Developing a stock assessment model for Main Hawaiian Islands Yellowfin Tuna Fishery

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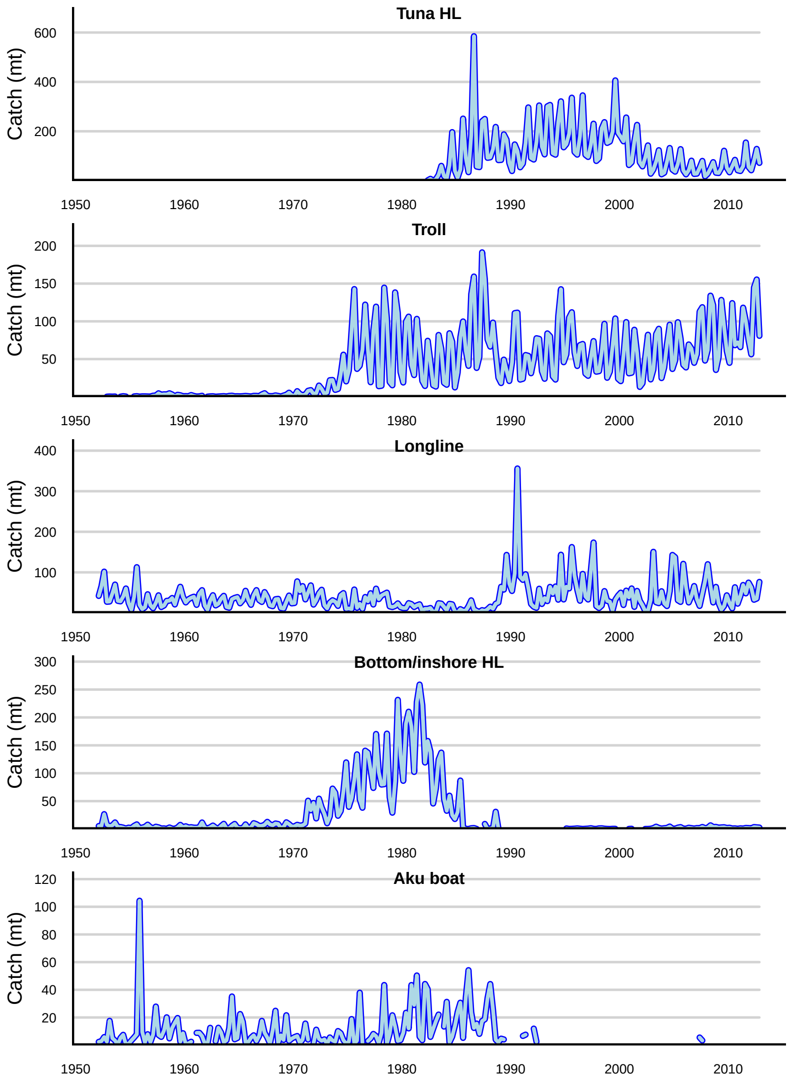
Model Assumptions

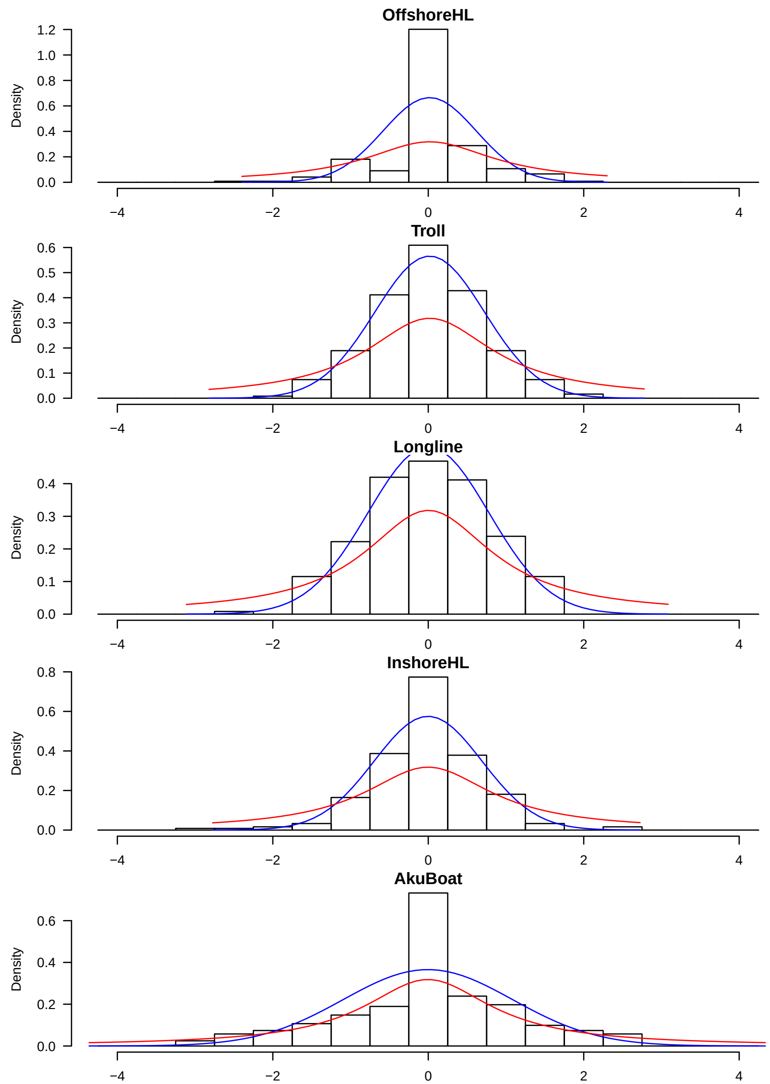
1. The Pacific Ocean is divided into two regions: MHI (1) and elsewhere (2).
2. Fish immigrate from region 2 to region 1, and mix completely.
3. Fish emigrate from region 1 to region 2, but have no effect on region 2 dynamics.
4. Immigration into region 1 is dependent on biomass in region 2 estimated by some other model, e.g., MULTIFAN-CL or SEAPODYM.
5. The fishery comprises several gear types or fleets, each characterized by a distinct fishing mortality time series.
6. Ninety percent of the fish resident in region 1 are assumed to be locally spawned and reared.

