

Two-compartment models of Main Hawaiian Islands Yellowfin Tuna Population Interim Report

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Introduction

The Yellowfin Tuna (YFT) population in main Hawaiian Islands (MHI) is embedded in a larger pan-Pacific stock. Nevertheless, local fishermen believe that the MHI supports a “resident” yellowfin population. Some scientific observations are consistent with this belief. Recent tagging, tracking and studies show that the rate of exchange between the MHI population and the larger stock is low (Itano and Holland 2000). Analysis of YFT otoliths sampled from throughout the Pacific conclude that approximately 90% of the MHI population was reared in the MHI (Wells et al 2012). The Hawaii

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based longline along with various small-scale fisheries land a combined catch approximately 5000 mt of YFT annually (ref). Management of these fisheries is an important an important local issue deserving of scientific support.

This paper explores some potential models that might be used to analyze options for the management of fisheries for YFT in the MHI.

The principle assumptions for modeling the MHI YFT population are:

1. The Pacific Ocean near Hawaii is divided into two regions: MHI (region 1) and elsewhere (region 2); see Figure ??.
2. Fish emigrate from region 1 to region 2, but emigrant fish have no effect on region 2 population dynamics. Region 2 is an “infinite sink”.
3. Fish immigrate from region 2 to region 1, and mix completely.
4. Immigrant fish are indistinguishable from “resident” fish (i.e. both groups of fish have the same population dynamics) and interact with the fishing gear identically.
5. Immigration into the MHI is dependent on the biomass of the yellowfin population outside of the MHI as estimated by some other model, e.g., MULTIFAN-CL or SEAPODYM.
6. The fishery comprises of several gear types, each with characteristic fishing mortality.
7. The evolution of fishing mortality over time is a random walk where the current fishing mortality in the current time step is equal to the

fishing mortality in the previous time step plus a random deviation (equation 3).

Data

Several sources of data used are used in this analysis:

1. Yellowfin catch weights reported to the Hawaii Department of Aquatic Resources (HDAR) from 1949 to 2014 from the Offshore Handline, Toll, Inshore Handline, Longline, and Aku Boat fleets.
2. Longline yellowfin catch weights reported to the National Oceanic and Atmospheric Administration, National Marine Fisheries Service (NOAA) under the federally mandated log book program from 1995 through 2013.
3. Measurements of individual yellowfin weights fish sampled at the Honolulu auction by NMFS staff from 2000 through 2013.
4. Model estimates of yellowfin biomass for MFCL regions 2 and 4 provided by the Oceanic Fisheries Programme at the Secretariat of the Pacific Community (SPC) in Noumea, New Caledonia. These estimates span the period 1952 through 2012.

All data are reported by quarter of the year.

The HDAR data comprise catch reports for the following gear categories”

“Aku boat”, “Bottom/inshore HL”, “Longline”, “Troll”, “Tuna HL”, “Casting”, “Hybrid”,

“Shortline”, “Other”, and “Vertical line”. For this analysis catches by “Casting”, “Hybrid”, “Shortline”, “Other”, and “Vertical line” are combined into a new category, “Misc.”. The “Misc” catches are highest after year 2000, but represent a small proportion of the catch. The catch time series for the HDAR data are shown in Figure 1. These time series exhibit marked quarterly cycles suggesting a strong seasonal signal in the catches by all fleets. Some series also contain sustained periods of zero catch which document the development and subsequent shift away from a specific gear type. It is assumed that these declines in catches represent a “collapse” of a fishery due more to social and economic factors than to a decline of stock. Some time series are punctuated by brief, one or two quarters in length, of zero catches. Again it is assumed that these zero catches are not caused by low stock levels. The “Aku Boat” fishery was a small pole and line fishery targeting skipjack tuna in Hawaii, for which yellowfin was an incidental catch ceased operation because of problems marketing fresh skipjack.

