Modelling to regionalise the safe and just operating spaces concept for the Chilika lagoon fishery, India

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Model rationale

Chilika's fishery is valued at US$25 million annually, supporting 35,000 fishers and 200,000 secondary dependents[1]. However, Chilika has a legacy of productivity collapse, having transitioned from 7200 tonnes/year (1980s average) to 3100 tonnes/year (1990s average), affecting various aspects of the fishery system, including fisher income[2], export levels[3] and migration from the Chilika region[4]. Despite recovery after the opening of the new tidal outlet in 2000, the future of the fishery is uncertain under natural and socioeconomic changes. Drivers of Chilika's fishery are projected into the future to explore causes of productivity collapse and design pathways to a "regional safe and just operating space"[5] (RSJOS).

Model purpose and structure

A system dynamics model (SDM) integrates natural and human determinants of Chilika's monthly fish catch (figure 1). Freshwater and sediment inputs influence Chilika's ecohydrological conditions, which modify fish survival and the annual migration of 70% of Chilika's stock through the tidal outlet to the Bay of Bengal (Fig.1-green feedback). Non-motorised and motorised fleets extract from Chilika's mature and juvenile fish stocks. Four key socioeconomic feedbacks exist: (i) Fisher populations are limited by a carrying capacity, equalling the number of livelihoods Chilika's production can support (Fig.1-blue); (ii) relatively 'affluent' traditional fishers can purchase motorised boats (Fig.1-red), (iii) fish abundance positively influences days fished (Fig.1-green), but (iv) effort losses are compensated by increased juvenile extractions (Fig.1-orange).

