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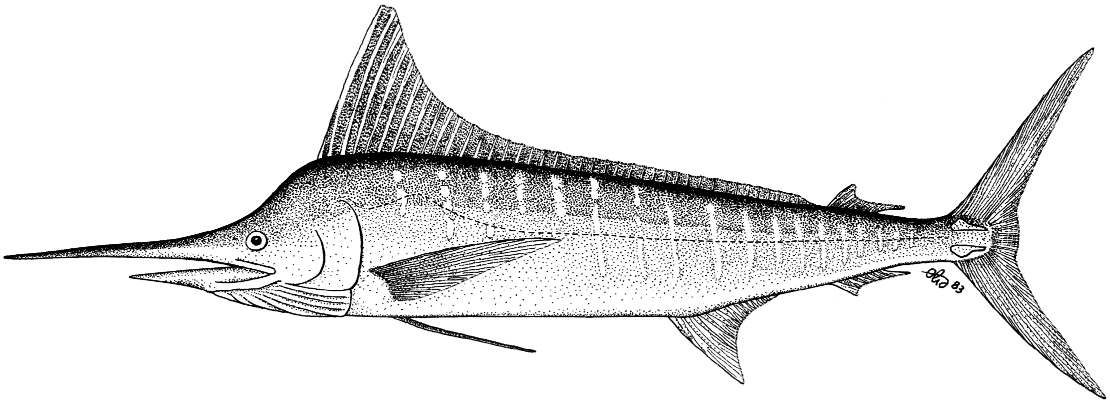

A preliminary report on age, growth, and reproductive dynamics of striped marlin (*Kajikia audax)* in the southwest Pacific Ocean

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Abstract

Striped marlin are the most commercially valuable species of billfish in the family Istiophoridae and are an important recreational resource throughout their distribution in the Indo-Pacific region. Age estimates and reproductive condition were examined from a sample of 489 striped marlin that were collected from five exclusive economic zones (EEZ's) in the southwest Pacific Ocean (0-45°S latitude, 145°E-145°W longitude) between 2006 and 2008. Ages were indirectly validated using otolith micro-increment counts, fin spine annuli counts, and a marginal increment analysis. Ages ranged from 130 estimated days in a 4kg whole weight (1120 mm, Lower Jaw –Fork Length, LJFL) male to eight estimated years in a 168kg (2871 mm, LJFL) female. Growth of young striped marlin was rapid, with both sexes attaining 70-75% of their maximum body length during the first two years of life. Striped marlin showed significant sub-regional differences in age-structure and spawning condition with the oldest fish common at higher latitudes and increased relative abundance of juveniles in tropical and equatorial waters. Histological examination of gonad tissue showed that females matured at between 1.5 and 2.5 years while males matured about six months earlier. Females released multiple batches of up to 4.1 million hydrated oocytes with a spawning interval ranging from one to four days between events. Spawning occurred between 15-30°S extending from the east coast of Australia to Fiji with ripe females observed as far east as French Polynesia (144°W) during the fourth quarter of the year.

Introduction

The striped marlin, *Kajikia audax* is the most commercially valuable species of the Istiophorid billfishes (marlin, sailfish, and spearfish) and is retained and opportunistically targeted in longline fisheries throughout the Indian and Pacific Oceans (Bromhead et al. 2004). The stock structure of striped marlin in the Pacific Ocean is more complex than previously thought but the SWPO is generally regarded as a semi-independent population (Langley et al. 2006; Graves and McDowell 2003). It is one of the top five species caught in the Australian longline fishery with annual landings having exceeded 700 mt. In the wider southwest Pacific Ocean (SWPO), commercial landings peaked at over 12,000MT in the early 1950's and have since stabilised at around 2500MT since the 1990's (Langley et al. 2006).

Striped marlin are also a key component of off-shore recreational fisheries, particularly off the coasts of New Zealand, south-eastern Australia, and western Mexico (Ortega-Garcia et al. 2003; Kopf et al. 2005). There is potential therefore for impacts on the existing stock from both the commercial and recreational fisheries, and for competition between the two groups that fish them. Despite their high public profile and value to world fisheries, most billfish species including striped marlin, have been a low priority for research funding bodies and have been the subject of relatively little scientific investigation. Biological information on striped marlin is particularly sparse in the SWPO because most research effort has been focused on the eastern or north-western regions (Koto 1963; Kume & Joseph 1969; Eldrige & Wares 1974). Previous research on age and growth in the SWPO was not validated, sampling was restricted to a small geographic range, and results were often contradictory (Davie & Hall 1989; Skillman & Yong 1976; Melo-Barrera 2003; Kopf et al. 2005). Information about reproductive biology of striped marlin in the SWPO is confined to one study in the Coral Sea (Hanamoto 1977) and several larval distribution surveys (Ueyanagi and Wares 1974; Nishikawa 1985).

Due to the challenges of validating age estimates and the difficulty of collecting an adequate range of samples for reproductive studies, there remains considerable uncertainty in the key biological parameters required for stock assessment. The status of striped marlin stocks throughout their distribution in the Indo-Pacific Ocean is largely uncertain. Since the commencement of this investigation in 2006 a stock assessment was conducted on striped marlin in the SWPO and concluded that the results should be "considered preliminary as there remains a great deal of uncertainty" regarding key biological parameters (Langley et al. 2006). This lack of biological information "severely hinders understanding of the species vulnerability to overexploitation and the assessment of stock status, with flow on effects for the ability of fisheries managers to manage this resource" (Bromhead et al. 2004). The present report provides an overview of preliminary results and implications of an investigation focused on age, growth, and reproductive dynamics of striped marlin in the SWPO.

Methods

Paired sagittal otoliths , spines 1-6 from the first dorsal (D1-6) and 1-3 from the first anal fins (A1-3) and gonads were collected from striped marlin caught in commercial longline and recreational fisheries throughout the SWPO (Table 1 and 2). A total of 489 striped marlin were sampled but complete sets of biological tissues not available from every fish. Samples were collected between January 2006 and December 2008 between 14.61°S – 36.04°S latitude and 152.56° E-178.08°W longitude. Fisheries observers and scientists in Australia and New Zealand sampled four fisheries including longline fisheries on the eastern coast of Australia (AUS COMM), Pacific Island Countries and Territories (PICT COMM) including Fiji and New Caledonia and French Polynesia and recreational fisheries in New South Wales, Australia (AUS REC) and Northland New Zealand (NZ REC) (Figure 1).

Age and growth

Frozen fin spines were thawed in hot water (60-70°C) for 30-60 minutes in order to loosen fat and connective tissue. Resin blocks containing the spines were sectioned using a low speed (approximately 1600 RPM) lapidary saw fitted with a 150mm diameter, 0.15mm thick diamond edged wafering blade (ProSlicer 2008). Sections were made at four levels of fin spines and were cut relative to the maximum condyle width (1/4CW, 1CW, 2CW, 3 CW) (Figure 2). Sections were rinsed in 100% ethanol and mounted on a microscope slide. A complete annulus was defined as a wide opaque zone (fast growth) followed by a narrow translucent zone (slow growth). Final age estimates were assigned based on the total number of annuli counted outside of the vascularized area plus the number of annuli lost due to vascularization. To predict the total number of missing annuli, radii statistics from sections where the first annulus was visible were matched with fin spine sections from fish that were affected by vascularization (see Hill et al. 1989).

The radius of the first annulus in fin spine sections was identified by comparing presumed otolith daily micro-increment counts with radius measurements of matching sets of fin spines (De Martini et al. 2007). Otoliths were removed from thawed head sections following the methods of Radtke (1983) and transverse sections were ground manually ground with wet/dry sandpaper and secured on a micro-scope slide with thermoplastic glue. Micro-increment counts were made on 28 juvenile or young adult striped marlin which had fin spine annuli estimates of 0, 1, or 2. To evaluate whether or not micro-increments formed each day, hatch dates of young striped marlin were estimated by subtracting otolith micro-increment counts from the date of capture.

Age estimates were made on transverse sections of fin spines, D4-6 or A3, ¼ - 1 CW, from 425 striped marlin including 28 individuals which were also aged using otolith daily micro-increment counts. To test the hypothesis of a 12 month cycle of annuli formation mean monthly marginal increment ratio’s (MIR’s) were fit to a three parameter Gaussian peak regression equation. Growth histories of male and female striped marlin were back-calculated using measurements from the focus to the edge of each annulus (annulus radius, mm) (Figure 2). Daily age estimates including LJFL-at-age 0.5 years were predicted based on a Gompertz regression of otolith daily age estimates and LJFL of young striped marlin. Growth was modelled using a standard von Bertalanffy growth curve (VBGC) (von Bertalanffy 1938) and a generalized VBGC (Richards 1959). An unbiased age-length and subsequent age-length key were developed from the proportion of striped marlin sampled in age-classes, mean length-at-age from the generalized VBGC, a regression line fit to variance (standard deviation) in length-at-age, and the proportion female observed in 100 mm length classes. The age-length model converted length or weight frequencies to sex-specific age frequencies. The age-structure of fisheries was calculated from 11,055 striped marlin caught in commercial longline and recreational fisheries between 2006 and 2008.

The age-structure of the AUS COMM fishery, also known as the Eastern Tuna and Billfish Fishery (ETBF), was determined from 7301 trunked (head, gills, and organs removed) weights (kg) collected between 2006 and 2008. A variety of conversion factors were required to standardize size data (Table 3). The age-structure of the AUS REC fishery was determined from 2753 tag-and-release weight estimates collected recreational fishers between 2006 and 2008. The age-structure of the NZ REC fishery was determined from 778 whole weight measurements (± 0.5 kg) collected by recreational fishing clubs during 2006 and 2007. The age-structure of PICT's was determined from 223 observer length measurements collected during 2006 and 2007. Spatial patterns in age-structure and relative abundance of YOY were determined from length measurements and associated latitude and longitude estimates of 16,685 striped marlin caught between 1998 and 2008. Contour plots of mean age by season were contrasted to the most comprehensive data available on commercial longline Catch Per Unit Effort (CPUE). Japanese longline CPUE data on striped marlin (N = 91,981) were plotted by five degree squares latitude and longitude and pooled from 1970 to 1998. Age contours and CPUE contours nearest neighbour algorithm.

Reproduction

Gonads were excised from female (N=186) and male (N=209) striped marlin caught in recreational and commercial longline fisheries. Two 1-2cm thick transverse sections were removed from the cranial and caudal third of the largest gonad and preserved in 10% neutral buffered formalin. The most advanced single oocyte and the most advanced mode of developing oocyte were recorded for each histological section. Post-ovulatory follicles (POF's) in histological sections where identified as absent, fresh, or degraded The most advanced gamete in histological sections of male striped marlin gonads were classified into four categories including spermatogonia (SG), spermatocytes (SC), spermatids (ST), or spermatozoa (SZ) (Merrett 1970; Grier 1981). The presence of SZ in fully developed sperm ducts was determined for each histological section. Both the main sperm duct, otherwise referred to as the vas deferens (Merrett 1970), and secondary sperm duct's were evaluated for the presence of SZ.

Batch fecundity estimates were made on paired ovaries of four striped marlin with unovulated hydrated oocytes, no atresia, and no post ovulatory follicles using the gravimetric method (Hunter et al. 1985). The spawning interval was estimated by the 'hydrated oocyte method' (Hunter and Macewicz 1985). The LJFL (mm)(L_{50}) and age (A_{50}) at which 50% of the population was sexually mature was estimated for females and males by fitting the proportion mature in 100mm LJFL and age classes to a four parameter sigmoidal regression. Regression equations were weighted by the square root of the sample size in each length class. The proportion of mature and immature fish in catches of the AUS COMM, PICT COMM, AUS REC, and NZ REC fisheries was estimated from length and weight data sourced from each fishery during the study period.

