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Determination of southwest Pacific swordfish growth and maturity

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Abstract

At the 9th session of the Western and Central Pacific Fisheries Commission Scientific Committee, concern was expressed regarding biological aspects of the 2013 South Pacific Swordfish (SWO) stock assessment. The stock assessment had a high degree of uncertainty that was attributed to uncertainty in the accuracy of growth and maturity parameters. The SC recommended that additional work on age, growth and age validation be undertaken. In response to this, and a call for research by the Australian Fisheries Management Authority Research Committee (ARC), CSIRO submitted an ARC proposal to re-examine SWO age, growth and maturity in the southwest Pacific. The WCPFC Secretariat supported this proposal financially and suggested an expansion of the research in collaboration with the NOAA/PIFSC Honolulu Fisheries Laboratory to include Hawai'ian swordfish data in the study to meet the needs of the WCPFC. This paper presents the research plan and anticipated outcomes of the project, including revised growth and maturity estimates, description of any unresolved uncertainties, and an indication of the stock status implications in the context of the 2013 stock assessment. We welcome feedback from the SC on the proposed research plan.

1 Background

Broadbill swordfish are a large pelagic species distributed between ~50°N and 50°S in all the major oceans. In the Pacific, there is genetic evidence of three independent populations (north, southwest and southeast) with no mixing across the equator in the western Pacific (Reeb et al. 2000). Recent tagging work suggests there may be structure within the southwest population as fish tagged off eastern Australia showed little propensity to move far to the east remaining instead within the western half of the Coral and Tasman Seas (Evans et al, 2014). The 'Australian population' may range from the east coast to approximately 165°E.

In the late 1990s, the SWO fishery expanded off eastern Australia and New Zealand and concerns were raised about the sustainability of catches since catch rates and the size of fish caught were both declining. There was an urgent need to determine the status of the stock and develop a stock assessment. Unfortunately, life-history parameters for input to stock assessments of SWO were not available at the time. In response, CSIRO undertook two studies in the early 2000s to estimate key parameters such as length-at-age, longevity, sex ratio, maturity, spawning frequency and fecundity (FRDC projects 1999/108, 2001/014). The reproductive work was published (see Young et al. 2003) but the age, growth and maturity work were not because some of the methods and results were called into question by the NOAA/PIFSC Honolulu Fisheries Laboratory, which had been doing similar work (DeMartini et al., 2000; 2007). As a consequence of these methodological uncertainties, the alternative growth and maturity parameters were both admitted into southwest Pacific stock assessments as equally likely alternative hypotheses (Kolody et al. 2008; Davies et al. 2013).

The different biological assumptions, however, have important implications for the stock status advice (Davies et al. 2013). Using the Australian growth curve, the assessment indicated that "overfishing was occurring but that the stock was not in an overfished state" while the Hawai'ian curve indicated "that no overfishing is occurring and that the stock is not in an overfished state" (Davies et al. 2013).

In 2013, WCPFC SC acknowledged the inconsistencies in the Australian and Hawaii growth schedules and "recommended that additional work on age, growth and age validation be undertaken" as a high propriety project (Anon 2013). In response to this, and a call for research by the AFMA Research Committee (ARC) in

Australia, CSIRO submitted an ARC proposal to re-examine SWO age, growth and maturity in the southwest Pacific. The WCPFC Secretariat supported this proposal financially and suggested an expansion of the research in collaboration with the NOAA/PIFSC Honolulu Fisheries Laboratory to include Hawai’ian swordfish data in the study to meet the needs of the WCPFC. This paper presents the proposed research plan and anticipated outcomes of the project. We welcome feedback from the SC on the research plan.

2 Alternate life-history parameters

2.1 Age/growth

The direct age of SWO is most commonly estimated from counts of assumed annuli in sectioned anal fin rays. In the Pacific Ocean, age was estimated by both Australian (CSIRO) and Hawai’ian (NOAA/PIFSC) laboratories using fin rays collected in their respective regions (Young & Drake 2004; DeMartini et al., 2007). Both studies used indirect validation methods to verify the age estimates obtained, and estimated growth parameters for male and females by fitting the von Bertalanffy growth model to the data. CSIRO fitted the model to the raw length-at-age data while the NOAA/PIFSC fitted it to back-calculated length-at-age (i.e., spines were used to estimate fish length at a previous age).