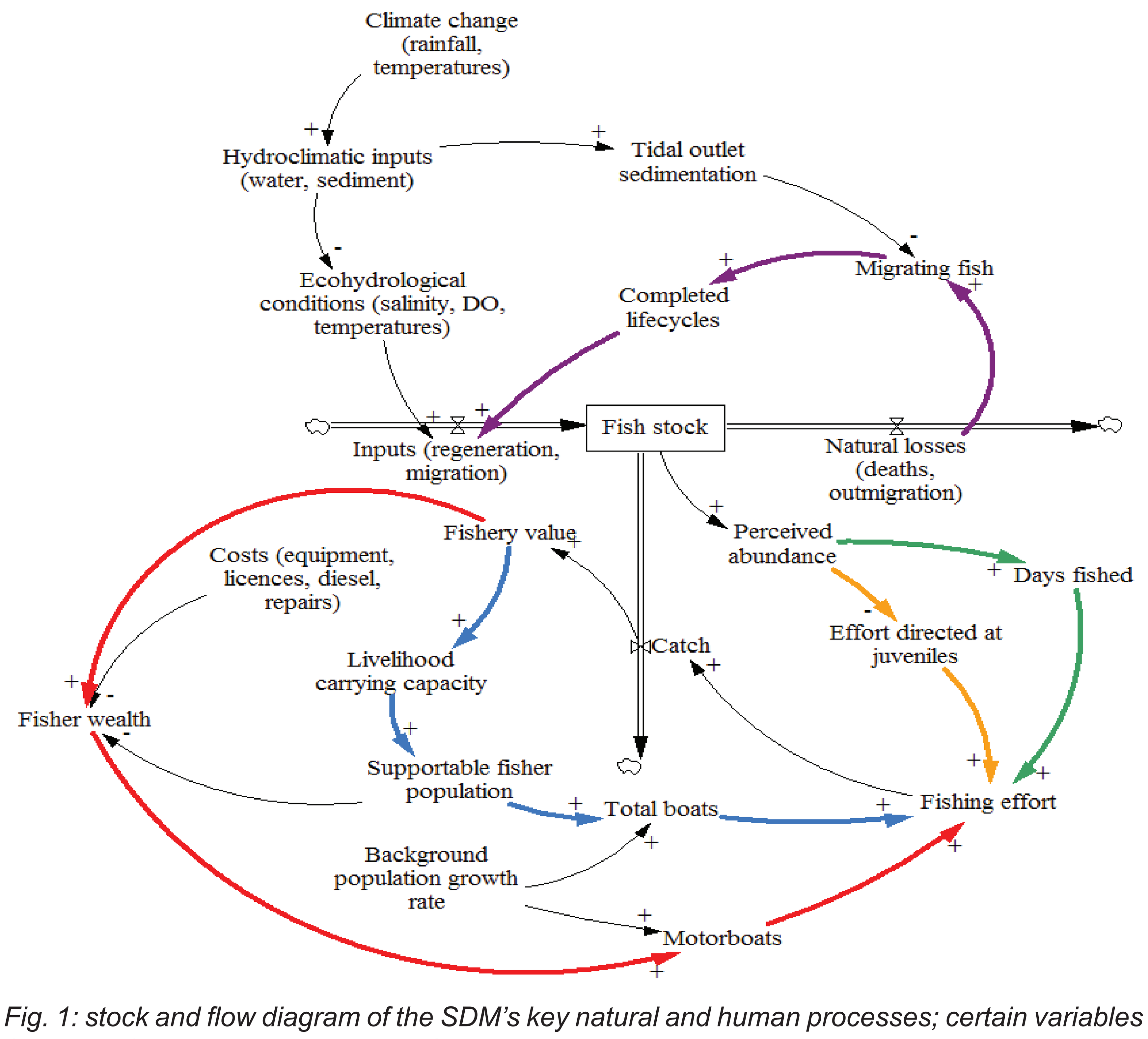

Fig. 1: stock and flow diagram of the SDM's key natural and human processes; certain variables (e.g. costs) have been aggregated for brevity.

Designing plausible futures

The SDM is parameterised to explore future dynamics under an array of external driver trajectories and regional governance scenarios. 'Safe' (2050-60 fish catch averages between max. sustainable yield bounds), 'dangerous' (economic value of catch unable to support fisher population) and 'cautionary' fish catches are identified, in order to classify corresponding driver trajectories and critical thresholds between states.

External driver	Plausible range	Unit	Source
Rainfall	[0 - +20] by 2100	%	IPCC (2014)
Temperature	[0 - +4] by 2100	°C	as above
Fish price	[0 – 30]	INR / kg / year	CDA data historical maximum inter-annual increase
Diesel price	[0 – 7]	INR / litre / year	as above
Birth-death rates (Malthusian's 'r')	[0 – -2.20]	% / year	Induce stable population by 2060

Policy scenario	Description
Only tidal outlet maintained (OM)	Outlet dredged every 10-15 years to rejuvenate fish migration and ecological conditions
Outlet maintenance and fishing bans (OB)	From 2025, fishing within the 70 km^2 outlet is banned. Fishing effort falls by ~7%; assuming efforts are homogenous across Chilika.
Outlet maintenance, bans and alternative livelihoods (OL)	From 2017, fishers from both traditional and motorised stocks are removed at a rate of 0.05% / month (total = 1 in 1000 / month)

Fishery production outputs

The model is run 1000 times per policy to capture many combinations of internal and external driver trajectories. Outputs argue that system resilience and sustainability increase with policy interventions.

