Science and Technical Approaches to Data Rich Stocks: Pacific Blue Marlin

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Thank FRMD leadership for supporting and reviewing the work.
Stock Assessment Process

INPUT
Habitat and environmental information

DATA and INPUT
1. Fishery-dependent data
2. Fishery-independent surveys
3. Life history information

PROCESS
Population Dynamics (statistical models)

OUTPUT
Stock Trajectory
(Biomass, fishing intensity, recruitment)

OUTPUT
Stock Status
Overfished? Overfishing?

OUTPUT
Forecast (what-if)

improves and informs

improves and informs
Data and input for Pacific blue marlin

Life history information
- Stock structure
- Growth
- Maturity and reproduction
- Natural mortality
- Steepness

Fishery-dependent data
- Catch data (commercial and recreational)
- Abundance index from catch-and-effort data (logbooks or observers)
- Size information sampled from the catch
Stock structure

- DNA-based stock structure study in 2003: there is no evidence of population structuring in the Pacific.
- All available fishery data in the Pacific were used.
- To model observations, assume that there was an instantaneous mixing of fish throughout the stock area on a quarterly basis.
Growth

- Variability in length-at-age growth studies
- Sexual dimorphism for age >1
- Lack of otolith microstructure counts for age 0-1 and could not corroborate the first annulus

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Region</td>
<td>Hawaii waters</td>
<td>Hawaii waters</td>
<td>Taiwan waters</td>
<td>Taiwan waters</td>
<td>Japan waters</td>
</tr>
<tr>
<td>Sex-specific</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Size range (EFL)</td>
<td>45-310 cm</td>
<td>95-325 cm</td>
<td>125-225 cm</td>
<td>95-240 cm</td>
<td>160-215 cm</td>
</tr>
<tr>
<td>Samples</td>
<td>length frequency data</td>
<td>Hard parts (Otoliths, Dorsal and Anal spines)</td>
<td>Hard parts (Anal spines)</td>
<td>length frequency data</td>
<td>Hard parts (Dorsal spine)</td>
</tr>
</tbody>
</table>
Growth

- Mean of length-at-age 1 based on Shimose’s otolith daily growth increments study (no sexual dimorphism)
- Mean of length-at-age > 1 based on meta-analyses of growth studies (sexual dimorphism)
Meta-analysis of various studies (Brodziak 2013)

(Sun et al. 2009)

Samples were from northwest Pacific Ocean
Natural mortality

- M was assumed to be age- and sex-specific.

- Meta-analysis of various indirect methods (maximum age, life history correlates, and evolutionary-ecology theory).

- Not estimated from direct methods (analyses using the actual data) (e.g. tagging data)
  - Concerns with tagging analysis: representative sampling, non-reporting of tags, tag shedding, and tag induced mortality (either initial or long-term)

![Lorenzen size-mortality relationship graph]
Sixteen fisheries were defined on the basis of country, gear type, and reported unit of catch, which represents relatively homogeneous fishing units.

Define fisheries in which changes in selectivity and catchability between fisheries are greater than temporal changes between years and between seasons.
Catch data

Misidentified species for Japan catch

Taiwan catch increase
Japan catch drop; Taiwan, China, and Korea catch increase

Catch by gear

Majority of catch are from longliners
What is best available scientific information on Catch?

✓ Accurate species identification (catch is assumed to be well known)

✓ Characterization of uncertainty in catch reporting including discards (total removal from the fisheries)

✓ Spatiotemporal estimates of catch, fishing effort and size by fishing fleet and gear
Size information sampled from the catch

