

SocModelAnalysis

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Function:

$$\begin{aligned}\frac{dF_1}{dt} &= r_1 F_1 (1 - F_1) - \frac{h_1 * F_1 (1 - X_1)}{F_1 + s_1} - i_2 F_1 + i_1 F_2 \\ \frac{dF_2}{dt} &= r_2 F_2 (1 - F_2) - \frac{h_2 * F_2 (1 - X_2)}{F_2 + s_2} - i_1 F_2 + i_2 F_1 \\ \frac{dX_1}{dt} &= k_1 X_1 (1 - X_1) [\frac{1}{F_1 + c_1} - \omega_1 + d_1 (2X_1 - 1) + \rho_1 (2X_2 - 1)] \\ \frac{dX_2}{dt} &= k_2 X_2 (1 - X_2) [\frac{1}{F_2 + c_2} - \omega_2 + d_2 (2X_2 - 1) + \rho_2 (2X_1 - 1)]\end{aligned}$$

Table 1: Default parameter values used in this analysis

Parameter	Population_1	Population_2	Def
r	0.35	0.35	Fish net growth
s	0.8	0.8	Supply and demand
h	0.5	0.5	Harvesting efficiency
k	1.014	1.014	Social learning rate
ω	0.35	0.35	Conservation cost
c	1.5	1.5	Rarity valuation
d	0.5	0.5	Social norm strength (within pop)
i	0.2	0.2	Fish immigration (from patch)
ρ	0.5	0.5	Social norm strength (opposite pop)

Table 2: Starting values used in this analysis

Parameter	Population_1	Population_2
F	0.406	0.406
X	0.240	0.240

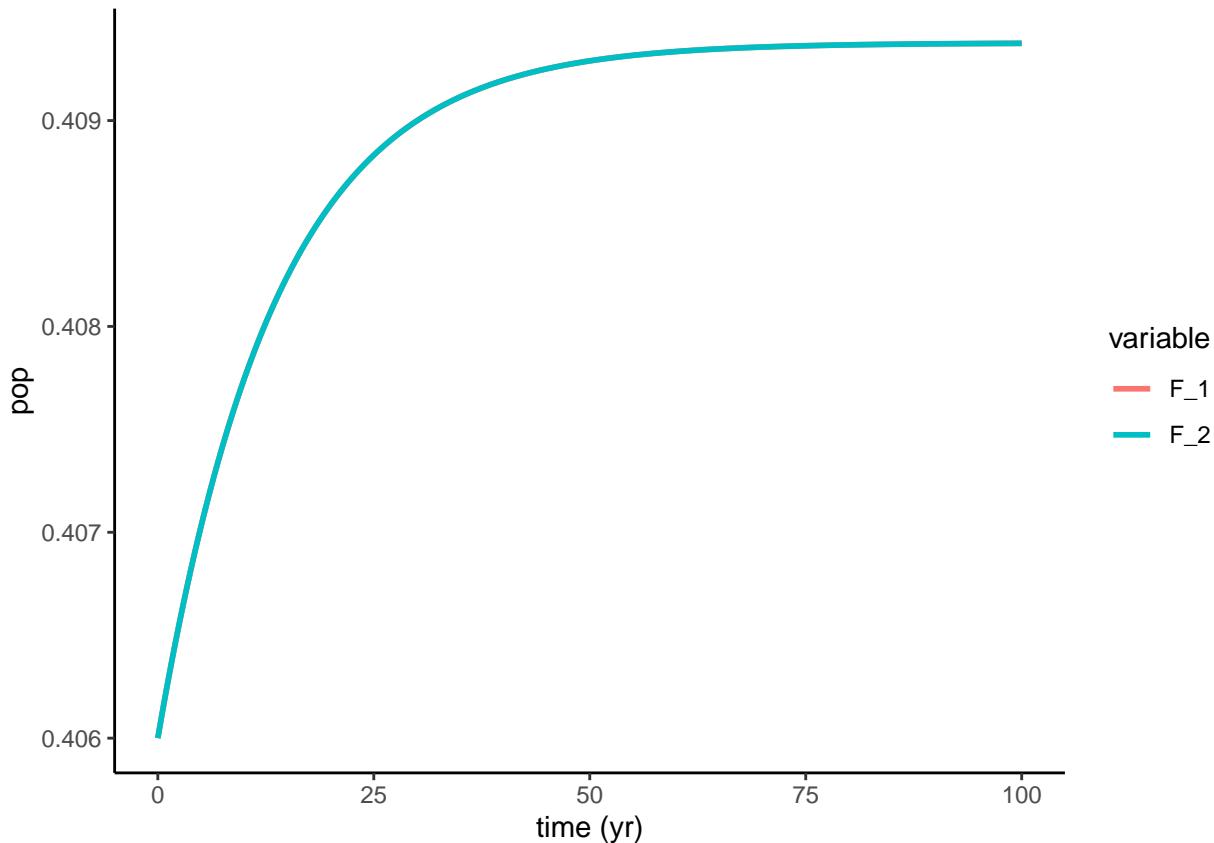


Figure 1: Model without social dynamics

Observations:

- Fishing remains sustainable UNLESS more than 50% of people are fishing

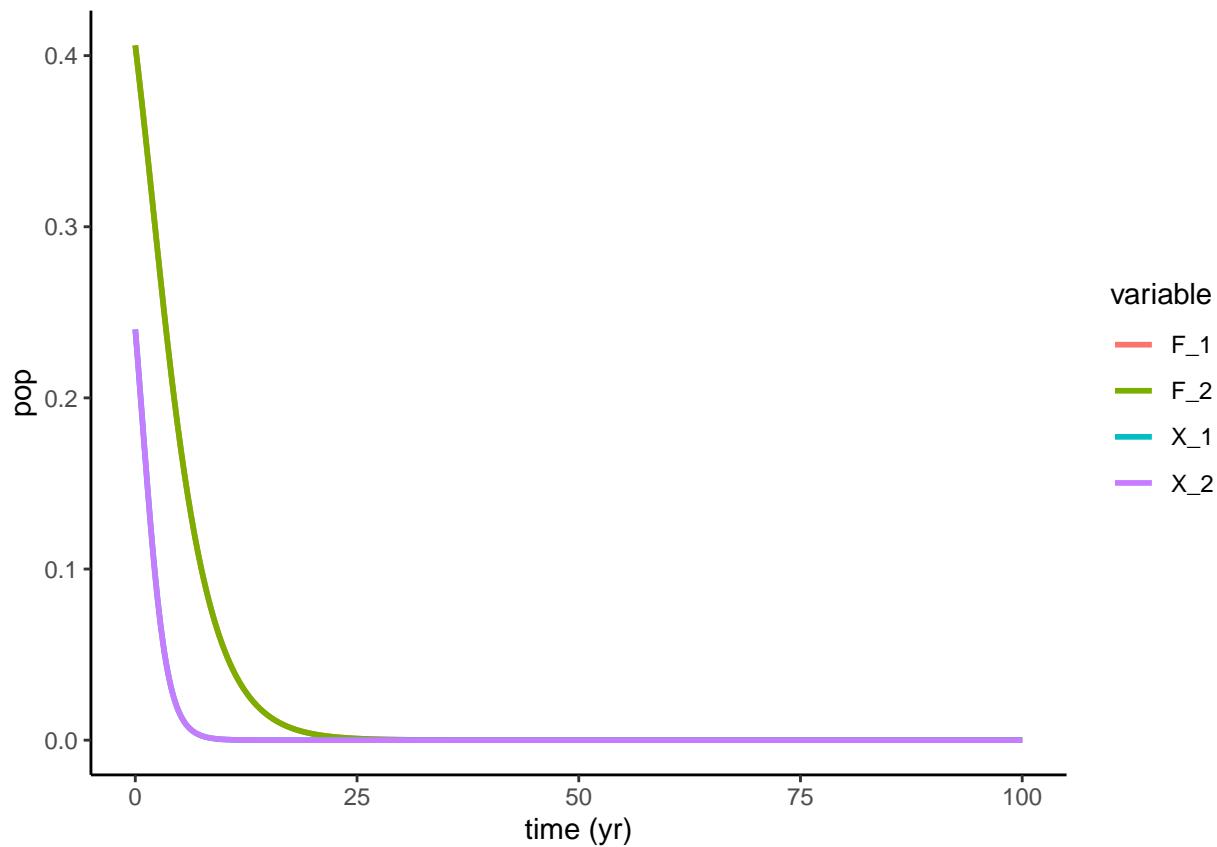
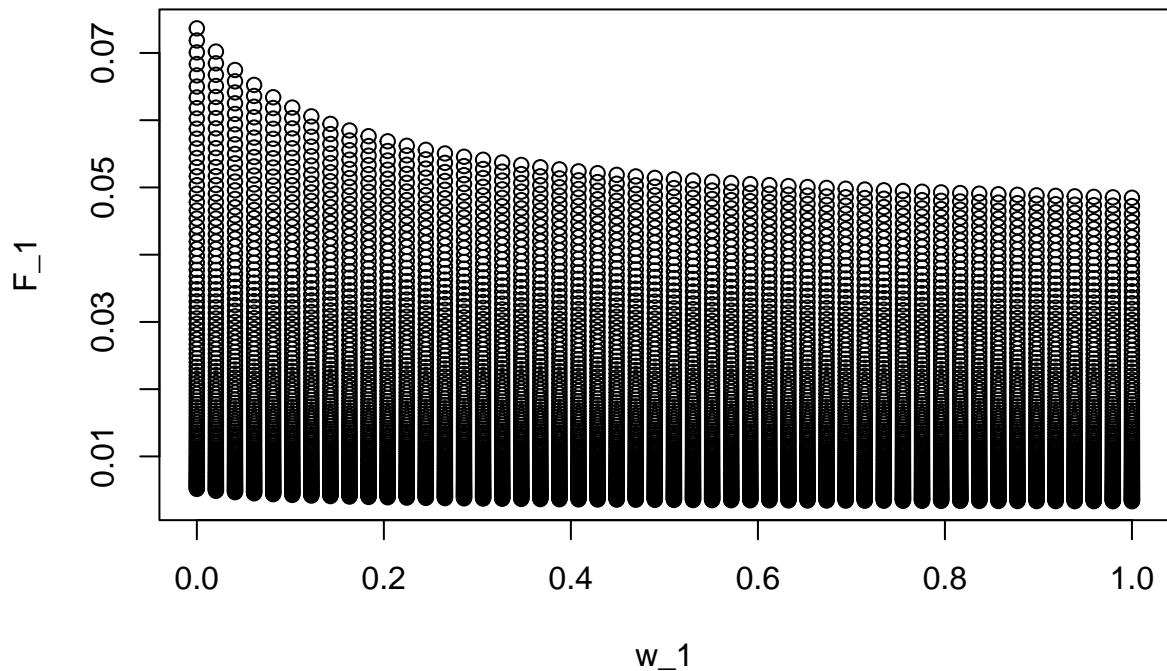


Figure 2: New Model with social dynamics

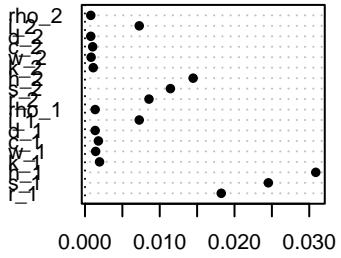
Observations:

- Still decreasing

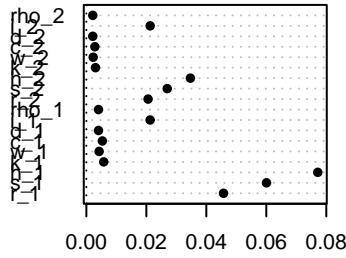


##	value	scale	L1	L2	Mean	Min	Max	N
## r_1	0.35	0.35	0.01823	0.0457	0.01823	0.0000	0.164	1001
## s_1	0.80	0.80	0.02453	0.0601	0.02453	0.0000	0.210	1001
## h_1	0.50	0.50	0.03087	0.0772	-0.03087	-0.2763	0.000	1001
## k_1	1.01	1.01	0.00195	0.0058	-0.00195	-0.0262	0.000	1001
## w_1	0.35	0.35	0.00143	0.0043	-0.00143	-0.0193	0.000	1001
## c_1	1.50	1.50	0.00179	0.0053	-0.00179	-0.0242	0.000	1001
## d_1	0.50	0.50	0.00136	0.0041	-0.00136	-0.0183	0.000	1001
## i_1	0.20	0.20	0.00726	0.0213	0.00726	0.0000	0.092	1001
## rho_1	0.50	0.50	0.00136	0.0041	-0.00136	-0.0183	0.000	1001
## r_2	0.35	0.35	0.00856	0.0206	0.00856	0.0000	0.071	1001
## s_2	0.80	0.80	0.01143	0.0270	0.01143	0.0000	0.092	1001
## h_2	0.50	0.50	0.01447	0.0347	-0.01447	-0.1200	0.000	1001
## k_2	1.01	1.01	0.00110	0.0030	-0.00110	-0.0124	0.000	1001
## w_2	0.35	0.35	0.00082	0.0023	-0.00082	-0.0093	0.000	1001
## c_2	1.50	1.50	0.00103	0.0028	-0.00103	-0.0116	0.000	1001
## d_2	0.50	0.50	0.00077	0.0021	-0.00077	-0.0087	0.000	1001
## i_2	0.20	0.20	0.00726	0.0213	-0.00726	-0.0915	0.000	1001
## rho_2	0.50	0.50	0.00077	0.0021	-0.00077	-0.0087	0.000	1001