Results and Discussion

Age and growth

A method of estimating the age of striped marlin using fin spine annuli and otolith micro-increments was indirectly validated. This study represents the first quantitative evidence to support annual increment formation in the fin spines of striped marlin and supplements previous research highlighting the value of fin spines for estimating the age of billfishes (Speare 2001; Hoolihan 2006; DeMartini et al. 2007). The combined application of otolith micro-increments and fin spine annuli was first applied on swordfish (De Martini et al. 2007) and proved to be a powerful tool for determining growth and corroborating age of one year old striped marlin (Figure 3). Marginal increment ratio's showed that annuli were formed on a yearly basis (Figure 4) but daily micro-increment counts confirmed that false increments were present in fin spines and were common during the first year of life (Figure 5). It was likely that the presence of false increments formed in fin spines during the first year of life accounted for age overestimation and growth underestimation in previous unvalidated aging studies on this species (Kopf et al. 2005). The presence of false increments during the first year of life has previously been identified in albacore tuna (Santiago and Arrizabalaga 2005) and may be a common feature of fin spines in other oceanic fishes.

The development of a reliable aging procedure for striped marlin relied firstly on the collection of a wide range of ages and lengths sampled throughout the year; an achievement that had not been accomplished by previous age and growth studies on this species (Skillman and Young 1976; Davie and Hall 1989; Melo-Barrerra et al. 2003; Kopf et al. 2005). In order to derive complete age estimates for striped marlin there was a need to combine annuli counts in fin spines, replacement of annuli lost due to vascularization, and counts of otolith daily micro-increments (Figure 6). A pilot study determined that the most suitable fin spines for counting annuli were the fourth through sixth dorsal fin spines (D4-6) or the third anal fin spine (A3) sectioned near the base. These spines displayed the greatest number of clear annuli and showed the lowest amount of vascularization. Back-calculation of micro-increment counts predicted larval hatch dates within the known spawning period which suggested that one otolith micro-increment was formed each day (Table 4). Indirect evidence, including a marginal increment analysis and daily micro-increment counts demonstrated that sections from the fourth dorsal fin spine were a reliable source of age information in this species.

Examination of otolith micro-increments (Figure 6) from young striped marlin facilitated the development of a daily growth model (Figure 7). The most reasonable estimate of growth combined fin spine estimates of length at age one with the length at age 0.5 years predicted from otolith micro-increments (Table 6). The generalized VBGC predicted that male and female striped marlin attained a length of 1289-1291 mm LJFL during the first 6 months of life and a length of 1603-1607mm LJFL by age one. Growth rates during the first year of life were amongst the fastest of any teleost fish in terms of body length but were less than daily growth estimates from juvenile blue marlin (Prince et al. 1991) and larval growth rates estimated for other open ocean fishes (Brothers et al. 1983). Although growth was rapid in terms of body length, the relative increase in body mass with length was less than other large-pelagic Scombrids and amounted to a mean weight of approximately 24kg whole weight by age one.

Ages of striped marlin ranged from 130 estimated days in a 4kg whole weight (1120 mm, Lower Jaw –Fork Length, LJFL) male to eight estimated years in a 168kg (2871 mm, LJFL) female (Figure 8). Females grew to a larger maximum length, weight, and age compared to males but there were no significant differences in von Bertalanffy growth curve parameters (Table 5). Growth was rapid during the first two years of life, during which time both sexes achieved 75-80% of maximum body length (~2749mm LJFL). The size range of samples examined in the present study was greater than previous age and growth investigations on the species but the maximum age estimate of eight years was less than previous estimates of 11 and 12 years from Mexico (Melo-Barrerra et al. 2003) and Hawaii (Skillman and Yong 1976) respectively. Comparable studies based on validated age estimates from other regions of the Pacific and Indian Oceans are required to conclusively determine whether there are regional differences in longevity or growth rates of striped marlin.

Biological information from the sample of aged fish (Table 6) was used to develop a model for converting length frequency information to sex-specific proportions at age (Figure 9 and 10). There was significant latitudinal partitioning of age-classes (figure 11) with young-of the-year most common at tropical latitudes and the oldest (4-8 years) striped marlin most common at sub-tropical latitudes. Accordingly, tropical Pacific Island longline fisheries caught the majority of young (0-2 years) fish while recreational and commercial fisheries in Australia caught intermediate ages (2-4 years), and New Zealand recreational fisheries caught the highest proportion of old (4-8 years) striped marlin. Although it is probable that a small percentage of males and females will achieve ages greater than 7 or 8 years old, comprehensive sampling of record sized striped marlin (120-168kg; 2500-2871mm LJFL) showed that the majority of fish in the SWPO do not live beyond the ages of four of five years old.

Reproductive dynamics

A histology-based reproductive staging model was developed and applied to describe the reproductive condition of female and male striped marlin (Table 7 and 8). Females were classified as multiple batch spawning teleosts with asynchronous oocyte development (Murua and Saborido-Rey 2003), while males conformed to the unrestricted type of testicular development (Greir 1981). The histology-based model may be useful for discriminating reproductive stages in other large-pelagic batch spawning teleosts, especially in species where juveniles are not present on the spawning ground.

Spawning activity of striped marlin in the Coral Sea during the present study was correlated with the spatio-temporal distribution of high catch rates (CPUE > 3 striped marlin per 1000 hooks) observed by the Japanese longline fleet between 1970 and 1999 (Figure 12). The reproductive season in the Coral Sea extended from October through January but concentrated spawning activity only occurred during November and December (Figure 13) in waters warmer than 24°C. Results from the present investigation were comparable to the spawning pattern reported Hanamoto (1977) who examined GSI's of striped marlin in the Coral Sea over thirty years ago. The majority of spawning activity took place off the east coast of Australia between 20° - 30°S latitude and 154°- 160° E longitude but the present investigation identified additional reproductive activity in the EEZ's of Fiji, New Caledonia, and French Polynesia during the same period. Historical observations of larvae from oceanic waters near Fiji and French Polynesia (Nishikawa 1985) verify the long-term stability of these spawning grounds.

The percentage of females observed in 100mm LJFL classes increased significantly between the lengths of 1900mm to 2800mm LJFL in all fisheries sampled (Figure 14). The spatial distribution of spawning striped marlin was significantly different to mature resting individuals and other reproductive stages. There is now no doubt that spawning grounds and feeding grounds of striped marlin are spatially segregated between warm tropical waters and more productive sub-tropical waters. After spawning in the Coral Sea during the fourth quarter of the year, females migrated south, as was confirmed by the presence of recovering stage ovaries sampled in New Zealand and the south-coast of New South Wales during the first quarter of the year.

The length and age at 50% maturity (L_{50}, A_{50}) was estimated for the first time in female and male striped marlin (Figure 15). The L_{50} for females was 2026 ± 72 mm SEM while the L_{50} for males was 1889 ± 19.8mm SEM. Estimates of $A_{50's}$ were 1.9 ± 0.06 years for females and 1.4 ± 0.26 for males. However, the majority of reproductive activity in the Coral Sea was undertaken by females greater than 2300mm LJFL and three years or older and by males that were greater than 2100mmLJFL and two years or older.

Catches of striped marlin from commercial longline and recreational fisheries were primarily composed of mature fish (males, 81-95%; females, 68-88%) except for longline fisheries from Pacific Island Countries and Territories (PICT's) where more than half (58%) of the catch was immature (Figure 16). Immature fish showed a restricted tropical distribution that was consistent with the observation of increasing age with latitude. The spatial variation in maturity composition between fisheries was related to natural differences in distribution of developmental stages of striped marlin rather than an effect of growth overfishing.

Similar to most large-pelagic fishes (Schaefer 2001), striped marlin were capable of spawning every 24-48hrs with a minimum of four and a maximum of 41 spawning events per season. It seems unlikely, however, that all females spawn continuously throughout a three month period (15 October – 15 January) since recovering stage ovaries were observed during the spawning season. A more plausible spawning frequency is that females release approximately four batches of oocytes three times per year but this is an untested hypothesis. Striped marlin exhibited a mean spawning fraction of 2.2 days and a mean batch fecundity of 3.1 million hydrated and migratory nucleus oocytes or 29.7 ± 8 oocytes per gram of body weight. With a minimum of four and maximum of 41 (2.2/90days) spawning events per season, the annual batch fecundity of an average sized (100kg) female could range from 12 to 122.7 million oocytes.

Implications for fisheries and ecosystem management

Uncertainty in the population status of striped marlin continues to restrict the ability of fisheries managers to make informed decisions concerning the sustainability of fishing practices for this species. This uncertainty led in part to the adoption by the WCPFC of a precautionary Conservation and Management Measure (CMM) in 2006. The CMM was aimed at preventing increases in fishing mortality until the population status of striped marlin could be estimated with greater certainty. The CMM represents an important first step to ensuring the long-term sustainability of fisheries for striped marlin (WCPFC 2006), although in its current form it does not directly limit total fishing mortality on the stock; it restricts the number of fishing vessels.

It is worth noting that, despite the relatively rapid growth rate, early maturity, and high fecundity of striped marlin, there is some uncertainty over the resilience of the species to fishing pressure in the SWPO. A preliminary assessment of striped marlin in the North Pacific has suggested that the stock may be overfished, and a closely related species, white marlin, is overfished in the Atlantic (i.e. estimated biomass of approximately 12% of that required to produce MSY (ICCAT 2002; 2003). Striped marlin are clearly vulnerable to commercial longline fishing practices, and the most recent SWPO assessment indicated a long-term decline in stock abundance since the 1950's (Langley et al. 2006). Some of the stock assessment scenarios for striped marlin in the SWPO indicated that overfishing was occurring, while others suggested the stock was being fished sustainably. These uncertainties and observations all add a level of urgency for improving biological inputs and updating the stock assessment for striped marlin in the SWPO. An updated stock assessment would allow managers and policy makers to critically evaluate the economic and ecological benefits of current and future fisheries management measures.

The overlap between peak commercial longline catches of striped marlin in the Coral Sea and peak spawning activity (Figure 12) warrants careful management consideration in order to ensure that spawning stock biomass is fished at a sustainable level. Size-based indicators are increasingly being used in fisheries management and could be a useful tool to monitor the population status of striped marlin between periods when formal stock assessments are conducted. Careful monitoring of mean length and CPUE in longline fisheries during the primary spawning season (November and December) in the Coral Sea may provide some insight into the stability of the spawning population. Over the duration of the present investigation, there was no indication of a declining mean size of spawning striped marlin in the Coral Sea but longer-term trends were not investigated. The large mean size of striped marlin caught in fisheries on the south-coast of New South Wales and New Zealand would also seem to be a good indicator of changes in the oldest age-classes present in the SWPO (see Kopf et al. 2005).

This study showed that different developmental stages of striped marlin occupied significantly different regions, and therefore pelagic habitats, in the SWPO (Figure 11). The spatial variation in age-structure and reproductive condition of striped marlin has several important implications for fisheries and ecosystem-based management. One management implication is that sub-regional spatial and temporal fisheries management measures within the SWPO could be implemented to conserve particular developmental stages or ecological areas important to the species. Time-area management strategies could be aimed at spawning grounds, feeding grounds, or focused on reducing total catch of juveniles, or the oldest age-classes in the population. Data from the present investigation showed that the species is taking advantage of a wide array of pelagic habitats throughout the lifetime of an individual but that specific developmental stages utilise, and are probably dependent on, unique and spatio-temporally confined pelagic environments. For example, nutrient rich coldwater upwellings and other productive pelagic environments at high latitudes around New Zealand and the south-coast of New South Wales are important feeding grounds for post-spawning adult striped marlin. Conversely, the geographic position and timing of spawning suggests that warm (>24°C), less turbulent waters of the Coral Sea are critical to the survival of larvae and rapid growth of larvae.

The distribution of juveniles and young-of the-year (YOY) appears restricted to tropical latitudes, and while these areas contain significant longline fisheries, the total catch of striped marlin is currently and has always been relatively low. The low proportion of immature and YOY fish captured in most fisheries of the SWPO and, there fore low total catch, suggests that that the risk of over-exploiting this portion of the population may be low. This is in stark contrast to longline fisheries based out of Hawaii, a similar latitude to Fiji and New Caledonia that catch a much greater number of juvenile and young adult striped marlin.

