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**COMPARISON OF MATURITY AND AGEING OF SWORDFISH FROM
HAWAIIAN AND AUSTRALIAN WATERS**

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Comparison of maturity and ageing of swordfish from Hawaiian and Australian waters³

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Introduction

From the many documented studies of swordfish age and growth, and size and age at maturity, a wide range of estimates have been determined (Figs. 1, 2). Differences among estimates may reflect variability in the responses of the fish to differing physical and biological oceanographic conditions, both within and between oceans. However, the differences could also result from different methodologies and interpretations of collected data. In the Pacific Ocean there are a number of differing estimates, particularly those from the southwestern Pacific which gave a preliminary estimate of age at 50% female maturity between 8 and 10 years (Patterson et al. 2002). This estimate is significantly different from other estimates and if true for all stocks would have important implications for fishery and conservation management. In contrast, De Martini et al. (2000) reported an age at female maturity of between 4 and 5 years from the Hawaiian swordfish fishery. Given the significant difference between estimates, and with funds provided by the Joint Institute for Marine and Atmospheric Research (JIMAR), a study was carried out by the authors at the PIFSC Aiea Heights Research Facility in Hawaii on original material of archived slides of gonads and anal fin rays from swordfish collected from the eastern Australian and Hawaiian longline fisheries.

The objective of the study was to determine whether the difference in length at 50% female maturity between Australia (~195 cm EFL) and Hawaii (144 cm EFL) was real or the result of different interpretations of the available material. Length of males at 50% maturity was the same for both studies (102 cm EFL). One of the critical questions examined was whether the differences between females is real (regional biological variation) or an artifact of sampling biases and/or the product of different histological criteria for distinguishing immature from mature females. Sampling bias would be in terms of not having all available sizes present when sampling an area during the spawning season. The main issue, however, was determining whether female gonads were correctly classified as either immature or mature-inactive. Generally, the presence of atretic oocytes and/or post-ovulatory follicles (POF) will show whether a fish has spawned. However, these are highly temporal features as they are quickly reabsorbed in the ovaries making it difficult for researchers to determine whether the animal had

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previously spawned. That is, a female that had previously spawned but which did not contain atretic cells or POFs visible in histological ovary sections could be misinterpreted as being immature.

The second question was whether readings of anal fin rays (at this stage the most reliable measure of swordfish age) were comparable between readers from the two laboratories. Although there is yet to be a validated study, paired light and dark bands that extend from one perimeter of the ray to the other are considered to constitute an annual band. Because there is considerable variability in the clarity of these bands within and between fish, there is a degree of subjectivity in the readings made, particularly between different readers. Other methods are therefore needed to verify fin ray counts. The most accurate method would be detailed examination of hard parts from mark-recapture experiments, which are yet to be done. Other methods include tag recaptures and comparative ageing using otoliths.

Methods

During June 25-July 4, 2007, the authors reviewed histological slides of female swordfish gonadal sections in various stages of reproductive development and in early 2008 they examined a series of anal fin ray sections from a range of different sized fish from the western South Pacific Ocean. A further comparison of the same fin rays was completed at CSIRO Marine and Atmospheric Research in early 2008 by an independent reader.

Reproductive histology

A series of randomly sourced reproductive histology and anal fin ray slides from the Australian study were taken to the NMFS Aiea Heights Research Facility where they were reread against the background of an archive of Hawaiian slides of similar type. Slides were read blind according to the protocols and staging criteria outlined in DeMartini et al. (2000). All specimens were scored for maturity using fundamental criteria established for swordfish. Specimens were considered “mature” if scored as gonadal Stage 4 or higher and “immature” if scored as Stage 3 or lower (DeMartini et al. 2000). Characteristics of internal ovarian lamellae (degree of lobulation, vascularization, and development of internal support tissue) were additionally considered to help distinguish cryptic Resting (Stage 7) fish lacking atretic remnants of prior spawning from Developing-Immature (Stage 2) fish. Specimens were viewed with a compound microscope at 60-150 X total magnification and were scored without reference to body size or date of collection. A single experienced NMFS reader performed all of the scorings.