The growth parameters estimated by the two labs were very different, with slower growth/year (k) and higher mean asymptotic length (L_{50}) for both males and females in the southwest Pacific relative to Hawai’ian waters (Fig. 1). The difference in growth curves may be due to genuine differences in SWO growth between regions and/or differences in fin ray interpretation (methodological) as suggested by Young et al (2008). Fin rays often contained ‘split’ translucent growth zones, which are often difficult to interpret, and rays are also subject to resorption and vascularisation of the core area making age estimation for large individuals difficult. Age determinations can be reliable and reproducible; however, without direct validation it is impossible to ensure the ages are accurate.

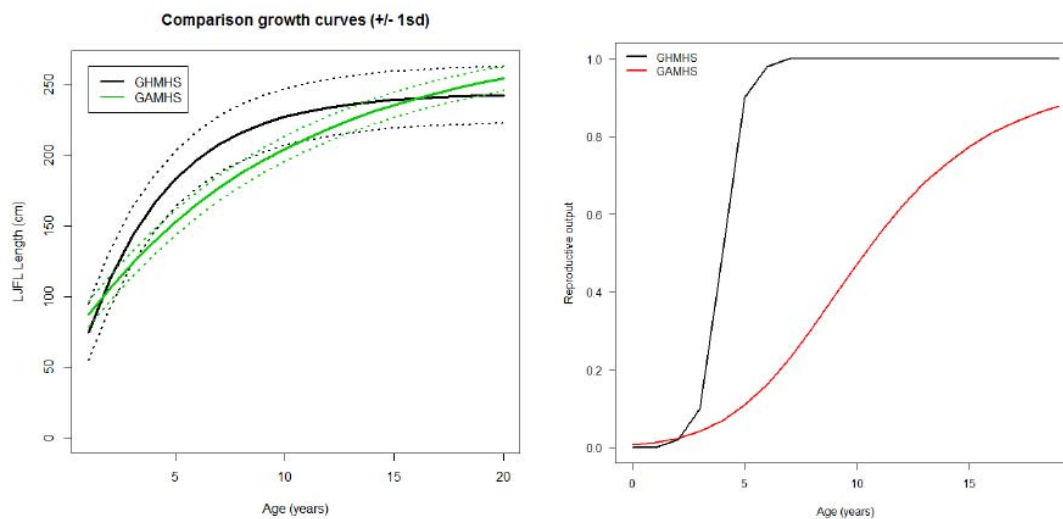


Figure 1. Alternate growth (left) and maturity (right) assumptions used in the 2008 and 2013 SWO stock assessments. Figure from Davies et al. (2013). GHMHS = Hawai’ian growth/maturity schedule; GAMHS = Australian growth/schedule.

2.2 Maturity

Maturity schedules for fish are typically obtained by examining gonads using histological techniques to determine maturity status of individuals, and applying statistical models to determine the proportion mature as a function of length or age. Estimates of average length and/or age at which 50% of the

individuals are sexually mature (L_{50} , A_{50}) are the biological parameters often reported in maturity studies. For many species, L_{50} is estimated for females only as it is assumed that male sperm production is much less limiting.

Similar to the direct ageing work above, the maturity of female SWO was estimated by both CSIRO and NOAA/PIFSC laboratories using ovaries collected in their respective regions (Young & Drake 2002; DeMartini et al., 2000). Both studies prepared histological sections of the ovary material and used standard (although slightly different) classification schemes to determine the maturity status of each fish. Predicted L_{50} for fish from the southwest Pacific was 193-199 cm orbital fork length (OFL) depending on the analytical model used, compared to only 144 cm OFL for females from Hawai'i. Using the corresponding length-at-age data, A_{50} is predicted at 8-10 years for Australia fish (Young et al. 2008) compared to only 4-5 years for Hawai'ian fish (DeMartini et al. 2000).

