INTER-AMERICAN TROPICAL TUNA COMMISSION

WORKSHOP ON AGE AND GROWTH OF BIGEYE AND YELLOWFIN TUNAS IN THE PACIFIC OCEAN

La Jolla, California (USA)
23-25 January 2019

REPORT OF THE WORKSHOP

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1. BACKGROUND

Age and growth models, and their estimates of asymptotic length (L_∞), have been shown to be highly influential in assessing the status of bigeye tuna in integrated assessment models. Although there are documented differences in the life history characteristics of the bigeye stocks from the eastern Pacific Ocean (EPO) and the western and central Pacific Ocean (WCPO), the magnitude of the discrepancies in the estimated length-at age data, growth models, and L_∞ estimates used in the recent IATTC and WCPFC stock assessments, along with the major differences in the interpretation of stock status of bigeye across the Pacific Ocean, are reasons for concern.

The IATTC received funds to organize a workshop to evaluate differences in age estimation methods and the resulting growth models used in current stock assessments of bigeye tuna by the IATTC and WCPFC (IATTC project E.2.b). Since the stock assessments of yellowfin tuna from the EPO and WCPO are also greatly influenced by growth estimates, that species was also included in the scope of the workshop (see agenda, Appendix 1).

The workshop, held in La Jolla, California, USA, on 23-25 January 2019, was chaired by Mark Maunder, head of the IATTC staff Stock Assessment Group. In addition to IATTC staff in attendance, a group of external scientists involved in tuna age and growth studies in the WCPO was invited (see list of participants, Appendix 2). Several participants gave talks as background for the discussions (presentations available here; see abstracts in Appendix 3).

The workshop addressed the following objectives:

1. Evaluate methodologies being employed for counting daily and annual increments in the otoliths of bigeye and yellowfin tunas from the eastern and western Pacific;
2. Compare daily and annual increment counts from pairs of otoliths from both species;
3. Compare growth rates from length-at-age data based on otolith increment counts with those from tagging data;
4. Evaluate the growth models being used in stock assessments for bigeye and yellowfin tunas in the EPO and WCPO;
5. Based on objectives 1-4, develop a work plan to resolve any scientific and technical issues that

may emerge from the evaluations and comparisons considered at the workshop.

This report summarizes the key points noted by the IATTC staff during discussions, along with the recommendations of the workshop for inclusion in a work plan.

2. KEY POINTS

Several issues regarding age and growth studies were identified at the workshop, many of which can be addressed by collecting more data and carrying out further direct validation studies. Additional ageing data should be collected to cover the spatial range of the stocks and to see whether growth rates have changed over time, since there appears to be spatial and temporal variation in growth rates. There is also a need to collect data from older fish to inform estimates of asymptotic length. In general, this will require tags to be recovered after long periods at liberty, tagging large individuals, or validating increment formation in otoliths for old individuals. Substantial effort is needed to ensure reliable recapture data, including dedicated personnel at unloading ports. Correlations between otolith weight and fish length might be useful for investigating spatial distribution in growth. Otoliths from fish with archival tags will allow the investigation of whether growth is affected by spatial or environmental conditions. Development of a tissue bank (otoliths, spines, vertebrae, tissues, stomachs, gonads, *etc*.) for the EPO should be considered to provide data for future analyses.

The current studies on direct validation of daily and annual increment deposition rates in otoliths of bigeye and yellowfin tunas are limited in space, time, and age range , and should be extended for better coverage. However, before extensive validation studies are carried out, the ageing protocols should be further refined and comprehensively described. Several aspects of the protocols can cause biases. In particular, the daily increment method using frontal sectioning needs to be validated in the WCPO, and annual ageing needs to be validated for both species throughout the Pacific. To aid validation, future tagging programs should consider chemical marking of fish at release, with oxytetracycline (OTC), for example.

Investigations should also be conducted to better understand the relationship between increment formation and age. For example, understanding the mechanisms for increment formation would help interpretation of age readings. Dates of hatching and the time period of annual increment formation are uncertain, and should be given more consideration when developing annual ageing methods. The value of increment width for providing information on growth patterns and for parameter estimation should be investigated. Consideration should be given to using daily increments, which have higher precision, for ageing bigeye and yellowfin tunas up to a maximum of 4 years, for which daily increments have been validated for bigeye and yellowfin tunas in the EPO. Annual increment counts, following validation studies, should be considered for direct ageing of older individuals for both species in the Pacific.

Further development of methods for analyzing the data and including them in stock assessment models is needed. Age estimates from otoliths and high-confidence tagging data should be used simultaneously in integrated growth models. Predicted age-length estimates in stock assessments should be aggregated to match the appropriate age scale in the observed data (*e.g*. aggregate quarterly ages in the assessment to annual ages to fit to annual otolith data). Integrating the estimation of growth into the stock assessment model would benefit from development of the functionality to include tag growth increment data. However, all the types of growth data should be analyzed outside the model, simultaneously and independently, as a diagnostic check. Measurement error in length measurements (or time at liberty or recapture location) from tagging data needs to be accounted for (*e.g*. only use reliable (high-confidence) data or explicitly model measurement error). Shrinkage of fish due to death, freezing, and thawing, as well as measurement error, need to be accounted for appropriately in all data (tagging, size composition, etc.) Complex growth patterns should be considered to deal with slowing of growth at small sizes.

3. PROGRESS TOWARDS OBJECTIVES

Objective 1. *Evaluate methodologies being employed for counting daily and annual increments in the otoliths of bigeye and yellowfin tunas from the eastern and western Pacific*

A planned technical workshop for a small group of experts from IATTC and those working with WCPFC to compare otolith daily and annual increment ageing methodologies had to be postponed due to the US Federal Government shutdown. Several aspects, however, were evaluated based on presentations and discussions. This work will be continued as soon as possible.

Objective 2. *Compare daily and annual increment counts from pairs of otoliths from both species*

Evaluations of daily and annual increment counts from paired otoliths of bigeye and yellowfin tunas from the EPO were presented (Appendix 3). Both evaluations showed higher estimates of ages for fish greater than 130 cm, for the decimal ages from annual increment counts compared to estimates from daily increment counts. Further work on both species will be undertaken at the postponed technical workshop.

Objective 3. *Compare growth rates from length-at-age data based on otolith increment counts with those from tagging data for bigeye and yellowfin tunas from the EPO and WCPO*

Some discrepancies were found and discussed in the growth rates estimated from daily increment counts or annual zone counts from otoliths of bigeye tuna, and tagging data, from the EPO and WCPO, respectively. Separation of EPO tag releases at 95°W and 140°W (also different release periods) showed different growth rates, despite predominantly eastward movement of fish tagged at 140°W. The 95°W data were similar to the daily increment otolith data. EPO bigeye tuna tagging data suggest that there is two-stage growth, but daily otolith data do not. The WCPO tagging data included larger fish than those observed in the otolith data set and the integrated growth model using the otolith and tagging data produced a higher L_∞ estimate than analyses of the otolith data alone. The yellowfin tuna comparisons of growth rates from length-at-age data based on otolith increment counts with those from tagging data in the EPO and WCPO are based on limited data, but showed some discrepancies.