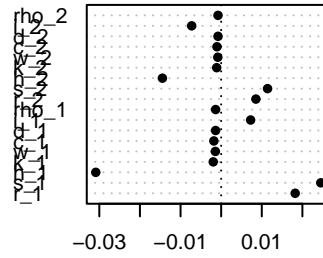
L1



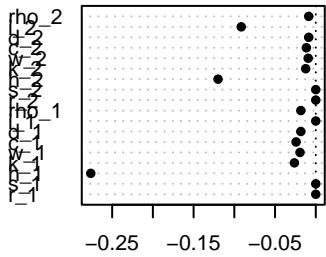
L2



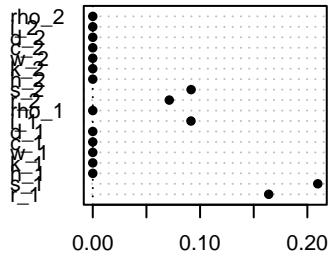
Mean



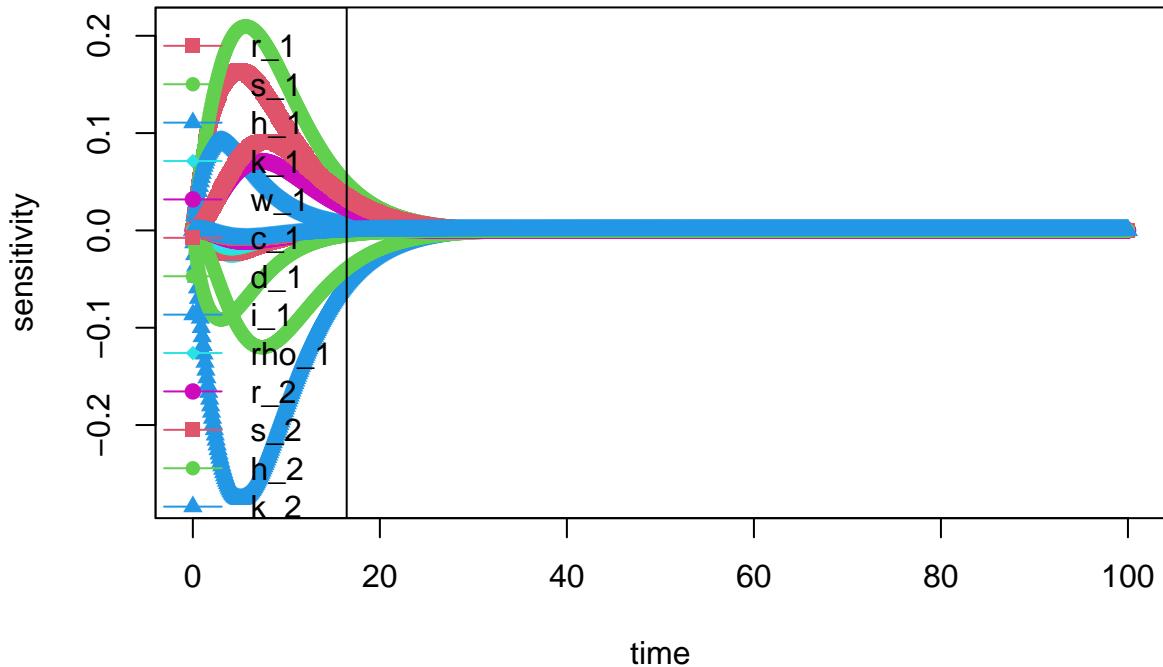
Min



Max



Sensitivity all vars



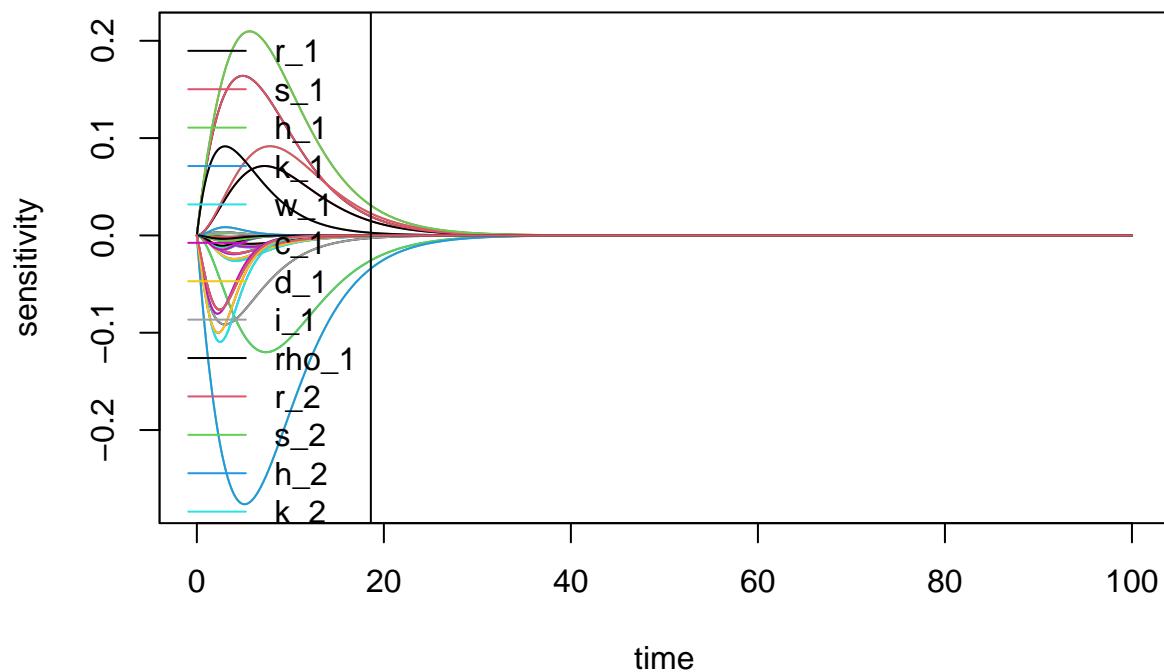
##	value	scale	L1	L2	Mean	Min	Max	N	var
## r_11	0.35	0.35	1.8e-02	0.04574	1.8e-02	0.0000	0.1640	1001	F_1
## r_12	0.35	0.35	8.6e-03	0.02058	8.6e-03	0.0000	0.0713	1001	F_2
## r_13	0.35	0.35	2.4e-04	0.00093	-2.4e-04	-0.0053	0.0000	1001	X_1
## r_14	0.35	0.35	6.8e-05	0.00026	-6.8e-05	-0.0015	0.0000	1001	X_2
## s_11	0.80	0.80	2.5e-02	0.06007	2.5e-02	0.0000	0.2097	1001	F_1
## s_12	0.80	0.80	1.1e-02	0.02697	1.1e-02	0.0000	0.0916	1001	F_2
## s_13	0.80	0.80	2.7e-04	0.00104	-2.7e-04	-0.0058	0.0000	1001	X_1
## s_14	0.80	0.80	7.5e-05	0.00029	-7.5e-05	-0.0016	0.0000	1001	X_2
## h_11	0.50	0.50	3.1e-02	0.07716	-3.1e-02	-0.2763	0.0000	1001	F_1
## h_12	0.50	0.50	1.4e-02	0.03469	-1.4e-02	-0.1200	0.0000	1001	F_2
## h_13	0.50	0.50	3.8e-04	0.00149	3.8e-04	0.0000	0.0084	1001	X_1
## h_14	0.50	0.50	1.1e-04	0.00041	1.1e-04	0.0000	0.0023	1001	X_2
## k_11	1.01	1.01	1.9e-03	0.00579	-1.9e-03	-0.0262	0.0000	1001	F_1
## k_12	1.01	1.01	1.1e-03	0.00304	-1.1e-03	-0.0124	0.0000	1001	F_2
## k_13	1.01	1.01	4.8e-03	0.01913	-4.8e-03	-0.1095	0.0000	1001	X_1
## k_14	1.01	1.01	5.7e-04	0.00243	-5.7e-04	-0.0149	0.0000	1001	X_2
## w_11	0.35	0.35	1.4e-03	0.00426	-1.4e-03	-0.0193	0.0000	1001	F_1
## w_12	0.35	0.35	8.2e-04	0.00228	-8.2e-04	-0.0093	0.0000	1001	F_2
## w_13	0.35	0.35	3.4e-03	0.01373	-3.4e-03	-0.0805	0.0000	1001	X_1
## w_14	0.35	0.35	4.5e-04	0.00193	-4.5e-04	-0.0120	0.0000	1001	X_2
## c_11	1.50	1.50	1.8e-03	0.00533	-1.8e-03	-0.0242	0.0000	1001	F_1
## c_12	1.50	1.50	1.0e-03	0.00284	-1.0e-03	-0.0116	0.0000	1001	F_2
## c_13	1.50	1.50	4.3e-03	0.01728	-4.3e-03	-0.1001	0.0000	1001	X_1
## c_14	1.50	1.50	5.6e-04	0.00237	-5.6e-04	-0.0147	0.0000	1001	X_2
## d_11	0.50	0.50	1.4e-03	0.00406	-1.4e-03	-0.0183	0.0000	1001	F_1

```

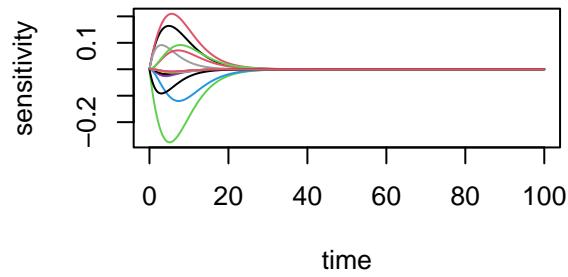
## d_12      0.50  0.50 7.7e-04 0.00214 -7.7e-04 -0.0087 0.0000 1001 F_2
## d_13      0.50  0.50 3.3e-03 0.01332 -3.3e-03 -0.0763 0.0000 1001 X_1
## d_14      0.50  0.50 4.1e-04 0.00172 -4.1e-04 -0.0106 0.0000 1001 X_2
## i_11      0.20  0.20 7.3e-03 0.02127  7.3e-03  0.0000 0.0915 1001 F_1
## i_12      0.20  0.20 7.3e-03 0.02127 -7.3e-03 -0.0915 0.0000 1001 F_2
## i_13      0.20  0.20 1.5e-04 0.00060 -1.5e-04 -0.0035 0.0000 1001 X_1
## i_14      0.20  0.20 1.5e-04 0.00060  1.5e-04  0.0000 0.0035 1001 X_2
## rho_11     0.50  0.50 1.4e-03 0.00406 -1.4e-03 -0.0183 0.0000 1001 F_1
## rho_12     0.50  0.50 7.7e-04 0.00214 -7.7e-04 -0.0087 0.0000 1001 F_2
## rho_13     0.50  0.50 3.3e-03 0.01332 -3.3e-03 -0.0763 0.0000 1001 