Although regional variation in length-at-maturity is likely to exist for SWO in the Pacific, differences in maturity schedules may also have occurred through different interpretations of the maturity status from histological sections, as also suggested by Young et al. (2008). A difficulty occurs when trying to differentiate immature (virgin) from mature-resting (post-spawning) females outside the spawning months. This is because after spawning, females absorb all their yolked eggs and appear histologically similar to immature females. Young and Drake (2002) classified all females with unyolked eggs (as the most advanced present) as immature. If a proportion of these fish were mature-resting females (especially large fish), it may explain the relatively high L_{50} estimate obtained compared to the NOAA/PIFSC work, which may have used additional histological criteria to identify mature-resting females.

2.3 Recent developments

Preliminary comparative work did not resolve the uncertainty surrounding the biology of SWO in the Pacific (Young et al., 2008). Work over the last decade, however, has shown that age estimates from otoliths in tuna are more accurate than those from other hardparts including spines, vertebrae and scales (see Farley et al. 2013a and references therein). A study by Nishimoto et al. (2006) suggests that sectioned sagittal otoliths may also be useful to estimate the age of SWO (Fig. 2). Although otoliths were collected in the Australian SWO studies, only a subsample were used to estimate the (assumed) daily age of small fish and to verify the location of the first annuli in fin rays. The remaining otoliths are archived at CSIRO ($n > 400$) and the majority are from fish aged using fin rays by Young & Drake (2004). It may be possible to use these otoliths to verify the age estimates obtained from the fin rays. There is also the potential to validate growth rates in the southwest Pacific using Australian tag-return data.

In addition, recent reproductive work on tuna has identified 'maturity markers' in histological sections of ovaries (e.g. Farley et al. 2013b). They are considered to be signs of prior yolk development or reproductive activity, and have been used in many studies to identify mature-resting females during the non-spawning period (Kjesbu 2010; Brown-Peterson 2011). Given the synergy between projects, the methods could be applied to SWO using the archive of ovary histology from Young and Drake (2002). Preliminary examination of the histology indicate that the 'maturity markers' are present in SWO ovaries.

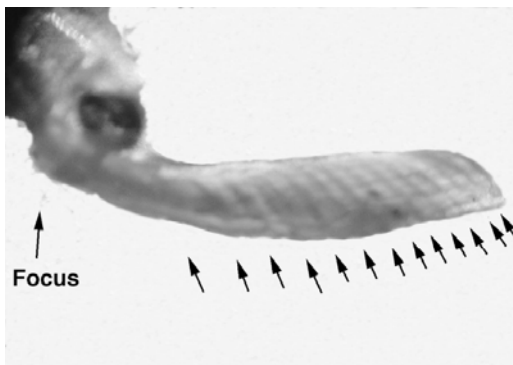


Figure 2. Transverse section of a SWO sagitta showing broader, darker, opaque bands nearer the focus and closer-spaced, more defined and narrower bands toward the dorsal margin. Figure from Nishimoto et al. (2006).

3 Objectives

Given the difference in the life-history parameter estimates between studies in the Pacific, and their ramification for management, the aim of the current project is to re-examine SWO age, growth and maturity in the southwest Pacific using samples already collected and prepared (e.g. sectioned fin rays and ovary histology) and additional length-at-age information from sectioned otoliths and tag-return data. The specific objectives are:

1. Evaluate the use of otoliths to estimate the annual age of SWO in the southwest Pacific.
2. Re-examine ageing methodology of Young and Drake (2004) and confirm age estimates obtained for a representative sample of fin ray sections.
3. Re-examine the ovary histology from Young & Drake (2002) and use new methods to estimate the maturity status of females.
4. Undertake a range of verification and/or indirect validation methods to determine the accuracy of age and maturity interpretations from fin spines, otoliths and ovaries.
5. Collaborate with NOAA/PIFSC scientists (Hawaii) to resolve possible methodological differences in direct age and maturity estimation.
6. Examine the effect of the different growth curves and maturity ogives on population models and make recommendations for future assessment and harvest strategy evaluation activities.

4 Proposed methods

The CSIRO has already collected biological samples (anal fin rays, otoliths and/or gonads) from nearly 2000 SWO in the southwest Pacific as part of three CSIRO/FRDC-funded projects (Clear et al. 2000; Young and Drake 2002; 2004). Sectioned fin rays are available for 1500 fish and ovary histology sections for 775 females. CSIRO's hardparts archives also contain otoliths from over 400 fish, of which fin rays and ovaries were analysed from ~380 and ~210 respectively.

