Exploring the social-ecological sustainability of the Chilika lagoon fishery using system dynamics modelling

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Model rationale

The Chilika Lagoon of the southern Mahanadi delta provides ecosystem services for ~800,000 people[1], underpinning regional food and livelihood securities. These socio-economic factors and dynamic biophysical processes (e.g. freshwater and sediment influx, salinity, aquatic macrophytes) drive interannual variability in Chilika's fish catch levels.

Three breakpoints[2] divide the last 60-yrs of production into distinct regimes (fig.1). The 1990s decline affected various aspects of the fishery system, including fisher income[1], export levels[3] and migration from the Chilika region[4]. Despite recovery after the opening of a new tidal outlet in 2000, the future persistence of the fishery is uncertain under plausible scenarios of climatic, socio-economic and governance changes.

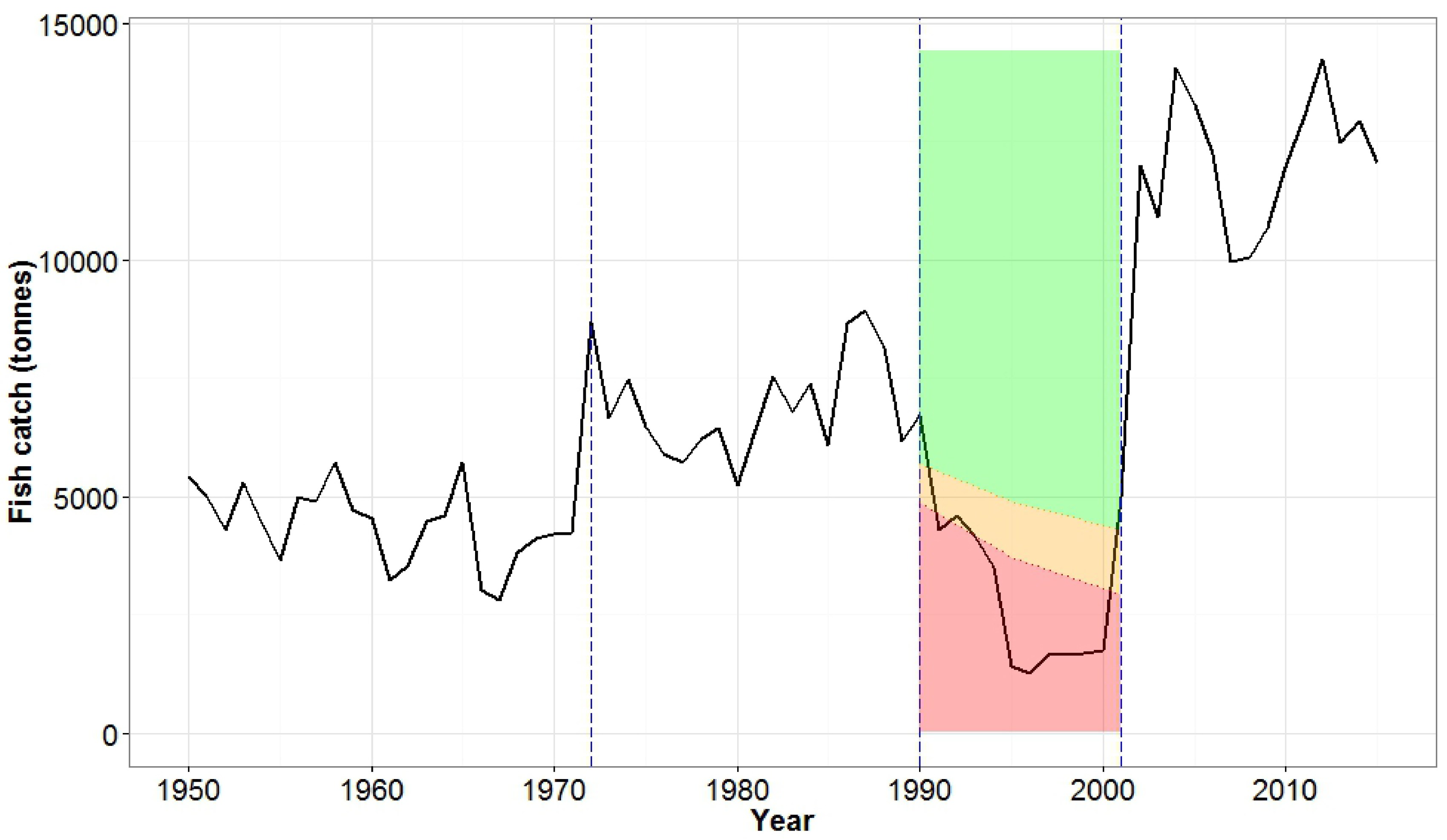


Fig.1: breakpoint analysis of reported Chilika fish catches since 1950 and ARIMA (0,1,1) analysis of the 1990s collapse. Dashed lines represent timeseries breakpoints ($p<0.05$). ARIMA key: green- within ARIMA forecast range, orange- beyond 80% CI, red- beyond 95% CI.

Model purpose and structure

A system dynamics model explores natural and human determinants of Chilika's monthly fish catch. Freshwater and sediment inputs influence Chilika's eco-hydrological conditions, which modify fish survival. Non-motorised and motorised fleets extract from Chilika's mature and juvenile fish stocks. Three key socio-economic feedbacks exist: (i) days fished is positively influenced by fish abundance (B2); (ii) fisher populations are limited by a livelihood carrying capacity Chilika can support (R3a and R3b); (iii) relatively 'affluent' traditional fishers can purchase motorised boats (B3).