- Size frequency data were compiled by year, season, and fishery

<table>
<thead>
<tr>
<th>What is measurement precision?</th>
<th>Japan LL and driftnet</th>
<th>Taiwan LL</th>
<th>Hawaii LL</th>
<th>Various flags LL</th>
<th>EPO PS</th>
</tr>
</thead>
<tbody>
<tr>
<td>nearest 1 or 5 cm or nearest 1 kg</td>
<td>nearest 2 cm</td>
<td>nearest 1 cm</td>
<td>nearest 2 cm</td>
<td>nearest 1 mm</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>How was the measurement taken?</th>
<th>Japan LL and driftnet</th>
<th>Taiwan LL</th>
<th>Hawaii LL</th>
<th>Various flags LL</th>
<th>EPO PS</th>
</tr>
</thead>
<tbody>
<tr>
<td>landing ports by samplers or onboard measure by crew</td>
<td>onboard measure by crew</td>
<td>onboard measure by observer</td>
<td>landing ports by samplers or onboard measure</td>
<td>onboard measure by observer</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sampling design</th>
<th>Japan LL and driftnet</th>
<th>Taiwan LL</th>
<th>Hawaii LL</th>
<th>Various flags LL</th>
<th>EPO PS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample first 30 fish</td>
<td>Sample first 30 fish</td>
<td>Sample from every 3rd fish</td>
<td>Not available</td>
<td>Sample first 50 fish</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Spatial coverage</th>
<th>Japan LL and driftnet</th>
<th>Taiwan LL</th>
<th>Hawaii LL</th>
<th>Various flags LL</th>
<th>EPO PS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pacific</td>
<td>Pacific</td>
<td>Hawaii waters</td>
<td>Pacific</td>
<td>eastern Pacific</td>
<td></td>
</tr>
</tbody>
</table>
- EFL (cm) or processed weight (kg)

- Size data were not identified to gender
**Abundance index from catch-and-effort data**

- Catch and effort data were compiled by fishery and used to develop standardized annual indices of relative abundance by the ISC members.

<table>
<thead>
<tr>
<th>Source</th>
<th>Japan LL</th>
<th>Taiwan LL</th>
<th>Hawaii LL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data resolution (time-area strata)</td>
<td>Operational, 5X5 degree</td>
<td>Aggregated monthly, 5X5 degree</td>
<td>Operational, 1X1 degree</td>
</tr>
<tr>
<td>Source</td>
<td>Catch and effort data (Logbook)</td>
<td>Raised catch and effort data (Category II)</td>
<td>Observer</td>
</tr>
<tr>
<td>Spatial coverage</td>
<td>Pacific</td>
<td>Pacific</td>
<td>Hawaii waters</td>
</tr>
</tbody>
</table>
Abundance index from catch-and-effort data

Delta GLM

Habitat-based standardization

GAM

Delta GLM

CPUE

GAM

GAM
What is best available scientific information on **CPUE standardizations**?

✓ Fishery descriptions including history of fishery development and changes

✓ Describe data selection, CPUE standardization model, and CPUE estimates

✓ Provide model diagnostics and goodness of fit criteria relative to alternative model configurations

✓ Compare nominal and standardized CPUE

✓ Characterize uncertainty in estimates of standardized CPUE
Stock Assessment Process

**INPUT**
Habitat and environmental information

**DATA and INPUT**
1. Fishery-dependent data
2. Fishery-independent surveys
3. Life history information

**PROCESS**
Population Dynamics (statistical models)

**OUTPUT**
Stock Trajectory (Biomass, fishing intensity, recruitment)

**OUTPUT**
Stock Status
Overfished? Overfishing?

**OUTPUT**
Forecast (what-if)
Integrated assessment model

1) an observational component that consists of the observed data such as catch or length/age composition,

2) a statistical component that quantifies the fit of model predictions to the data using a negative log-likelihood function,

3) a population component that creates age-structured population dynamics using fixed and estimated model processes.

Stock Synthesis Version 3.24f
## Life history information

<table>
<thead>
<tr>
<th>Parameter (unit)</th>
<th>Value</th>
<th>Estimated</th>
</tr>
</thead>
<tbody>
<tr>
<td>natural mortality (M, age-specific\text{\textsuperscript{yr}})</td>
<td>female: 0.42-0.22, male: 0.42-0.37</td>
<td>fixed</td>
</tr>
<tr>
<td>length\text{_at\text{_}1 yr} (EFL cm)</td>
<td>female: 144, male: 144</td>
<td>fixed</td>
</tr>
<tr>
<td>length\text{_at\text{_}26 yr} (EFL cm)</td>
<td>female: 304.178, male: 226</td>
<td>fixed</td>
</tr>
<tr>
<td>VonBert_K</td>
<td>female: 0.107, male: 0.211</td>
<td>fixed</td>
</tr>
<tr>
<td>\text{\textit{w}}=aL^{b} (kg)</td>
<td>female: 1.844E-05, 2.956, male: 1.37E-05, 2.975</td>
<td>fixed</td>
</tr>
<tr>
<td>Size at 50-percent-maturity (EFL cm)</td>
<td>female: 179.76</td>
<td>fixed</td>
</tr>
</tbody>
</table>
## Recruitment parameters

