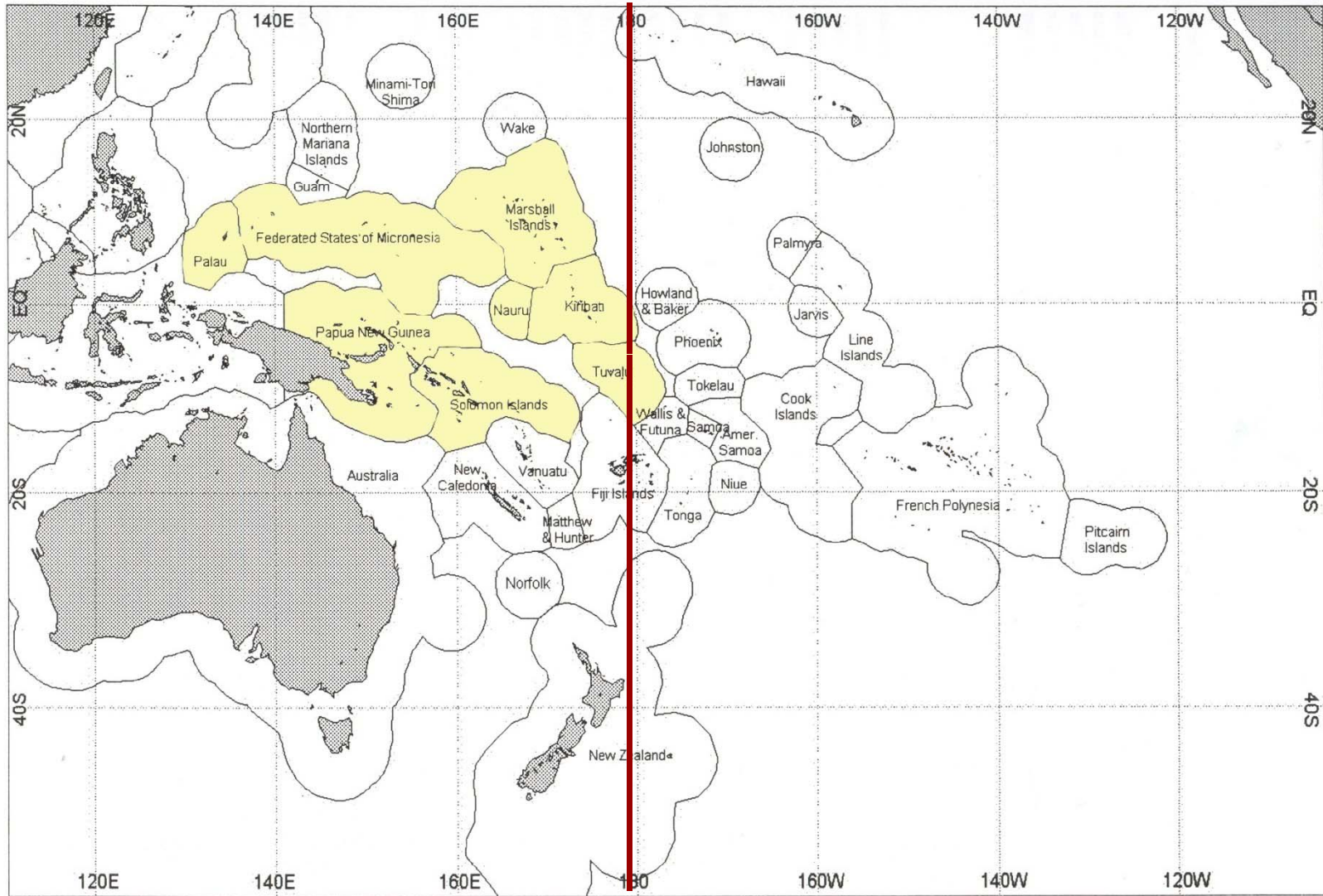
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# EEZs in the Western and Central Pacific