Fin ray sections

A random selection of fin ray sections taken from Australian-caught fishes were reread using characters described by DeMartini et al (2007) and compared with fin ray counts previously determined for the same sections (Young and Drake 2004). The resulting length at age plots from the two fin ray readings were compared with growth increments for swordfish which had been tagged and recaptured (CSIRO, unpublished data)

Results

Comparison of reproductive parameters

We reviewed CSIRO's previous work on swordfish maturation and concluded that females were recognized as mature when they reached Stage 3 and higher. When the analysis included Stage 2 and higher as mature, the size at 50% maturity shifted from 193 cm EFL to ~150 cm EFL, close to that of DeMartini et al. (2000) (Table 1). In the latter paper, immature females were defined histologically by the presence of only partly to moderately yolked oocytes as the most advanced developmental stages present without substantial atresia (Stage 3 or lower).

Comparison of age at length from anal fin rays

Recounts of fin ray sections from the CSIRO collection by a NMFS scientist were less than original CSIRO estimates (reader CSIRO 1; Fig. 3). Therefore the same rays were reread by an independent CSIRO scientist (CSIRO 2) who had previous experience with the reading methodology (Fig. 4, 5). These last readings agreed closely with the counts made by the NMFS.

Discussion

Determining maturity in female swordfish

Ovarian histological slides (Australia) were deemed inadequate for scoring maturity; these tissues had their microscopic features somewhat to largely obscured and appeared overstained. It is likely that these tissue specimens had degraded as a result of cell lysis prior to fixation and staining. Presumably, either gonad specimens were not fixed quickly after fish had died, the tissues were harvested from ovaries that had been frozen (then thawed at room temperature, before they were fixed for histology -Young et al. 2003), or varying combinations of both. Some of the fine structures of lamellae that help discriminate between ovaries in Stage 2 (Developing-Immature) and cryptic Stage 7 (Mature-Resting ovaries lacking atretic remnants) are apt to become unrecognizable if tissues are degraded or frozen-thawed. This apparently occurred despite the apparent resilience to freezing-thawing of structures like atretic oocytes and POFs in swordfish ovaries (Table 3 of Young et al. 2003). Hydrated oocytes and POFs are typically lysed when ovaries are frozen-thawed in many fish species with less robust ovarian tissues (EED, unpubl. obs.). All of the Hawaii slides used ovarian tissues fixed at sea when fish were first brought aboard ship (DeMartini et al. 2000).

Distinguishing immature from mature-resting fish

Cryptic Stage 7 Mature-Resting female swordfish (i.e., fish whose ovaries lack evidence of atresia of oocytes from prior spawnings) are very difficult to identify based on histological features alone. Recognizing them is greatly compromised if tissue specimens are not high quality. If less-than-high quality specimens are all that are available (the present case for Australia fish), perhaps the best way to distinguish true Stage 2 from apparent Stage 2 (i.e. Stage 7 ovaries lacking atretic remnants of prior spawnings) is to consider month and location of capture as classification variables. Histological evidence would then provide only one of several bases for classification of maturity. The classification of fish by season and location of capture (spawning versus non-spawning) could be made once temporal and spatial dynamics of spawning are initially defined based on gonad indices and the temporal occurrence of Imminent-Spawners (Stages 5-6) throughout the year. Mature and immature fish might then be distinguished by either logistic regression or discriminant analysis (DeMartini and Lau 1999), using input such as a maturity score based on histology plus either a gonad index (gonad weight standardized to body size) or egg size and body size, with the latter variables distinguished by season.

Age and growth

The original age assignments readings made by CSIRO were high when compared to readings done at the NMFS laboratory on the same fin rays. This would have had the effect, if substantiated, of overestimating the age at length of SW Pacific swordfish. We therefore conducted a separate reading of the same fin rays, this time by an independent reader from CSIRO. These last readings agreed closely with those from the NMFS indicating that the latter (i.e. NMFS) readings were more likely to reflect the age of swordfish off eastern Australia. We conclude that the initial CSIRO readings were consistently higher than the subsequent readings and that for the present, the Hawaiian growth curve should be used for the Australian population.