<table>
<thead>
<tr>
<th>Parameter (unit)</th>
<th>Value</th>
<th>Estimated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spawning season</td>
<td>2</td>
<td>fixed</td>
</tr>
<tr>
<td>Recruitment season</td>
<td>2</td>
<td>fixed (best model fit to age-0 fish fisheries)</td>
</tr>
<tr>
<td>spawner-recruit steepness (h)</td>
<td>0.87</td>
<td>fixed (Beverton and Holt SR model; borrowed from striped marlin)</td>
</tr>
<tr>
<td>unfished Recruitment Ln(R0)</td>
<td></td>
<td>estimated</td>
</tr>
<tr>
<td>standard deviation of recruitment</td>
<td>0.32</td>
<td>fixed (iteratively rescaled to match the expected variability)</td>
</tr>
<tr>
<td>recruitment deviations</td>
<td>1971-2010</td>
<td>estimated</td>
</tr>
<tr>
<td>initial age structure</td>
<td>5 years</td>
<td>estimated</td>
</tr>
</tbody>
</table>

Little information on recruitment extends more than 5 yrs explained by the fast growth before they mature around age 3.
Fishery dynamic process

- Two processes are used to describe the fishery dynamics:

  - Selectivity is used to characterize age/length-specific pattern for the fishery.
    - Estimate selectivity for each fishery as a function of size.
    - Because size data were not identified to gender, assume that same size of fish from female and male is equally selected by fisheries in a well-mixed ocean.
    - In single area model, selectivity pattern is a combination of gear/operations effects and spatial distribution of the population.

  - Catchability is used to scale vulnerable biomass.
    - Assume to be constant over time for all indices.
Selectivity Patterns General Principles

- Estimate selectivity patterns as flexible as possible so that the assessment result is not constrained by particular parametric structures. (domed-shaped and time-varying patterns)

Fishery dynamic process Selectivity

- Change in the area of fishing
Statistical component

Catch, CPUE, Size

- Observed catch data were assumed to be
  - unbiased and precise,
  - a lognormal with a SE= 0.05 reflecting high precision.

- CPUE indices were assumed to be
  - lognormal with annual CPUE and SE from the standardization analyses.

- Size composition data were assumed to be
  - multinomial with variance described by the estimated effective sample size.
Selection among CPUEs

- An abundance data set is representative of stock abundance/trend

- When series are in conflict with other representative series:
  Francis (2011) proposed-
  Provide alternative assessments
  (two groups: A - the data set is consistent; or B - it is not)

- If we simply downweight the inconsistent data set we will produce a result that lies somewhere between these two assessments. This result will be wrong in case A, and it will be wrong in case B.
Selection among CPUEs

**Correlation matrix**

<table>
<thead>
<tr>
<th></th>
<th>JP LL1</th>
<th>JP LL2</th>
<th>HW LL</th>
<th>TW LL1</th>
<th>TW LL2</th>
<th>TW LL3</th>
</tr>
</thead>
<tbody>
<tr>
<td>JPLL1 (1975-1993)</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>15</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>JPLL2 (1994-2011)</td>
<td>NA</td>
<td>17</td>
<td>0</td>
<td>6</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>HWLL (1995-2011)</td>
<td>NA</td>
<td>0.36</td>
<td>0</td>
<td>5</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>TWLL1 (1971-1978)</td>
<td>0.20</td>
<td>NA</td>
<td>NA</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>TWLL2 (1979-1999)</td>
<td>0.15</td>
<td>0.15</td>
<td>-0.48</td>
<td>NA</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>TWLL3 (2000-2011)</td>
<td>NA</td>
<td>0.46</td>
<td>-0.27</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
</tbody>
</table>