EEZs = Extended Economic Zones of Coastal States

# Single season - stock dynamics

Climatic fluctuations affect stock distribution across 3 areas: 2 coastal EEZs ( $\alpha$  and  $\beta$ ) & one high seas area ( $\gamma$ )

$$\begin{array}{l} \nearrow \\ \mathbf{R} \rightarrow \mathbf{R}_\alpha = \theta_\alpha \mathbf{R} \rightarrow \mathbf{S}_\alpha = \mathbf{R}_\alpha - \mathbf{H}_\alpha \\ \searrow \\ \mathbf{R} \rightarrow \mathbf{R}_\beta = \theta_\beta \mathbf{R} \rightarrow \mathbf{S}_\beta = \mathbf{R}_\beta - \mathbf{H}_\beta \\ \nearrow \\ \mathbf{R} \rightarrow \mathbf{R}_\gamma = \theta_\gamma \mathbf{R} \rightarrow \mathbf{S}_\gamma = \mathbf{R}_\gamma - \mathbf{H}_\gamma \end{array} \rightarrow \mathbf{S} = \mathbf{S}_\alpha + \mathbf{S}_\beta + \mathbf{S}_\gamma = \mathbf{R} - \mathbf{H}_\alpha - \mathbf{H}_\beta - \mathbf{H}_\gamma \rightarrow \mathbf{R}^+ = \mathbf{G}(\mathbf{S})$$

**R** = recruitment, **H** = seasonal harvest, **S** = end-of-season escapement.

# Players' Current Goals

**RFMC:** Specify current-season escapement  $\mathbf{S}$  to increase  $\mathbf{R}^+$ ; This objective is attained indirectly through constraints on current fleets'  $\mathbf{E}_\mu$  and EEZs'  $\mathbf{F}_\nu$ .

Then optimal reduction of the next season's effort capacity  $\mathbf{E}_\mu^+$  is attained through financing vessel buybacks.

**Each EEZ:** Maximizes seasonal payoff  $\sum_\mu [\hat{b}_{\mu\nu} \mathbf{E}_{\mu\nu} + \hat{c}_{\mu\nu} \mathbf{F}_{\mu\nu}]$  by discriminatory allocation of  $\mathbf{F}_{\mu\nu}$  and taxation of  $\mathbf{E}_{\mu\nu}$  and  $\mathbf{F}_{\mu\nu}$ .

**Each fleet:** Maximizes

$$\sum_\nu [p_\nu \mathbf{H}_{\mu\nu}(\mathbf{E}_{\mu\nu}, \mathbf{F}_{\mu\nu}) - (b_{\mu\nu}^\circ + \hat{b}_{\mu\nu}) \mathbf{E}_{\mu\nu} - (c_{\mu\nu}^\circ + \hat{c}_{\mu\nu}) \mathbf{F}_{\mu\nu}],$$

conditional on quantity constraints and tax rates imposed by the RFMC and EEZs, and actions of the competing national fleets

# The Players and their In-Season Actions

Fleets:  $\mu = 1, 2$ ; and EEZ Regions:  $\alpha$  and  $\beta$ , and High Seas ( $\gamma$ );  
and Management Commission (RFMC)

## RFMC ACTIONS:

Specifies end-of-season escapement  $\mathbf{S}$  and sets quantity constraints (consistent with  $\mathbf{S}$ ):

On effort: Fleet effort-capacity  $\mathbf{E}_\mu \leq \bar{\mathbf{E}}_\mu$  and/or EEZ effort-time  $0 \leq \mathbf{F}_\nu \leq \bar{\mathbf{F}}_\nu$

and on royalty rates:  $\hat{b}_{\mu\nu} \leq \bar{b}_{\mu\nu}$  and/or  $\hat{c}_{\mu\nu} \leq \bar{c}_{\mu\nu}$

## COASTAL EEZ'S ACTIONS:

Distributes seasonal effort-time  $\bar{\mathbf{F}}_\nu$  among fleets, and imposes discriminatory royalty rates:

For  $\nu = \alpha$  or  $\beta$ , choose  $\mathbf{F}_{1\nu} + \mathbf{F}_{2\nu} \leq \bar{\mathbf{F}}_\nu$ , (where  $\mathbf{F}_{\mu\nu} \leq \mathbf{E}_{\mu\nu} \mathbf{T}_\nu$ )

and set unit royalty rates  $\hat{b}_{\mu\nu}$  on  $\mathbf{E}_{\mu\nu}$  and/or  $\hat{c}_{\mu\nu}$  on  $\mathbf{F}_{\mu\nu}$

## INDIVIDUAL FLEET'S ACTIONS:

Distributes its active effort capacity among regions:

For  $\mu = 1$  and  $2$ ,  $\mathbf{E}_\mu = \mathbf{E}_{\mu\alpha} + \mathbf{E}_{\mu\beta} + \mathbf{E}_{\mu\gamma}$ ;

and choose seasonal effort-time  $\mathbf{F}_{\mu\nu} \leq \bar{\mathbf{F}}_{\mu\nu}$ , where  $\mathbf{F}_{\mu\nu} \leq \mathbf{E}_{\mu\nu} \mathbf{T}_\nu$ .