Combined HDAR and NOAA Catch Time Series

Quarterly



First Differences of log(C)



Model Characteristics

1. State-space model; separates process error from observation error.

$$\alpha_t = T(\alpha_{t-1}) + \eta_t \quad (1)$$

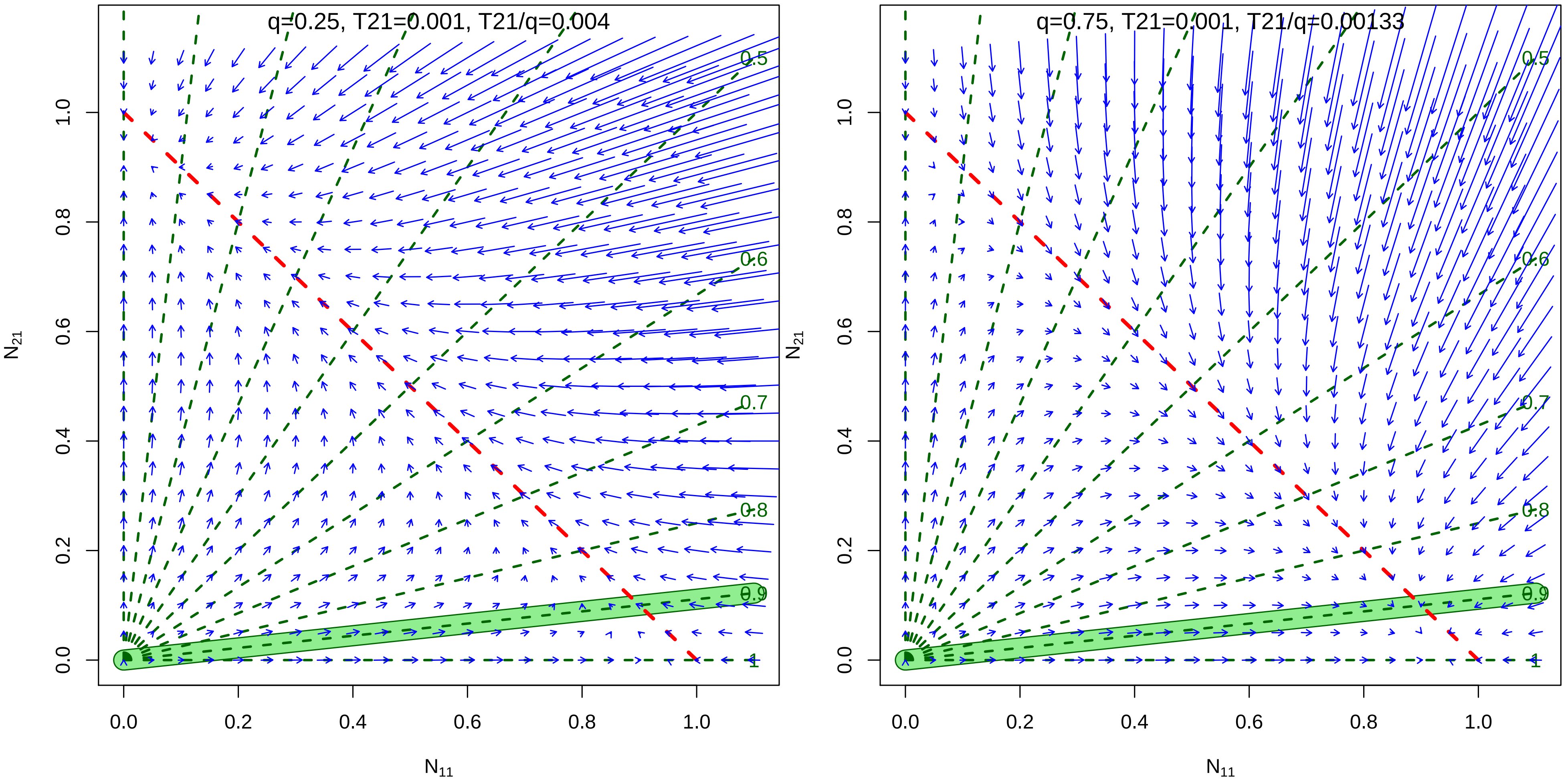
$$x_t = O(\alpha_t) + \varepsilon_t \quad (2)$$

2. Fishing mortality as random walk: $\log F_{g,t} = \log F_{g,t-1} + \xi_t; \quad \xi_t \sim N(0, \sigma^2_\xi)$
3. Transition equation: Coupled logistic simultaneous ordinary differential equation (4)
4. Observation equation: robust likelihood (8)
5. "Off-line" coupling to MULTIFAN-CL region 2 biomass from 2014 assessment (16)
6. Bayesian prior on proportion local: $L(p) \sim N(L(\bar{p}), \sigma^2_{L(p)})$ (20)
7. Model states are random effects