Fisheries data suggest targeted recreational and commercial longline fisheries in the SWPO occur in spatial areas or habitats (horizontal and vertical) where adult striped marlin occur and that these areas are not frequented by juveniles. Another possible explanation for the low total catch of YOY is that they migrate or drift away from the spawning ground during the first year of life. A similar process has been proposed for striped marlin in the northern hemisphere where young striped marlin spawned off the coast of Japan move eastward to the north-central Pacific Ocean (Squire and Suzuki 1989). There is some evidence to suggest there may simply be higher recruitment (more juveniles) in the north Pacific compared to the SWPO. For example, the north Pacific has been estimated to yield nearly three times the biomass (18,000mt) of the south Pacific (6,000mt) (Squire and Suzuki 1989). Even though long-term size data show that fisheries near Hawaii have consistently yielded a higher proportion of juveniles compared to the SWPO (Squire and Suzuki 1989), the increased presence of juveniles in the north Pacific may also be attributed, in part, to the status of the stock

Application to stock assessment

Results from this investigation are expected to improve the accuracy of a stock assessment model for striped marlin in the SWPO. Key differences between results from the present investigation and biological projections used in the previous stock assessment for striped marlin (Langley et al. 2006) were related to mean length-at-age one, as well as the observation of sex-specific, and spatial differences in age-structure within the SWPO. The following biological parameters estimated in this study are recommended for use in an updated stock assessment: sex-specific generalized VBGC parameters and associated mean length-at-age one (Table 5 and 6), latitudinal stratification of catch statistics, sex ratio by length-class (Figure 14), sex-specific length and age at 50% maturity (Figure 15), and biological characteristics associated with reproductive output and spawning activity.

The sex-specific generalized VBGC is recommended as the most biologically accurate representation of striped marlin growth. The most noteworthy difference between the present investigation and biological estimates used in the previous recent stock assessment (Langely et al. 2006) was the difference in mean length-at-age one. Mean length-at-age one, 1603-1607mm LJFL, estimated in the present investigation diverged from the value, 650mm LJFL, used in the preliminary stock assessment. The previous estimate was based on an unvalidated age estimates (Kopf et al. 2005). It is believed that the presence of false increments (Figure 5) in fin spines during the first year of life accounted for age over-estimation and growth under-estimation in previous unvalidated aging studies. The revised length-at-age one suggests that striped marlin begin to recruit commercial longline fisheries (1000-1200mmLJFL) at four to five months old or sometime between March and May.

The previous stock assessment also did not consider sex-specific differences but several biological parameters estimated in the present investigation suggest that that variance in the model may be reduced by separating catch statistics by sex. It may be possible to convert historical size data into sex-specific proportions at length using the regression equations developed in the present study (Figure 14). Although there were no significant sex-specific differences in growth, the higher proportion of females in older age-classes compared to males (Figures 9 and 10) indicated that there might be differences in natural or fishing mortality rates between the sexes. Mortality rates were not estimated in this study but some inferences may be useful. For example, observed proportions-at-age showed a reduction (~ total mortality) of 37% (51/137) for females and 75% (78/104) for males between the ages of three and four. High natural mortality rates combined with under-reporting could contribute to the low (less than 2%) conventional tag-recapture rate of striped marlin (Ortiz et al. 2003), especially since most tag-releases are made on fish greater than three years old. Even though tag-recaptures of other closely related Istiophorid billfishes have displayed maximum longevities of greater than 15 years (Ortiz et al. 2003) evidence from the present investigation suggests that long-lived (> 7 years) individuals make up a very small fraction (< 3%) of the adult population.

There was a significant trend of increasing percentage of females with length class that was presumably related to different rates of natural or fishing mortality (Figure 14). The trend was generally consistent throughout all fisheries and years sampled. However, there was some evidence to suggest bias in the New Zealand recreational fishery in that fishermen were catching (or retaining) an unusually high proportion of females compared recreational fisheries in Australia based at a similar latitude (south-coast of New South Wales). Length and age at 50% maturity were also different between the sexes with females maturing at larger sizes and older ages than males (Figure 15). Two years old was the previous age at 50% maturity assumed for females in the most recent stock assessment that matched very well with 1.9 years determined in the present study.

Consideration for age at maturity should account for the fact that estimates for females were based on spawning and non-spawning individuals. Therefore, there was a significant difference in length at which 50% of females were mature (L_{50} = 2026mm LJFL) and the mean length (2367mm LJFL) of reproductively active females observed directly on the spawning ground. Due to this difference, the percent frequency of reproductively active females observed in different age and length-classes on the spawning ground may provide a more accurate representation of maturity than the L_{50} or A_{50}. Previous assumptions regarding a spring (4th quarter) spawning period used in the most recent stock assessment matched well with results from the present investigation. However, the spawning period was slightly more restricted with peak activity not starting observed until mid-November.

The presence of strong latitudinal partitioning of age-classes within the SWPO (Figure 11) suggests that increased spatial stratification of catch statistics within fisheries, potentially by 5° latitudinal bands, could reduce variance in a stock the assessment model. The growth rate ($k = 0.44$) estimated by the standard VBGC for both sexes combined was lower than the value ($k = 0.60$) estimated in the most recent stock assessment. The difference in growth rates was partially driven by the lower asymptotic length ($L\infty$ = 2636mm, LJFL) predicted in this study compared to stock assessment ($L\infty$ = 3000mm LJFL). Although historically there may have been a significant age-class of striped marlin with a mean length of approximately 3000mm LJFL, this length/age-class is no longer caught in meaningful numbers in longline or recreational fisheries in any region of the SWPO. The proportion of females in age-classes six, seven, and eight combined was estimated to be 1% of the total catch in the SWPO while the proportion for males was 0.6%. Therefore, the accuracy of the VBGC within the most common age classes (0-5 years) in the SWPO may be compromised if the asymptotic length ($L\infty$) were extended to 3000mm without increasing the maximum age estimate. If historical size data showed a modal length-class of striped marlin that exceeded the asymptotic length predicted by the standard VBGC, it would be reasonable to assume that longevity of striped marlin could exceed eight years. Conventional tag-and-recapture studies on other species of billfish (Ortiz et al. 2003) support this possibility even though the maximum age observed in the present study was eight years.

Limitations and recommendations for future research on striped marlin

This study provided the first estimates of several biological parameters pertaining to age, growth, and reproductive dynamics of striped marlin. As first estimates, these data may need to be refined as new information becomes available and as the fishery and pelagic ecosystem in the SWPO changes. Growth and length-at-age estimates in the present investigation were dependent on indirect evidence that suggested daily deposition of micro-increments in otoliths and yearly deposition of annuli in fin spines. Indirect validation of first annulus formation and annulus periodicity should not be extrapolated to imply absolute validation or validation of all age classes. Direct validation of age estimates, particularly for the older (4+) age classes should be a priority for future aging studies on billfishes.

The majority of the parameters estimated in the present investigation were subject to unknown sampling bias, potentially caused by spatial and temporal differences in sampling effort and by fisheries selectivity. The sampling strategy employed in this investigation was aimed at producing a representative sample of striped marlin by utilising two different fishing methods, from four spatially distinct fisheries, that were sampled seasonally over a three year time period. Although the present investigation was certainly affected by size selectivity, particularly as striped marlin do not recruit to longline fisheries until about 1000mm LJFL (Bromhead et al. 2004), all attempts were made to reduce bias.

A similar age, growth, and reproductive biology study for striped marlin is underway in the North Pacific Ocean and is being conducted by the NOAA Pacific Islands Fisheries Science Research Center. Results from this investigation should be available within the next few years and may provide an opportunity to compare regional differences in biological characteristics of striped marlin. Collaboration with NOAA researchers has resulted in a manuscript (Kopf et al. in press) focused on standardizing aging methods for billfishes, so that future comparisons can be made between the two regions. Conventional tag-recapture studies on small striped marlin that are seasonally abundant near Hawaii may also provide an opportunity to directly validate the growth rate of juveniles. Further international collaborations focused on developing standardised methods for acquiring and processing biological information from highly migratory fishes would benefit the conservation and management of these species.

Further research concerning natural mortality, recruitment, and dispersal patterns of striped marlin may help refine a regional stock assessment model. The relative absence of YOY striped marlin in the SWPO and particularly within the main spawning ground in the Coral Sea has not been fully resolved. Several YOY collected in the present investigation may provide a starting point for developing a better understanding of the movement patterns and distribution of this developmental stage. It has become clear that the primary distribution of YOY and juveniles lies within the tropics and is therefore distinctly different to the distribution of adults. The divergent distributions of young and adult striped marlin within the SWPO has implications for sub-region spatial fisheries management measures and is an area of research that merits further attention.

There remains uncertainty in individual movement patterns and residency time of adult striped marlin on the spawning ground in the Coral Sea. For example, the length of time individual females spawn can not be measured by histological examination of ovaries but may be answered using satellite tagging technology. Further research regarding the movement patterns and dispersal rates of striped marlin from spawning grounds in the Coral Sea, Fiji, and French Polynesia may benefit stock assessment. It will also be important to determine whether or not the different spawning populations across the SWPO represent the same genetic make-up or if individuals exhibit spawning site fidelity. It has been firmly established that aggregations of striped marlin in the Coral Sea are related to spawning activity. However, the factors influencing the sporadic numbers of striped marlin available on the south-coast of New South Wales between February and April remains a mystery. Anecdotal evidence suggests that these are feeding aggregations targeting large schools of coastal pelagic fishes, namely mackerel (*Trachurus spp.*).

Research focused on larval mortality, survival, and dispersal of large-pelagic fishes in the Coral Sea would be useful for understanding fluctuations in recruitment to commercial longline fisheries and for stock assessment. Larval survival or mortality accounts for a large portion of the annual changes in recruitment that occur in most pelagic fisheries. However, relatively little is known about the early life history of striped marlin and other large-pelagic fishes commercially harvested in the Coral Sea. This is particularly surprising since the Coral Sea is a confirmed spawning area for other commercially valuable large-pelagic species including yellowfin tuna (McPherson 1991), swordfish (Young et al. 2003) and others. Additionally, the spawning stock biomass and recruitment relationship is a key parameter for stock assessment but this relationship has not been empirically tested for any large-pelagic fish species in the Coral Sea. The spawning stock and recruitment relationship for most pelagic fishes, including striped marlin, is assumed to be weak but this is a contestable assumption.

The development of new techniques to evaluate the biology and ecology of large-pelagic fishes and their environment will be critical for making the transition from a single-species to an ecosystem-based approach to fisheries management. Many of the traditional methods of age estimation and classification of reproductive condition employed in this study will remain essential but could benefit greatly from new technologies and new techniques. For example, radiometric aging of calcified hard-parts has been useful to validate ages of many fish species but has only been applied to a few highly migratory fishes (Andrews et al. 2001; Campana 2001). Stable isotopes, fatty acids, and other biochemicals are proving to be useful indicators for studying the pelagic ecosystem (Revill et al. 2009). Biological tissues from striped marlin were collected from a broad spatial area and time-series during this research and provide a good opportunity to explore the potential of new biochemical techniques.

Conclusion

This research contributed new insight into the life history of striped marlin and generated base-line biological information useful for the conservation and management of this species. The biological parameters quantified will reduce some of the uncertainty in stock assessment of this species that will hopefully have flow on effects that benefit management of commercial longline and recreational fisheries and the pelagic ecosystem. It should be noted, however, that the benefit of knowledge gained by this research would not be fully realized until an updated stock assessment is conducted and subsequent management policies are adopted. The biological information reported here is cautiously encouraging and generally, falls within the more productive range of values explored in the preliminary stock assessment model for striped marlin the SWPO (Langley et al. 2006). However, the broader ecosystem effects of harvesting large-pelagic fishes are poorly understood and there remains a considerable degree of uncertainty regarding the basic biology, ecology, and population status of striped marlin.

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Table 1. Number (N) and mean length (LJFL, mm) of striped marlin (± Std.Dev.) sampled for age and growth analyses by quarter of the year and fishery from 2005-2008. Sampled fisheries included the Australian commercial longline (AUS COMM); Australian recreational (AUS REC), New Zealand recreational (NZ REC); and commercial longline fisheries from Pacific Island Countries and Territories (PICT) including Fiji and New Caledonia.

