ON COUPLED DYNAMICS AND REGIME SHIFTS IN COUPLED HUMAN-WATER SYSTEMS

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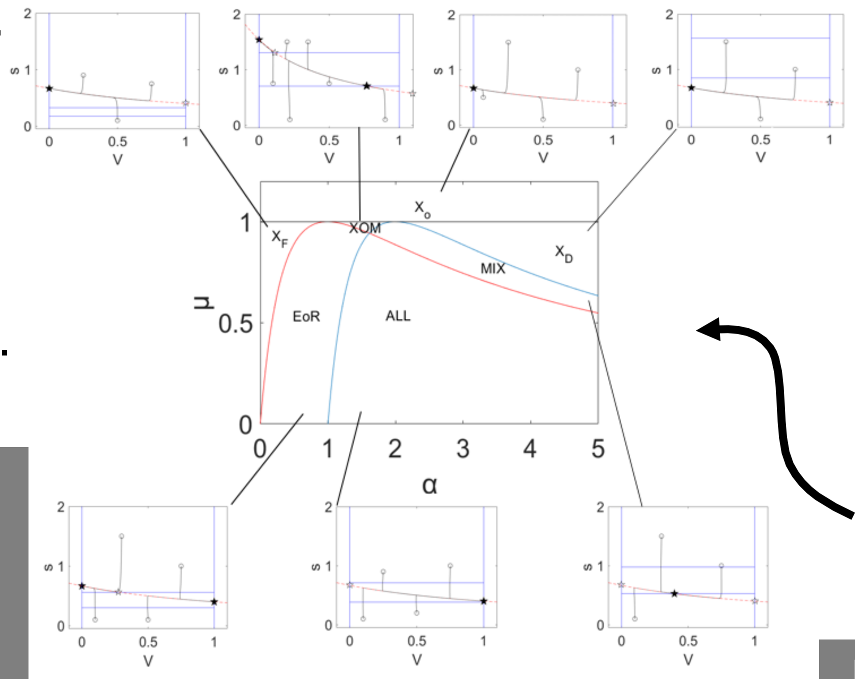


We developed a stylized model that combines hydrological and social dynamics of a generic **coupled human-water system (CHWS).** In this model, The population self-organizes to respond to relative benefits they derive from the water system and outside opportunities. Despite its simplicity, the model yields **different regimes, governed by hydrological and socioeconomic factors.**

HRPO ARL 18-114, ARL 18-115, ARL 18-116

Minimalistic model for a CHWS

A stylized model to capture the key dynamics of a generic CHWS is developed and then…

Rate of change of water storage, *S*

Inflow

Human extraction

Natural loss

$$\frac{dS}{dt} = I - rNVS - lS$$

$$\frac{dV}{dt} = r'V(1-V)(\pi - w)$$

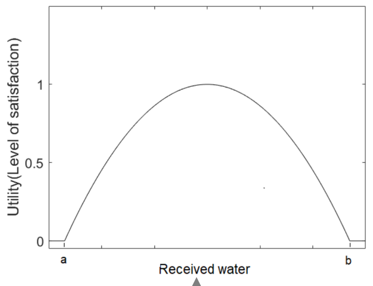
Rate of change in fraction of efforts spent inside system

Replicator dynamics

Payoff difference between inside and outside the system

$$\pi = XpU \quad U = \begin{cases} C'\left(Sr - a'\right)\left(b' - Sr\right), & a' < Sr < b' \\ 0, & \text{Otherwise} \end{cases}$$

Payoff for working inside the system…



…depends on the amount of water received: too little (drought) or too much (flood) is not good.

…simplified via non-dimensionalization.

"Water" eq.

"Human" eq.