Objective 4. *Evaluate the growth models being used in stock assessments for bigeye and yellowfin tunas in the EPO and WCPO*

The growth models ignore spatial variation. There are some inconsistencies in the length-composition data used in the assessment models and the growth models. Stock assessment results and management recommendations are sensitive to L_∞. Differences in the L_∞ used in the EPO and WCPO assessments of bigeye are representative of size composition in these stocks, as EPO fish grow to larger sizes. There is still uncertainty in the estimates of L_∞, and more data need to be collected.

Objective 5. *Based on the above, develop a work plan to resolve any scientific and technical issues that may emerge from the evaluations and comparisons considered at the workshop*

See recommendations below.

4. RECOMMENDATIONS

a. Hold a technical workshop to compare methodologies, and exchange additional otoliths from the EPO and WCPO, as soon as possible.
b. Include the following elements in the work plan:
    i. Improve and document the protocols for daily and annual ageing.
    ii. Conduct spatial analyses based on otolith weight, using all available otoliths
    iii. Extend the validation of daily and annual otolith counts across the Pacific by incorporating

some oxytetracycline (OTC) marking in tagging programs.

iv. Extend the spatial/temporal/size/gender distribution of EPO daily increment otolith data.
v. Develop Pacific-wide assessments that can accommodate spatial variation in growth rates and reflect stock structure and movement hypotheses.

Appendix 1. Agenda

INTER-AMERICAN TROPICAL TUNA COMMISSION

WORKSHOP ON AGE AND GROWTH OF BIGEYE AND YELLOWFIN TUNAS IN THE PACIFIC OCEAN

La Jolla, California (USA)
23-25 January 2019

AGENDA

Wednesday 23 January

1. 0900: Introductions, notifications, background, objectives, products (*Mark Maunder, Chair*)

2. Bigeye: Investigations of the daily and annual increment deposition rates in otoliths and their usefulness for estimation of age and growth

0930: Investigations of daily and annual increment deposition rates in otoliths and their usefulness for estimation of the age and growth of fish (*Chris Francis)*
1000: Daily deposition rates: oxytetracycline-marking experiments (*Daniel Fuller*)
1100: Annual and daily deposition rates: strontium-marking experiments (*Jessica Farley*)
1130: Discussion

3. Bigeye: Age estimation based on counts of otolith increments

1300: EPO (*Dan Fuller*)
1330: WCPO (*Jessica Farley*)
1400: Challenges in the 'art' of ageing: a brief history of 20 years working on age estimation studies, with a focus on the difficulties encountered in recent ageing of bigeye from the EPO and WCPO using otolith annual increment counts (*Kyne Krusic-Golub*)
1430: Discussion

4. Bigeye: Evaluations of daily and annual increment counts from otoliths

1530: EPO (*Kurt Schaefer*)
1600: WCPO (*Jessica Farley*)
1615: Work plan for a collaborative WCPFC-IATTC ageing exercise (*Jessica Farley*)
1630: Discussion

Thursday 24 January

5. Bigeye: Comparisons of growth rates derived from tagging data and otolith increment counts

0900: EPO (*Haikun Xu*)
0930: WCPO (*Matthew Vincent*)
1000: Discussion

6. Bigeye: Growth models currently utilized in IATTC and WCPFC stock assessments and future considerations

1100: EPO (*Mark Maunder*)
1130: WCPO (*John Hampton*)
1300: Estimating fish growth for stock assessments using both age-length and tagging-increment data (*Chris Francis*)
1330: Growth models for bigeye in the WCPO based on annual ageing data, including an assessment of spatial variation in growth (*Paige Eveson*)

7. Bigeye: Length composition data included in regional stock assessments and the sensitivity of assessment results to the estimated L_∞ value obtained from growth models

1430: EPO (*Haikun Xu*)
1500: WCPO (*Matthew Vincent*)

8. Bigeye: Resolving discrepancies in age and growth in the EPO and WCPO

1530: Synopsis by Chair, discussion
1630: Conclusions and recommendations

Friday 25 January

9. Yellowfin: Investigations of daily and annual increment deposition rates in otoliths and their usefulness for estimation of the age and growth

0900: Daily deposition rates: oxytetracycline-marking experiments (*Jeanne Wexler*)
0930: Discussion

10. Yellowfin: Age and growth based on otolith increment counts

1030: EPO (*Dan Fuller*)
1100: Preliminary estimation of the age-at-length of yellowfin from the WCPO based on otolith annual increment counts (*Jessica Farley*)
1130: Challenges in ageing yellowfin from the EPO and WCPO using otolith annual increment counts (*Kyne Krusic-Golub*)

11. Yellowfin: Evaluations of daily and annual increment counts from otoliths

1300: EPO (*Kurt Schaefer*)
1330: WCPO (*Jessica Farley*)

12. Yellowfin: Growth rate estimates obtained from tagging data

1400: EPO (*Carolina Minte-Vera*)
1430. WCPO (*Graham Pilling*)

13. Yellowfin: Growth models currently utilized in IATTC and WCPFC stock assessments and future considerations

1530: EPO (*Carolina Minte-Vera*)
1600: WCPO (*Graham Pilling*)
1630: Discussion and recommendations

SCHEDULE:
0900 Start
1030-1100 Break (1000-1030 Friday)
1200-1300 Lunch
1400-1430 Break (1500-1530 Friday)
1700 Close
All presentations will be 20 minutes, plus 10 minutes for questions/comments.