**Down-weighting analyses**

<table>
<thead>
<tr>
<th></th>
<th>JP LL1</th>
<th>JP LL2</th>
<th>HW LL</th>
<th>TW LL1</th>
<th>TW LL2</th>
<th>TW LL3</th>
</tr>
</thead>
<tbody>
<tr>
<td>DW JPLL</td>
<td>-13.2</td>
<td>0.0</td>
<td>-0.6</td>
<td>6.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DW HWLL</td>
<td>0.0</td>
<td>-11.6</td>
<td>0.0</td>
<td>-0.1</td>
<td>-4.0</td>
<td></td>
</tr>
<tr>
<td>DW TWLL</td>
<td>0.0</td>
<td>5.4</td>
<td>-5.1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A negative value - better fit

- **Two different population trajectories:**
  - Group A: JPN_LL and TW_LL
  - Group B: JPN_LL1 and HW_LL
Selection among CPUEs

Group A

- Japan longline: RMSE = 0.14
- Hawaii longline: RMSE = 0.48
- Taiwan longline: RMSE = 0.21

Group B

- Japan longline: RMSE = 0.16
- Hawaii longline: RMSE = 0.28
- Taiwan longline: RMSE = 0.26

- Japan longline: RMSE = 0.35
- Taiwan longline: RMSE = 0.09
- Taiwan longline: RMSE = 0.34
Stock Assessment Process

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**PROCESS**
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**OUTPUT**
Stock Trajectory (Biomass, fishing intensity, recruitment)

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Stock Status
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**OUTPUT**
Forecast (what-if)

**INPUT**
Habitat and environmental information

Improves and informs
Model checking

Convergence

- No evidence of a lack of convergence as
  - Hessian was positive-definite,
  - Variance-covariance matrix was estimable,
  - Correlation coefficients between parameters were acceptably low.

Diagnostics

- Randomly perturbing the parameter starting values and phases of parameters
- Goodness of fit: residuals analysis
- Likelihood profile of virgin recruitment
- Retrospective analysis
Model diagnostics

- Randomly perturbing the parameter starting values and phases of parameters

We could not find a better fitting model.
Goodness of fit

- Predicted catch data were unbiased and precise estimates as the model removed >99% of the total catch from all fisheries.
- The model represented trends of abundance reasonably well where predictions are within the confidence intervals of the observations.
- Predicted size compositions were reasonable approximations of the observed size compositions.
Model diagnostics

- Likelihood profile of virgin recruitment ($R_0$)
  - the degradation in model fit (DNLL: NLL - the minimum of NLL)

1. Identify how much information there is on scaling from that component
2. Identify where conflicts in the data occur

Wang et al. 2014
Model diagnostics

- Likelihood profile of virgin recruitment \((R_0)\)

<table>
<thead>
<tr>
<th>Estimate of (\ln(R_0))</th>
<th>(\ln(R_0))</th>
<th>Composition data components</th>
<th>Index data components</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(F1)</td>
<td>(F2)</td>
</tr>
<tr>
<td>(6.5)</td>
<td>(6.86)</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>(6.6)</td>
<td></td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>(6.7)</td>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>(6.8)</td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>(6.9)</td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>(7.0)</td>
<td></td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>(7.1)</td>
<td></td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>

- Internally consistent model regarding scale where composition component DNLL <3 units and index component DNLL <2 units at the \(R_0\) when estimated
Model diagnostics

- Retrospective analysis
Compare to alternative models

- SS model 5 and AS model: relative biomass declined by 50% during the first 10 years.

- A hybrid production model: relative biomass showed a less decline.

- Results from each of the alternative models were similar at the end of the time series, showing the robustness of the assessment results.
Stock trajectory

- Estimates of spawning biomass declined from the 1970s through the early 2000’s, before stabilizing in the last few years.

- Recruitment levels remained relatively stable.

- Estimated fishing mortality increased from 1971 to 2003, thereafter declining.
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improves and informs
Stock status

- The population is
  - not overfished
  - not experiencing overfishing
  - fully utilized
Impacts of alternative assumptions on stock status

- Alternative M and h had large impacts on stock status (e.g. stock is overfished and experiencing overfishing for scenario 3, 5 or 6);

- Incorporating catch back to 1952 (scenario 1) had little impact.
Stock Assessment Process

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Stock Status
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**OUTPUT**
Forecast (what-if)
Future projections

- When the current level is maintained, the stock is projected to be stable at roughly 26,200 t by 2020.
- If fishing increases to the MSY level, the projected SSB decrease gradually to the MSY level by 2020.
- If fishing increases to the 2003-2005 level, the projected SSB would be below SB at MSY level by 2015.
- If fishing is reduced to $F_{30\%}$, the projected SSB would gradually increase.
What is best available scientific information on *fishery stock assessment*?