Model Parameters

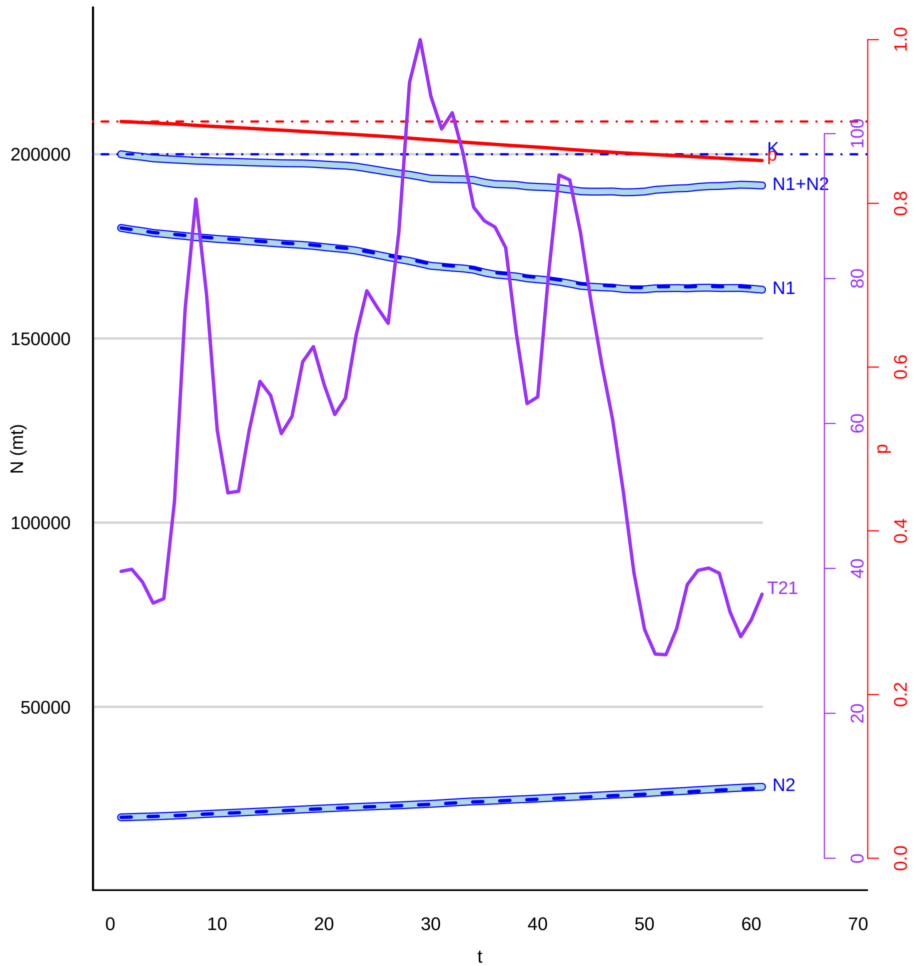
Variable	Definition
r	Instantaneous growth rate (y^{-1})
K	Asymptotic biomass (mt)
T_{12}	Emigration rate (y^{-1})
T^*_{21}	Immigration rate (y^{-1})
q	Nonlinear mortality apportionment factor
σ_η	Population growth standard deviation
σ_ξ	Fishing mortality random walk standard deviation
σ_ε	Observation error standard deviation
$a_g \; g = 1 \ldots n$	Observation error contaminated by fat-tailed distribution
$\bar{p}$	Mean proportion local
$\sigma_{L(p)}$	Standard deviation logit transformed $\bar{p}$