The longline fishery has changed drastically over time. In the late 1940s, it was a relatively small fishery using traditional Okinawan-style gear (*reference*), usually labeled “flag line”. Participation in this fishery generally declined from 1950 to late 1980s, as can be seen in the time series plots. In the 1990s, the longline fishery expanded rapidly with the introduction of US fishing boats from the Atlantic ocean with modern monofilament longline gear and deeper sets.

Figure 1 also displays the first order differences between successive quarters. This statistic emphasizes the seasonal periodicity of all fishing fleets

and helps to identify potential anomalies in the data such as changes in reporting protocol. Potential anomalies can be seen in the late 1980s in the Tuna HL fleet, the early 1990s in the longline fleet, and the mid 1950s in the Aku Boat fleet.

The partial autocorrelations within each time series are shown in Figure 2. These correlations confirm the periodic nature of the catch time series which have significant positive correlations at lags of 1,3 and 4 quarters.

NOAA began to collect data from the longline fleet under a federally mandated logbook program in 1990, and in 1995 the deep and shallow setting are distinguished in the data. The HDAR data does not distinguish between deep and shallow sets. Figure 3 shows the correspondence between the HDAR and NOAA time series. The combined deep plus shallow catches from NOAA line up fairly well with the overlapping HDAR data. The simple average of the HDAR data with the combined NOAA deep plus shallow data appears to have roughly the same autocorrelation structure as the constituent time series, Figure 4. *Data are also available from NOAA for the period 1990-1995, but have not yet been included in this analysis.*