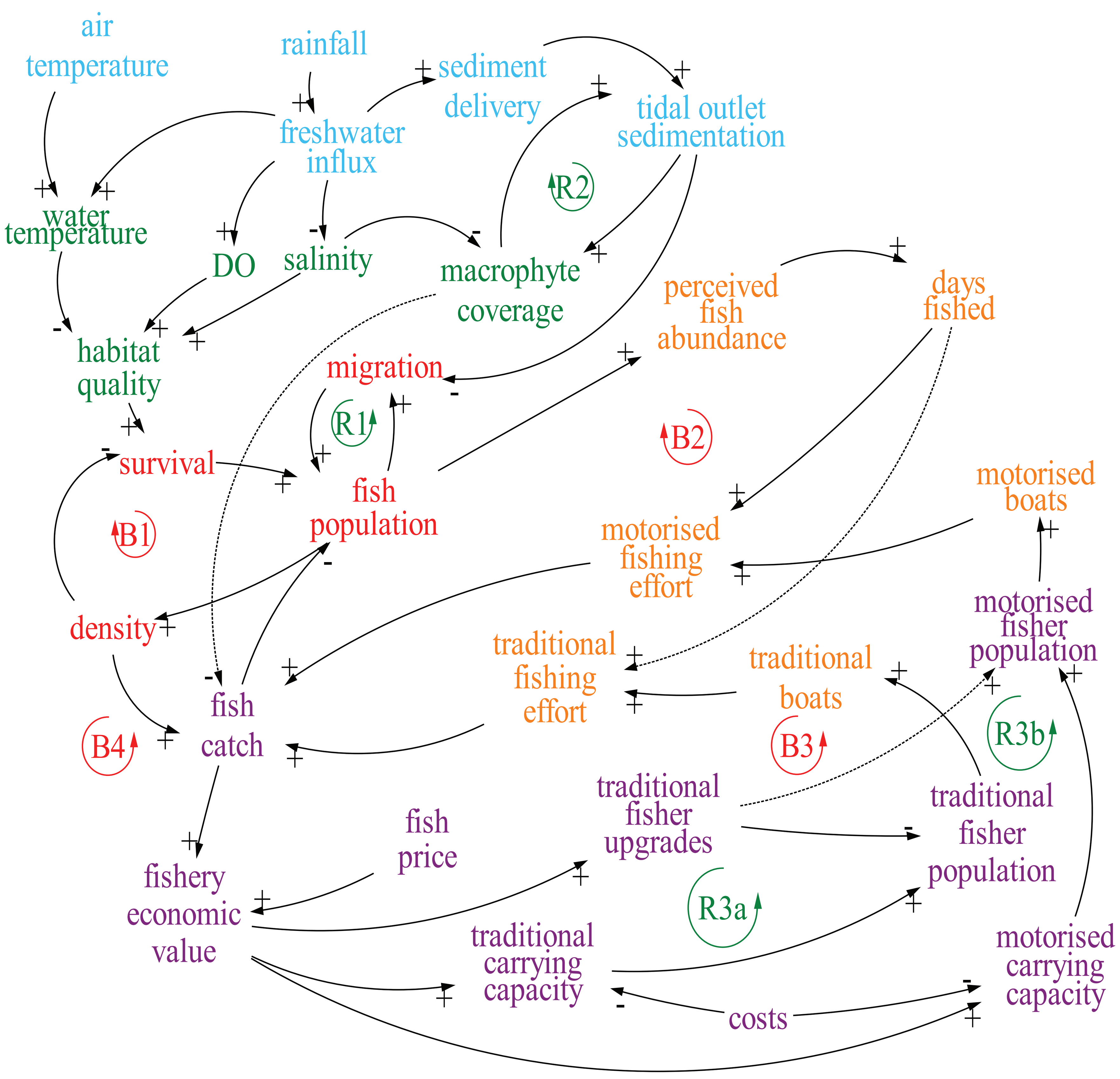


Fig.2: causal-loop diagram of the key natural and human processes; certain variables (e.g. costs) have been aggregated for brevity. Key: blue- hydro-climatic, green- eco-hydrological, red- core fishery, orange- fishing effort, purple- socio-economic.

Initial performance analysis

The SDM has undergone qualitative (unit consistency, structural reality and dataset reliability) and quantitative assessment[5] (behaviour reproduction, extreme test and sensitivity analysis). The modelled fishery output shows good coherence with observations (figure 3), whilst Chilika's fish stock is found insensitive to individual parameters.