LOCATION:
Embassy Suites Hotel, La Jolla
4550 La Jolla Village Drive
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Appendix 2. Participants

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Appendix 3. Abstracts

INVESTIGATIONS OF DAILY AND ANNUAL INCREMENT DEPOSITION RATES IN OTOLITHS AND THEIR USEFULNESS FOR ESTIMATION OF THE AGE AND GROWTH OF FISH

Chris Francis

This talk will address the following questions:

1. Rather than choosing between daily and annual rings, we should be asking what the best ageing protocol for our species is.
2. In a tuna stock assessment growth model the description of the variation of length at age is at least as important as the mean length at age curve.
3. We need to think more clearly about what it means to validate an ageing protocol

TAG-RECAPTURE OXYTETRACYCLINE-MARKING EXPERIMENTS TO INVESTIGATE DAILY INCREMENT DEPOSITION RATE IN BIGEYE TUNA OTOLITHS

Daniel W. Fuller and Kurt M. Schaefer

Daily increment deposition rates were evaluated in frontal sections (primordium-post-rostral tip) of bigeye tuna sagittal otoliths utilizing oxytetracycline (OTC) marked and recaptured fish from two experiments conducted by IATTC. The first experiment was conducted southwest of the Hawaiian Islands during 1995 and 1996 where 1,043 bigeye tuna (36 -105) cm were captured, injected with OTC, tagged, and released. A total of 46 otolith pairs were recovered from 101 total tag returns (9.7%). The second experiment was conducted in equatorial waters of the eastern Pacific during 2000 and 2002 to 2004, where 1,094 bigeye tuna (46 -139 cm) were captured, injected with OTC, tagged, and released. A total of 81 otolith pairs were recovered from 424 total tag returns (38.8 %).

A subset of 70 otoliths were selected from the 127 otolith pairs to obtain a comprehensive sample for both fork length (38 – 135 cm) and days at liberty (15 – 551 days). Otoliths were mounted in epoxy blocks and sectioned on a low speed isomet saw using diamond wafering blades. Sections were mounted to slides using crystalbond thermoplastic and polished to obtain a thin, scratchless section (~10 microns). Otoliths were viewed at 900x magnification under ultra violet light to fluoresce the OTC mark. Increments, from the OTC mark to the post-rostral tip, were counted 5 times each by two independent readers without knowledge of the days at liberty.

A paired sample t-test indicated no significant difference between the counts of the two readers ($t = -0.13$, $DF = 69$, $P > 0.05$). The relationship between the mean number of increments from the OTC mark to the postrostral tip and days at liberty is: $I = 0.9998D – 1.0353$ ($r2 = 0.999$, $n = 70$), where I is the number of increments counted and D is the days at liberty. The slope is not significantly different from 1 ($t = 0.06$, $df = 69$, $P > 0.05$) indicating that bigeye tuna (38-135 cm) deposit daily increments in sagittal otoliths along the primordium to post-rostral axis.

BIGEYE ANNUAL & DAILY INCREMENT DEPOSITION RATES: STRONTIUM-MARKING EXPERIMENTS

Jessica Farley

This presentation describes work undertaken by CSIRO and SPC to developed techniques to validate estimates of annual and daily age of bigeye tuna through a strontium chloride mark-recapture experiment. Three tagging programs were undertaken in the Coral Sea in the 1990s and early-2000s. As part of that program, bigeye tuna (and yellowfin tuna) were captured, injected with a strontium chloride solution (250 mg g-1 of body weight) and released. A total of 34 bigeye were recaptured after being at liberty for 207 days to 6.6 years, and the otoliths were obtained. The fish were 72-125 cm FL at release and 85-157 cm at recapture. Of the otoliths collected, 11 otoliths were sectioned (transverse) and examined using a scanning electronic microscope to locate the strontium mark. The number of 'annual' increments visible in the otoliths after the mark was equal to or within the range expected, given the time at liberty, for all fish. This validation experiment showed that the 2nd to 9th increments in otoliths were deposited annually. The number of 'daily' increments counted in the otoliths after the mark underestimated the days at liberty by 7.7% to 29.4% (mean 18.6%), when examined using the SEM. This underestimate could be explained to some extent by an interruption in growth after tagging. However, the high underestimation of age and low confidence assigned to the counts from otoliths of the larger fish analysed indicate using Sr-marked bigeye for validating daily age estimates has limited value for large fish. Daily ageing, however, was used to confirm the location of the first two annual zones.

ESTIMATION OF AGE-AT-LENGTH FOR BIGEYE TUNA FROM THE EASTERN PACIFIC OCEAN BASED ON OTOLITH DAILY INCREMENT COUNTS

Daniel W. Fuller and Kurt M. Schaefer

Tagging and oxytetracycline marking experiments conducted in the central and eastern Pacific Ocean (EPO) demonstrated that bigeye tuna 38 to 135 cm deposit daily increments in the primordium to post-rostral axis of their sagittal otoliths. Assuming bigeye tuna deposit increments at the same daily rate when less than 38 cm and greater than 135 cm, age estimates from daily increment counts will provide accurate estimates of age at length up to about 150 cm. The objective of this study was to use validated daily increment counts along the primordium – post rostral axis to estimate the age at length of bigeye tuna captured in the EPO.

Sagittal otoliths were collected from 378 bigeye tuna between 2000 and 2004, throughout the range of the surface fishery between 5°29'N and 16°05 S and 84°23 W and 142°27 W. Selected otoliths were mounted in epoxy blocks, sectioned in the primordium – postrostral axis, and mounted to slides using crystalbond thermoplastic. The mounted sections were hand polished to obtain thin (5-15 microns), clear, and scratchless sections. A composite digital image of the counting path was created using a Diagnostic Instruments SPOT RT digital camera and Image Pro Plus software, yielding a final magnification of 1425x. Counts were made from the primordium to the post-rostral tip using Image Pro Plus software. Increments were marked along the transect of the counting path and increment widths measured.

In total, 254 bigeye tuna sagittal otoliths were read to provide direct estimates of their ages in days. Daily increment counts for bigeye tuna (30.4 to 149.1cm) ranged from 139 to 1453 d (0.4 to 3.98 years). The mean width of the last 50 increments of the 20 oldest bigeye in this study is 2.51µ (range 1.59µ to 3.74µ), which is well above the limit of optical resolution of ~0.3µ. This suggest it may be possible, using the methods employed in this study, to derive age estimates for bigeye larger than 150 cm (4 years), however further validation work would be necessary. A GAM was fit to the age at length data for females and males and the results indicated no significant difference in age at length between the two sexes.

ESTIMATION OF AGE-AT-LENGTH OF BIGEYE FROM THE WCPO BASED ON OTOLITH ANNUAL INCREMENT COUNTS

Jessica Farley.

This presentation described work undertaken by CSIRO and SPC on bigeye tuna age and growth in the WCPO. Otolith were selected from fish caught between 120°W-150°E and 10°N-40°S. The otoliths were prepared and read by Fish Ageing Services using validated annual ageing protocols based on counts of opaque zones in transverse sections. Fish ranged in length from 28 to 192 cm FL and zone counts ranged from 0 to 14 (n=1186). A decimal age was estimated for each fish using an algorithm that used the zone counts, a nominal birth date, capture date and the state of completion of the marginal increment (edge classification) of the otolith. After examining several options, a birth date of 1 July was selected. Based on marginal increment and edge type analysis, it was determined that opaque zones are completed in the period between April and September, and used 1 July as the point for adjusting the counts of opaque zones to assign individuals into their correct age class. Annual ages ranged from 0.25 to 14.6 years. Daily age estimates were also obtained for 70 fish from counts of micro-increments in longitudinal sectioned otoliths. However, otolith sections were difficult to interpret after 300 zones and only daily ages of fish age < 1 were included in the growth final analysis. The annual and daily age estimates were combined with historic daily age estimates (age < 1 year) to obtain von Bertalanffy growth parameters for the WCPO bigeye tuna population. The resulting L_{∞} estimate was 156.9 cm FL, which is substantially lower than used in earlier stock assessments.