		Fishery											
		AUS COMM			AUS REC			NZ REC			PICT COMM		
Qrtr.	Year	N	Mean LFJL (mm)	± Std. Dev	N	Mean LFJL (mm)	± Std. Dev	N	Mean LFJL (mm)	± Std. Dev.	N	Mean LFJL (mm)	± Std. Dev.
1	2005	-	-	-	1	1860	-	-	-	-	-	-	-
	2006	-	-	-	11	2252	171	83	2366	150	-	-	-
	2007	-	-	-	21	2223	173	33	2355	119	1	2270	-
	2008	20	2191	118	18	2230	156	-	-	-			-
2	2005	-	-	-	1	2710	-	-	-	-	-	-	-
	2006	4	2215	222	-	-	-	6	2469	73	-	-	-
	2007	17	2272	169	13	2405	100	11	2422	102	4	1853	550
	2008	18	2113	312	-	-	-	-	-	-	11	1334	256
3	2006	1	2200	-	-	-	-	-	-	-	-	-	-
	2007	2	2180	297	-	-	-	-	-	-	14	1984	191
	2008	9	2201	140	-	-	-	-	-	-	2	2055	64
4	2006	33	2212	220	-	-	-	-	-	-	4	2141	85
	2007	51	2233	211	-	-	-	-	-	-	14	1968	120
	2008	22	2282	171	-	-	-	-	-	-	-	-	-
Total		177	2219	207	65	2268	181	133	2373	138	50	1847	356

Table 2. Number (N), range, and mean length (LJFL, mm) of female and male striped marlin, *Kajikia audax* sampled in the southwest Pacific Ocean for histological examination of gonads during 2006 through 2008 by quarter of the year.

		Female LJFL (mm)					Male LJFL (mm)				
Quarter	Year	N	Min.	Max.	Mean	Stdev.	N	Min.	Max.	Mean	Stdev.
1	2006	16	2130	2650	2348	149	12	2050	2500	2294	168
	2007	30	1678	2630	2350	172	25	2060	2458	2248	108
	2008	12	2110	2460	2250	99	26	1970	2460	2191	149
2	2006	1	2500	2500	2500	-	2	1980	2260	2120	198
	2007	26	2220	2548	2382	97	20	1120	2540	2206	338
	2008	15	990	2446	1687	523	17	1220	2380	1962	374
3	2006	-	-	-	-	-	2	2111	2200	2156	63
	2007	2	2070	2580	2325	361	10	1850	2010	1950	51
	2008	6	2010	2450	2207	163	4	2040	2300	2160	114
4	2006	33	1640	2649	2283	233	24	1980	2500	2201	130
	2007	23	1770	2690	2326	226	40	1490	2480	2100	173
	2008	20	2080	2580	2375	135	26	2000	2520	2226	109
Total		184	990	2690	2277	286	208	1120	2540	2161	213

Table 3. Regression equations and parameters used to standardize length and weight information of striped marlin in the southwest Pacific Ocean. Regression equations were developed to convert: Eye – Fork Length (mm, EFL); Upper Jaw – Fork Length (mm, UJFL) and whole weight (kg, Wt) to Lower Jaw – Fork Length (mm, LJFL) and to convert Trunk (head, gills, and organs removed) weight (kg, Twt) to whole weight. Percent female (% Fem.) in 100 mm LJFL classes was estimated using a four parameter Gompertz equation. The number of males was determine by subtracting the predicted number of females from the total number of fish observed in each 100mm LJFL class.

Regression equation	Sex	R^2	N	*a*	*b*	X_0	Y_0
EFL = a x LJFL + b	Both sexes	0.95	301	0.834	36.61	-	-
	Female	0.96	136	0.838	23.75	-	-
	Male	0.94	159	0.827	49.83	-	-
UJFL = a x LJFL + b	Both sexes	0.87	299	1.060	211.31	-	-
	Female	0.92	81	1.067	192.85	-	-
	Male	0.88	51	1.021	319.35	-	-
Wt = a x LJFL ^{b}	Both sexes	0.93	214	1.012×10^{-10}	3.55	-	-
	Female	0.95	120	4.171×10^{-11}	3.67	-	-
	Male	0.89	89	1.902×10^{-9}	3.16	-	-
[1] Wt = a x Twt ^{b}	Both sexes	-	254	1.179	0.99	-	-
% Fem. = Y_0 + a x e (–e ^ - (LJFL*class* - Xo) / b))	-	0.96	257	0.853	314.49	2374	0.3

1. Regression equation to convert trunk (head, gills, and organs removed) weight (kg) to whole weight (kg) was sourced from Langley et al. (2006).

Table 4. Daily age estimates from sagittal otoliths (N=28) of individual striped marlin caught in the exclusive economic zones (EEZ) of Fiji (FJ) and Australia (AUS). Catch information included Lower jaw-fork length (LJFL), estimated weight (kg), location (Latitude and Longitude) and date. An estimated hatch date was calculated by subtracting the daily age estimate from the date of capture.

Age estimate (days)	Precision (± days)[1]	Length (mm, LJFL)	Estimated weight (kg)[2]	Sex	Lat.	Long.	Hatch date (dd mm yyyy)
140	4	990	5	M	18.1 S	176.2 E	23 12 2007
130	7	1120	7	M	20.5 S	173.4 E	19 12 2006
160	2	1130	7	F	18.1 S	176.2 E	3 12 2007
170	4	1220	9	M	17.1 S	172.6 E	28 10 2007
163	4	1230	9	M	17.1 S	173 E	1 11 2007
192	7	1290	11	M	17.2 S	173.2 E	6 10 2007
176	14	1320	12	F	17.1 S	172.5 E	19 10 2007
181	19	1320	12	F	17.1 S	173.6 E	17 10 2007
158	8	1330	12	F	17.1 S	172.5 E	6 11 2007
200	20	1350	*12	F	25.1 S	154.1 E	16 9 2007
216	12	1410	15	F	16.2 S	176 E	24 9 2007
208	10	1420	15	F	16.2 S	176 E	2 10 2007
383	21	1490	*19	M	25.6 S	154.6 E	4 11 2006
366	14	1640	24	F	30 S	158.4 E	7 12 2005
429	30	1703	28	F	27.4 S	155.5 E	5 9 2005
309	27	1740	30	UK	25.1 S	176.4 E	12 10 2006
480	9	1770	31	M	36 S	150.3 E	21 12 2005
344	45	1770	30	F	18.6 S	179.3 E	26 10 2006
590	88	1850	37	M	20.5 S	177.6 E	11 1 2006
868	34	1910	52	M	14.7 S	177.2 W	4 6 2005
731	39	1910	41	M	19.5 S	178.5 W	24 10 2005
682	73	1920	41	M	20.1 S	178.5 W	14 11 2005
627	161	1930	42	M	20.1 S	177.5 E	7 12 2005
649	73	1930	42	M	16.4 S	174.4 E	27 1 2006
640	40	1970	45	M	27.4 S	154 E	14 11 2005
616	50	1980	46	M	29 S	160 E	6 3 2005
562	41	2000	48	M	11.2 S	176.2 E	19 1 2006
630	98	2140	60	F	27.5 S	153.4 E	20 3 2005

Table 5. Standard and generalized vonBertalanffy growth models fitted to mean back-calculated length (LJFL, mm) at age for male, female, and combined sexes of striped marlin caught in the southwest Pacific Ocean during 2006-2008. L_∞ = asymptotic length; k and K = growth coefficients; t_0 = hypothetical age at length zero; *m* = best-fit fourth parameter of the generalized model; SSQ = Sum of squares difference from back-calculated mean length, N = number of age classes.

	Standard von Bertalanffy growth			Generalized von Bertalanffy growth			
Parameter	Female	Male	Combined	Parameter	Female	Male	Combined
L_∞	2634	2525	2636	L_∞	2722	2581	2749
k	0.45	0.51	0.44	K	0.11	0.16	0.09
t_o	-1.02	-0.92	-1.07	t_o	-0.07	-0.14	-0.01
				m	-1.56	-1.29	-1.80
SSQ	3054	2379	3612		383	1196	165
N	8	7	8		8	7	8

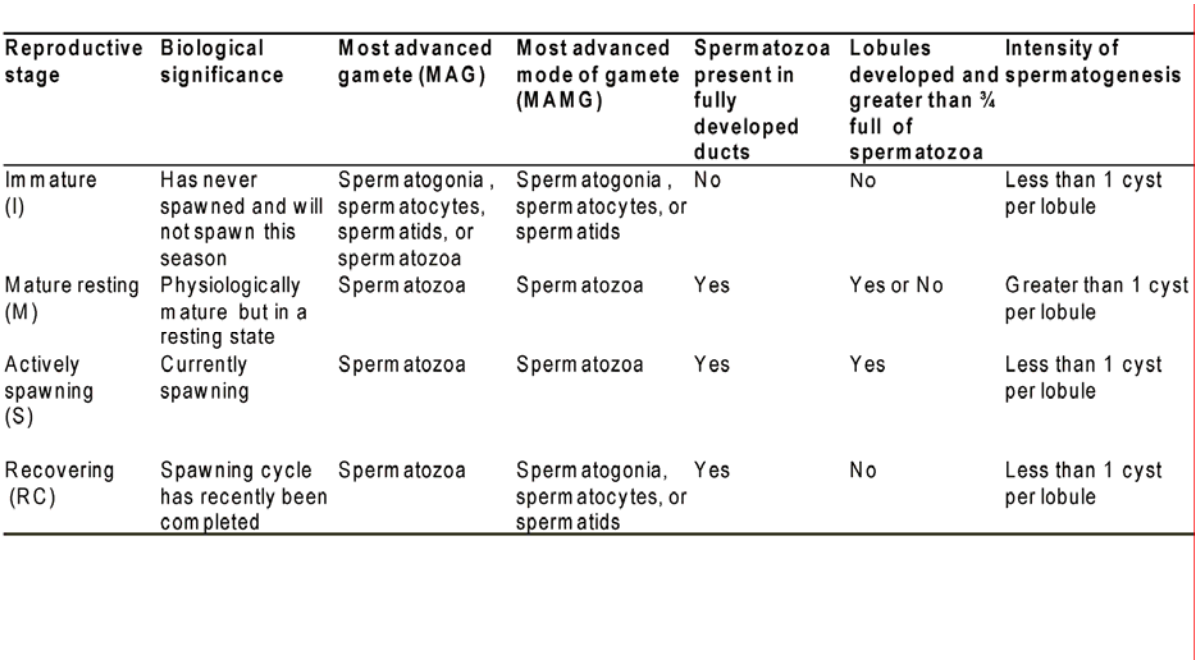
Table 6. Sex-specific model parameters for length (LJFL, mm)-at-age of striped marlin used to develop age-length keys. Proportion N = the proportion of striped marlin in each age class; N = number in each age-class; GVBGM = LJFL-at-age predicted by the generalized vonBertalanffy growth model; and Stdev. = the standard deviation in LJFL-at-age predicted from back-calculated estimates.

	Females				Males			
Age	Proportion (N) age class[1]	N	GVBGC LJFL (mm)	+/- Stdev.[3]	Proportion (N) age class[2]	N	GVBGM LJFL (mm)	+/- Stdev.[3]
0.5	0.03	35	1288	179	0.02	22	1291	179
1	0.04	48	1607	152	0.07	74	1603	152
2	0.13	141	1978	132	0.32	354	1968	132
3	0.29	323	2199	116	0.40	439	2177	116
4	0.28	310	2345	104	0.11	125	2309	104
5	0.12	127	2446	95	0.02	25	2396	95
6	0.04	46	2518	88	0.02	20	2454	88
7	0.03	35	2571	83	0.02	20	2494	83
8	0.03	35	2609	79	0.02	-	-	-

Table 7. Histological criteria used to define reproductive stages of female striped marlin in the southwest Pacific Ocean.