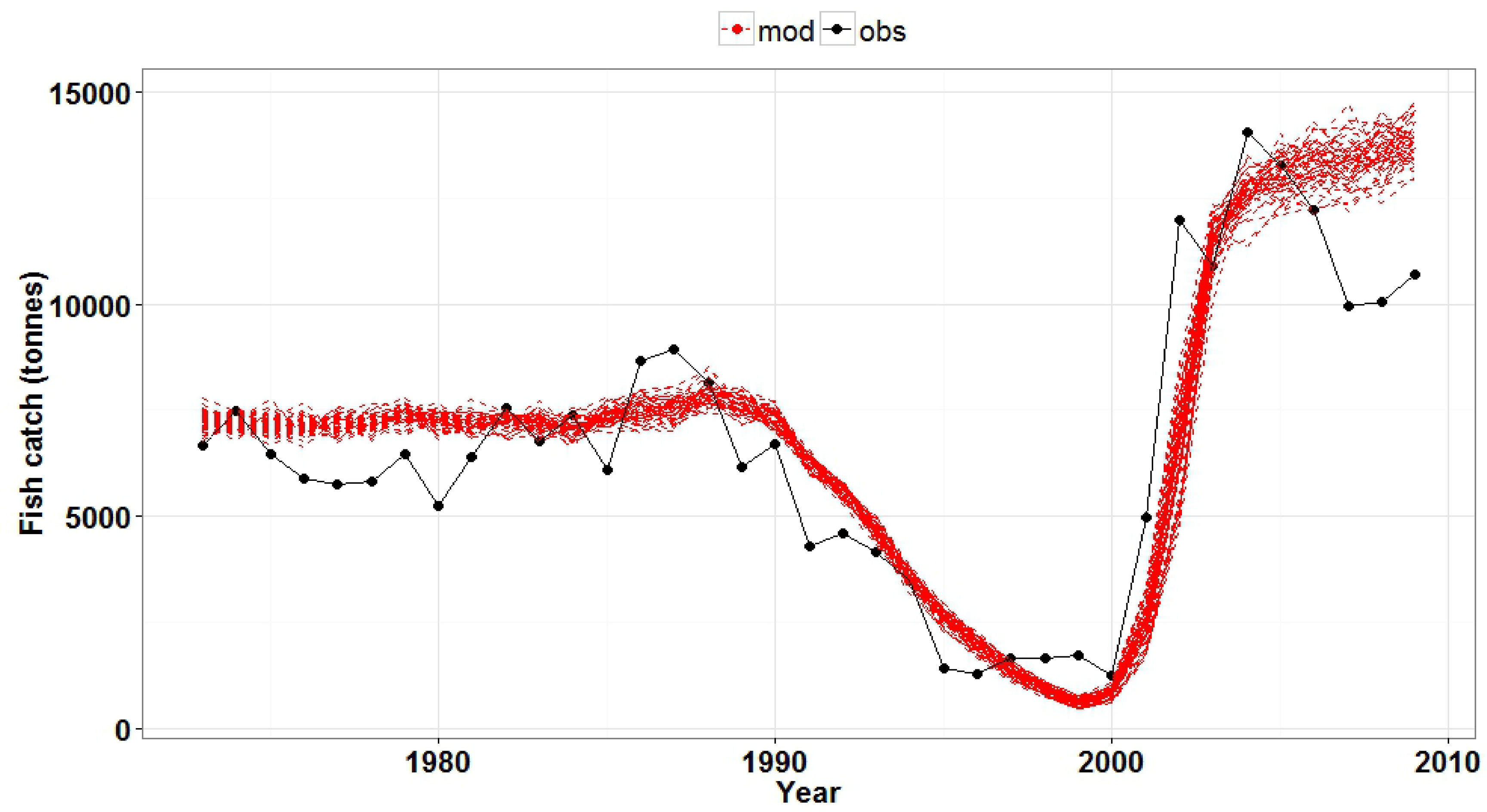