CHALLENGES IN THE ‘ART” OF AGEING: A BRIEF HISTORY OF 20 YEARS WORKING ON AGE ESTIMATION STUDIES, WITH A FOCUS ON THE DIFFICULTIES ENCOUNTERED IN RECENT AGEING OF BIGEYE FROM THE EPO AND WCPO USING OTOLITH ANNUAL INCREMENT COUNTS.

Kyne Krusic-Golub.

While the initial fast growth of tuna species is unique, many of the challenges encountered with ageing species from this family are not limited to just tuna. During the past 20+ years working in this field of research I have had the ability to examine otoliths from >250 different species for the purpose annual ageing and >60 species for daily ageing. During this time, I have made many observations relating to the field of age estimation. This presentation introduces several key observations that are hopefully relevant to this workshop in the hope that they can provide some necessary background information on key discussion points that are likely to arise. The second part of the presentation focuses on the difficulties encountered with ageing Bigeye Tuna and provides context to how the efforts to validate and verify the ageing method for this species in the WCPO have helped resolve some of these difficulties.

EVALUATIONS OF DAILY AND ANNUAL INCREMENT COUNTS FROM OTOLITHS OF BIGEYE TUNA CAPTURED IN THE EASTERN TROPICAL PACIFIC OCEAN

Kurt Schaefer, Daniel Fuller, and Keisuke Satoh

The objectives of this investigation are to evaluate the apparent differences in age estimates derived from daily and annual increment counts from paired bigeye tuna (BET) otoliths, including paired otolith samples from the eastern Pacific Ocean (EPO), to help elucidate the basis for the discrepancies in the bigeye growth models for the EPO and western and central Pacific Ocean (WCPO).

A direct comparison was conducted of the annual versus daily increment counts using the same 70 otolith pairs from BET ranging from 80-150 cm FL, collected in the equatorial EPO (EEPO), primarily between 2N to 6S and 95W to 130W, during December 2000 to December 2001. Comparisons of the daily increment counts were made with the annual zone counts and with the annual counts adjusted to decimal ages. Another comparison was conducted of the otolith decimal ages for 133 BET (112-207 cm) captured in the southern EPO (SEPO) primarily between about 6S-16S and 86W-119W, during July 2012 to January 2016, to the otolith daily increment counts for the same previously mentioned 70 BET (80-150 cm FL). The decimal ages for BET greater than 150 cm FL were compared with the integrated growth model for BET from the EPO, including high confidence tagging data for fish from 150-201 cm.

Comparisons of daily and annual decimal age estimates from the 70 BET otolith pairs, shows an apparent systematic overestimation of the ages for fish 130-150 cm, for the decimal ages compared to estimates from daily increment counts.

For BET from 120-150 cm, the decimal age estimates from the SEPO are on average 1.3 year (range: -0.3 – 3.6 years) older compared to the estimated age at length for BET from the EEPO based on the integrated growth model. For BET 150-200 cm from the SEPO, the adjusted annual increment counts are on average over estimating age at length by 2.4 years (range: -2.6 – 12.5 years) compared to the estimated age at lengths from the EEPO BET integrated growth model.

There appears to be fundamental issues in the objective discrimination of annual increments based on the comparative evaluations from 70 pairs of otoliths from BET 80-150 cm from the EEPO. Apparently, there are no discernable annual increments in the otoliths of BET less than 2 years of age and about 110 cm. It also appears annual increments in larger BET are difficult to discriminate, which compounds the inaccuracy in age estimation of BET using annual increments.

EVALUATION OF DAILY AND ANNUAL INCREMENT COUNTS FROM PAIRS OF BIGEYE OTOLITHS FROM THE WCPO

Jessica Farley

This presentation focused on the results of a study comparing daily and annual age estimates from paired otoliths of 35 bigeye tuna from the WCPO. The work was part of a larger study of four tuna species by Williams et al. (2013) (doi:10.1093/icesjms/fst093). The fish studied ranged in size from ~50-175 cm fork length. Counts of opaque zones (annual age) were obtained from transverse sections of one otolith and the counts of microincrements (daily age) were obtained from both transverse and frontal sections of the sister otoliths in each pair. Annual age was generally higher than daily age (in both transverse and frontal sections) for fish older than two years. A daily age of a fish aged 14 y could not be obtained (175 cm) due to poor readability of the otolith. It was noted that further work is needed to compare ageing methods.

WORK PLAN FOR AN INTER-LAB AGEING EXERCISE AND TECHNICAL MEETING: COMPARE AGEING APPROACHES BETWEEN WCPFC AND IATTC

Jessica Farley

This presentation described work being undertaken by CSIRO, Fish Ageing Services (FAS) and IATTC to assess and improve consistency in BET and YFT ageing methods using otoliths. The 2018 SPC Pre-Assessment Workshop noted there are differences in length-at-age estimates from daily counts across the Pacific and recommended an inter-lab ageing workshop be arranged to compare techniques and age estimates, to standardise approaches. The work plan is for laboratories to (1) read strontium or oxytetracycline (OTC) marked otoliths from the WCPO for daily/annual age validation, (2) directly compare daily and annual age estimates from sister otoliths, and (3) directly compare daily age estimates from the same otoliths. Otoliths were selected for analysis and one otolith or otolith sections were sent to IATTC for preparation and/or reading. Sister otoliths were prepared by CSIRO or FAS. The strontium/OTC marks in otoliths were located and image taken. The images were sent to IATTC to assist in locating the marks in sister otoliths. Ageing work at IATTC could not be undertaken due to the US government shutdown. The inter-lab workshop also planned to occur prior to the current IATTC age and growth workshop was also postponed. The otolith preparation/reading and the inter-laboratory ageing workshop is scheduled to be completed by late June 2019.