# Single Season of the Dynamic Game

A Three-Stage subgame-perfect Nash Equilibrium (NE)

Actions	Players	Analysis
Given $\mathbf{R}$ , choose $\bar{\mathbf{E}}_\mu, \bar{\mathbf{F}}_\nu$ for desired $\mathbf{R}^+$	RFMO	Knows EEZs, Fleets reaction to $\bar{\mathbf{E}}_\mu, \bar{\mathbf{F}}_\nu$
$\Downarrow$		$\Uparrow$
Given $\bar{\mathbf{E}}_\mu, \bar{\mathbf{F}}_\nu$ sites choose $\hat{b}_{\mu\nu}, \hat{c}_{\mu\nu}$ , and $\bar{\mathbf{F}}_{\mu\nu}$ for site NE	Sites	Sites know Fleets' reaction to $\bar{\mathbf{E}}_\mu, \bar{\mathbf{F}}_{\mu\nu}, \hat{b}_{\mu\nu}, \hat{c}_{\mu\nu}$
$\Downarrow$		$\Uparrow$
Given $\bar{\mathbf{E}}_\mu, \bar{\mathbf{F}}_{\mu\nu}$ plus $\hat{b}_{\mu\nu}, \hat{c}_{\mu\nu}$ fleets distribute $\mathbf{E}_{\mu\nu}$ between sites	Fleets	Knowing $\bar{\mathbf{E}}_\mu, \bar{\mathbf{F}}_{\mu\nu}, \hat{b}_{\mu\nu}, \hat{c}_{\mu\nu}$ , fleets arrive at NE

## Information known at beginning of Harvest Season:

$\mathbf{R} = (\mathbf{R}_\alpha, \mathbf{R}_\beta, \mathbf{R}_\gamma)$  and  $\mathbf{E} = (\mathbf{E}_1, \mathbf{E}_2)$  for season  $t$ ;

RFMC specifies

- current  $\mathbf{S}$ ; and Targeted  $\mathbf{R}^+$
- $\mathbf{E}$ -max and its distribution among fleets
- $\mathbf{F}$ -max and its distribution among sites;
- Target  $(\mathbf{F}^+)$ -max+ and its distribution among sites.