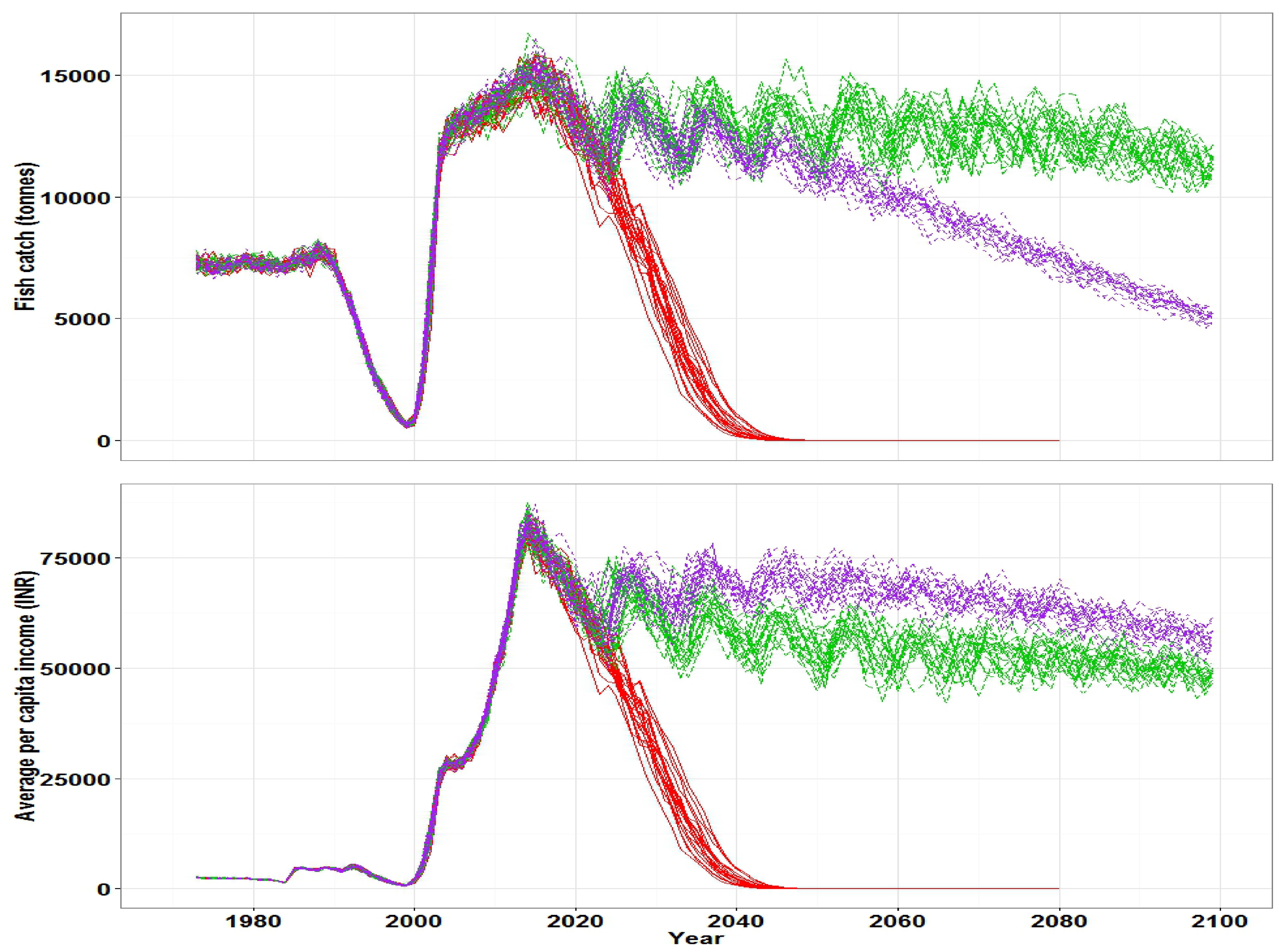