COMPARISONS OF LENGTH-BASED GROWTH RATES FROM MODELS FIT SEPARATELY TO HIGH CONFIDENCE TAGGING DATA AND LENGTH-AT-AGE DATA BASED ON DAILY INCREMENT COUNTS FROM BIGEYE OTOLITHS FROM THE EPO

Haikun Xu

The current stock assessment of bigeye tuna in the eastern Pacific Ocean uses the Richard growth model, of which the parameters are estimated outside the stock assessment model. Specifically, the estimation is done via an integrated approach that use both otolith length-at-age data and tagging length-increment data. In this presentation, we compare the estimated growth curve based on otolith and tagging data separately to understand their discrepancy. The otolith data suggest a larger asymptotic size and smaller growth rate, while the tagging data suggest a smaller asymptotic size and higher growth rate. The obvious residual pattern in fitting to the tagging data indicates that the Richard growth model is not still flexible enough to describe bigeye growth and a better growth curve (e.g., the growth cessation model) is needed in future assessments. Also, we found that the residual patterns for the fish tagging at 95W and 140W are notably different. As such, there may be a longitudinal gradient in the growth rate of bigeye tuna in the eastern Pacific Ocean.

COMPARISON OF LENGTH BASED GROWTH RATES FROM MODELS FIT SEPARATELY TO HIGH

CONFIDENCE TAGGING DATA AND LENGTH AT AGE DATA BASED ON ANNUAL INCREMENT COUNTS (DECIMAL AGE) FROM BIGEYE OTOLITHS FROM THE WCPO

Matthew Vincent

Otoliths collected west of 150°E were aged and converted to decimal ages and those with good readability were retained leaving 984 otoliths. Of these otoliths, 926 were aged via annuli counts by FAS, 30 were aged via daily increment counts by FAS, and 28 were aged via daily increment counts by SPC. A von Bertalanffy growth curve was fit to the otolith data using Bayesian methods with uninformative priors. The von Bertalanffy model fit to otolith only data yielded an estimate for L_∞ = 156.85, k = 0.30, and t0 = -0.69. The otolith data were filtered to remove any otoliths that had been aged by annuli counts and were less than 1 year old to test the impact of the assumed birthdate on the model fit. The model fit to these filtered data were similar to parameter estimates from the full dataset. A von Bertalanffy model that integrated tagging data and otolith data was used to estimate growth parameters for bigeye in the WCPO. A dataset of 612 high quality tag recoveries, which were measured by scientists, observers, or port samplers, were incorporated with the full otolith dataset into an LEP von Bertalanffy model. The model assumed a random effect parameter for the age at release of each tag sample and for the L_∞ for each otolith and tag sample. The model yielded estimates of L_∞ = 161.37, k = 0.30, and t0 = -0.61. The residuals of the tagging data tended to show that the recapture lengths were generally larger than the length predicted by the model. The observed length of tag recoveries was also generally larger than those observed in the otolith data. The estimate of L_∞ was sensitive to the integration of tagging data but the t0 and k parameters were not.

GROWTH IN THE EPO ASSESSMENTS

Mark Maunder

Stock assessment results and management advice are sensitive to the estimates of growth used in the bigeye and yellowfin stock assessments, particularly the asymptotic length. The bigeye tuna growth curve was estimated using both the otolith age-length data and the tagging growth increment data. A new growth curve, the growth cessation model, has been developed that provides better estimates of the asymptotic length. However, this growth curve is not currently available in Stock Synthesis, which is used for the IATTC stock assessments. Data weighting methods have been developed to produce a result for bigeye similar to the growth cessation model using the Richards growth curve, which is available in Stock Synthesis. Modes in the length composition data for bigeye tuna from purse seine sets on floating objects show similar growth rates to those estimated by the otolith age-length data. Length composition data for bigeye from the 1950's longline fleet when the population was lightly exploited were analyzed to estimate the asymptotic length. The estimates of the asymptotic length were lower than used in the assessment, but they were sensitive to the assumed value of the variation of length at age. The maximum likelihood estimate of the variance parameter was considered implausibly low. Finally, it is also important to point out that growth information from age-length data will be biased by age or length based selectivity or availability and this should be considered in any growth study or analysis.

GROWTH MODELS UTILIZED IN RECENT BIGEYE TUNA ASSESSMENTS IN THE WCPO, AND FUTURE CONSIDERATIONS

John Hampton

Recent bigeye tuna assessments in the WCPO have utilized the MULTIFAN-CL integrated stock assessment software, in which growth is parameterized as a von Bertalanffy growth function, with parameters L1 – the mean length of the youngest age-class in the model, L2 – the mean length of the oldest age-class in the model, and K – the Brody growth coefficient. Two additional parameters may be estimated (or specified) to define the way in which the standard deviation of length-at-age changes with age-class. In recent bigeye tuna assessments, growth has been estimated by fitting to both length- and weight-frequency data that have been collected over the history of the fishery. In the most recent (2017, updated in 2018) assessment, a large data set of otolith-based age-at-length data has been available. Alternative models have been employed fixing growth at parameter values derived from external analyses of the otolith data (the method used for the 2017/18 assessment), and also by integrating the otolith data into the assessment as conditional age-at-length data with an assumed multinomial distribution. For the latter, the data have been aggregated into quarterly age-classes using the decimal age estimates from the otolith ring counts with an assumed birth date. However, we have realised that the assumed common birthdate introduces an artefact into the quarterly age data, whereby observations only occur every 4th quarterly age-class. Therefore, a better approach would be to use the data in annual age format and configure MULTIFAN-CL to produce predictions in this format.

The growth estimates based on the independent analysis of the otolith data are quite different from estimates used previously for the bigeye assessment. The new estimates predict a substantially smaller L_∞ and generally smaller fish at a given age than the growth curve used in earlier assessments. This has impacted the estimates of stock status, making them substantially more optimistic than previously.

Future research on growth and its use in MULTIFAN-CL-based integrated stock assessments will focus on the following:

- Use of the conditional age-at-length data in assessment models, with the data and equivalent model predictions configured in annual age-class form;
- Include tag length-increment data in the assessment model;
- Model spatial variability in growth using a "growth morphs" approach (equivalent to growth being genetically determined depending on region of origin), and in the longer term, using a length-based modelling approach incorporating region-specific estimated growth transition matrices (equivalent to growth being environmentally determined according to the region fish occupy at any time).

ESTIMATING FISH GROWTH FOR STOCK ASSESSMENTS USING BOTH AGE-LENGTH AND TAGGING-INCREMENT DATA

Chris Francis

In this talk I will illustrate the problems that can arise in estimating growth from age-length and tagging data by considering some of the difficulties I encountered using the AMSFc method (Francis et al. 2016, Fish. Res. 180: 77–86) with data for EPO bigeye tuna. Goodness-of-fit diagnostics are important, and factors that affect these include fish shrinkage (caused by freezing and thawing); tagging-induced growth inhibition; ageing bias; and conflict between data sets.