We should keep in mind, however, that the growth of swordfish caught in the SW Pacific and off Hawaii is unlikely to be identical. At present the age data supporting the growth curve is not directly validated. Validation is necessary to ensure the accuracy of the age determinations. Limited validation is provided by a small number of tag returns (<10 fish). The three returns for the Hawaiian data agree closely with estimated growth curves indicating that the NMFS method of counting fin rays was accurate (see DeMartini et al. 2007). In contrast, tag returns off eastern Australia showed a wide range of predicted growth rates and could support the original CSIRO readings (Fig. 6).

Without direct validation, age determinations from hard parts are subjective. Fin rays in particular are difficult to interpret as they are composed of skeletal material and so are more likely to reflect the effects of migration and other events leading to physiological stress. In addition, fin rays are subject to reabsorption and vascularization. A single annual translucent band is likely to be the result of normal annual environmental and physiological fluctuations, but it is possible that extra intra-annual translucent bands are the result of an event such as migration that will expose fish to different environments

and place them under additional physiological stress. It is likely that readers will interpret “multiple bands” and the “loss” of inner bands differently so, to overcome subjectivity by readers, protocols for interpreting and counting “multiple bands” in the growth increments in fin rays need to be established and followed. Vascularization of the core also can obscure the early growth zones in cross-sections of fin rays from older swordfish, particularly if the section is cut too near the basal condyle (DeMartini et al. 2007). This ‘loss’ of growth zones has been, in some tuna species, taken into account by estimating the positions of obscured early zones based on measured dimensions on cross-sectioned fin rays of younger fish, although to date attempts at doing so for swordfish have not been validated (Tserpes and Tsimenides 1995).

The study demonstrates the need for standardized methodologies in the determination of biological parameters for stock assessments, particularly for widespread species such as swordfish. Further comparative studies of this sort should be encouraged, particularly for South Pacific swordfish, the stocks of which are being fished by a number of countries. Validation of growth bands in particular should be a priority.

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Table 1: Comparison of maturity readings of histology slides of female swordfish from Australian waters by Hawaiian and Australian readers showing consensus agreement on mature fish Stages 4-7 (Hawaiian staging, equivalent to stage 3 and above for Australian staging) and only partial agreement for earlier stages (indet, indeterminate; IMM, immature; MAT, mature)

Australia Specimen #	Reproductive Stage	Hawaii		Australia	
		Mature/Immature	Stage*	Mat/Imm	
Broadbill 829	Indet	Indet	1	imm/rest	
Broadbill 1319	Indet	Indet	1	imm/rest	
Broadbill 587		5 MAT	5	MAT	agree
Broadbill 1316		7 MAT	1	imm/rest	disagree
Broadbill 1318	Indet	Indet	1	imm/rest	
Broadbill 1317		7 MAT	1	imm/rest	disagree
Broadbill 1310		7 MAT	2	MAT	agree
Broadbill 1357	Indet	Indet	2	MAT	
Broadbill 1311		1 IMM	1	immature	agree
Broadbill 1313		7 MAT	1	immature	disagree
Broadbill 736	Indet	Indet	1	immature	
Broadbill 597	Indet	Indet	1	immature	
Broadbill 1380		4 MAT	4	MAT	agree
Broadbill 161 (5)		7 MAT	2	MAT	agree
Broadbill 1401		3 IMM	3	MAT	
Broadbill 185 (2)		4 MAT	3	MAT	agree
Broadbill 718	Indet	Indet	1	immature	
Broadbill 417		6 MAT	4	MAT	agree
Broadbill 840		4 MAT	3	MAT	agree

* data from Appendix 1 in Young and Drake (2002)