The project is divided into three parts:

4.1 Age/growth

Approximately 300 of the 1500 fin ray sections prepared by Young and Drake (2004) will be re-examined. The sections will be selected based on size and sex of fish, month of capture and the presence of otoliths from the same fish in CSIRO's hardparts archives. Where possible, preference will be given to fish with daily age estimated from 'sister' otoliths and maturity status determined from histology.

The number of opaque growth zones in the fin ray sections will be counted based on the techniques developed by Clear et al. (2000). New methods to account for obscured growth zones (due to vascularisation/reabsorption at the core) will be used following Farley et al. (2013a), and decimal age will be calculated, which accounts for the month of capture, assumed birth date and time of opaque zone formation.

In addition, otoliths from approximately 300 fish with fin spines analysed (above) will be selected from CSIRO's hardparts archive. The otoliths will be cleaned and dried prior to being prepared for ageing by Fish Ageing Services Pty Ltd (FAS). The otolith sections will be read at FAS and CSIRO using methods described by Nishimoto et al. (2006) and previous direct ageing studies of tuna species.

Direct validation of the periodicity of zone formation in fin rays and otoliths is not possible during this study as it would require either a large-scale mark-recapture experiment or bomb radiocarbon dating of very early collected hardparts (which are not available for SWO in the southwest Pacific). However, a variety of indirect validation and verification methods will be carried out. These will include marginal increment and edge type analysis, comparison of counts between rays and otoliths from the same fish, daily ages (from Young and Drake, 2004) to locate the first opaque growth zones, multiple readers, inter-laboratory comparisons, and analysis of tag-return data to verify growth rates in the region.

Direct collaboration with scientists at NOAA/PIFSC will also be undertaken to resolve possible methodological differences in age estimation. This meeting is tentatively scheduled for early December 2014 in Honolulu.

An integrated statistical approach will be used to combine the most reliable data into a single model to describe sex-specific length-at-age.

4.2 Maturity

All 775 ovary histology sections prepared by Young and Drake (2004) will be re-examined. The maturity state of each fish will be determined following methods recently developed by Farley et al (2013b), which is similar to a standardized classification scheme developed by Brown-Peterson et al. (2011). Maturity markers such as late stages of atresia, muscle bundles and residual hydrated oocytes will be used to identify mature-resting females from immature females during the non-spawning season. Again, direct collaboration with scientists at NOAA/PIFSC (Hawaii) will be undertaken to resolve possible methodological differences in maturity estimation.

Statistical models will be applied to the maturity-at-length/age data obtained to confirm/update maturity schedules for female SWO in the southwest Pacific.

4.3 Assessing the implications of growth/maturity uncertainty in population models

The results of these studies will be used to make recommendations about how best to represent growth and maturity (including uncertainty) in future southwest Pacific swordfish population models. If life-history parameters appear to be very different from previous assumptions, the implications for stock assessment and harvest strategy evaluation models will be examined by re-running key models. If possible, we would seek to further extend this modelling exercise to explore the implications of sexual dimorphism. To date, swordfish stock assessments in the southwest Pacific have assumed sex-aggregated populations (due in part to the fundamental uncertainty about SWO age interpretation, but also due to historical limitations of the preferred modelling software, Multifan-CL developed by the SPC for tuna populations). All growth studies agree that sex dimorphism is substantial for swordfish, and stock assessments in other parts of the world do attempt to account for these sex differences. We do not propose to conduct a full stock assessment, but want to evaluate the importance of the growth, maturity and sex-disaggregation results to ensure that they are properly represented in the 2016 assessment.

5 Planned outcomes

The work will improve our understanding and estimation of SWO age, growth and maturity in the Australian region. The primary outcome will be the clarification of the degree to which differences in SWO growth and maturity parameters obtained in Australian and Hawai'ian studies are methodological or due to spatial variation in life-history. Following on from this will be recommendations for how the uncertainty in growth and maturity should be represented in the southwest Pacific via the stock assessment. It is expected that this will reduce the uncertainty for management.

If possible, standardised protocols will be developed for interpreting hardparts and ovaries of SWO in the southwest Pacific. The growth and maturity data obtained will be made available to scientists at the Secretariat of the Pacific Community (SPC) for the 2016 stock assessment.