X_1
## rho_14     0.50  0.50 4.1e-04 0.00172 -4.1e-04 -0.0106 0.0000 1001 X_2
## r_21       0.35  0.35 8.6e-03 0.02058  8.6e-03  0.0000 0.0713 1001 F_1
## r_22       0.35  0.35 1.8e-02 0.04574  1.8e-02  0.0000 0.1640 1001 F_2
## r_23       0.35  0.35 6.8e-05 0.00026 -6.8e-05 -0.0015 0.0000 1001 X_1
## r_24       0.35  0.35 2.4e-04 0.00093 -2.4e-04 -0.0053 0.0000 1001 X_2
## s_21       0.80  0.80 1.1e-02 0.02697  1.1e-02  0.0000 0.0916 1001 F_1
## s_22       0.80  0.80 2.5e-02 0.06007  2.5e-02  0.0000 0.2097 1001 F_2
## s_23       0.80  0.80 7.5e-05 0.00029 -7.5e-05 -0.0016 0.0000 1001 X_1
## s_24       0.80  0.80 2.7e-04 0.00104 -2.7e-04 -0.0058 0.0000 1001 X_2
## h_21       0.50  0.50 1.4e-02 0.03469 -1.4e-02 -0.1200 0.0000 1001 F_1
## h_22       0.50  0.50 3.1e-02 0.07716 -3.1e-02 -0.2763 0.0000 1001 F_2
## h_23       0.50  0.50 1.1e-04 0.00041  1.1e-04  0.0000 0.0023 1001 X_1
## h_24       0.50  0.50 3.8e-04 0.00149  3.8e-04  0.0000 0.0084 1001 X_2
## k_21       1.01  1.01 1.1e-03 0.00304 -1.1e-03 -0.0124 0.0000 1001 F_1
## k_22       1.01  1.01 1.9e-03 0.00579 -1.9e-03 -0.0262 0.0000 1001 F_2
## k_23       1.01  1.01 5.7e-04 0.00243 -5.7e-04 -0.0149 0.0000 1001 X_1
## k_24       1.01  1.01 4.8e-03 0.01913 -4.8e-03 -0.1095 0.0000 1001 X_2
## w_21       0.35  0.35 8.2e-04 0.00228 -8.2e-04 -0.0093 0.0000 1001 F_1
## w_22       0.35  0.35 1.4e-03 0.00426 -1.4e-03 -0.0193 0.0000 1001 F_2
## w_23       0.35  0.35 4.5e-04 0.00193 -4.5e-04 -0.0120 0.0000 1001 X_1
## w_24       0.35  0.35 3.4e-03 0.01373 -3.4e-03 -0.0805 0.0000 1001 X_2
## c_21       1.50  1.50 1.0e-03 0.00284 -1.0e-03 -0.0116 0.0000 1001 F_1
## c_22       1.50  1.50 1.8e-03 0.00533 -1.8e-03 -0.0242 0.0000 1001 F_2
## c_23       1.50  1.50 5.6e-04 0.00237 -5.6e-04 -0.0147 0.0000 1001 X_1
## c_24       1.50  1.50 4.3e-03 0.01728 -4.3e-03 -0.1001 0.0000 1001 X_2
## d_21       0.50  0.50 7.7e-04 0.00214 -7.7e-04 -0.0087 0.0000 1001 F_1
## d_22       0.50  0.50 1.4e-03 0.00406 -1.4e-03 -0.0183 0.0000 1001 F_2
## d_23       0.50  0.50 4.1e-04 0.00172 -4.1e-04 -0.0106 0.0000 1001 X_1
## d_24       0.50  0.50 3.3e-03 0.01332 -3.3e-03 -0.0763 0.0000 1001 X_2
## i_21       0.20  0.20 7.3e-03 0.02127 -7.3e-03 -0.0915 0.0000 1001 F_1
## i_22       0.20  0.20 7.3e-03 0.02127  7.3e-03  0.0000 0.0915 1001 F_2
## i_23       0.20  0.20 1.5e-04 0.00060  1.5e-04  0.0000 0.0035 1001 X_1
## i_24       0.20  0.20 1.5e-04 0.00060 -1.5e-04 -0.0035 0.0000 1001 X_2
## rho_21     0.50  0.50 7.7e-04 0.00214 -7.7e-04 -0.0087 0.0000 1001 F_1
## rho_22     0.50  0.50 1.4e-03 0.00406 -1.4e-03 -0.0183 0.0000 1001 F_2
## rho_23     0.50  0.50 4.1e-04 0.00172 -4.1e-04 -0.0106 0.0000 1001 X_1
## rho_24     0.50  0.50 3.3e-03 0.01332 -3.3e-03 -0.0763 0.0000 1001 X_2