Stability Considerations — Phase Plane Analysis

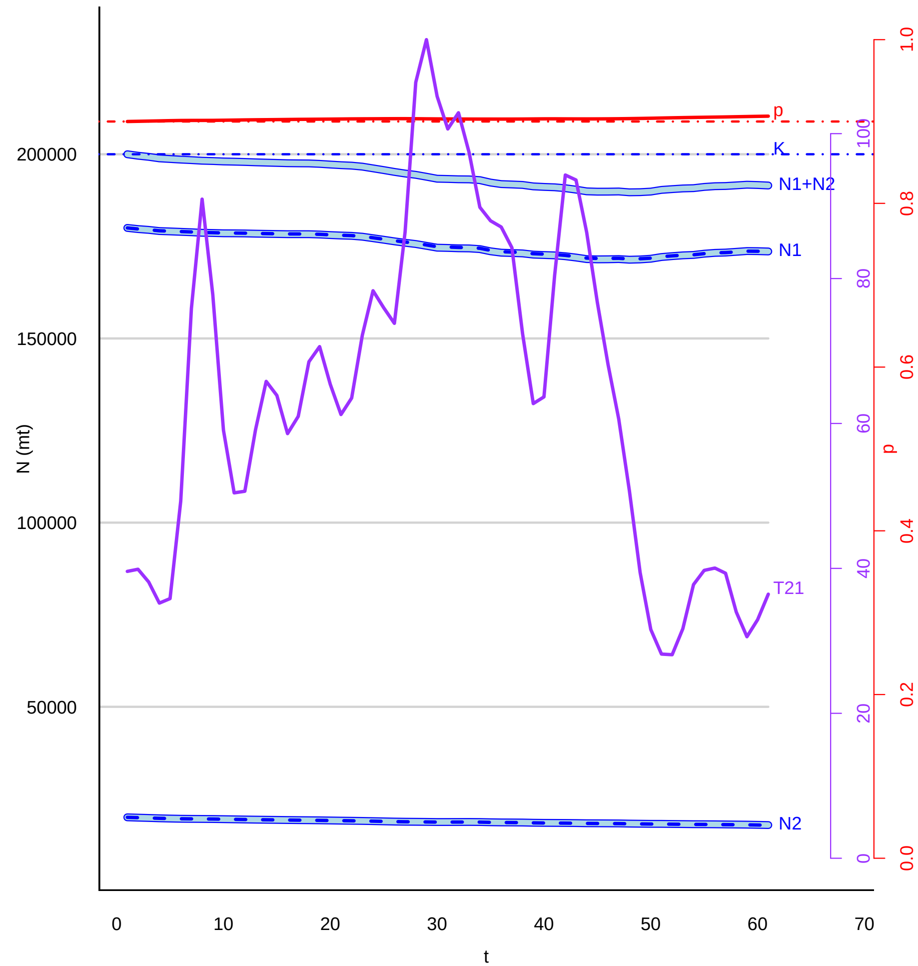


Simulated Populations

$q = 0.48; \sigma_\eta = 0$

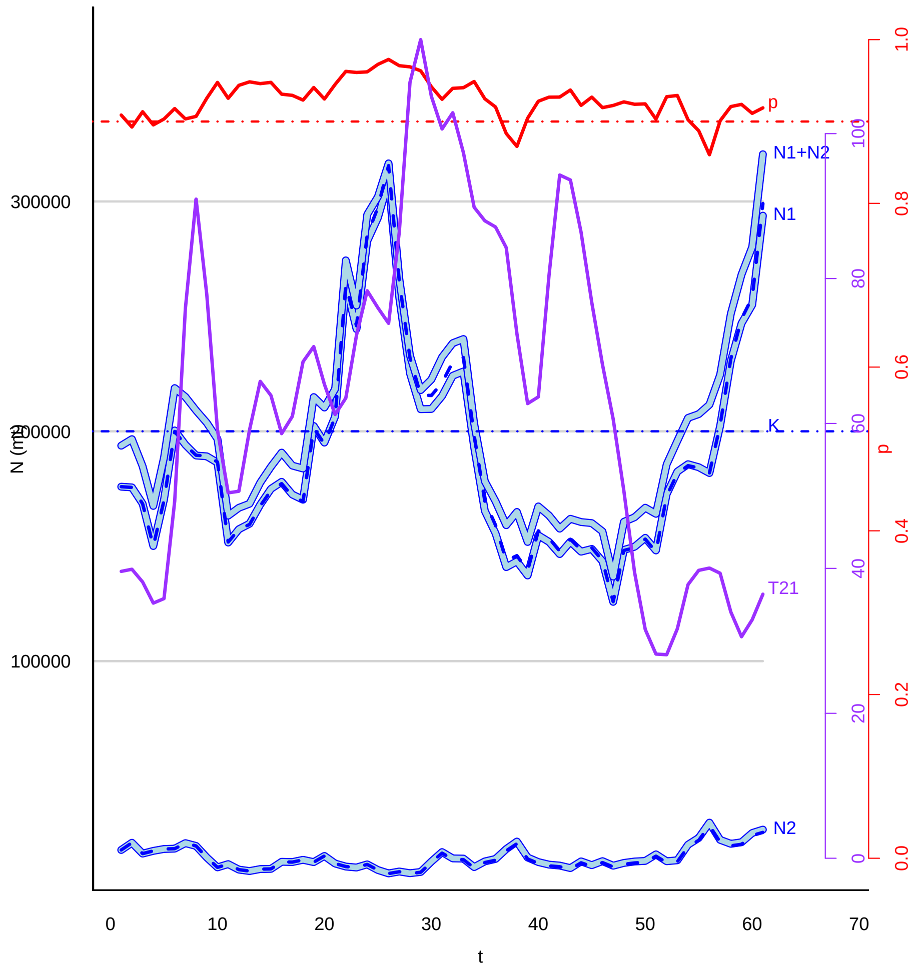


$q = 0.52; \sigma_\eta = 0$

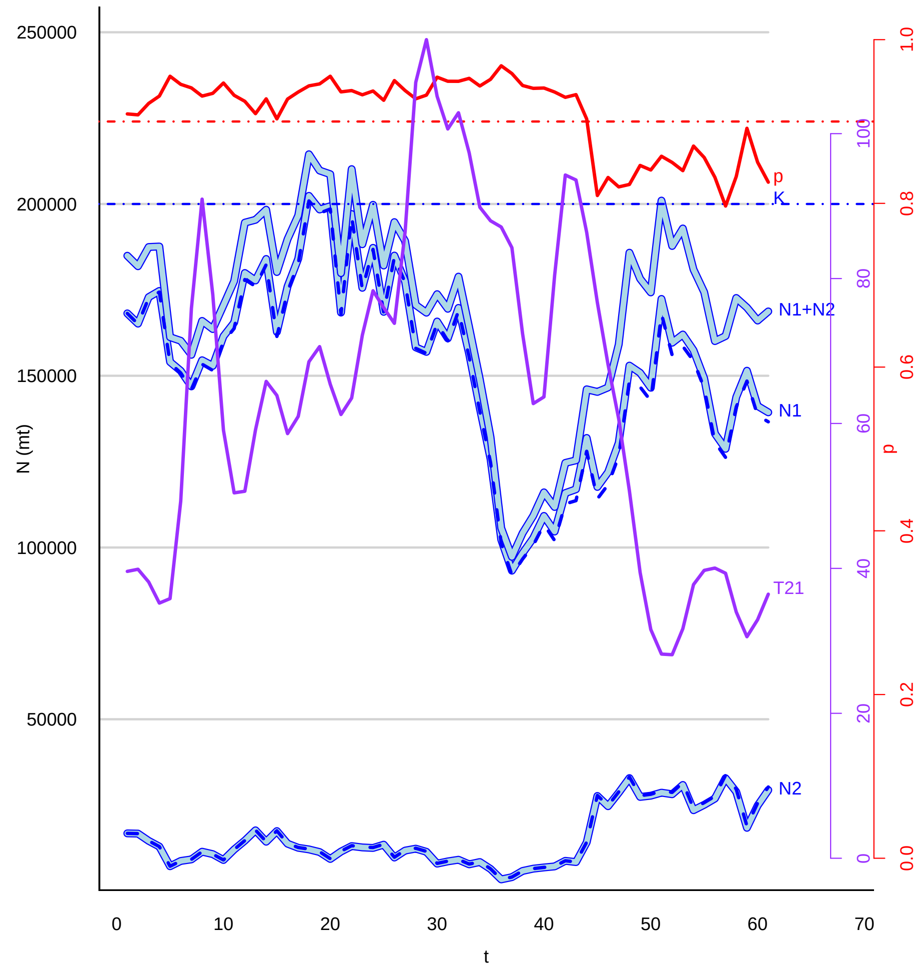


Simulated Populations with Process Error

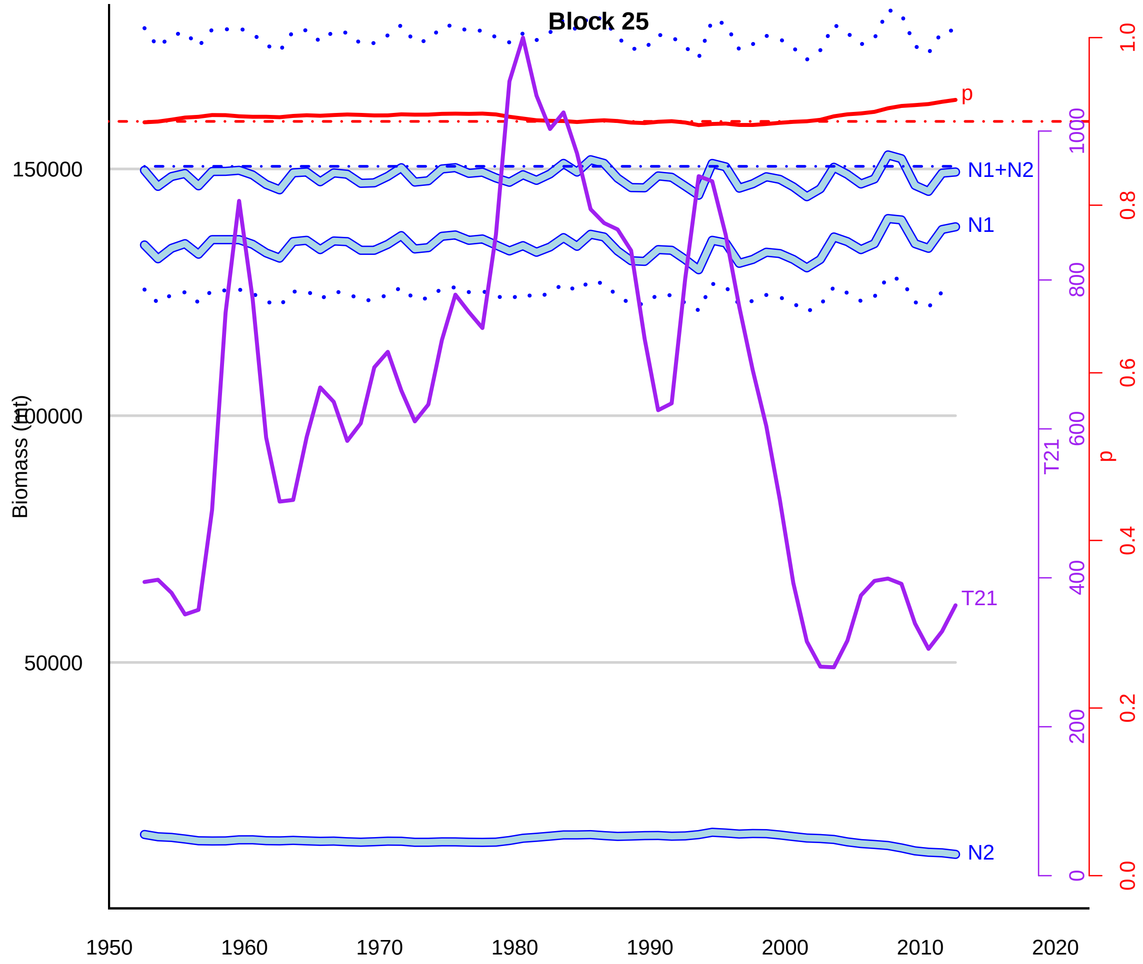
$q = 0.48; \sigma_\eta \sim 0.01$