INTEGRATING MULTIPLE DATA SETS INTO GROWTH MODELS

Paige Eveson

Growth models that integrate more than one source of data are desirable because different data sources often contain information about different portions of the life cycle and different aspects of growth. Two common sources of growth information are (i) direct age and length data where age is determined from otoliths, and (ii) release and recapture length and time at liberty data from tag-recapture experiments. Here we presented a brief overview of a maximum likelihood method we developed for fitting growth models to multiple data sets; similar to other contemporary methods for modelling growth using tag-recapture data, the tag-recapture component of the model treats the unknown age at release as a random effect (relative to a fixed t0 value, where t0 is the theoretical age at which a fish has length 0). One advantage of integrating multiple data sources is that it can help to reveal biases and inconsistencies in data sets; however, care must be taken when tag-recapture data are involved. Simulations were used to show that if there are biases in the direct age estimates, this may not be detectable when integrated with tag-recapture data because of the fact that the tag-recapture component of the model contains no information about t0, and can also estimate the (relative) release ages to be most compatible with the direct age data. The ability of the model to detect biases/incompatibility in the otolith and tag-recapture data sets will depend on: (i) the nature of the biases (for example, it is not possible to detect if the direct age estimates are all positively or negatively biased by a given amount since the t0 estimate will be biased but the fit to the tag-recapture data will be unaffected), and (ii) the sample sizes and age/length ranges of data sets (for example, if the age/length ranges of the two data sets do not have much overlap, then biases will be harder to detect).

INVESTIGATING SPATIAL VARIATION IN GROWTH OF BIGEYE IN THE PACIFIC BASED ON ANNUAL AGEING DATA

Paige Eveson

Differences in length at age of bigeye tuna have been observed between the Eastern and Western Pacific Ocean. This could be due to differences/biases in the otolith age estimates, or to actual spatial differences in growth. We investigated this issue using all annual ageing data we have for Pacific bigeye from otoliths read using the same reader and technique. A generalized additive model (GAM) was fit to the length data with age and (lat,lon) as one- and two-dimensional smooth terms respectively. The results suggest that there are significant spatial differences in length at age of Pacific bigeye, with fish in the Eastern Pacific having a larger mean length for a given age. However, limited sample sizes and age/length ranges by regions make full assessment difficult. In an attempt to overcome having limited data, we re-fit the GAM using otolith weight in place of age. The correlation between otolith weight and age is strong for bigeye (r=0.94), and we have otolith weight data from a reasonable number of samples without age estimates, particularly in the Eastern Pacific. The results showed a similar spatial pattern, with fish in the Eastern Pacific having a larger mean length for a given otolith weight; however, the differences were not as great.

LENGTH COMPOSITION DATA IN THE IATTC EPO BIGEYE STOCK ASSESSMENT, AND THE SENSITIVITY OF ASSESSMENT RESULTS TO THE ESTIMATED L INFINITY VALUE

Haikun Xu

The stock assessment of bigeye tuna in the eastern Pacific Ocean is conducted by fitting an integrated age-structured assessment model to a variety of datasets, including the length compositios of every fishery. Due to an apparent regime shift in estimated recruitment, which was believed to indicate model mis-speciation, all length compositions in the current stock assessment are down-weighted by a factor of 20. The current stock assessment uses a Richard growth model that is estimated outside the stock assessment model. We conduct an analysis to evaluate the sensitivity of model outputs to L2 (mean length of 10-year-old bigeye). The current assessment uses a L2 of 196 cm and our result shows that both population attributes and management quantities are very sensitive to L2. A smaller L2 corresponds to higher recruitment and spawning biomass, as well as lower fishing mortality rate and depletion rate in the terminal year. This result further underlines the importance of accurately specifying L2 to the stock assessment of bigeye tuna in the eastern Pacific Ocean.

LENGTH COMPOSITION DATA IN THE WCPFC WCPO BIGEYE STOCK ASSESSMENT AND THE SENSITIVITY OF ASSESSMENT RESULTS TO THE ESTIMATED L∞ VALUE

Matthew Vincent

The growth of fish in MFCL are modelled by a von Bertalanffy growth curve that is modelled between two specified ages and can allow the estimation of deviations from the curve for a specified number of age classes. Approximately 0.5% of the size composition data of bigeye used in the assessment were larger than 151 cm and less than 0.01% were larger than 184. Only the Philippines handline fishery and longline fishery in region 4 had a significant proportion of the samples larger than 151 or 184 cm. For the Philippines handline fishery the largest proportion of length composition samples in one year that were greater than 151 cm was 29%, while less than 1% were larger than 184 cm. For the longline fishery in region 4 the largest proportion of the length composition samples greater than 151 cm was 26% in one year, while 1% of the samples were larger than 184 cm. Changing the assumed value of L∞ in the assessment influenced the maturity and natural mortality ogives that were input into the model. The model using the old growth with L∞ = 184 cm estimated a dome shaped selectivity for all longline fisheries, while the model assuming the smaller updated growth model estimated asymptotic selectivity curves for these fisheries. The model with the old growth estimated the stock to be about 25% more depleted than the old growth model. Preliminary analysis of a conditional age-at-length model suggested that the starting values of the growth parameters could greatly influence the final model estimate and objective function value.

TAG-RECAPTURE OXYTETRACYCLINE (OTC)-MARKING EXPERIMENTS TO INVESTIGATE DAILY INCREMENT DEPOSITION RATE IN YELLOWFIN OTOLITHS

Jeanne Wexler, Alex Wild, and Terry Foreman

The first extensive oxytetracycline (OTC) otolith marking, tagging, and recapture experiments of yellowfin tuna were conducted by Alex Wild and Terry Foreman in 1976 and 1980-81 in the eastern Pacific Ocean (EPO). These experiments were designed to examine increment formation and periodicity in OTC-marked otoliths in order to accurately age yellowfin for growth analyses used in the IATTC stock assessments. The results of this work (Wild and Foreman, 1980; Wild et al., 1995) and the ageing and growth analyses (Wild, 1986) have been thoroughly described.

This presentation serves as a review of the tag-recapture and otolith marking experiments and how these results may be applicable to current validation, ageing, and growth studies of tunas.

A total of 10,909 yellowfin were tagged and released from chartered bait boat cruises and 32% of these fish were injected with OTC. Tag-recapture return rates indicated that the OTC injections did not consistently affect the survival of tagged yellowfin, and the return rates were generally fairly high for both the treatment and control groups, especially for the 1976 experiment.

The numbers of yellowfin used for the validation study were selected based on the return of both the fish and the tag, a known and reliable recapture date, and a representative range of elapsed time since tagging and injection. Recapture lengths were measured and the pair of sagittae otoliths were extracted, cleaned of tissue, and dried before storage. The OTC marks were located with an epifluorescence compound light microscope using ultraviolet light and increments were counted, usually after acid etching, at the distal surface at magnifications of 450-1200 x. Preliminary examination and analyses of the sagittae otoliths indicated that the postrostrum and rostrum regions provided the most resolvable and reliable counting paths for increments, and that the number of increments counted from the OTC marks were not significantly different between these two regions nor between the left and right otolith of a pair. Counts at the ventral edge, however, produced significantly fewer increments and consistently underestimated days at liberty for tagged yellowfin.