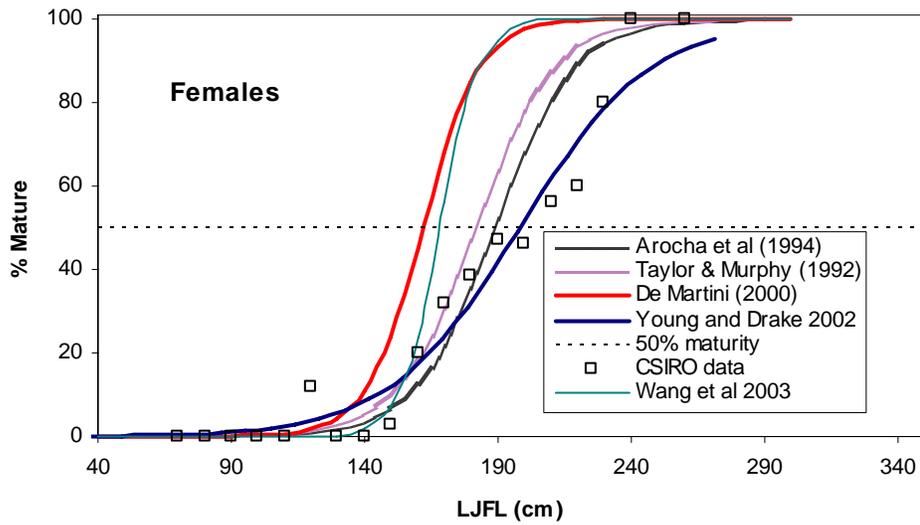


Figure 1: Plotted length at 50% maturity ogives of female broadbill swordfish from a range of studies showing variability in published results

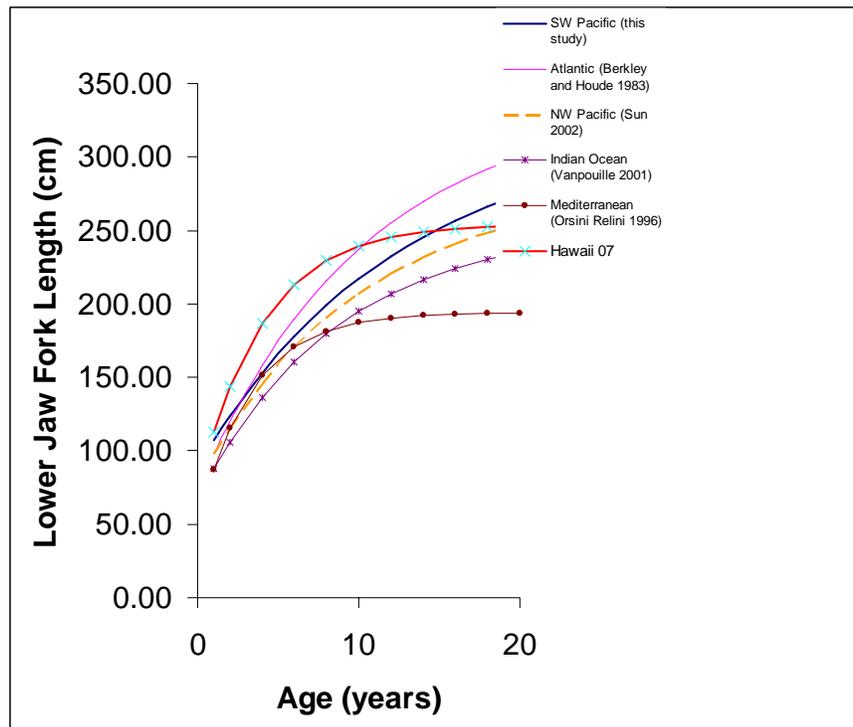


Figure 2: Length at age growth curves of broadbill swordfish from a range of studies showing variability in published results (SW Pacific refers to CSIRO 1)