6 References

Anon (2013) Commission on the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean: Scientific Committee Summary Report. Western and Central Pacific Fisheries Commission, Pohnpei, Federated States of Micronesia, 6–14 August. 207 p.

- Brown-Peterson NJ, Wyanski DM, Saborido-Rey F, Macewicz BJ, Lowerre-Barbieri SK (2011) A standardized terminology for describing reproductive development in fishes. *Mar. Coast. Fish.* 3: 52–70.
- Clear N, Davis TL O, Carter T (2000) Developing techniques to estimate the age of bigeye tuna and broadbill swordfish off eastern Australia: a pilot project. FRDC Grant 98/113.
- Davies N, Pilling G, Harley S, Hampton J (2013) Stock assessment of swordfish (*Xiphias gladius*) in the southwest Pacific Ocean. WCPFC-SC9-2013/SA-WP-05.
- De Martini EE, Uchiyama JH, & Williams HA (2000) Sexual maturity, sex ratio, and size composition of swordfish, *Xiphias gladius*, caught by the Hawaii-based pelagic longline fishery. *Fish. Bull.* 98:4 89-506.
- DeMartini EE, Uchiyama J.H, Humphreys RL, Sampaga JD, Williams HA (2007) Age and growth of swordfish (*Xiphias gladius*) caught by the Hawaii-based pelagic longline fishery. *Fish. Bull.* 105: 356–367.
- Evans K, Abascal F, Kolody D, Sippel T, Holdsworth j, Maru P (2014) The horizontal and vertical dynamics of swordfish in the South Pacific Ocean. *J. exp. Mar. Biol. Ecol.* 450: 55-67.
- Farley JH, Williams AJ, Clear NP, Davies CR, Nicol SJ (2013a) Age estimation and validation for South Pacific albacore tuna (*Thunnus alalunga*). *J. Fish. Biol.* 82: 1523–1544.
- Farley JH, Williams AJ, Hoyle SP, Davies CR, Nicol SJ (2013b) Reproductive dynamics and potential annual fecundity of South Pacific albacore tuna (*Thunnus alalunga*). *PLoS ONE* 8(4): e60577. doi:10.1371/journal.pone.0060577.
- Kjesbu OS (2010) The utility of gonadal histology in studies of fish reproduction and the subsequent management of fisheries and ecosystems, P11-14 in Wyanski DM, Brown-Peterson NJ (Eds) Proceedings of the 4th Workshop on Gonadal Histology of Fishes. El Puerto de Santa Maria, Spain.
- Kolody D, Campbell R, Davies, N (2008) A Multifan-CL stock assessment of south-west Pacific swordfish 1952-2007. Western and Central Pacific Fisheries Commission Working Paper WCPFC-SC4-2008/SA-WP-6 (rev. 1).
- Nishimoto RN, DeMartini EE, Landgraf KC (2006) Suitability of sagittae for estimating annular ages of swordfish, *Xiphias gladius*, from the central North Pacific. *Pacific Islands Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI* 96822-2396. *Pacific Islands Fish. Sci. Cent. Admin. Rep.* H-06-04, 34 p.
- Reeb CA, Arcangeli L, Block BA 2000. Structure and migration corridors in Pacific populations of the swordfish, *Xiphias gladius*, as inferred through analyses of mitochondrial DNA. *Mar. Biol.* 136: 1123–1131
- Young J, Drake A (2002) Reproductive dynamics of broadbill swordfish (*Xiphias gladius*) in the domestic longline fishery off eastern Australia. FRDC Final Report for project 1999/108.
- Young J, Drake A (2004) Age and growth of broadbill swordfish (*Xiphias gladius*) from Australian waters. FRDC Final Report for project 2001/014.
- Young JW, Drake A, Brickhill M, Farley JH, Carter T (2003) Reproductive dynamics of broadbill swordfish, *Xiphias gladius*, in the domestic longline fishery off eastern Australia. *Mar. Freshwat. Res.* 54: 315-32.
- Young J, Humphreys R, Uchiyama J, Clear N (2008) Comparison of maturity and ageing of swordfish from the Hawaiian and Australian waters. WCPFC-SC4-2008/BI-IP-2.