```

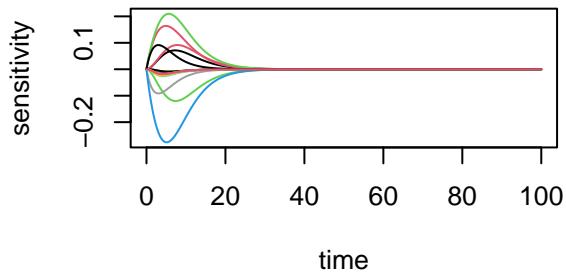
All variables



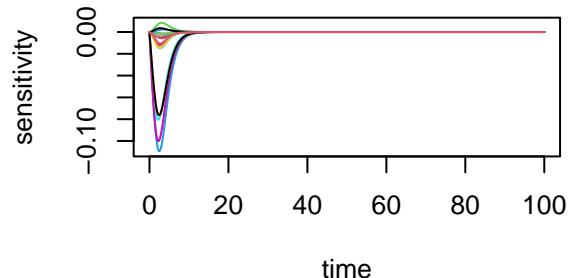
F_1



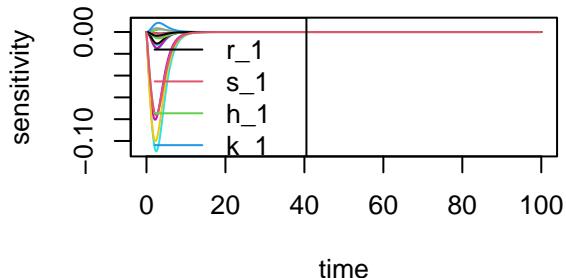
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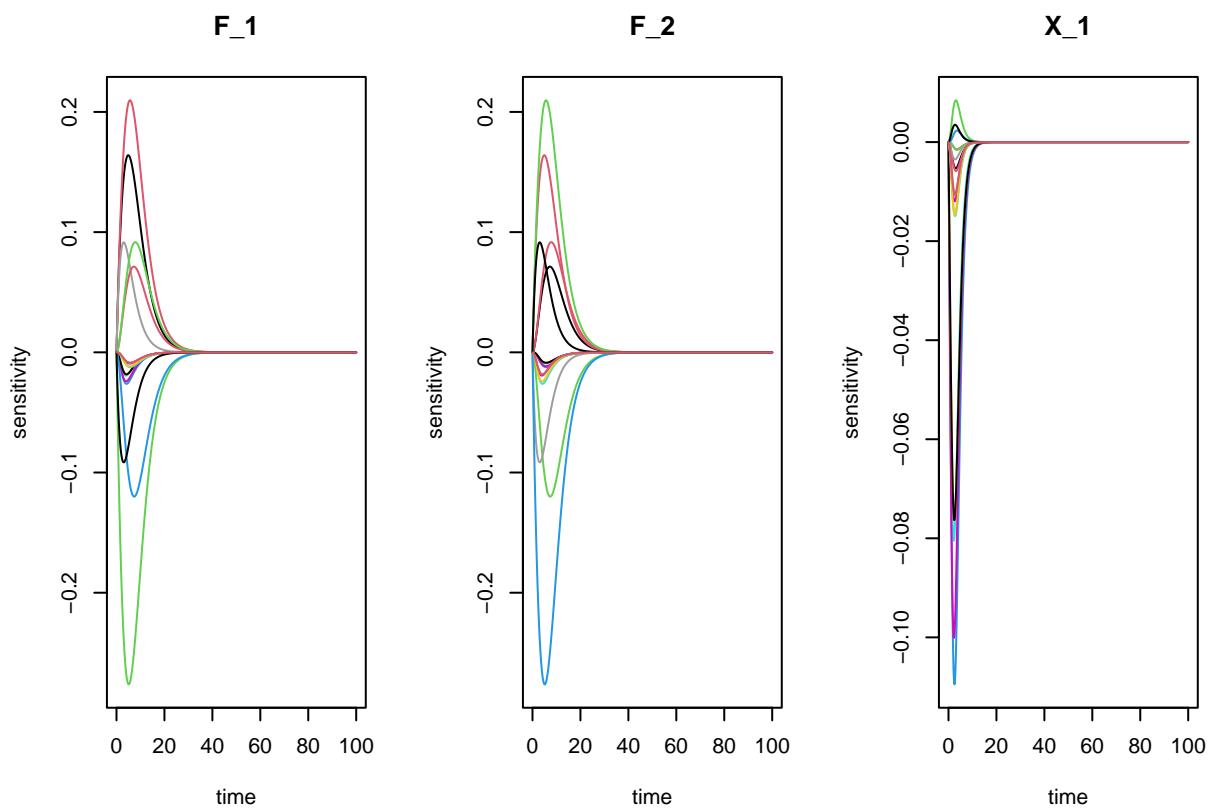