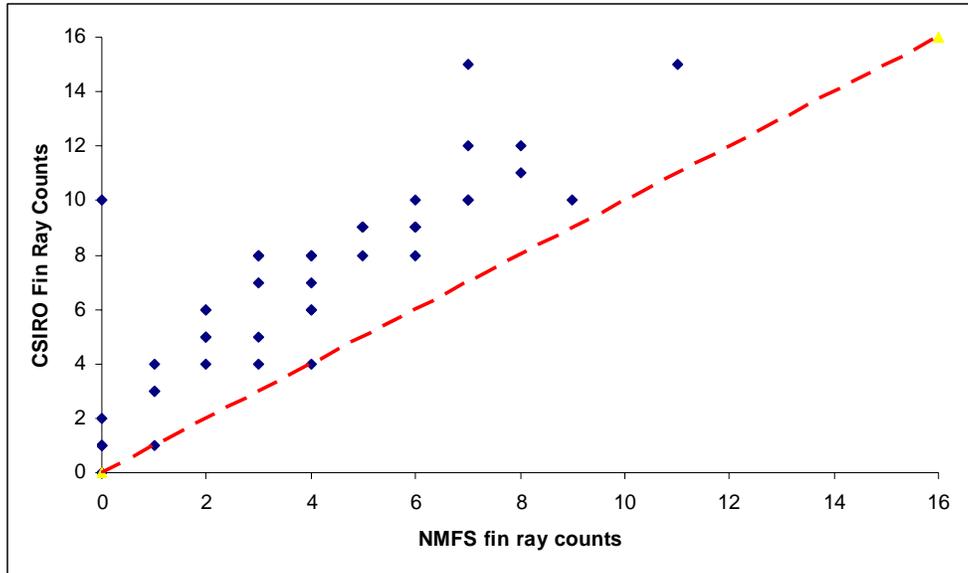


Figure 3: Fin ray counts of CSIRO 1 relative to those of NMFS. CSIRO 1 estimates are from Young and Drake 2004 and the NMFS estimates are by one of the co-authors (J. Uchiyama, unpublished data). The dashed line represents a 1:1 relationship.

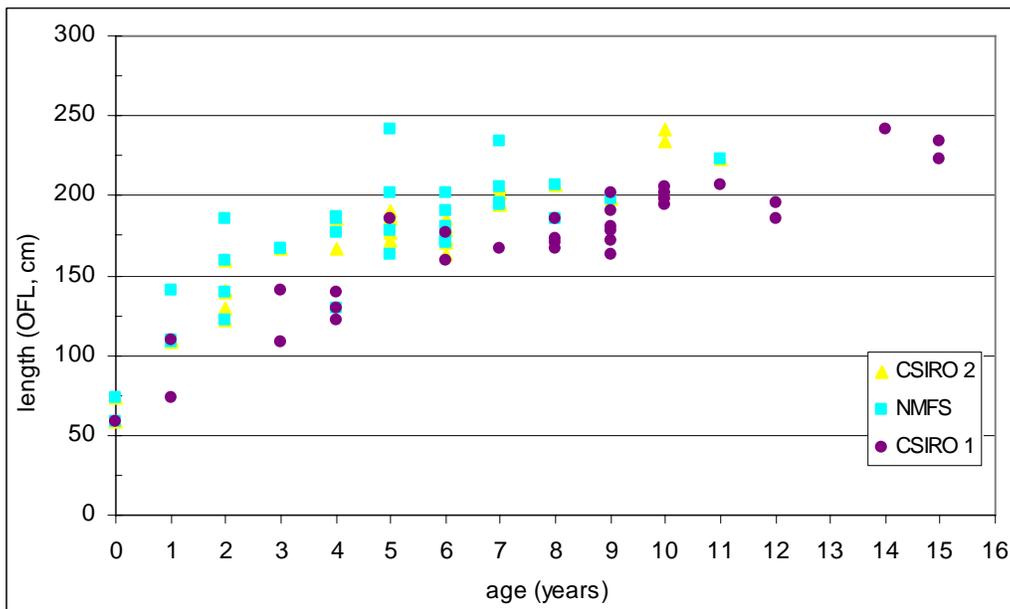


Figure 4. Length at age estimates for swordfish based on fin spine readings by 3 readers (NMFS, CSIRO 1 and CSIRO 2).