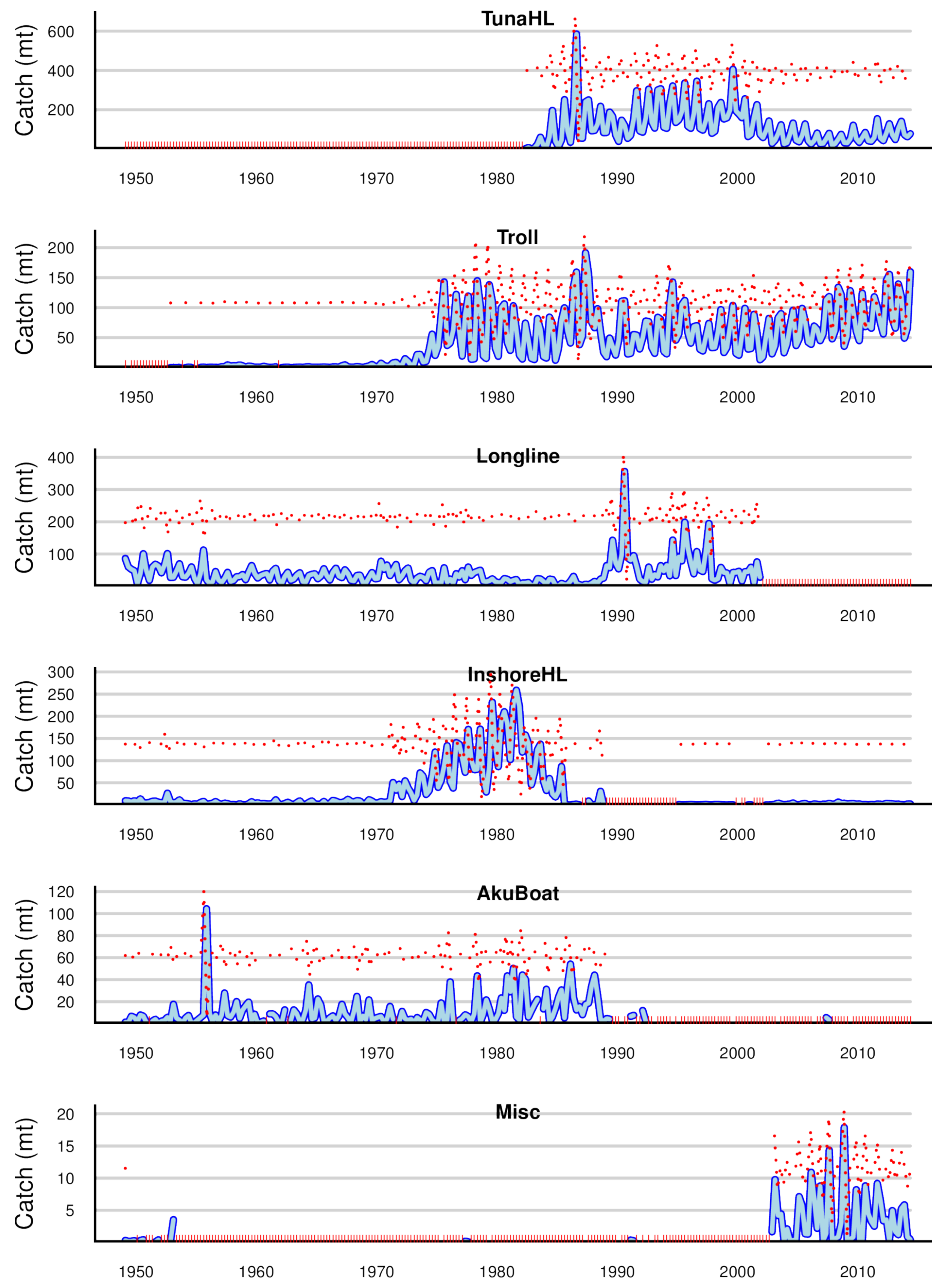


Figure 1: Yellowfin catch in metric tonnes by principle fisheries operating in the Main Hawaiian Islands from the HDAR data. The dotted red line superimposed on each time series is the difference in catch between successive quarters. The red tick marks on the abscissa indicate quarters where catches were zero.