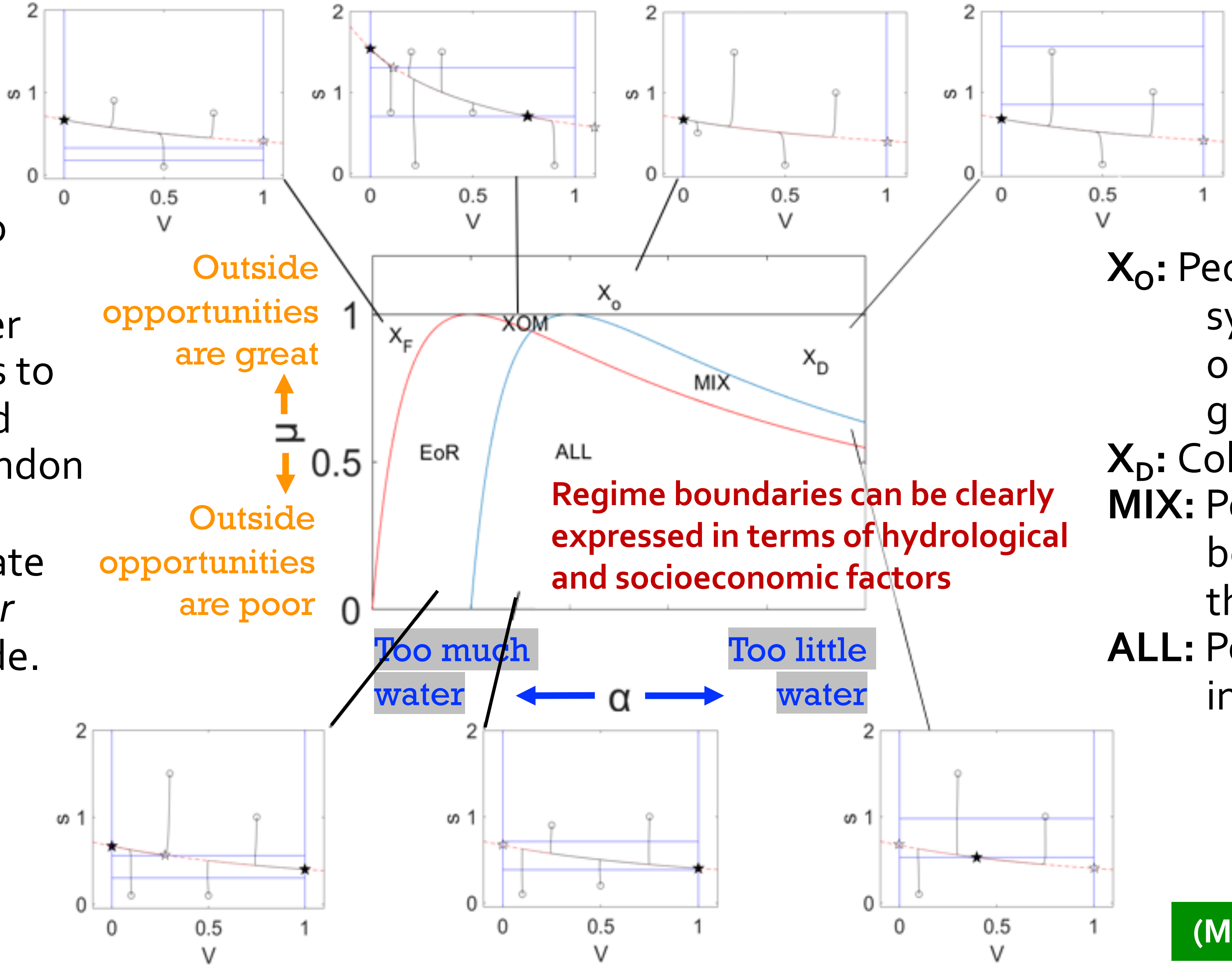
$$\frac{ds}{d\tau} = 1 - Vs - \alpha s$$

$$\frac{dV}{d\tau} = \beta V(1-V)(U - \mu)$$

Dimensionless groups	Mathematical Definitions	Interpretation
s	SNr/I	Re-scaled S
τ	rNt	Re-scaled t
μ	w/Xp	Relative benefit of outside opportunities compared to the maximum payoff inside the system
α	l/Nr	Relative natural loss rate compared to the withdrawal rate
β	$r'Xp/Nr$	Responsiveness of a water user to the associated payoff
a	$a'N/I$	Re-scaled a' indicating the lower threshold below which the level of satisfaction is zero
b	$b'N/I$	Re-scaled b' indicating the upper threshold above which the users are no longer satisfied
C	$C'I^2/N^2$	Re-scaled C' for dimensional consistency