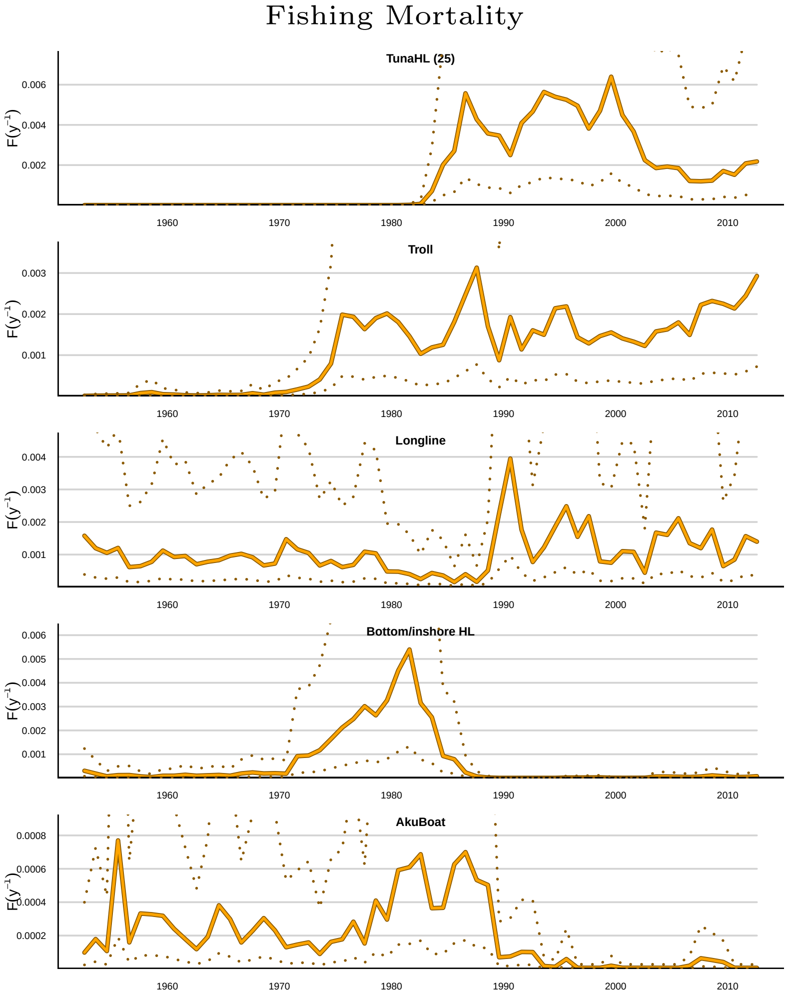
$q = 0.52; \sigma_\eta \sim 0.01$

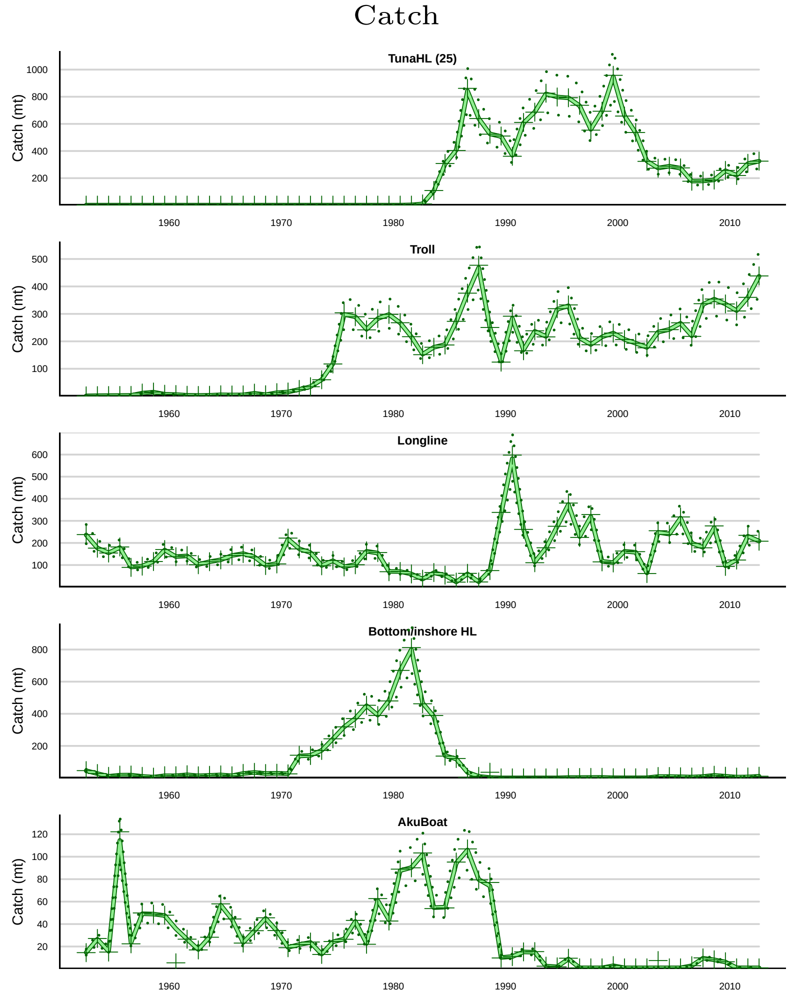


Estimation results: biomass



Estimation results: fishery



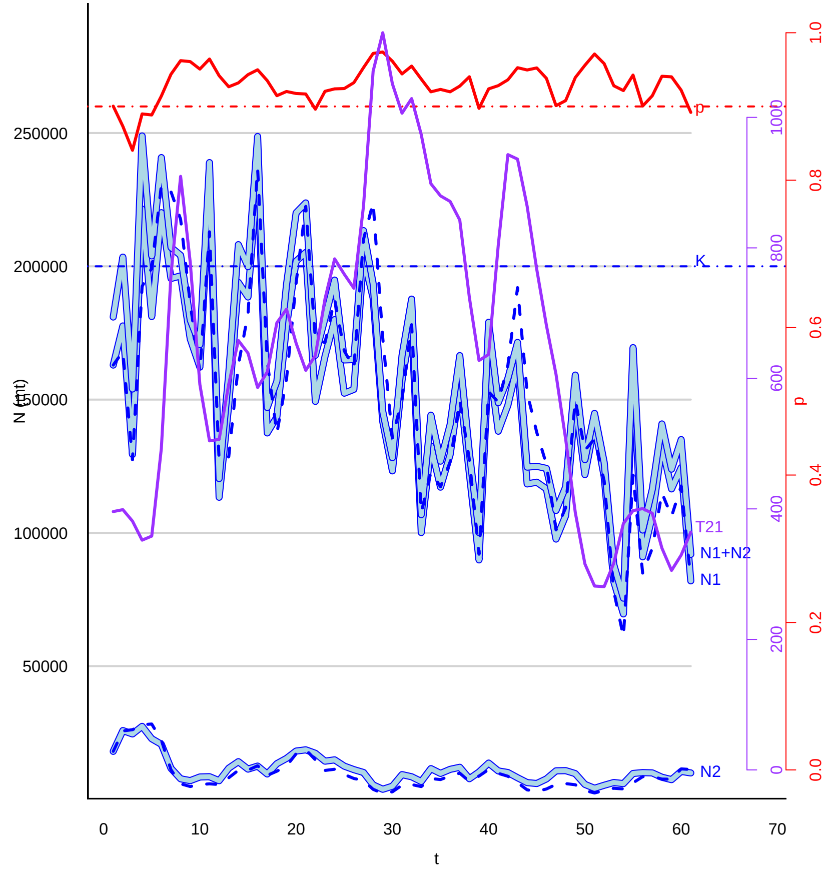


Estimation results: parameter values

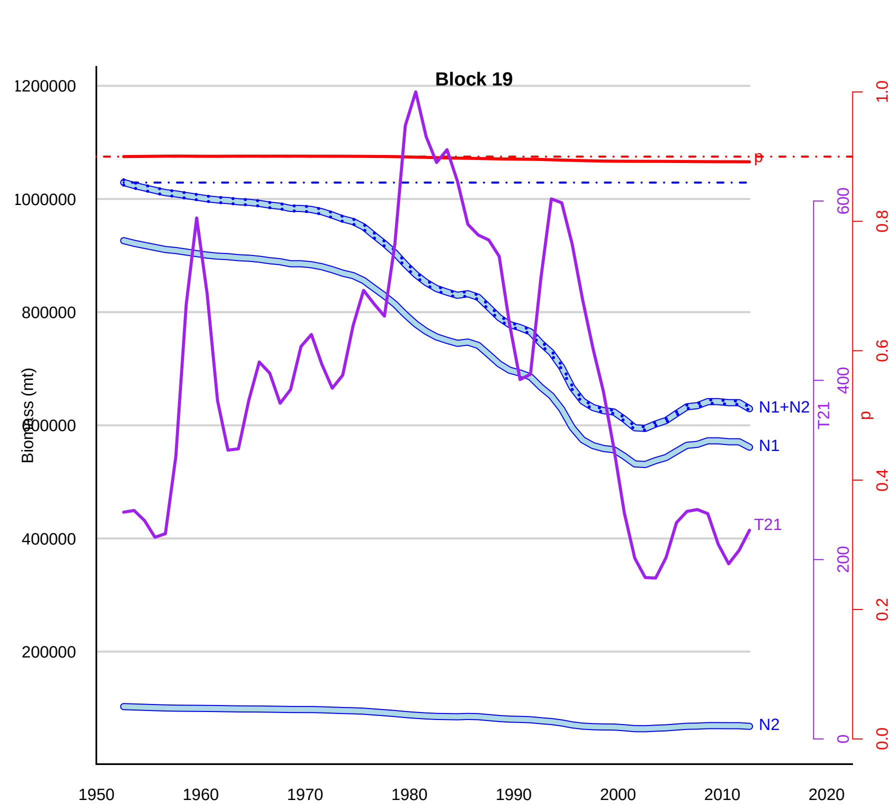
Variable	Initial Value	Final Value
r	1.20	1.30
K	150,000	151,000
T_{12}	0.01	0.00999
T^*_{21}	0.002	0.00199
q	0.54	0.525
σ_η	0.1	0.0880
σ_ξ	0.3	0.700
σ_ε	1.0	0.0913
$a_g \quad g = 1, \ldots, 5$	0.07	—
$\bar{p}$	0.9	—
$\sigma_{\bar{p}}$	0.8	—

Simulation: 100 X Fishing Mortality

Simulated



Estimated



Estimation: 100 X Fishing Mortality

Variable	Initial Value	Final Value
r	1.20	0.190
K	200,000	1,030,000
T_{12}	0.01	0.00524
T^*_{21}	0.02	0.00128
q	0.54	0.511
σ_η	0.1	0.00231
σ_ξ	0.3	0.704
σ_ε	1.0	0.367
$a_g \quad g = 1, \ldots, 5$	0.07	—
$\bar{p}$	0.9	—
$\sigma_{\bar{p}}$	0.8	—

Conclusions

What works:

- Random walk representation of fishing mortality
- Bayesian constraint on $\bar{p}$
- Off-line coupling
- Robust likelihood
- State-space framework

Not working:

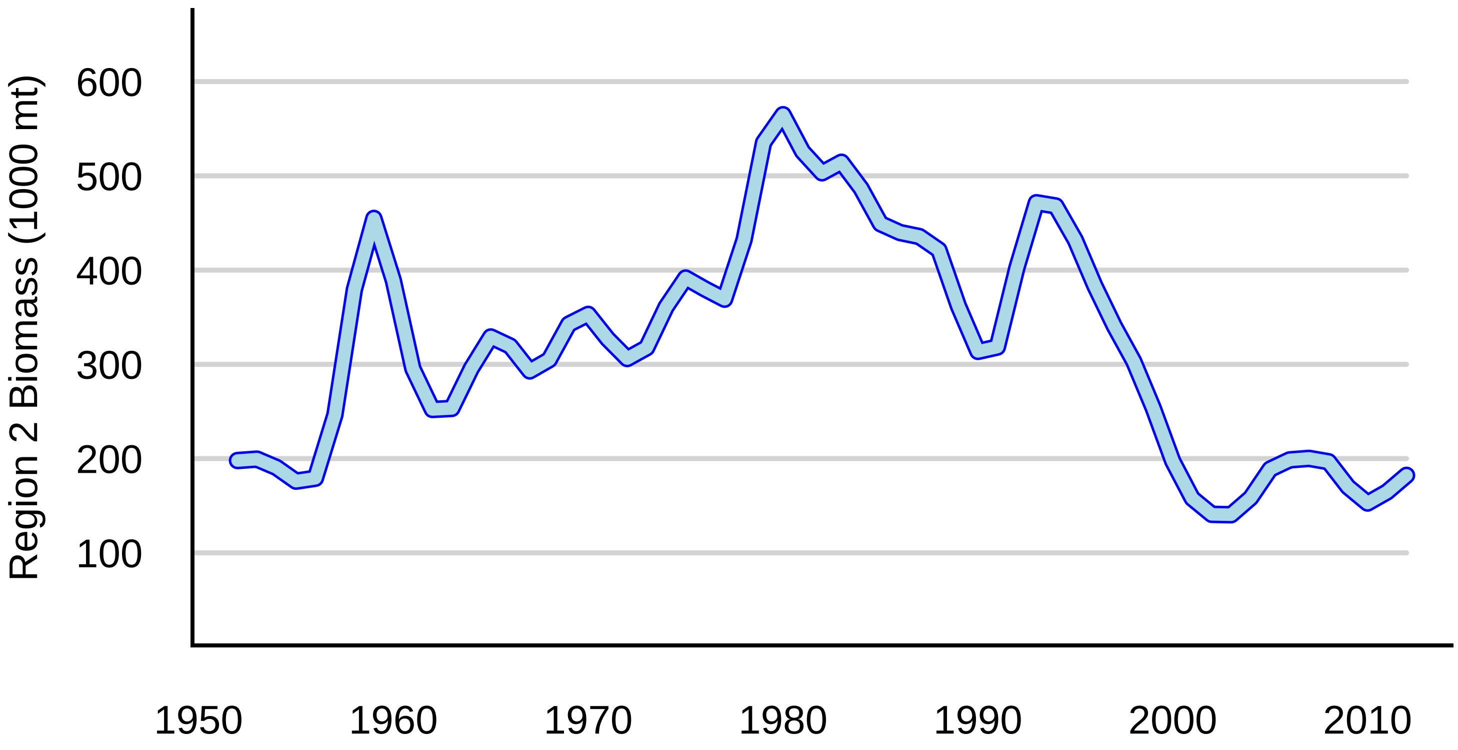
- Estimation procedure does not terminate normally
- Numerical instability in numerical approximation

Issues:

- Convergence, or lack thereof.
- Is $\bar{p} = 0.9$ since 1952?
- If so, are two subpopulations necessary?
- Intra annual variability caused by abundance, participation, reporting, weather, ... ?
- Recreational data? How to represent errors in observation equation?
- Should an age-structured model be developed?
- What are appropriate reference points for a stock segment?
- Use MFCL estimates as abundance index?

Back to the drawing board ...

Biomass Estimates for MFCL Region 2



Logistic Dynamics

$$\frac{d}{dt}(N_{1,1}+N_{2,1}) = (N_{1,1}+N_{2,1})\left[r\left(1-\frac{N_{1,1}+N_{2,1}}{K}\right)-F-T_{12}\right]+T_{21} \tag{3}$$

$$\begin{aligned}
\frac{dN_{1,1}}{dt} &= N_{1,1}\left[r\left(1-\frac{N_{1,1}}{K}\right)-F-T_{12}\right]-(1-q)2r\frac{N_{1,1}N_{2,1}}{K} \\
\frac{dN_{2,1}}{dt} &= N_{2,1}\left[r\left(1-\frac{N_{2,1}}{K}\right)-F-T_{12}\right]-q2r\frac{N_{1,1}N_{2,1}}{K}+T_{21}
\end{aligned} \tag{4}$$

State-space Transition Equation

$$\alpha_t = T(\alpha_{t-1}) + \eta_t \tag{5}$$

$$\begin{aligned}
\log N_{1,1_t} &= \log N_{1,1_{t-\Delta t}} \\
&+ \Delta t\left(r\left(1 - \frac{N_{1,1_{t-\Delta t}}}{K}\right) - \sum_{g=1}^{n} F_{g,t-\Delta t} - T_{12} - (1-q)2r\frac{N_{2,1_{t-\Delta t}}}{K}\right) + \eta_t \\
\log N_{2,1_t} &= \log N_{2,1_{t-\Delta t}} \\
&+ \Delta t\left(r\left(1 - \frac{N_{2,1_{t-\Delta t}}}{K}\right) - \sum_{g=1}^{n} F_{g,t-\Delta t} - T_{12} - q2r\frac{N_{1,1_{t-\Delta t}}}{K} + \frac{T21_{t-\Delta t}}{N_{2,1_{t-\Delta t}}}\right) + \eta_t
\end{aligned} \tag{6}$$

State-space Observation Equation

$$x_t = O(\alpha_t) + \varepsilon_t \tag{7}$$

$$\log C_{g,t} = \log\left(F_{g,t} \cdot \left(\frac{N_{1,1_{t-\Delta t}} + N_{1,1_t}}{2} + \frac{N_{2,1_{t-\Delta t}} + N_{2,1_t}}{2}\right)\right) + \varepsilon_t \tag{8}$$

$$\varepsilon_t \sim (1 - a_g) * N(0, \sigma_\varepsilon^2) + a_g * C(0, \sigma_\varepsilon^2); \quad a_g = 0.07 \tag{9}$$

Proportion Local Prior