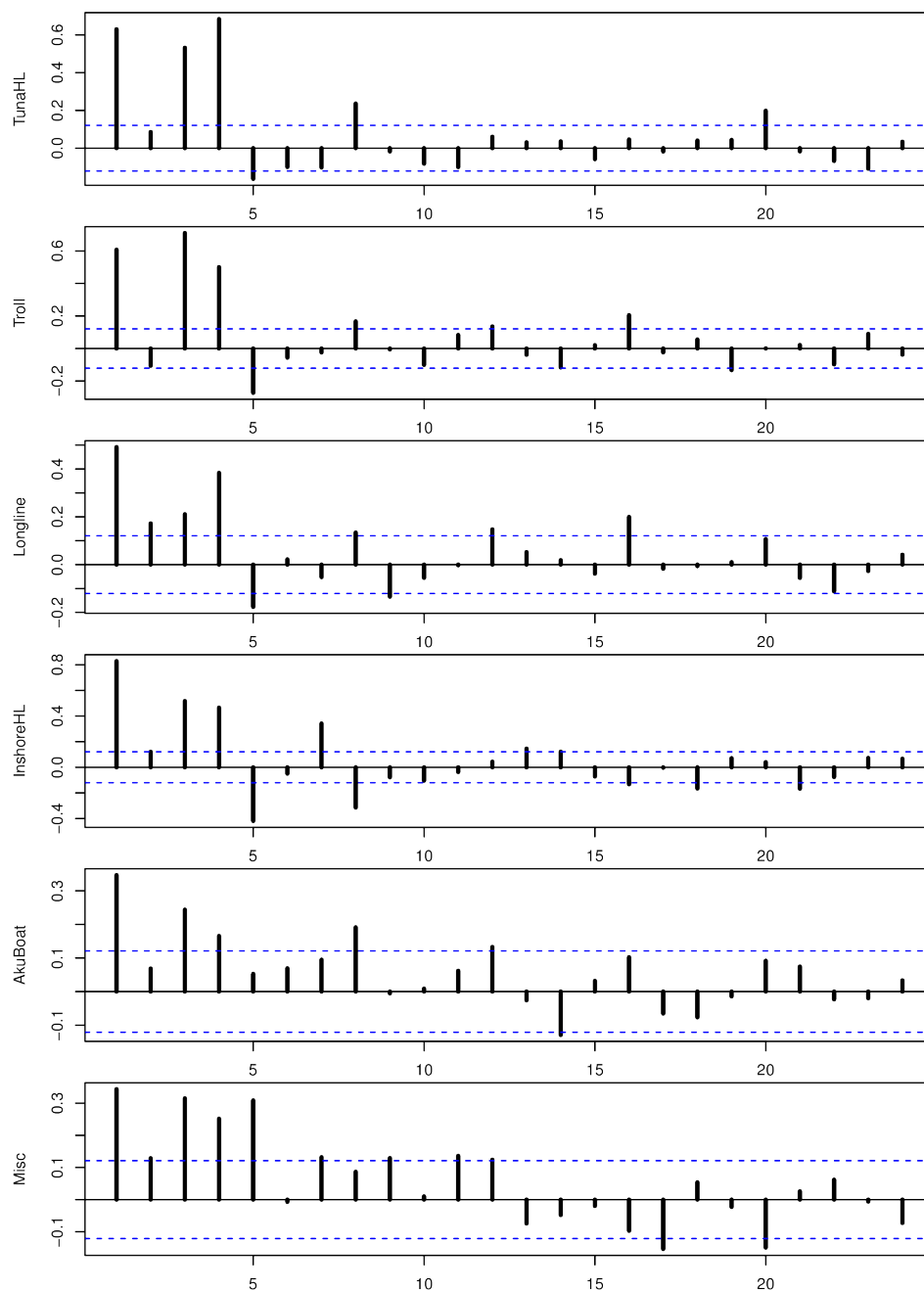


Figure 2: Partial autocorrelation coefficients of the catch time series. The dashed blue lines indicate approximate 95% confidence limits of the correlations.