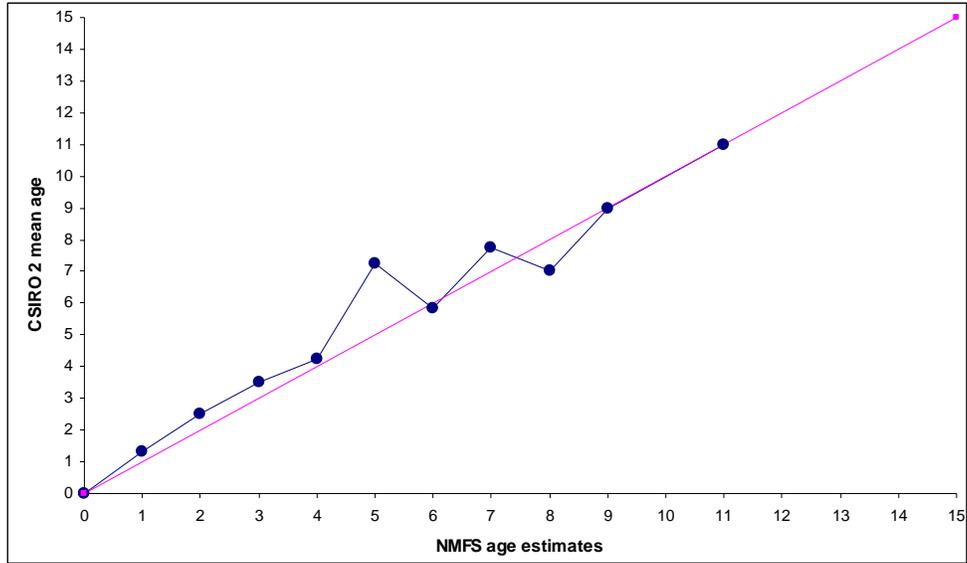


Figure 5. An age bias plot of paired age determinations by 2 readers (NMFS and CSIRO 2) indicates there is little age estimation difference between NMFS and CSIRO 2. Closed circles are the means of the age estimates by CSIRO 2 for each age group determined by NMFS. The closed line is the 1:1 relationship.

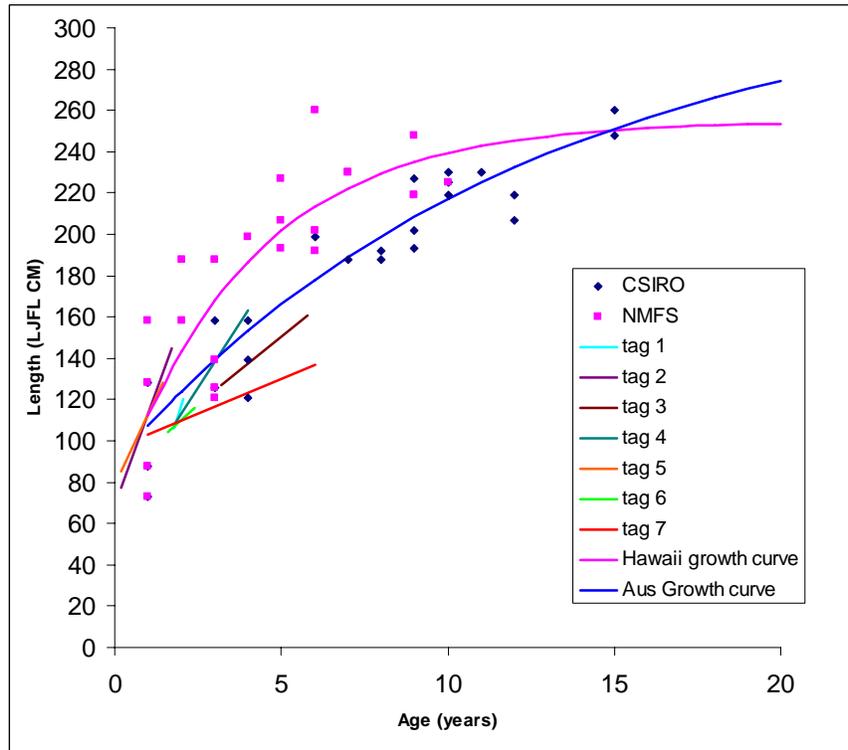


Figure 6: CSIRO (1) and NMFS age counts with overlays of growth curves from the two regions and tag recaptures from the Australian region