Results from these experiments indicated that increments were deposited at a rate of one per day for 40-148 cm FL yellowfin tuna in the EPO. Validation of daily increments in the otoliths of yellowfin tuna in other oceans is also discussed. Growth rates were estimated for the OTC-injected fish based on a growth curve relating the otolith length to the length of the fish, and from otolith measurements to and from the OTC mark, in order to obtain changes in FL over time.

References:

Wild, A. and T.J. Foreman. 1980. The relationship between otolith increments and time for yellowfin and skipjack tuna marked with tetracycline. IATTC Bull. 17(7): 509-560.

Wild, A. 1986. Growth of yellowfin tuna, *Thunnus albacares*, in the eastern Pacific Ocean based on otolith increments. IATTC Bull. 18(6): 423-482.

Wild, A., J.B. Wexler, and T.J. Foreman. 1995. Extended studies of increment deposition rates in otoliths of yellowfin and skipjack tunas. Bull. Mar. Sci. 57(2): 555-562.

ESTIMATION OF THE AGE-AT-LENGTH FOR YELLOWFIN TUNA FROM THE EASTERN PACIFIC OCEAN

BASED ON OTOLITH DAILY INCREMENT COUNTS

Daniel W. Fuller and Kurt M. Schaefer

Mark-recapture experiments using oxytetracycline to evaluate increment deposition rates for yellowfin tuna conducted by Wild and Foreman (1980) indicated that the relationship between increment count and time from the fluorescent mark to the post-rostral tip is 1 increment per day. Current estimates of length at age for yellowfin tuna are derived from a sample of 196 fish, 30-170 cm FL, collected during 1977 through 1979 from purse-seine vessels fishing north of the equator and east of 137°W. To reevaluate the age at length and to explore the possibility of spatiotemporal variability in growth and maturation of yellowfin tuna in the eastern Pacific Ocean (EPO), the Inter-American Tropical Tuna Commission initiated a spatially-stratified sampling program in 2009. The program utilized observers aboard purse-seine vessels, to collect sagittal otoliths and ovaries from female yellowfin tuna. Observers were instructed to sample yellowfin tuna, only when sea-surface temperatures were above 25°C, up to 5 fish per set within twelve 10 cm length strata between 40 and 160 cm fork length. Between 2009 and 2016 1,004 otoliths and 2,461 ovaries were collected from four distinct areas within the EPO. These four areas were defined as: (1) a northern area, north of 20°N, (2) a central offshore area 5°N - 15°N and west of 105°W, (3) a central nearshore area 5°N - 15°N and east of 100°W, and (4) a southern area south of 5°S.

Sagittal otoliths were weighed and measured, photographed, and placed in a 15mm x 15mm plastic mold and encapsulated in epoxy resin. Once cured, the epoxy block was removed from the mold and the embedded otolith was examined through the epoxy under a stereo microscope. The primordium and post-rostral tips were marked on the surface of the epoxy block to ensure proper alignment for sectioning. The epoxy block was positioned in a low speed diamond wafering saw and aligned to obtain a section containing both the primordium and the post-rostral tip. Sections were mounted on slides using crystalbond and polished to a thickness of approximately 5-15 µ. Polished sections were then etched for ~90 seconds with a 5% solution of Ethylenediaminetetraacetic acid to improve contrast and visibility of individual increments. Daily increments were counted on those otolith sections using a compound microscope at 1000x magnification.

To date, daily increment counts of 234 otoliths have been conducted, 128 from the central offshore region and 106 from the central nearshore region. A general additive model (GAM) was used to investigate whether differences in age at length exists between those two areas and to that of the 196 samples collected between 1977 and 1979.

YELLOWFIN ANNUAL & DAILY INCREMENT DEPOSITION RATES: STRONTIUM-MARKING EXPERIMENTS

Jessica Farley

This presentation provided information on three age validation studies for YFT in the WCPO. Two studies analysed whole otoliths from known age fish held in captive conditions in Hawaii, and one study analysed oxytetracycline marked otoliths from fish tagged in the Solomon Islands. Daily age estimates were validated in 16 small YFT (< 50 cm FL) using otoliths examine under transmitted light, and one medium sized YFT using a scanning light microscope (90 cm FL). Daily age was not validated in the 90 cm YFT using transmitted light microscopy. Different growth curves were obtained from the three studies and it is unclear whether the differences are the result of spatial/temporal variation in growth or differences in the preparation and reading methods used by the laboratories.

PRELIMINARY ESTIMATION OF AGE-AT-LENGTH OF YELLOWFIN FROM THE WCPO BASED ON OTOLITH ANNUAL INCREMENT COUNTS

Jessica Farley

This presentation described preliminary work undertaken by CSIRO and SPC to estimate the age and growth of yellowfin tuna in the WCPO using otoliths and fin spines. The main aims of the project are to develop ageing protocols for yellowfin tuna and read 1500 otoliths for annual age estimation. Forty otoliths and spines were selected for trial work from fish ranging in size from 30 to 172 cm FL. Counts of opaque zone ranged from 0 to 13. A comparison of zone counts from otoliths and spines showed that spines are useful to verify the location of the first three increments in otoliths, but spines are not suitable for annual age estimation beyond age three years as early zone are lost due to resorption and vascularisation. Clear microincrements (assumed daily) were observed in otoliths close to the primordium but there was an interruption at ~150-180 increments suggesting that counts of microincrements are not useful for ageing large/old yellowfin in the WCPO. Further work is needed to validate annual ageing protocols including examining strontium chloride and OTC marked otoliths and marginal increment analysis.

ANNUAL AGEING OF YELLOWFIN TUNA: WHERE ARE WE NOW

Kyne Krusic-Golub

The ageing of Yellowfin Tuna (Thunnus albacares) from annual counts on sectioned otoliths is currently still in its infancy. Preliminary results by Lang et al (2017) and Shin et al (2014) suggest that Yellowfin Tuna growth may be much slower than currently assumed. Also, preliminary results from reading a set of otoliths collected from large Yellowfin Tuna caught off Ascension Island suggest that this species may have a longevity of 20+ years. This presentation details the ageing completed so far on a set of 40 otoliths collected from the Western and Central Pacific and another set of 68 otoliths from collected from the Eastern Pacific.