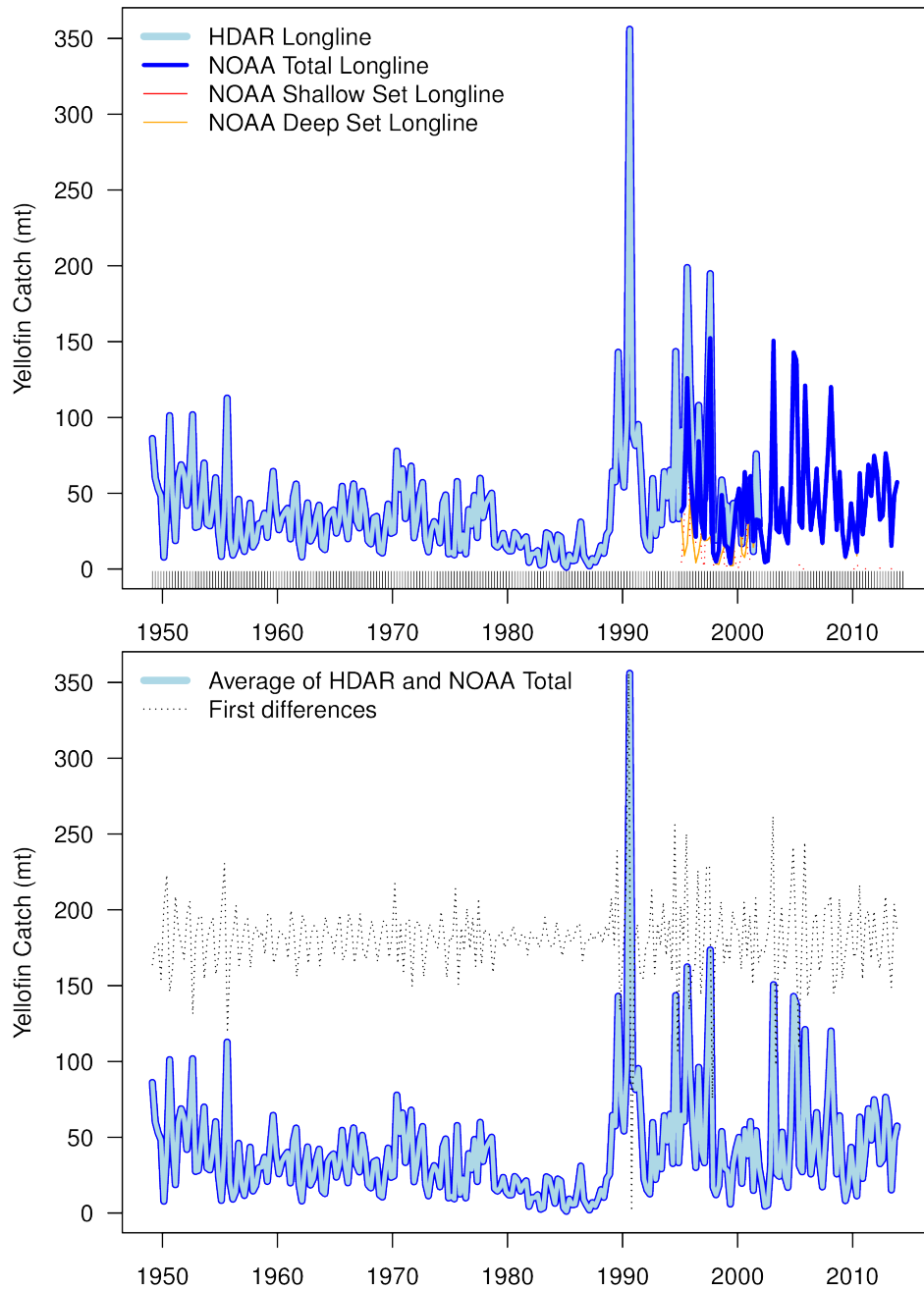


Figure 3: Comparison between HDAR and NOAA longline time series. The upper panel shows the NOAA deep and shallow set data superimposed on the HDAR data. The lower panel shows the time series produced by a simple average of the HDAR data and the sum of the NOAA deep and shallow catches.