Simple, but rich: 7 regimes

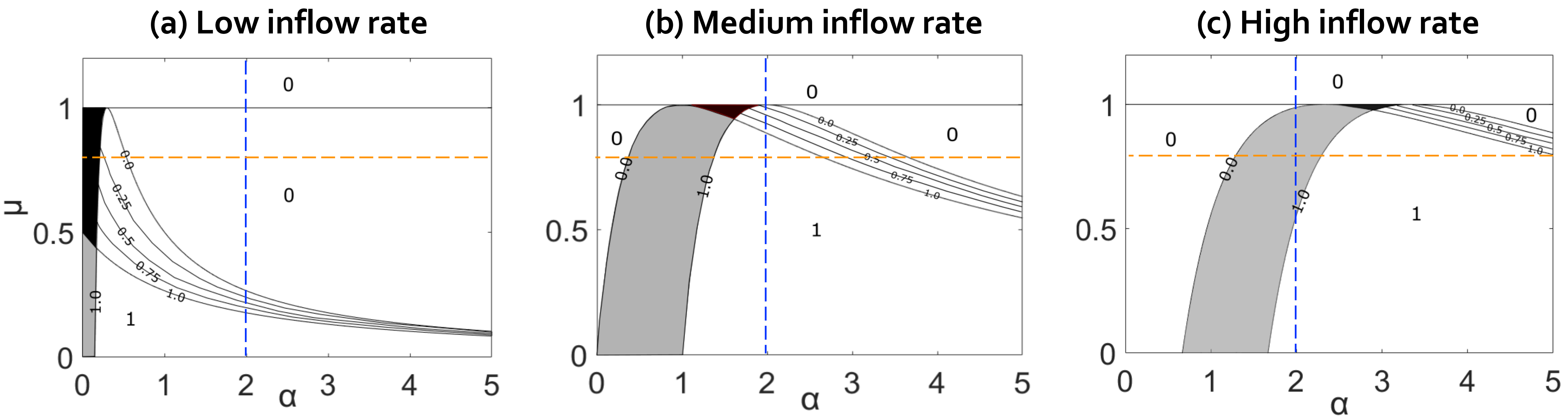
X_F: Collapse due to floods
XOM: People either allocate efforts to both inside and outside or abandon the system
EOR: People allocate efforts to *either* inside *or* outside.



X_O: People abandon the system because outside opportunities are too great
X_D: Collapse due to droughts
MIX: People allocate efforts to both inside and outside the system
ALL: People invest all efforts in working the system

(More details on Slide 5)

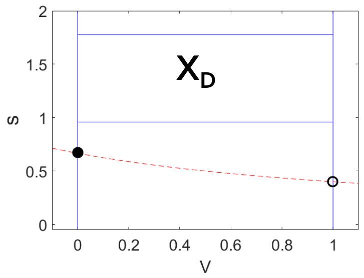
Climate change changes regime patterns

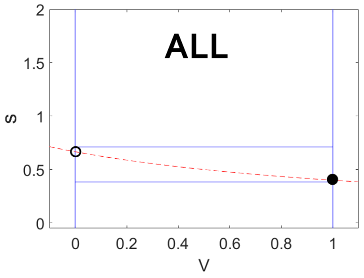


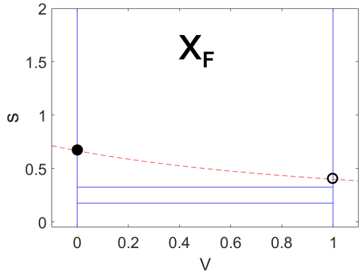
These are **contours of *V****,** fraction of efforts spent inside the system, which can be thought of as a proxy of migration: **lower *V**implies greater out-migration.** The black and gray areas correspond to the XOM and EOR regimes, both of which have two stable equilibrium points—which one the system would gravitate toward depends on the system's history. As the inflow rate is altered, the system can undergo transition to a different regime. Such transition has consequences (e.g., the changes in migration patterns implied by changes in *V**)

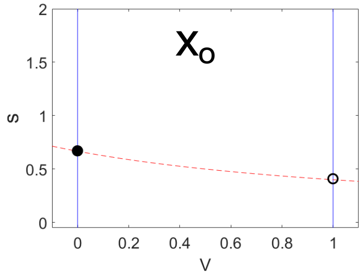
Clear understanding of such regime boundaries (thresholds) derived from this simple model contributes to insights on how one might cope with a complex socio-hydrological system under change.

Additional details on the equilibrium points









Regime	Stability	V^*	s^*
X_D	●	0	$1/\alpha$
	○	1	$1/(1+\alpha)$
MIX	○	0	$1/\alpha$
	●	$\frac{1}{s^*}-\alpha$	$\frac{1}{2}\left(a+b-\sqrt{(a-b)^2+\frac{4\mu}{C}}\right)$
	○	1	$1/(1+\alpha)$
ALL	○	0	$1/\alpha$
	●	1	$1/(1+\alpha)$
EoR	●	0	$1/\alpha$
	○	$\frac{1}{s^*}-\alpha$	$\frac{1}{2}\left(a+b+\sqrt{(a-b)^2+\frac{4\mu}{C}}\right)$
	●	1	$1/(1+\alpha)$
X_F	●	0	$1/\alpha$
	○	1	$1/(1+\alpha)$
XOM	●	0	$1/\alpha$
	○	$\frac{1}{s^*}-\alpha$	$\frac{1}{2}\left(a+b-\sqrt{(a-b)^2+\frac{4\mu}{C}}\right)$
	●	1	$1/(1+\alpha)$
	○	$\frac{1}{s^*}-\alpha$	$\frac{1}{2}\left(a+b+\sqrt{(a-b)^2+\frac{4\mu}{C}}\right)$
X_0	●	0	$1/\alpha$
	○	1	$1/(1+\alpha)$