Reproductive stage	Biological significance and sub-stages	Most advanced single oocyte (MASO)	Most advanced mode of developing oocytes (MAMDO)	Residual hydrated oocytes (RO)	Post-ovulatory follicles (POF)	Atresia of yolked oocytes
Immature (I)	Has never spawned and will not spawn this year (I1) or has never spawned but there is evidence of gonad development (I2).	Chromatin nucleolar, early stage perinucleolar (I1) or late stage perinucleolar (I2)	Chromatin nucleolar, early stage perinucleolar	Absent	Absent	Absent but may be present in unyolked oocytes
Mature resting (M)	In a resting state and physiologically capable of spawning this year (M1) or funtionally mature based on evidence of previous spawning (M2).	Late stage perinucleolar or pre-vitellogenic	Late stage perinucleolar	Yes (M2) or No (M1)	Absent	Alpha and/or beta atresia usually present
Ripening (RP)	In preparation for spawning (RP1) or in preparation for spawning but vitellogenesis terminated (RP2).	Pre-vitellogenic or fully vitellogenic	Pre-vitellogenic or vitellogenic	Absent	Absent	1-10% alpha atresia (RP1), 90-100% alpha atresia (RP2), Beta atresia may be present
Actively spawning (S)	Spawning is immanent (S) but has not occurred recently (S1), or spawning is in progress (S2), or spawning is immanent and has occurred in at least one previous reproductive cycle (S3).	Migratory or hydrated	Migratory or hydrated	Yes (S3) or No (S1)	Fresh (S2) or degraded (S3) POF's may be present or absent (S1)	1-10% alpha atresia, beta atresia may be present
Recovering (RC)	Spawning cycle has recently been completed (RC1) and is progressing into a new reproductive cycle (RC2)	Perinucleolar (RC1) or previtellogenic or more advanced (RC2)	Perinucleolar (RC1) or previtellogenic or more advanced (RC2)	Yes	Fresh or degraded POF's may be present or absent	90-100% alpha atresia of residual oocytes (RC1) with 0-10% alpha atresia of patchy pre-vitellogenic oocytes (RC2), beta atresia may be present

Table 8. Histological criteria used to define reproductive stages of male striped marlin from the southwest Pacific Ocean.



Reproductive stage	Biological significance	Most advanced gamete (MAG)	Most advanced mode of gamete (MAMG)	Spermatozoa present in fully developed ducts	Lobules developed and greater than ¾ full of spermatozoa	Intensity of spermatogenesis
Immature (I)	Has never spawned and will not spawn this season	Spermatogonia, spermatocytes, spermatids, or spermatozoa	Spermatogonia, spermatocytes, or spermatids	No	No	Less than 1 cyst per lobule
Mature resting (M)	Physiologically mature but in a resting state	Spermatozoa	Spermatozoa	Yes	Yes or No	Greater than 1 cyst per lobule
Actively spawning (S)	Currently spawning	Spermatozoa	Spermatozoa	Yes	Yes	Less than 1 cyst per lobule
Recovering (RC)	Spawning cycle has recently been completed	Spermatozoa	Spermatogonia, spermatocytes, or spermatids	Yes	No	Less than 1 cyst per lobule

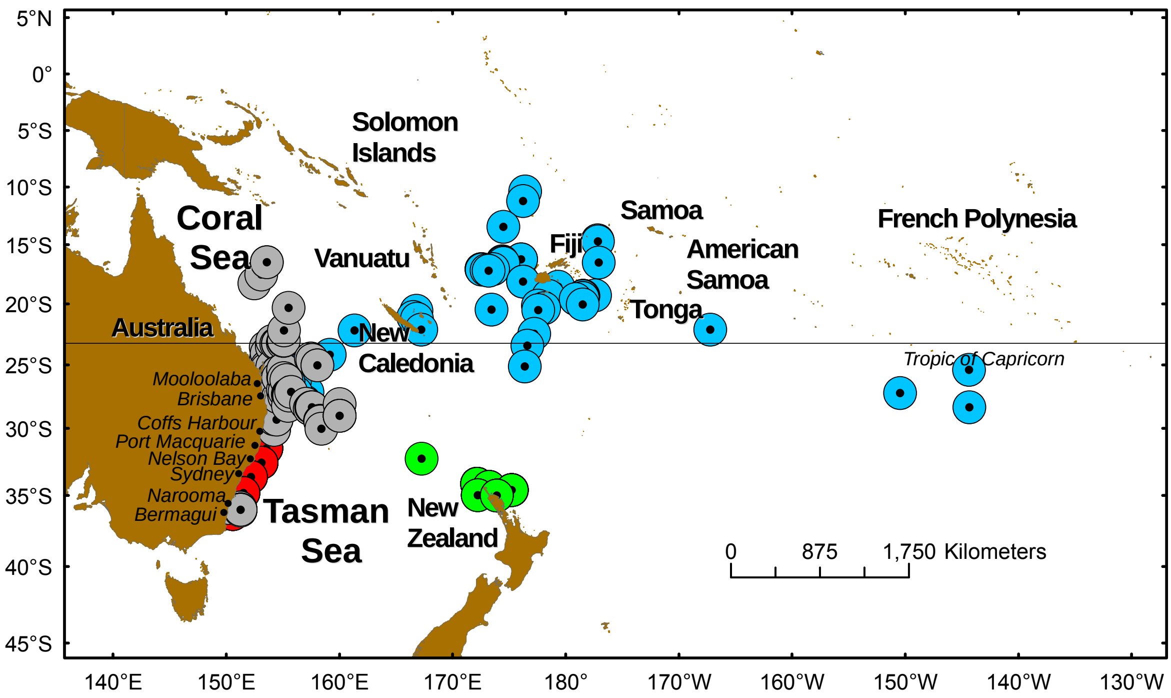


Figure 1. Spatial distribution of striped marlin (N=489) sampled for age, growth, and reproductive analysis in the southwest Pacific Ocean during 2006-2008. Fin spines, otoliths, and gonads were sampled from striped marlin caught in the Australian commercial longline fishery (Grey), Australian recreational fishery (Red), longline fisheries from Pacific Island Countries and Territories (Blue), and the New Zealand Recreational fishery (Green).

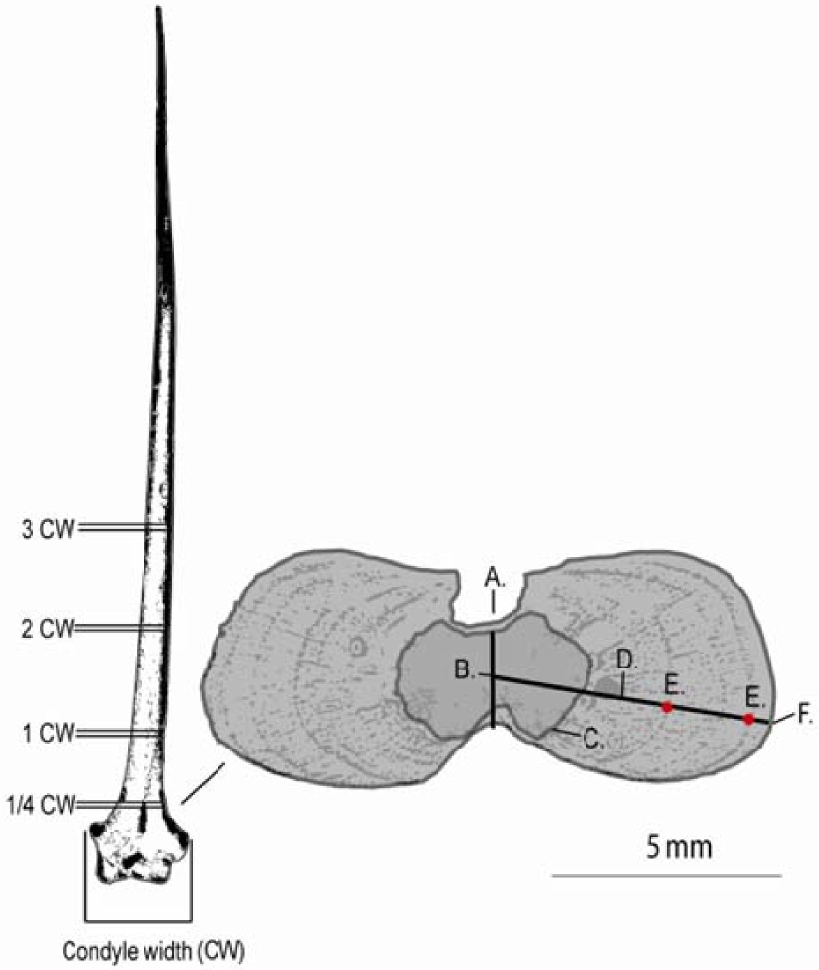


Figure 2. Diagram of a striped marlin dorsal fin spine showing levels at which sections were made including ¼ maximum condyle width (CW), 1CW, 2CW, and 3CW. Defining features of transverse sections included the anterior-posterior vertical axis (A), focus (B), vascularized perimeter(C), horizontal axis which served as the counting path and spine radius (D), annuli (E.), and the perimeter of the section used to calculate total surface area (F.). The area between the last annulus (E2.) and the perimeter (F.) is the marginal increment.

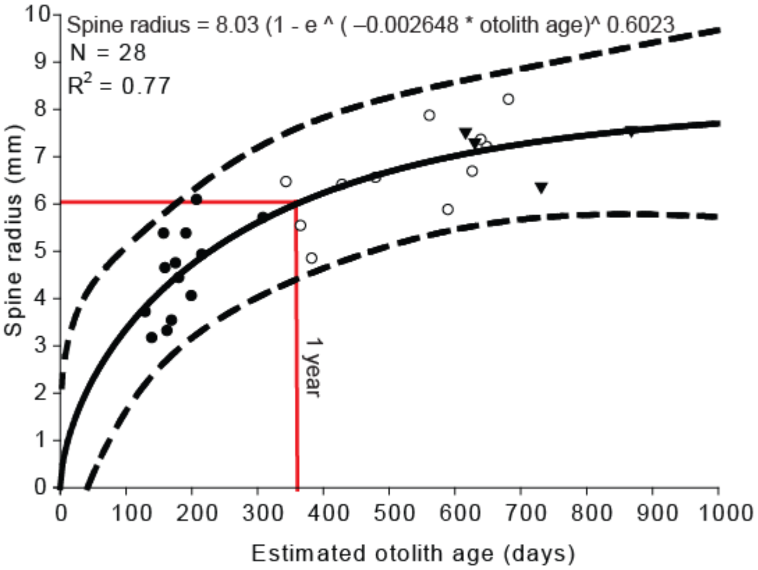


Figure 3. Relationship between estimated sagittal otolith age (days) and spine radius (mm) of dorsal fin spine 4, ¼ condyle width (CW) from a striped marlin. The dropline at 365 days shows the estimated radius of the first yearly annulus formed in fin spine sections. Spine sections from closed circles were age 0, open circles aged 1, and triangles aged 2. The dashed lines are 95% Prediction Bands.

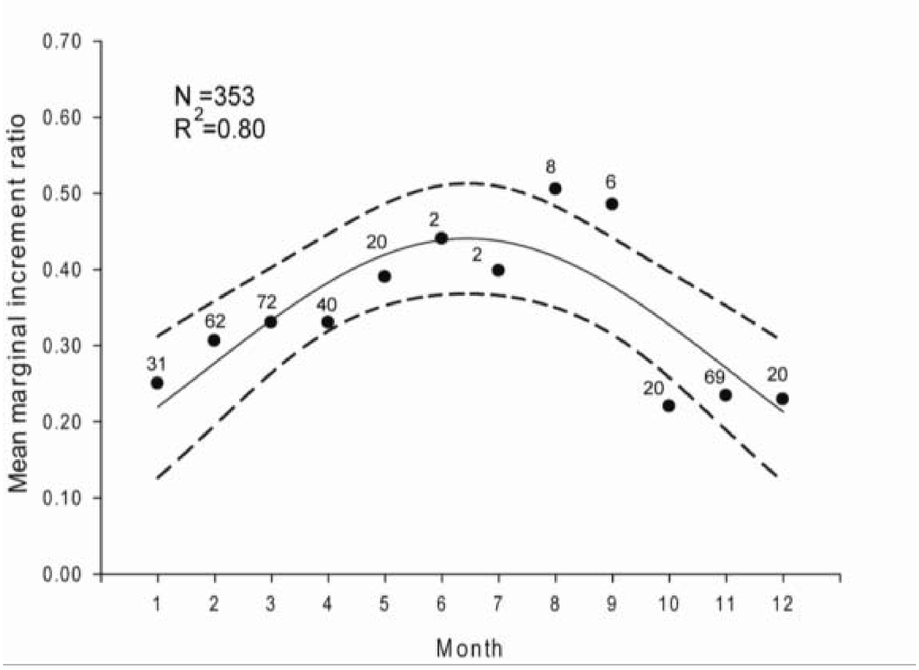


Figure 4. Mean marginal increment ratio by month and year from fin spine sections of striped marlin. Mean values were fit to a Gaussian Peak regression (solid line) which displayed a 12 month sinusoidal cycle of annuli formation and predicted peak marginal increment values to occur over the Austral winter (months 6-8). Dashed lines are 95% Confidence Intervals and numbers indicate the sample size (N) for month.