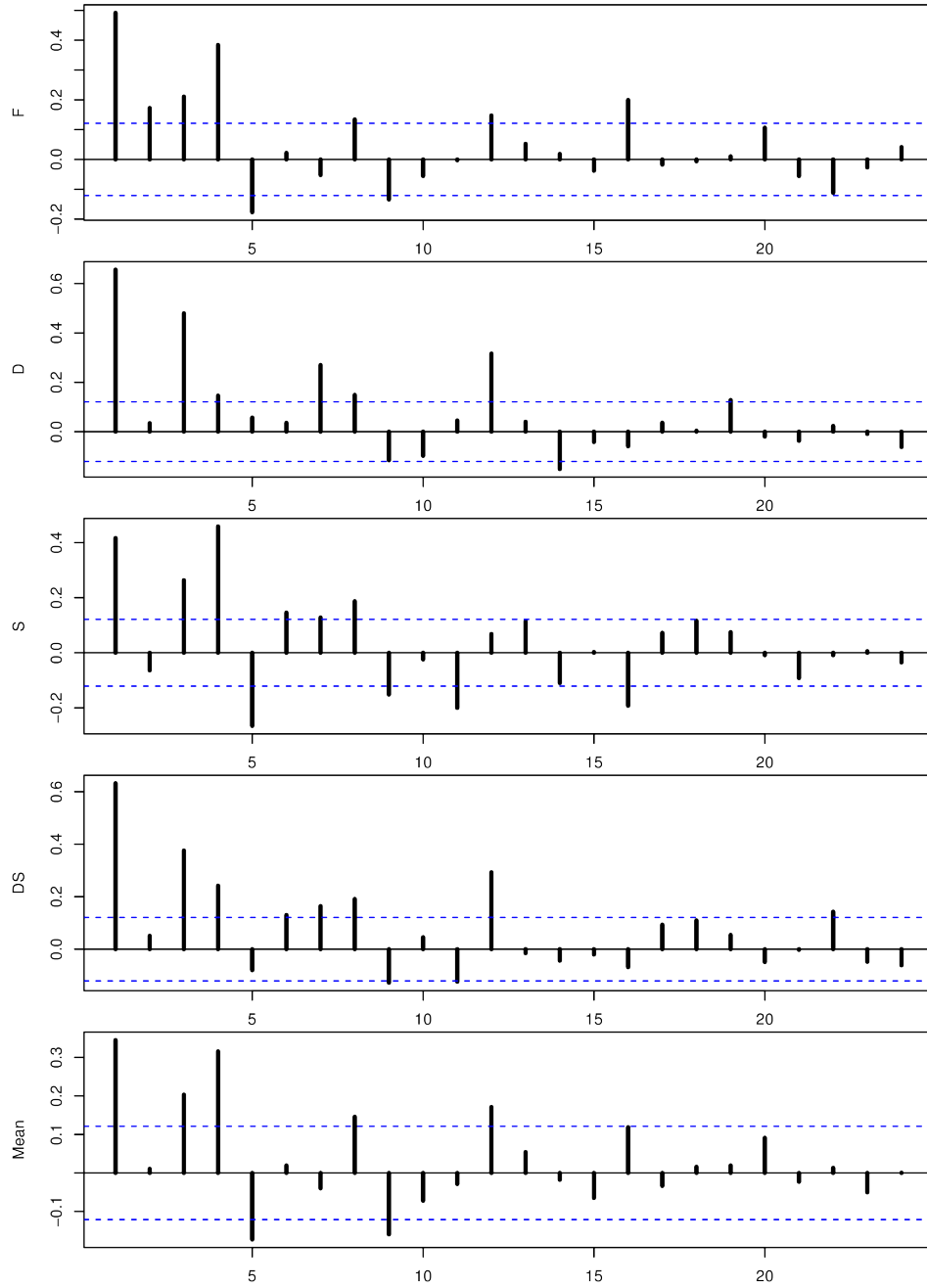


Figure 4: Partial autocorrelations within the NOAA and combined time series. F refers to the HDAR longline data, D refers to the NOAA deep set data, S to the shallow set data, DS to the combined deep and shallow set data, and Mean to the average of the HDAR and NOAA deep plus shallow.

Models

The general modeling approach is similar to the state-space model utilized by Nielsen and Berg (2014). State-space models separate variability in the biological processes in the system (transition model) from errors in observing features of interest in the system (observation model). The general form of the transition equation is

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

where the function T embodies the stock dynamics mediating the development of the state at time t from the state at the previous time with random process error, η . Similarly the general observation equation is

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

where the function O describes the measurement process and with error ε . Separation of process from measurement offers statistical advantages in estimating model parameters.

Fishing effort is not observed and fishing mortality is modeled explicitly. The logarithm of fishing mortality is assumed to follow a random walk with normal increments, i.e.

$$\log F_{g,t} = \log F_{g,t-1} + \xi_{g,t}, \quad \xi_{t,g} \sim N(0, \sigma_g) \quad (3)$$

where σ_g^2 is the characteristic variance of the fishing effort random walk for fleet g .

Age-aggregated model: logistic population dynamics (Schaefer Model)

Let $N_{1,1}$ equal the population size of fish originating in region 1 and residing in region 1 and $N_{2,1}$ equal the population size of fish originating in region 2 but residing in region 1. The total population size of fish residing in region 1 is thus $N_{1,1} + N_{2,1}$, and the dynamics of the population in region 1 is represented as

$$\frac{d}{dt}(N_{1,1} + N_{2,1}) = (N_{1,1} + N_{2,1}) \left[r \left(1 - \frac{N_{1,1} + N_{2,1}}{K} \right) - F - T_{12} \right] + T_{21} \quad (4)$$

where r is the per capita logistic growth rate per year K is the logistic “carrying capacity” measured in the same units as $N_{1,1}$ and $N_{2,1}$, F is the total fishing mortality in region 1, and T_{12} is the emigration rate from region 1 to region 2. T_{21} is the annual rate of immigration of fish from region 2 to region 1 measured in the same units as K per year.