EVALUATIONS OF DAILY AND ANNUAL INCREMENT COUNTS FROM OTOLITHS OF YELLOWFIN TUNA CAPTURED IN THE EASTERN TROPICAL PACIFIC OCEAN

Kurt Schaefer and Daniel Fuller

A direct comparison was conducted of the otolith daily versus annual increment counts, both non-adjusted and adjusted to decimal ages, for paired otoliths from 67 yellowfin tuna (YFT) (80 - 157 cm) captured in the eastern tropical Pacific Ocean (ETPO), primarily between about 6°N-16°N and 92°W-140°W, during January 2009 to November 2012.

Comparisons of daily and annual age estimates from the 67 YFT otolith pairs, shows an apparent trend in the underestimation of the ages for fish 80-105 cm, from non-adjusted annual increment counts compared to estimates from daily increment counts. However, there are a few samples where annual increments overestimate age. For YFT > 110 cm the annual age estimates are systematically over estimating age at length.

Applying the algorithm including assumed birthdate and otolith edge type to provide a decimal age estimate, decreases the amount of overestimation from annual counts for YFT less than about 110 cm. Adjusted decimal ages from annual increment counts for YFT >110 cm systematically overestimates age at length. For YFT > 120 cm, the adjusted annual age estimates are on average 1.9 years (range: 0.8-4.7 years) older compared to the estimated age at length from the daily increment counts.

There appears to be fundamental issues in the objective discrimination of annual increments based on the comparative evaluations from 67 pairs of otoliths from YFT 80-157 cm from the EPO. Apparently, there are no discernable annual increments in the otoliths of YFT less than 2 years of age and about 110 cm. It also appears annual increments in YFT larger than about 110 cm are difficult to discriminate, which compounds the inaccuracy in age estimation using annual increments.

EVALUATION OF DAILY AND ANNUAL INCREMENT COUNTS FROM PAIRS OF YELLOWFIN OTOLITHS FROM THE WCPO

Jessica Farley

A very brief presentation was made describing a comparison of daily and annual age estimates from paired otoliths of 30 yellowfin tuna from the WCPO. Again, this work was part of a larger study of four tuna species by Williams et al. (2013) (doi:10.1093/icesjms/fst093). The fish studied ranged in size from ~50-140 cm fork length. As found in bigeye tuna, annual age was generally higher than daily age for fish older than two years. Again, further work is needed to continue to compare ageing methods.

YELLOWFIN: GROWTH RATE ESTIMATES OBTAINED FROM TAGGING DATA IN THE EPO

Carolina Minte-Vera

The tagging data for yellowfin tuna with high confidence information for length at recapture was used to estimate a growth model, in combination with the length-at-age data from otoliths from Wild (1986). The model fit to tagging data and otolith data supported a smaller asymptotic size and larger growth rate than the model fit to the otolith data alone. The two data sets do not seem compatible with each other. The differences in the estimated growth may be due to (1) changes in growth rates over time (the tagging data is from 2000 on, the otolith data is from the late 1970's), (2) effect of shrinkage in fish lengths caused by death, freezing, and thawing , (2) different sampling locations of the otolith and tagging data

GROWTH RATE ESTIMATES OF YELLOWFIN FROM THE WCPO OBTAINED FROM TAGGING DATA

Graham Pilling

The growth model for yellowfin in the WCPO is estimated within recent MULTIFAN-CL assessments. Tagging data have not therefore routinely been used to estimate WCPO yellowfin growth external to the model. Two studies were presented that had used tagging data to inform WCPO yellowfin growth. The first was that of Lehodey and Leroy (1999), who investigated the pattern of juvenile yellowfin growth in particular using tagging data for the period 1989-1992. From the 1,187 tagging increments available from their filtered data set, a clear reduction in growth rate (cm/month) was identified in fish whose mid-size during their time at liberty was between 30 and 70cm. Growth estimated based upon daily ring counts also indicated a reduction in growth rates at younger ages. The second study was that of Hampton (2000), who estimated growth from tagging data as part of an analysis to estimate natural mortality in yellowfin and other tuna species. Growth slowed with increasing time at liberty, as expected. Von Bertalanffy parameter estimates were around 166cm for $L\infty$ and 0.25 for K. The extensive tagging data set that now exists for WCPO yellowfin tuna was noted, and the potential to include these data in the estimation of growth of this stock following identification of a suitable 'high confidence' data set was highlighted.

YELLOWFIN: GROWTH MODELS CURRENTLY UTILIZED IN IATTC STOCK ASSESSMENT AND FUTURE CONSIDERATIONS IN THE EPO

Carolina Minte-Vera

The growth model currently used in the stock assessment of yellowfin tuna in the EPO is a Richards model. The parameters were estimated by Maunder and Aires-da-Silva (2009) within the stock assessment model, which also included the length-at-age data from otolith daily increments from Wild (1986). Males and females are assumed to grow in a similar way. The current base case model assumes that the average length of a fish of 7.25 years of age is 182.8 cm (L2). The coefficient of variation at that age is assumed to be 10%, which means that 95% of the 7.25 year-old fish should have a length between 147.1 and 218.5 cm. The stock assessment results are sensitive to the assumption about L2, more optimistic perception of the status of the stock is obtained when L2 is 170 cm, and more pessimistic when L2 is 190 cm. Models with smaller L2 fit the stock assessment data better.

THE GROWTH MODEL UTILIZED IN RECENT WCPFC WCPO YELLOWFIN STOCK ASSESSMENTS AND FUTURE CONSIDERATIONS.

Graham Pilling

The approach used to estimate yellowfin growth within the 2017 WCPO MULTIFAN-CL stock assessment was described. Lengths-at-age were assumed to be normally distributed by age class, with means following the von-Bertalanffy growth curve, and the standard deviations of length for each age class assumed to be a log-linear function of mean length-at-age. Probability distributions of weight-at-age were a deterministic function of the lengths-at-age and a specified weight-length relationship. All processes were assumed to be regionally (and temporally) invariant. Given our understanding of alternative growth patterns in juvenile yellowfin, mean lengths of the first eight quarterly age-classes were allowed to be independent parameters, with the remaining mean lengths following a von Bertalanffy growth curve. Deviations from the curve at those younger ages attracted a small penalty to avoid over-fitting the size data. Within the 2017 assessment, non-von Bertalanffy growth of juvenile yellowfin was estimated in the 25–75 cm size range, with growth slower than predicted by the von Bertalanffy function. The diagnostic case model estimated an L2 of 153 cm, 0.4cm smaller than that estimated in the 2014 assessment. While the growth estimate was considered reasonable, further study of growth in yellowfin tuna was recommended, and this forms part of the current workshop. Further developments to MULTIFAN-CL to ensure maturity and natural mortality patterns with age internally consistent with estimated growth patterns were described.