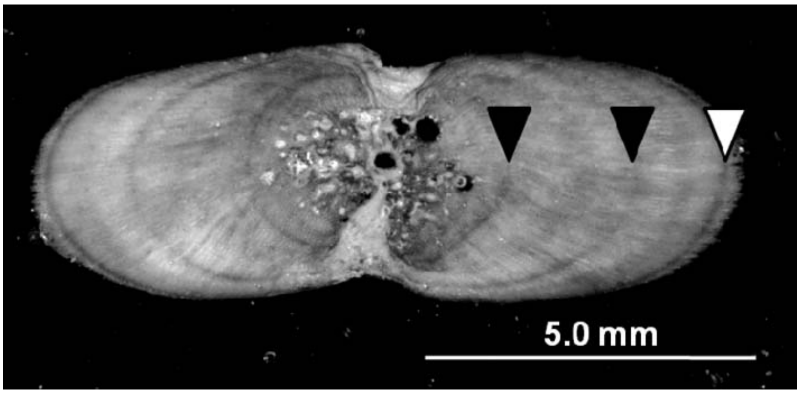


Figure 5. Transverse section of first dorsal fin spine four, ¼ condyle width (CW), from a 1490 mm Lower jaw – fork length striped marlin that was estimated to be 383 days old. The two black arrows indicate presumed false annuli that formed prior to the first yearly annulus indicated by the white arrow. The radius of the first yearly annulus closely matches the predicted spine radius at 365 days (6.34mm). Note that the fish was caught in November and the first yearly annulus is close to the edge of the section, which suggests that the annulus was recently formed.

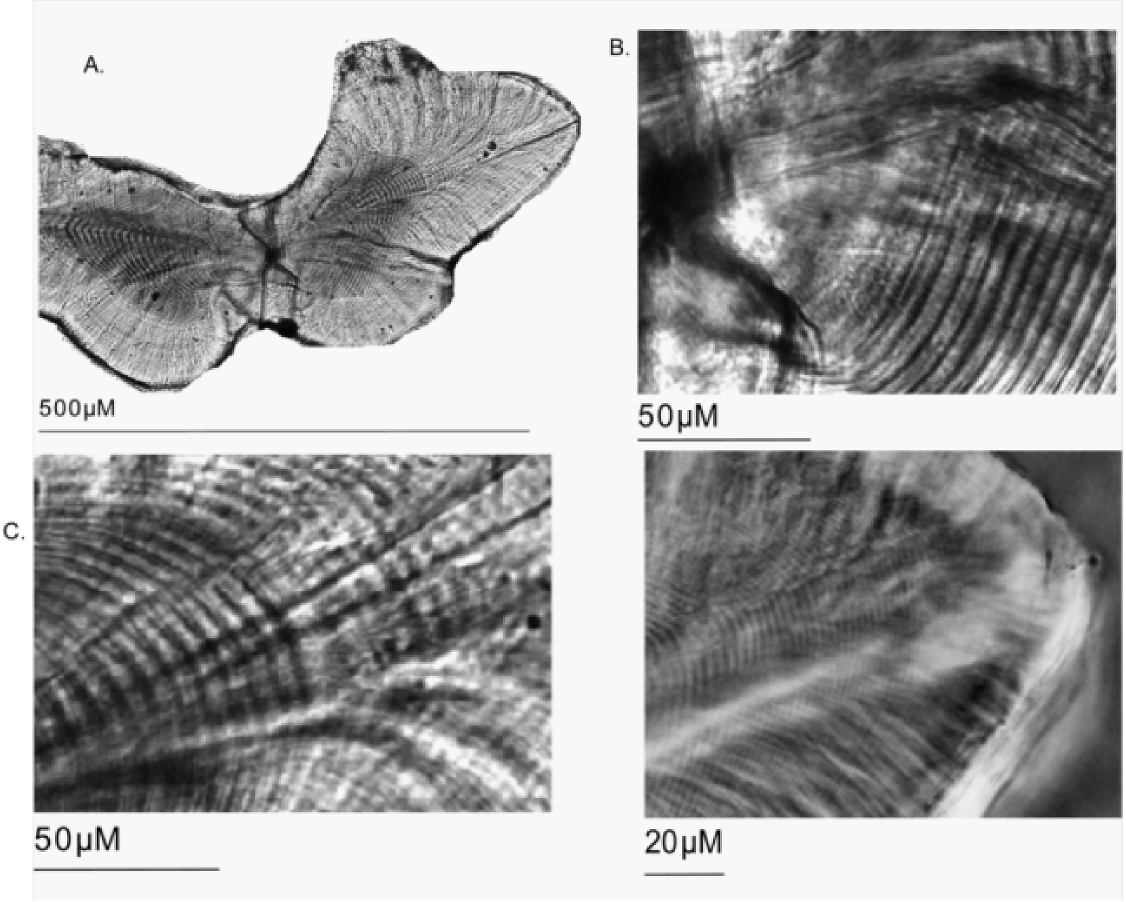


Figure 6. Images of presumed daily micro-increments from a 1120 mm Lower jaw-fork length striped marlin sagittal otolith that was aged 130 days. Images display the ventral lobe which was used as the counting path (A.), the primordium (B.), transition zone in the middle of the counting path (C.), and closely spaced micro-increments near the edge (D.)

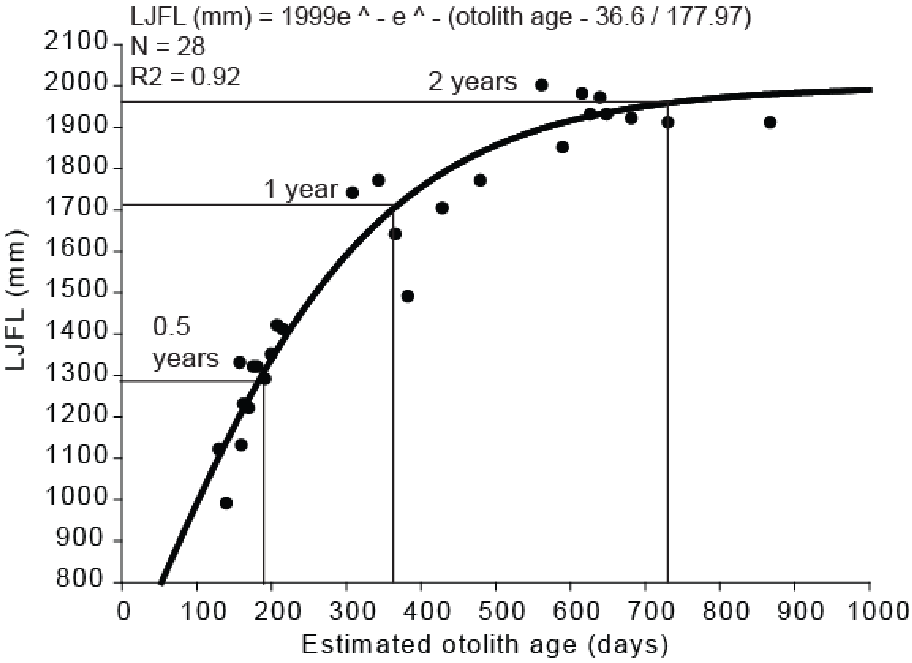


Figure 7. Relationship between estimated otolith age and lower-jaw fork length (LJFL) for combined sexes of striped marlin from the southwest Pacific Ocean. Drop lines indicate LJFL at estimated otolith ages 0.5, 1, and 2 years. A three parameter Gompertz regression equation best described the growth relationship.

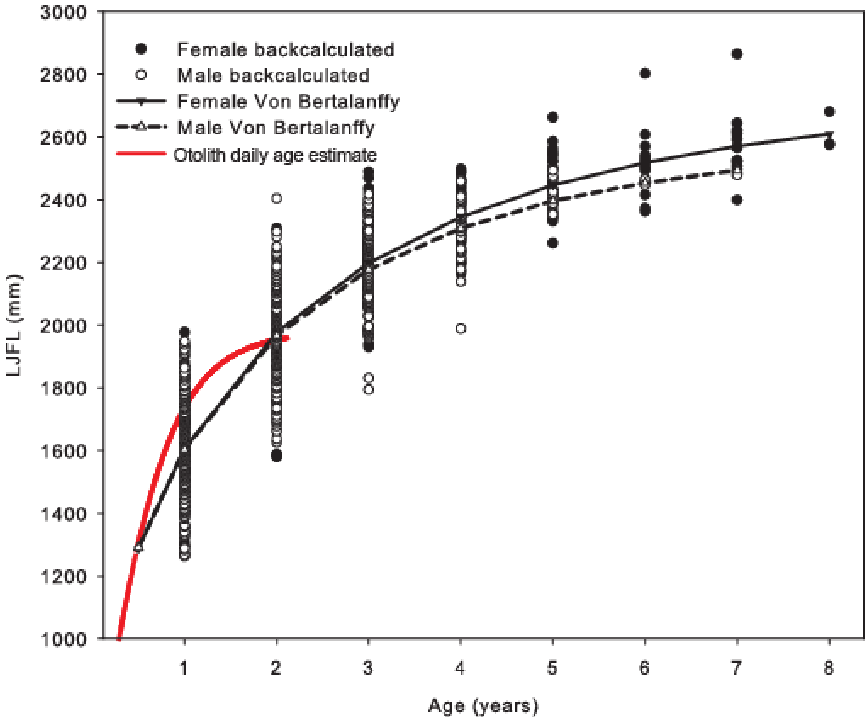


Figure 8. Generalized von Bertalanffy growth curves for female (N=179) and male (N=189) striped marlin from the southwest Pacific Ocean between 2006 and 2008. The red line represents growth curve estimated using daily otolith micro-increments.