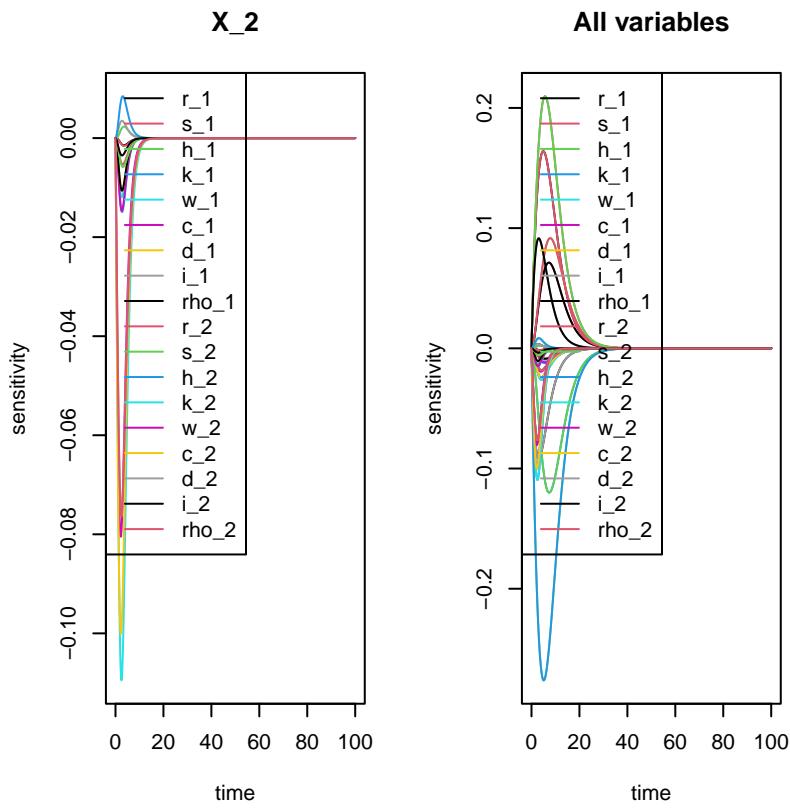
X_1

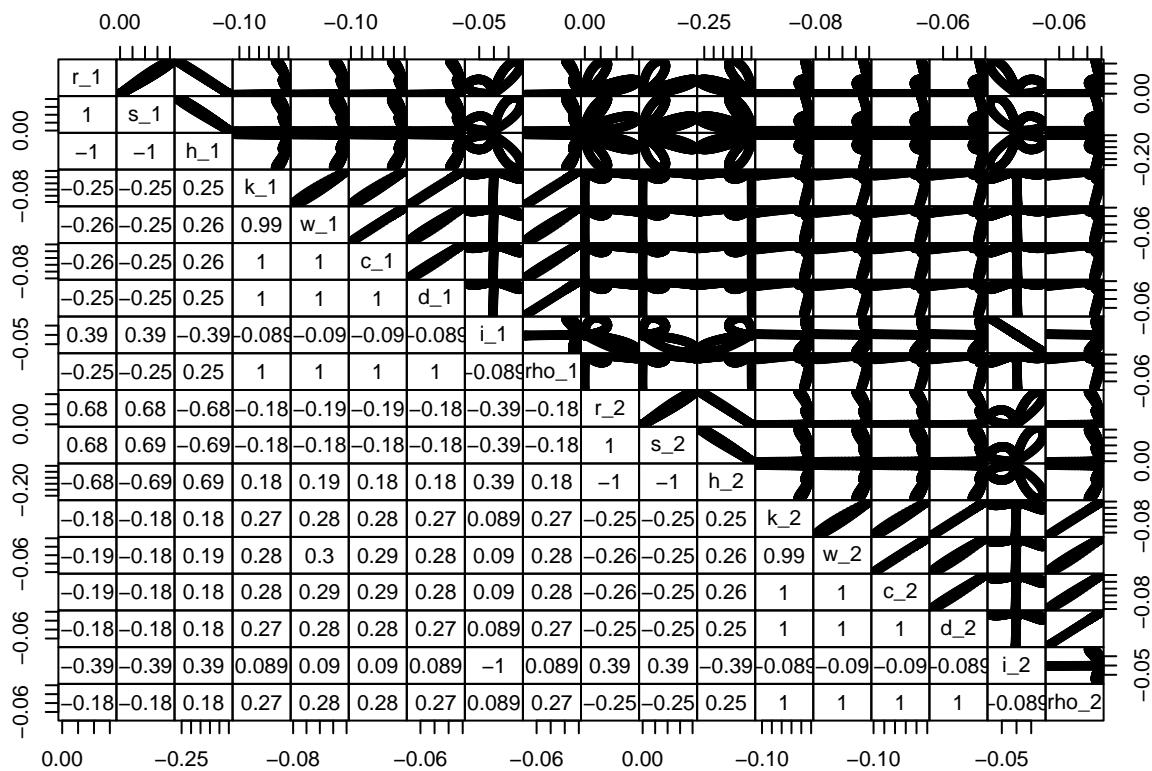


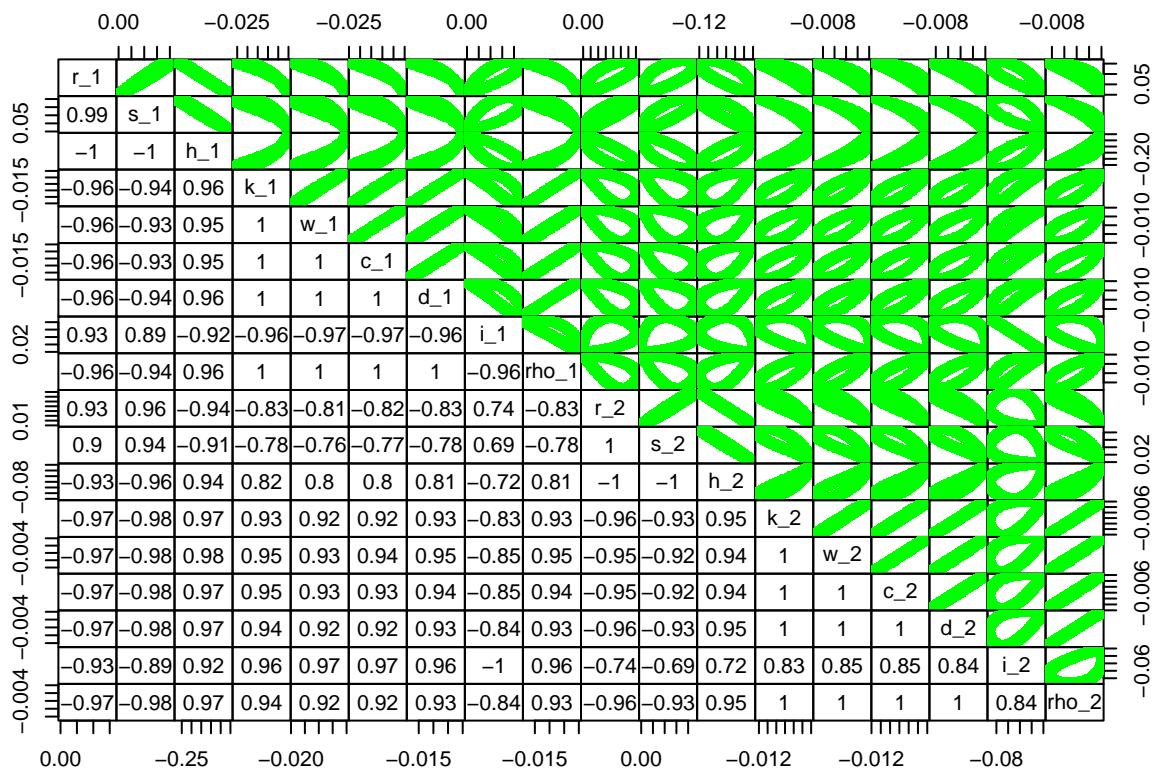
X_2

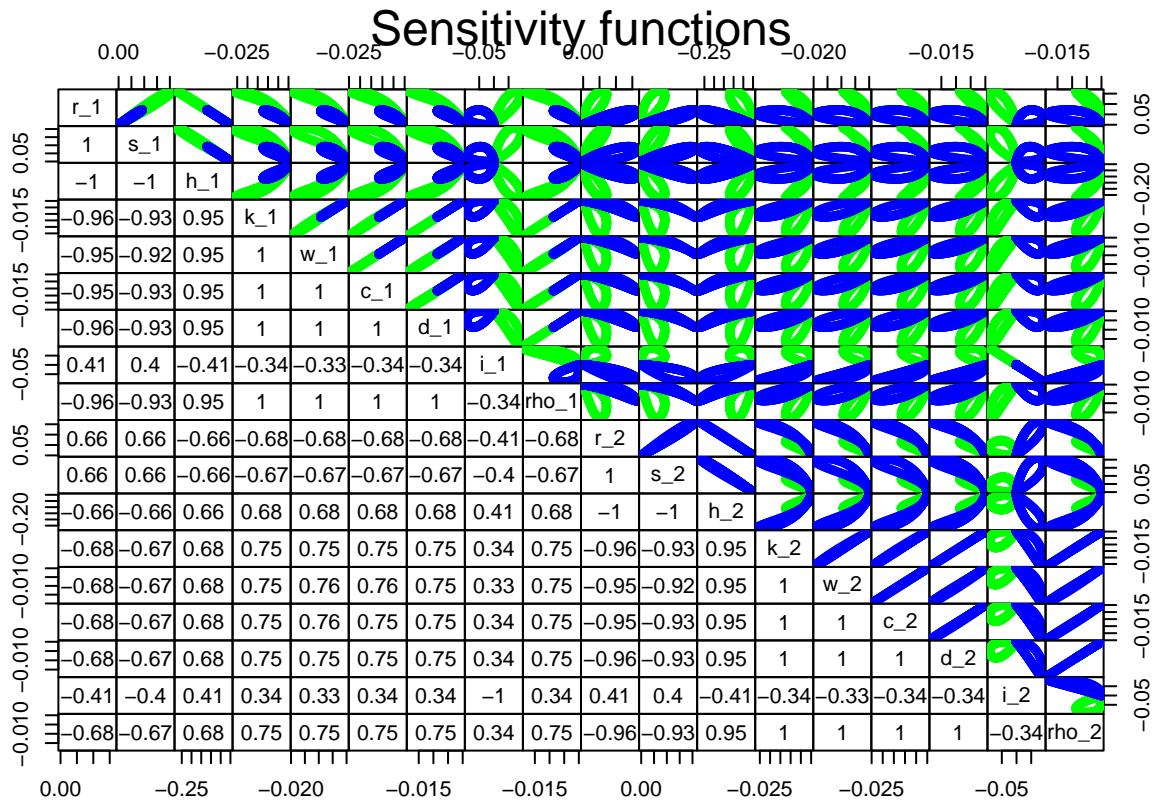












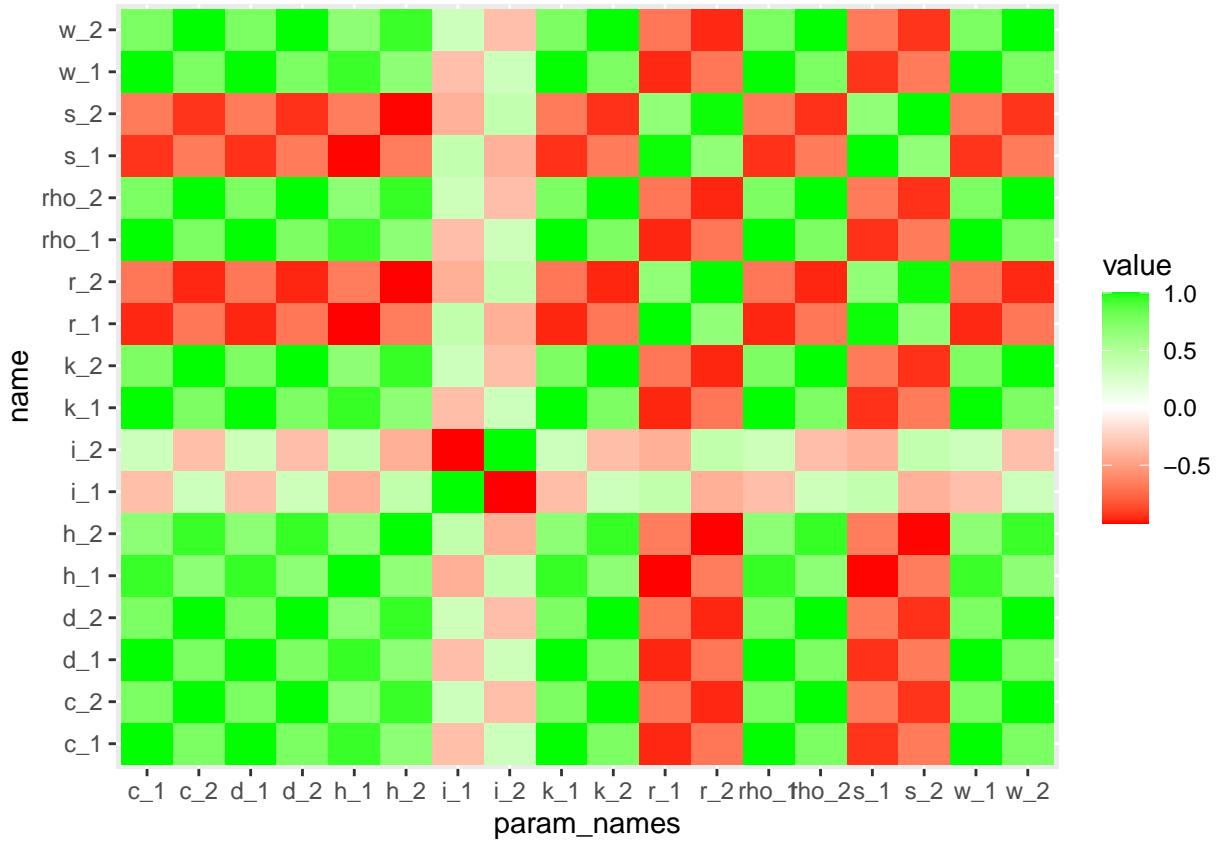


Table 3: Default parameter values used in this analysis

Parameter	Population_1	Population_2	Def
r	0.4	0.35	Fish net growth
s	0.8	0.8	Supply and demand
h	0.25	0.5	Harvesting efficiency
k	1.014	1.014	Social learning rate
ω	0.2	0.35	Conservation cost
c	1.5	1.5	Rarity valuation
d	0.5	0.5	Social norm strength (within pop)
i	0.2	0.2	Fish immigration (from patch)