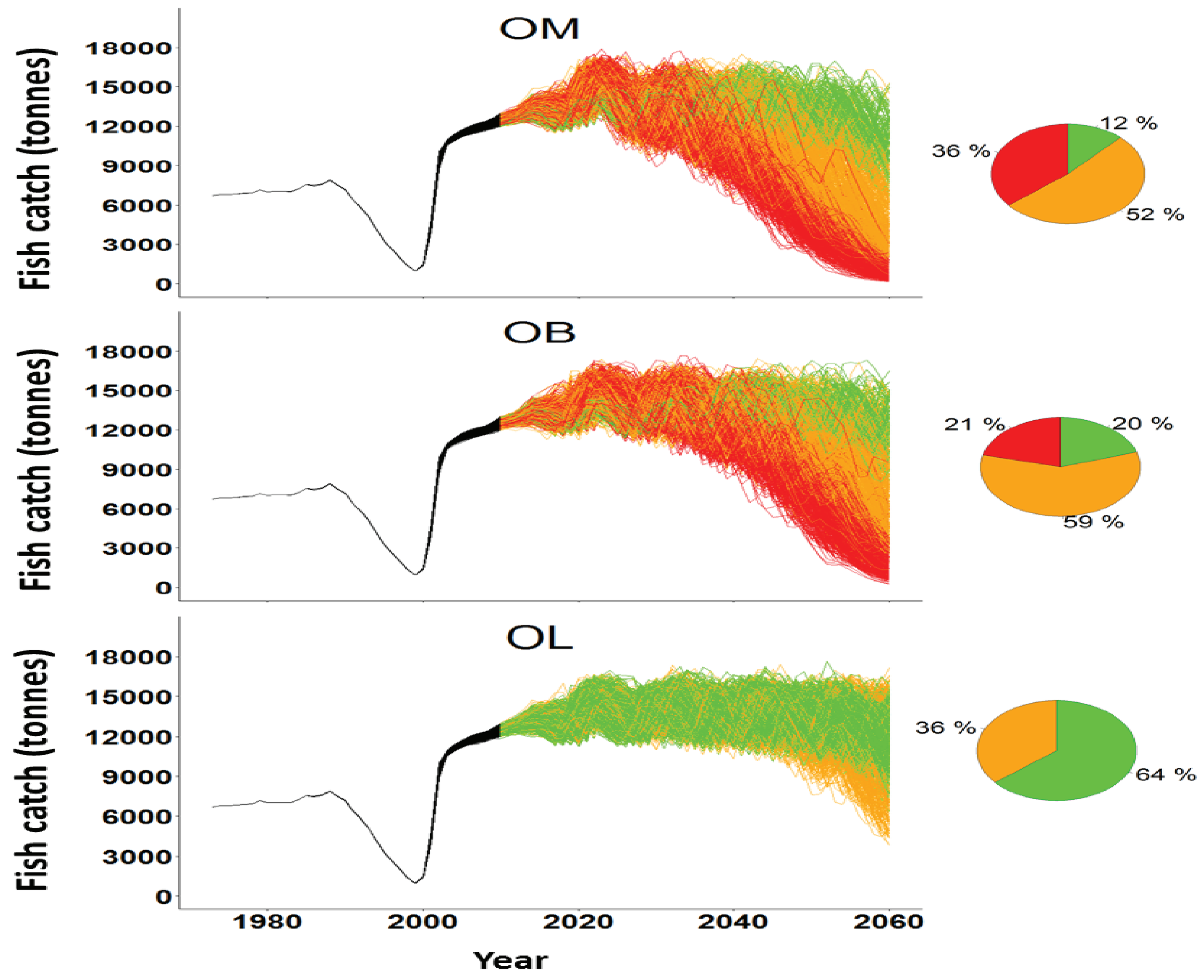

Fig. 2: plausible future fish catches under the three governance scenarios. Key: historical- black, green- safe and just, orange- cautionary, red- dangerous.

Chilika's safe and just operating spaces

Identifying limits of regional systems facilitates threshold-based management to guard against undesirable conditions[6]. Model outputs are traced back to their underlying driver pathways to design multidimensional pathways for system governors to follow towards sustainable futures.