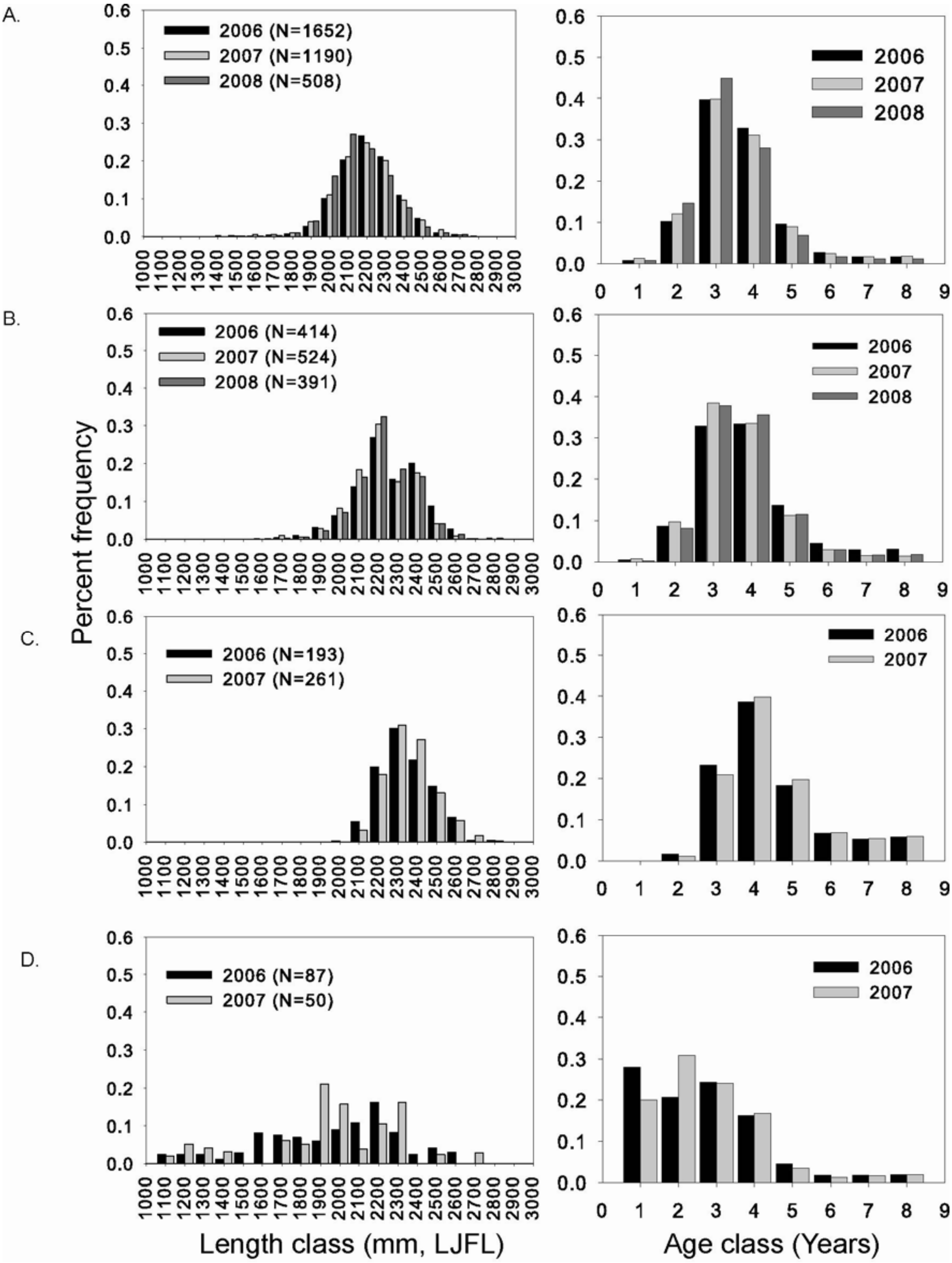


Figure 9. Length (LJFL) and age-structure of female striped marlin from 2006 - 2008 caught in (A.) the Australian commercial longline; (B.) Australian recreational; (C.) New Zealand recreational; and (D.) commercial longline fisheries of Pacific Island Countries and Territories including Fiji, New Caledonia, Tonga, and Papua New Guinea.

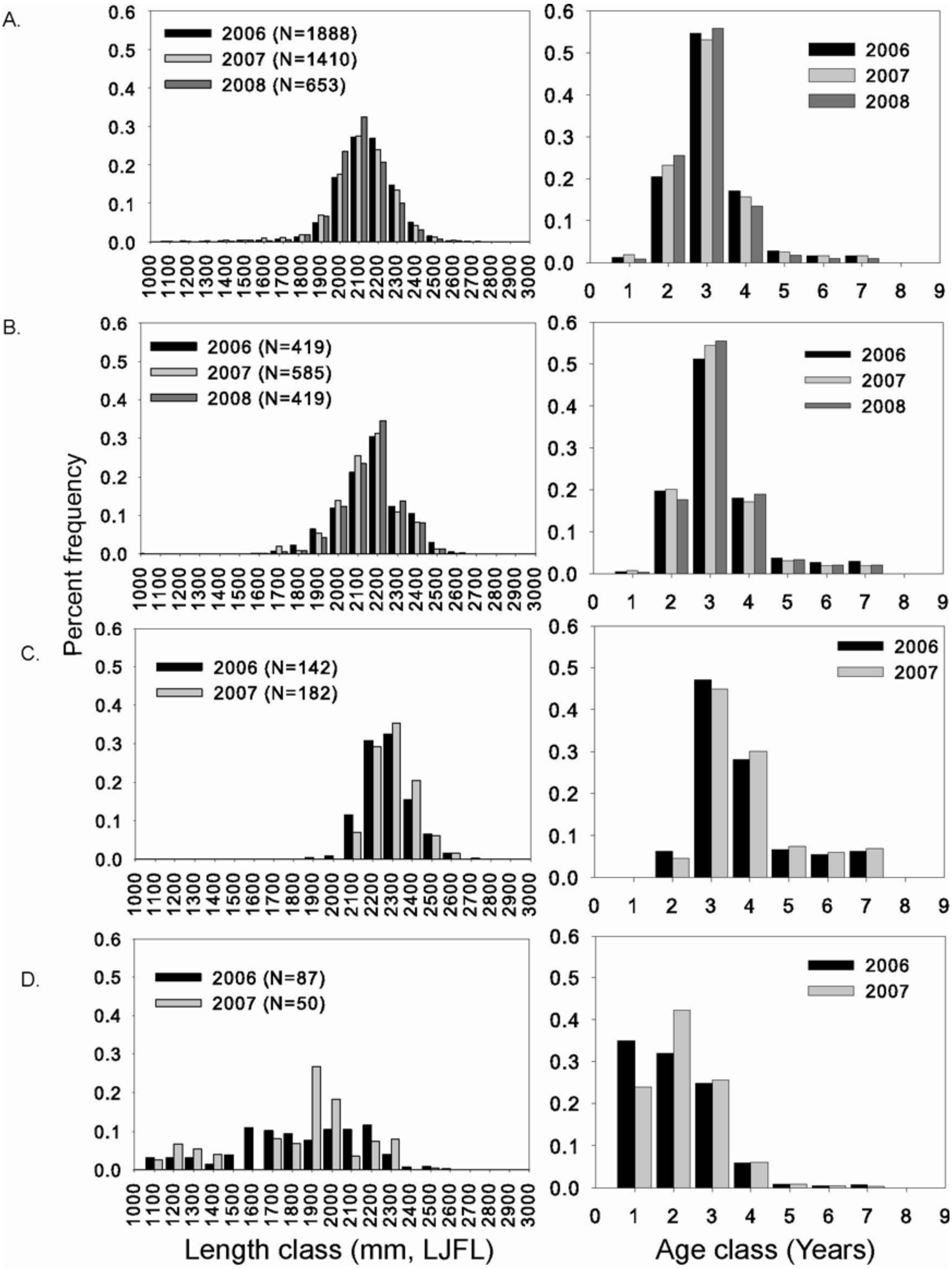


Figure 10. Length (LJFL) and age-structure of male striped marlin from 2006 - 2008 caught in (A.) the Australian commercial longline; (B.) Australian recreational; (C.) New Zealand recreational; and (D.) commercial longline fisheries of Pacific Island Countries and Territories including Fiji, New Caledonia, Tonga, and Papua New Guinea.

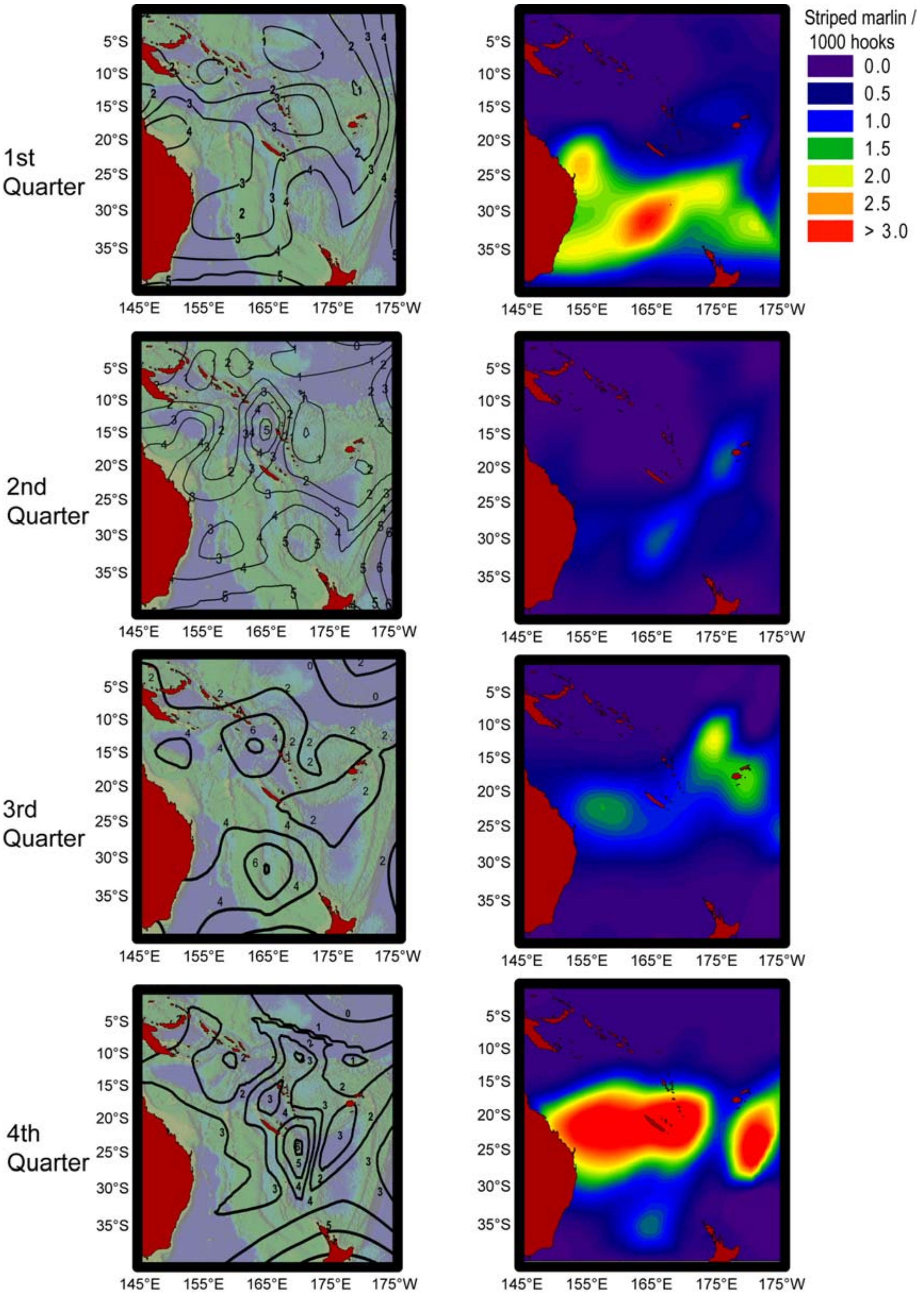


Figure 11. Spatial patterns in age-structure (left column) and catch per unit effort (CPUE; right column) of striped marlin in the southwest Pacific Ocean during quarters 1-4 of the year. Age contour plots were developed from pooled length measurements (N =16,685) from commercial longline and recreational fisheries between 1998-2008. CPUE was calculated by the number of striped marlin (N=91,981) caught per 1000 hooks by Japanese longline fishing vessels between 1970 and 1998.