✓ Description of model structure and assumptions

✓ Provide diagnostics of model fit to data

✓ Describe model results including stock status relative to biological reference points

✓ Characterize uncertainty in model results including sensitivity analyses for key parameters

✓ Provide projections of management actions

✓ External reviews (ISC Plenary, WCPFC-SC, CIE)
**Strengths**
- Meet best available scientific practice with ISC
- Use large-spatial scale fishery-dependent data
- Collaborate among nations and RFMOs
- Model matches data complexity
- Model contains enough process (e.g. sex-specific)
- Develop alternative models

**Weaknesses**
- No long-term large-scale fishery-independent survey
- Assume known catch
- Missing data for important model processes (e.g. sex-specific catch and size, tagging)
- Ignore regional difference (e.g. growth, CPUE)

**Opportunities**
- Develop indices from other fisheries (e.g. Korea, China)
- Improve catch reporting (e.g. discards)
- Collect sex-specific size
- Improve understanding of stock structure and life history
- Develop spatial structured model
- Develop international tagging program

**Threats**
- Lag between last year of data and assessment
- Indices always based on fishery-dependent data
- Management should cover the entire Pacific currently multiple RFMOs (WCPFC, IATTC)

**SWOT Analysis**

**Things we can control**

**Things we cannot control**
Steepness

- Steepness of the stock-recruitment relationship ($h$) was defined as the fraction of recruitment from a virgin population ($R_0$) when the spawning stock biomass is 20% of its virgin level ($SSB_0$).

- Independent estimates of steepness incorporated biological and ecological characteristic of striped marlin in the western and central North Pacific Ocean (Brodziak 2011) reported that mean $h$ was $0.87\pm0.05$.

- Due to the fast-growing characteristic on the early life history stages for both striped marlin and blue marlin, a fixed value at 0.87 was borrowed from striped marlin.
## Reference points

<table>
<thead>
<tr>
<th>Reference point</th>
<th>Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_{2009-2011}$ (age 2+)</td>
<td>0.26</td>
</tr>
<tr>
<td>$SPR_{2009-2011}$</td>
<td>0.23</td>
</tr>
<tr>
<td>$SSB_{2011}$</td>
<td>24990 t</td>
</tr>
<tr>
<td>$F_{\text{MSY}}$ (age 2+)</td>
<td>0.32</td>
</tr>
<tr>
<td>$F_{20%}$ (age 2+)</td>
<td>0.29</td>
</tr>
<tr>
<td>$SPR_{\text{MSY}}$</td>
<td>0.18</td>
</tr>
<tr>
<td>$SSB_{\text{MSY}}$</td>
<td>19437 t</td>
</tr>
<tr>
<td>$SSB_{20%}$</td>
<td>26324 t</td>
</tr>
<tr>
<td>$\text{MSY}$</td>
<td>19459 t</td>
</tr>
</tbody>
</table>
Sensitivity to alternative assumptions

Data
- Include catch for 1952-1970;
- Alternative stock trend for group B;

Biological assumptions
- Natural mortality rate (M):
  - low M schedule with adult M=0.12 females and 0.27 for males;
  - high M schedule with adult M=0.32 females and 0.47 for males;
- Stock-recruitment steepness (h): h=0.65, 0.75, and 0.95;
- Growth curve:
  - Smaller fish: Length at maximum reference age to be $L_{max} = 205$. Use a growth coefficient K that is consistent with the size-at-age 1 in the base case;
  - Larger fish: Length at maximum reference age to be $L_{max} = 225$. Use a growth coefficient K that is consistent with the size-at-age 1 in the base case;
  - Use growth parameters for males from Chang et al. (2013):
- Size-at-50 percent-maturity ($L_{50\%}$): $L_{50\%} = 197.736$ cm and $L_{50\%} = 161.784$ cm.
Future projections

- Fishing at the current level or at the MSY level should provide an expected safe level of harvest, where the average projected catches for 2012-2020 is close to MSY.