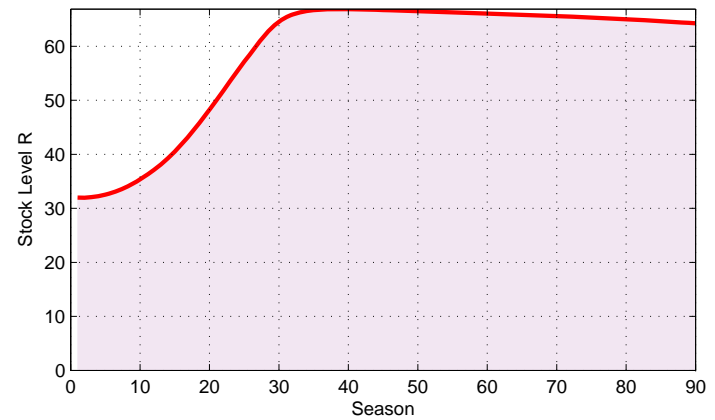
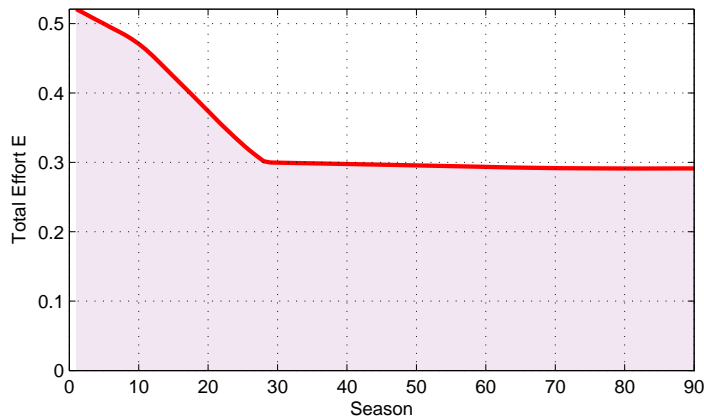
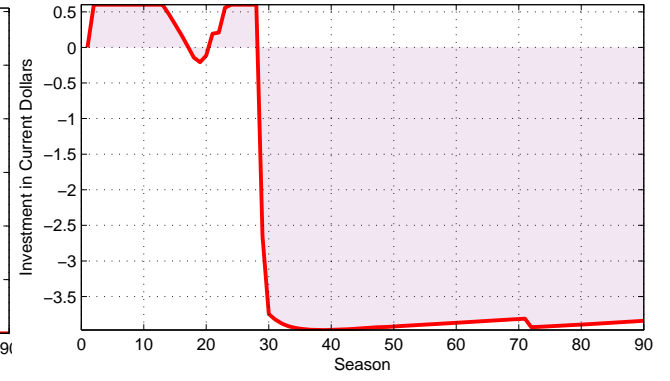
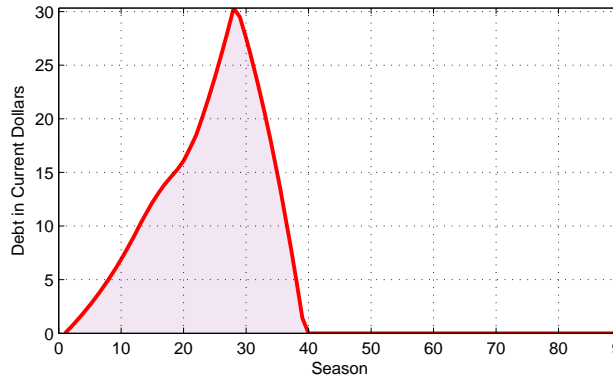
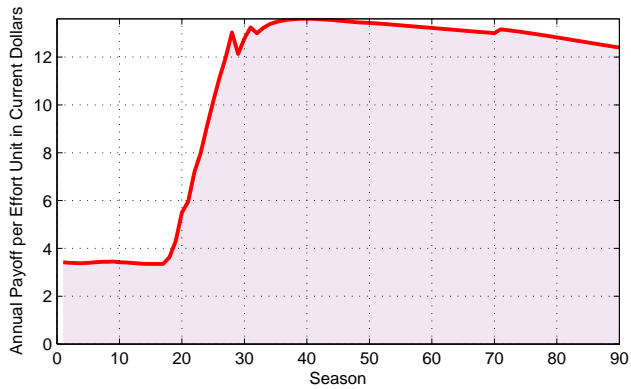
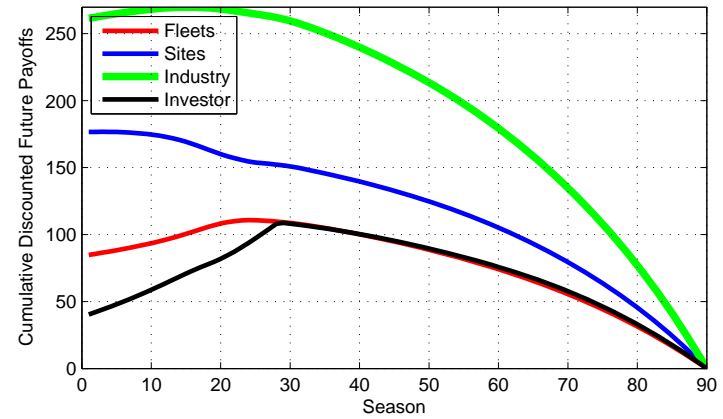
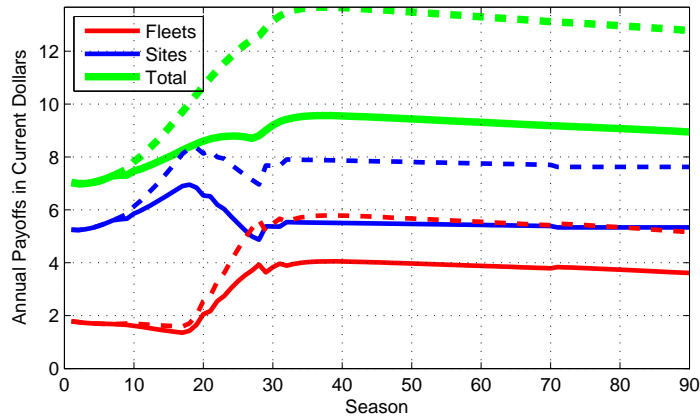
## During Season:

- Fleets and EEZs compete;
- RFMC assigns Fleets'  $\mathbf{F}^+$  quotas and
- launches buyback process, funded by Investors
- Each Fleet negotiates among vessel owners to minimize  $\mathbf{E}_\mu$  for assigned  $\mathbf{F}_\nu$

## Information known at end of season:

- Realized values of  $\mathbf{R}^+$  and
- RFMC specification of constraint up-dated to season  $t+1$

# Buyout with External Investments





# Buyout without External Investments