Figure 3: coherence between 50 simulations and observations, including two stochastic variables varying between known minimums and maximums: (i) proportion traditional fishers willing to upgrade [0: max. afford upgrades], (ii) average fishers per boat [3.5 to 5]. Coherence measures of average simulated: $R^2 = 0.801$ ($p<0.05$), MPE= -6.47%, RMSE=1650 tonnes.

Simulating plausible futures

Knowing the SDM is structurally sound, fairly insensitive and producing realistic behaviours, scenarios can assess the future state of Chilika's fishery (2009-2100). Future climatic inputs are sampled from observed probability distribution functions of each month and external socio-economic variables (e.g. fish price) continue gradients of the last ten years.

Scenarios (colours match graphs below)		Alternative livelihood uptake	
		0	$\frac{1}{1000}$ fishers from 2020
Outlet sedimentation	no maintenance	red	-
	maintained at 1970s level	green	purple



Chilika's tidal outlet maintenance should be prioritised to avoid collapse. The uptake of alternative livelihoods gradually declines catch rates in a healthy lagoon, but average income remains high. This suggests a policy dilemma between higher annual production rates and improved fisher livelihood conditions, which correspond to lower harvest stresses on Chilika's resource. Future modelling efforts will investigate multiple plausible (e.g. seasonal bans, climate change) and desirable futures[6] (e.g. MSY), to assess whether fishery collapses correspond to certain natural or human conditions, aiding the design of a safe operating space for Chilika.

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References: [1]Nayak 2014 *Ecol Soc*; [2]Zeileis 2015 *cran r-project [online];* [3]Kadekodi & Gulati *CMDR Mono Series 26;* [4]Robson & Nayak 2010 *Pop & Env;* [5]Sterman 2000 *Business Dynamics [book];* [6]Bai et al 2016 *Glob Env Change.*