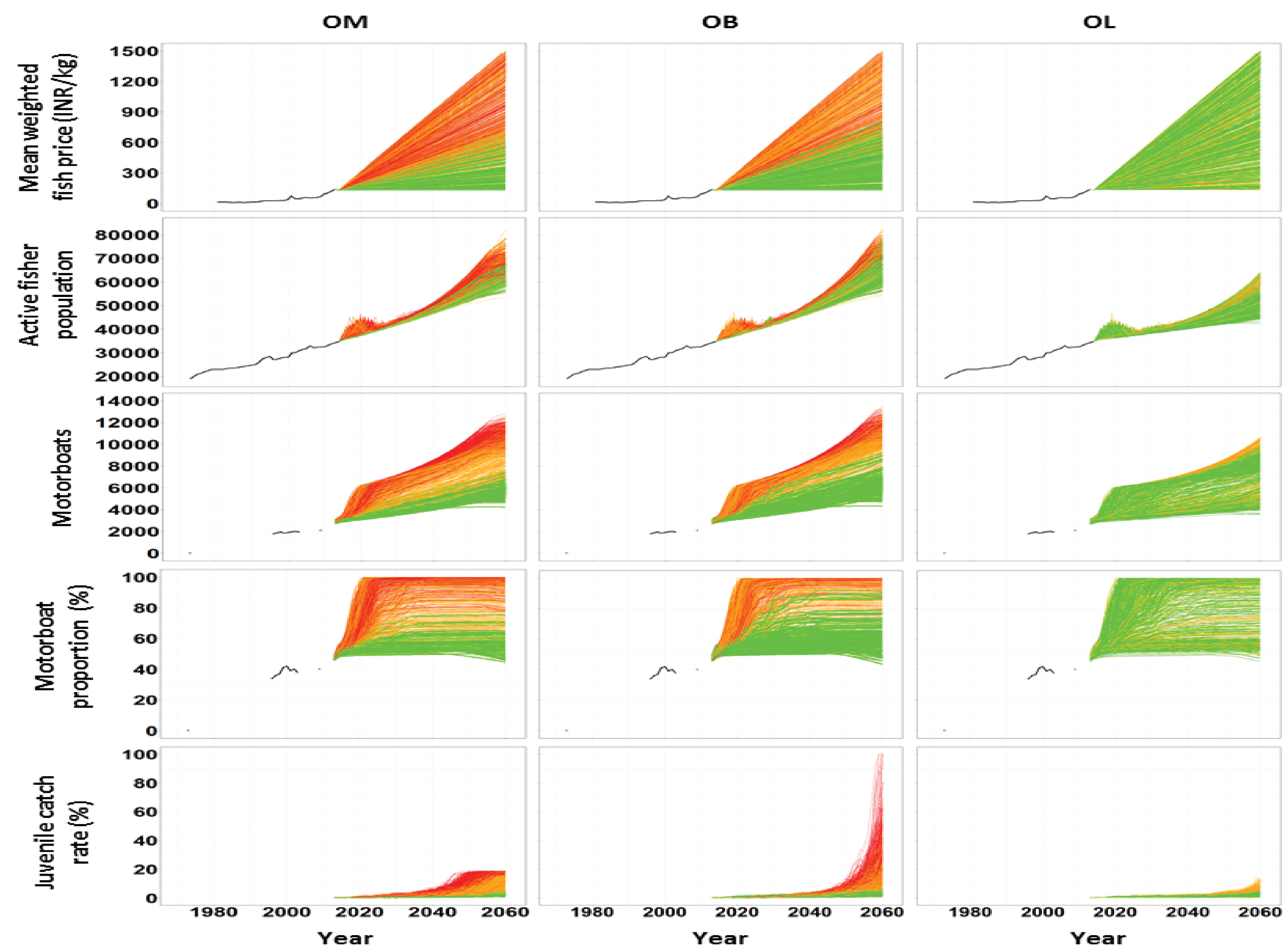

Fig. 3: Five socioeconomic driver trajectories causing the catch outputs of the governance scenarios (Fig. 2). Key: historical- black, green- safe and just, orange- cautionary, red- dangerous.

The system is vulnerable to overexploitation once the tidal outlet is periodically maintained to stabilise natural conditions. This represents a novel shift for Chilika, away from complete dependence on natural dynamics. In general, nonlinear rates of population growth and motorboat use are precursors for unsafe catch outputs. The range of safe trajectories increases with regulatory governance, with safe and just futures possible across the entire arrays of fish price and total boats under OL. These findings ultimately (i) present a method to project and visualise a multidimensional RSJOS (ii) suggest limits to guide multidecadal system stewardship (iii) advocate transitional governance of a common-pool resource to increase the resilience of pathways leading to safe and just futures.

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References: [1]Mohapatra et al 2007 *Wetlands Ecol Manage*; [2]Nayak 2014 *Ecol Soc*, [3]Kadekodi & Gulati *CMDR Mono Series 26;* [4]Robson & Nayak 2010 *Pop & Env;* [5]Dearing et al 2014 *Glob Environ Change;* [6]Kelly et al 2015 *Phil Trans Royal Soc B; IPCC 2014 AR5*