Equivalent differential equations could be devised for the dynamics of fish residing in region 2 (i.e., $\frac{dN_{2,2}}{dt}$ and $\frac{dN_{1,2}}{dt}$) but the dynamics of the fish population in region 2 is external to this model. T_{21} can be considered to be form of population forcing from the larger stock in which the MHI population is embedded, perhaps estimated from other models, such as MULTIFAN-CL or SEAPODYM, or perhaps represented by an autocorrelated stochastic process. The appearance of $N_{1,1} + N_{2,1}$ in the numerator of the logistic term reflects the assumption that the population dynamics fish immigrating into region 1 depend on the population dynamics in region 1. This assumption leads to an important non-linearity in the model that allows the possibility

of overwhelming of the local stock by a more numerous immigrant stock as is often characteristics of mixed-stock fisheries.

The ratio $\frac{N_{1,1}}{N_{1,1}+N_{2,1}}$ is of potential interest, so equation 4 needs to be expanded and rearranged leading to a set of simultaneous differential equation for the components of the population inhabiting region 1.

$$\begin{aligned}\frac{dN_{1,1}}{dt} &= N_{1,1} \left[r \left(1 - \frac{N_{1,1}}{K} \right) - F - T_{12} \right] - r \frac{N_{1,1}N_{2,1}}{K} \\ \frac{dN_{2,1}}{dt} &= N_{2,1} \left[r \left(1 - \frac{N_{2,1}}{K} \right) - F - T_{12} \right] - r \frac{N_{1,1}N_{2,1}}{K} + T_{21}\end{aligned}\tag{5}$$

The non-linear term from equation 4 appears the term $r \frac{N_{1,1}N_{2,1}}{K}$ in both of the above equations.

The equilibrium of this system can be found by setting $\frac{dN_{1,1}}{dt} = 0 = \frac{dN_{2,1}}{dt}$. After some simplification the result is $\frac{T_{21}}{N_{2,1}} = 0$. In other words, there is no equilibrium in this coupled system, other than the degenerate case of no immigration ($T_{21} = 0$) into the region 1. Thus, the notion of using equilibrium-based reference points such as MSY to manage fisheries for MHI yellowfin is ill advised.

The log transformed equivalent of equation 6 can be written as

$$\begin{aligned}\frac{d \log(N_{1,1})}{dt} &= r \left(1 - \frac{N_{1,1}}{K} \right) - F - T_{12} - r \frac{N_{2,1}}{K} \\ \frac{d \log(N_{2,1})}{dt} &= r \left(1 - \frac{N_{2,1}}{K} \right) - F - T_{12} - r \frac{N_{1,1}}{K} + T_{21}/N_{2,1}\end{aligned}\tag{6}$$

Equations 7 are solved by finite difference approximations using explicit

time stepping.

$$\begin{aligned} \log N_{1,1t} &= \log N_{1,1t-\Delta t} \\ &+ \Delta t \left(r \left(1 - \frac{N_{1,1t-\Delta t}}{K} \right) - F_{t-\Delta t} - T_{12} - r \frac{N_{2,1t-\Delta t}}{K} \right) + \eta_{1,t} \end{aligned} \quad (7)$$

$$\begin{aligned} \log N_{2,1t} &= \log N_{2,1t-\Delta t} \\ &+ \Delta t \left(r \left(1 - \frac{N_{2,1t-\Delta t}}{K} \right) - F_{t-\Delta t} - T_{12} - r \frac{N_{1,1t-\Delta t}}{K} + T_{21}/N_{2,1t-\Delta t} \right) + \eta_{2,t} \end{aligned}$$

Addition of process error terms $\eta_{1,t}$ and $\eta_{2,t}$ yields a form suitable for use as the transition equation in a state-space model.

The predicted catch in region 1 is the product of fishing mortality and the total population in region, $N_{1,1} + N_{2,1}$. Thus the observation model predicting catch in the region 1 under this model is

$$C_{g,t} = F_{g,t} \cdot (N_{1,1t-\Delta t} + N_{1,1t} + N_{2,1t-\Delta t} + N_{2,1t})/2 \quad (8)$$

where the total population in region 1 is the sum of the average population over the time step (Quinn and Deriso, 1999).

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