ρ	0.5	0.5	Social norm strength (opposite pop)

Scenarios

One groups unsustainable practices can tank whole fishery;

```
params_social$r_1 <- 0.4
params_social$r_2 <- 0.4
params_social$w_1 <- 0.2
params_social$w_2 <- 0.2
params_social$h_1 <- 0.25
params_social$h_2 <- 0.25 Goes up
```

Vs.

```
params_social$r_1 <- 0.4
params_social$r_2 <- 0.35
params_social$w_1 <- 0.2
params_social$w_2 <- 0.35
params_social$h_1 <- 0.25
params_social$h_2 <- 0.5 Goes down
BUT increasing rarity val can save that
params_social$c_1 <- 0.25
params_social$c_2 <- 0.25 Goes up
```

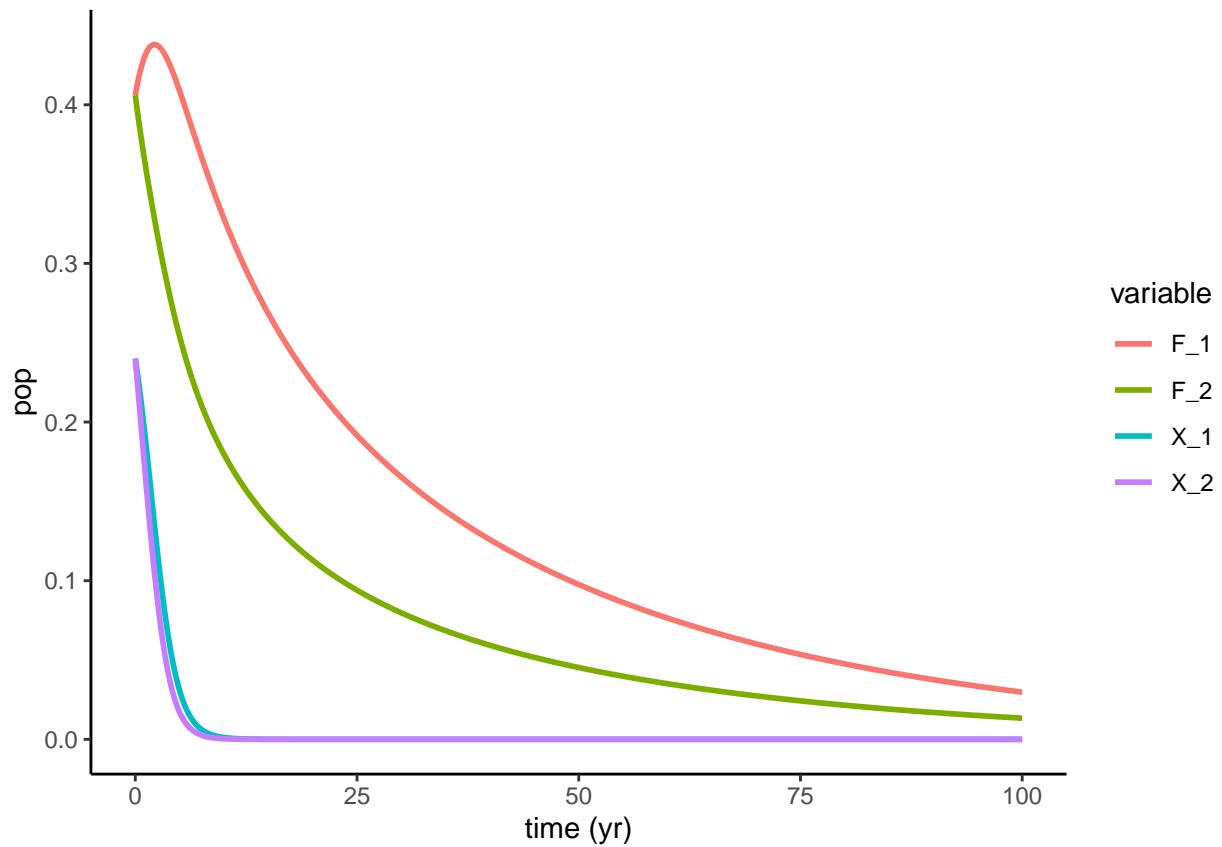


Figure 3: Social inequity scenario where $\rho_1 = 0.25$ and $h_1 = 1$

- Bifurcation plots
- Sensitivity Analysis: d, rho, s, w, c, i
- Scenarios
- Stability and dynamics - Sigdel 2017 good example
- Go through bauch, thampi, and other papers to see what analysis ideas I can also apply
- Bauch 2012 does probabilistic sensitivity analysis (PSA). Also see supporting info
- Phase plane analysis in cressman 2004 and go through your own phase planes to find interesting dynamics
- Maybe try this: <https://cran.r-project.org/web/packages/rootSolve/rootSolve.pdf>