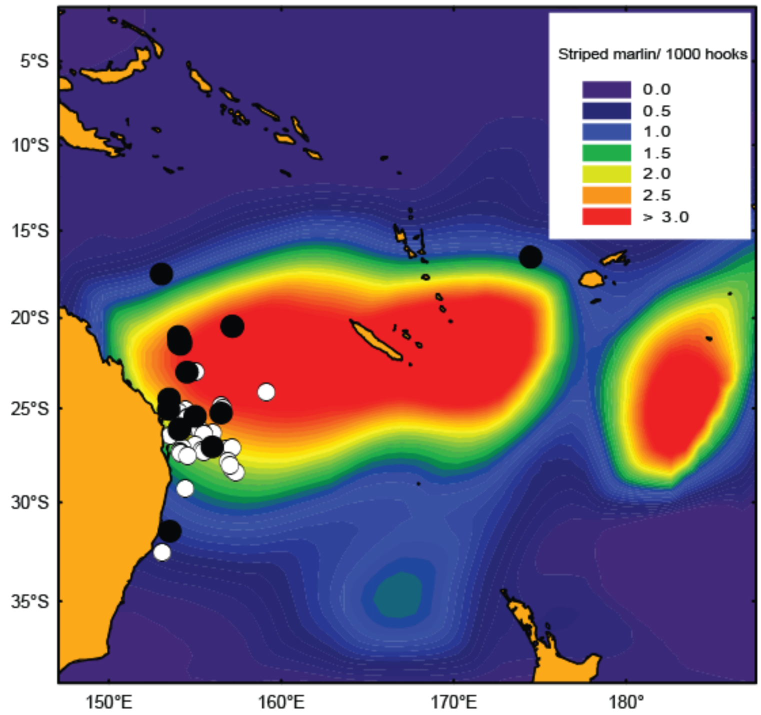


Figure 12. Spatial distribution of ripening (white dots) and spawning (black dots) female striped marlin, *Kajikia audax* in the Coral Sea between 2006 and 2008 in relation to nominal catch per unit effort (CPUE) of Japanese longline fishing vessels during the fourth quarter of the year between 1970 and 1999.

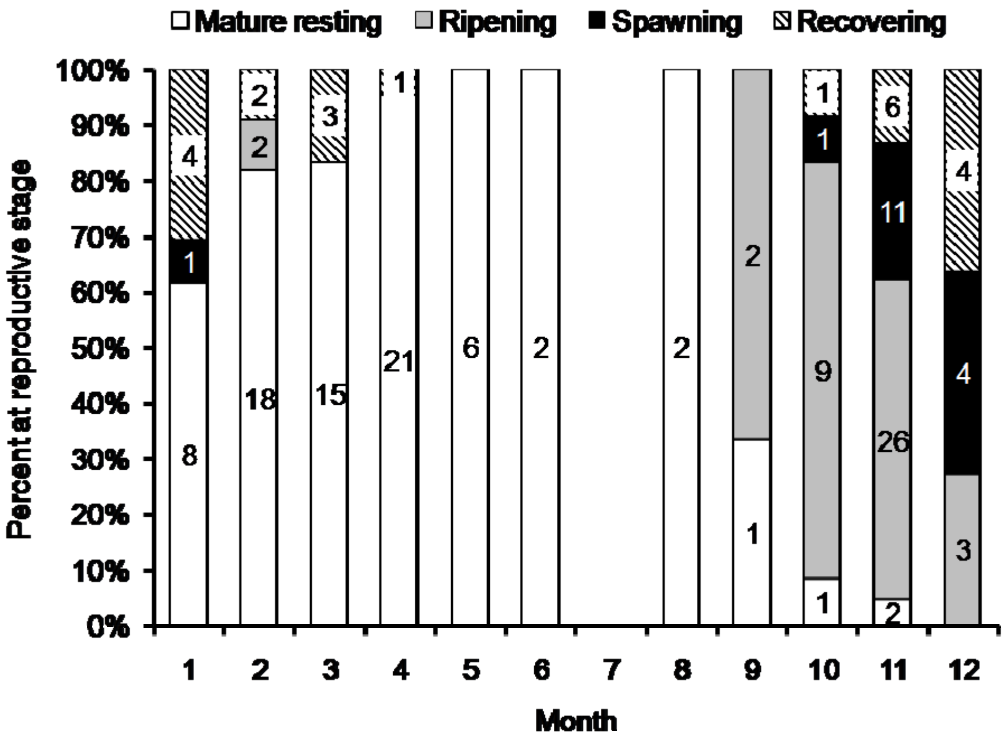


Figure 13. Proportion of female striped marlin, *Kajikia audax* at different reproductive stages sampled by month in the southwest Pacific Ocean.

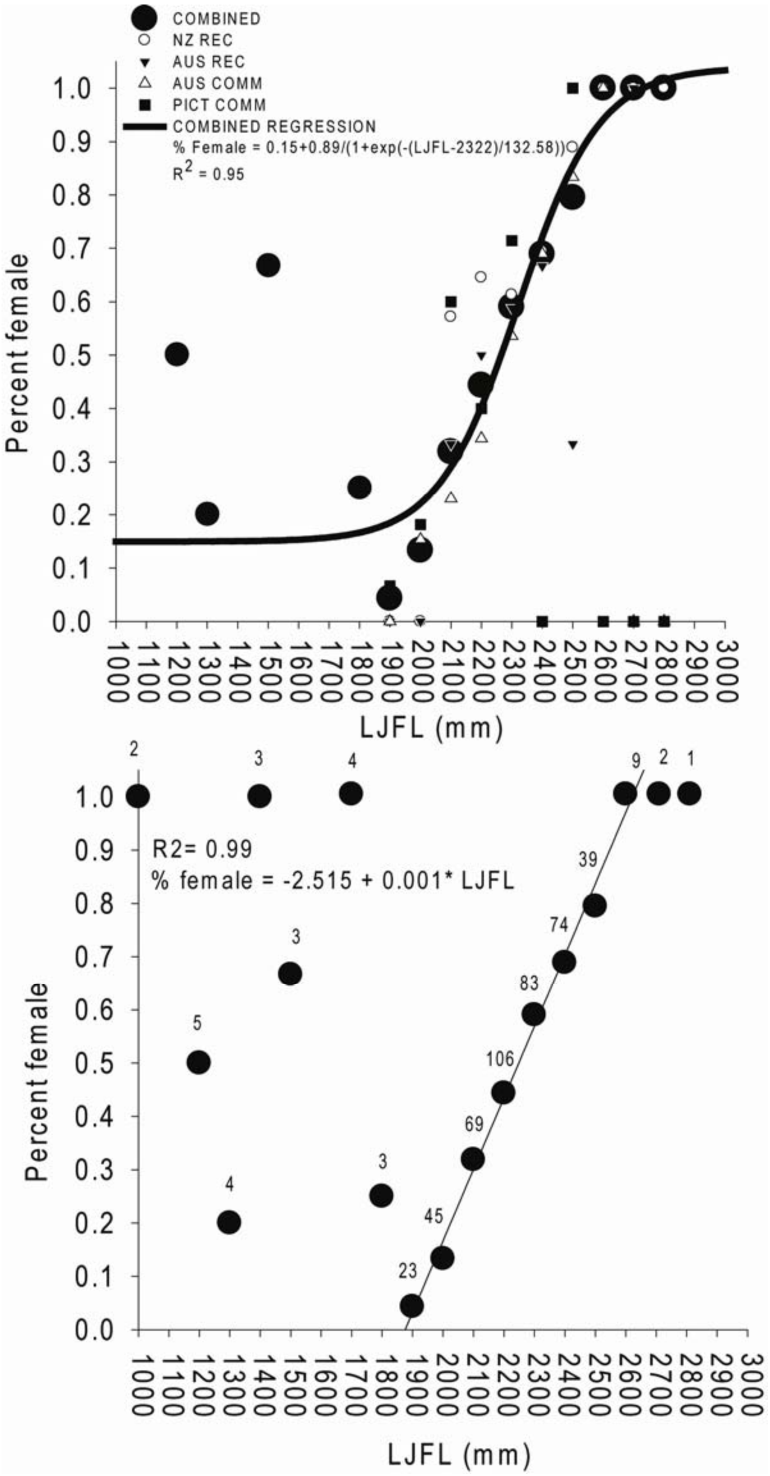


Figure 14. Percentage of female striped marlin, *Kajikia audax* observed in 100mm length classes (LJFL, mm) fit to a sigmoidal regression (A.) and linear regression fit to lengths between 1900 and 2600mm LJFL. Fisheries sampled included the New Zealand recreational (NZ REC).; Australian recreational (AUS REC.); Australian commercial longline (AUS COMM.) and longline fisheries of Pacific Island Countries and Territories (PICT COMM.).Numbers in figure (.B) denote sample size.

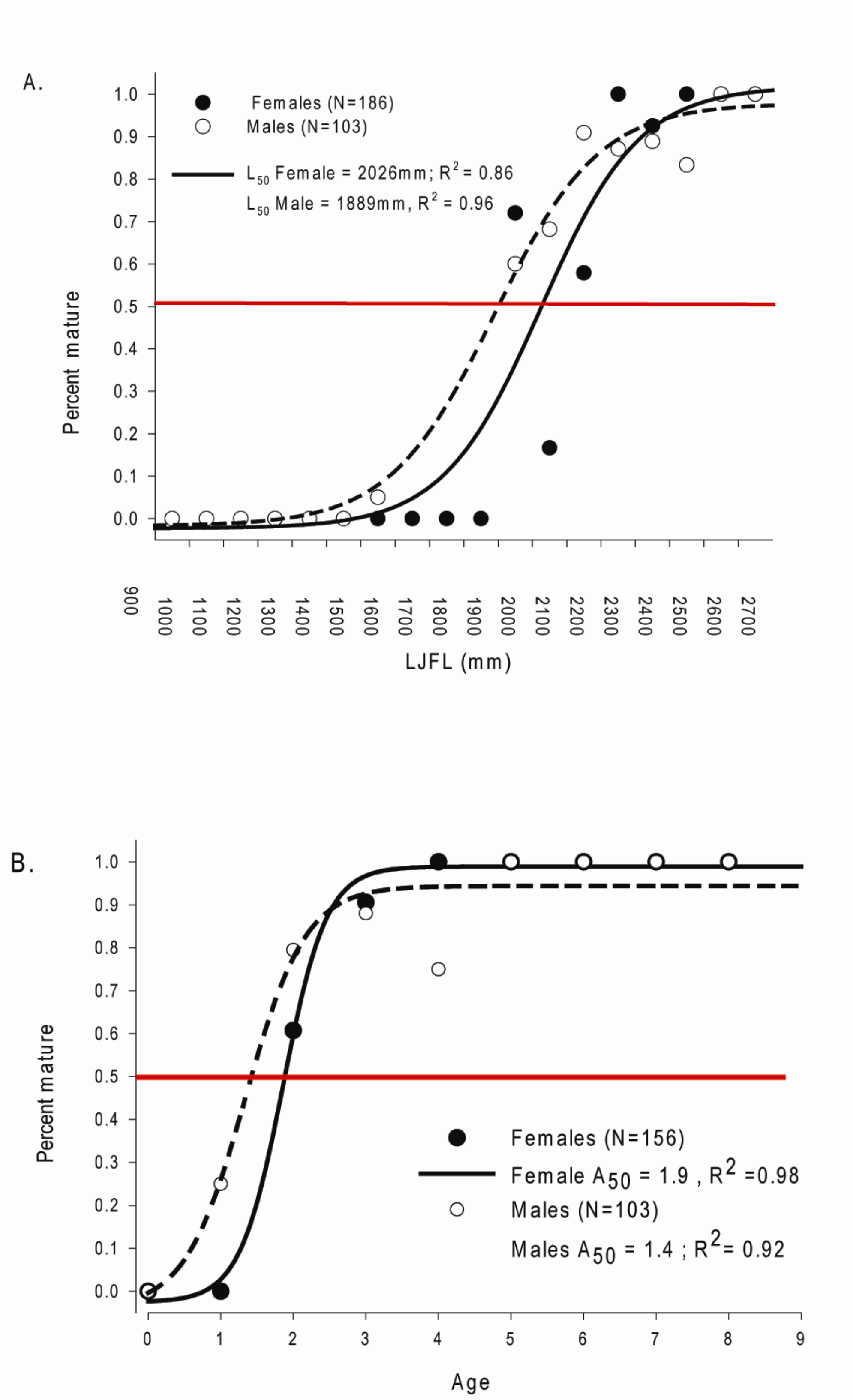


Figure 15. Percentage of striped marlin, *Kajikia audax* sexually mature at (A.) Lower Jaw – Fork Length (mm, LJFL) (L_{50}) and (B.) age (A_{50}) in the southwest Pacific Ocean between 2006 and 2006.

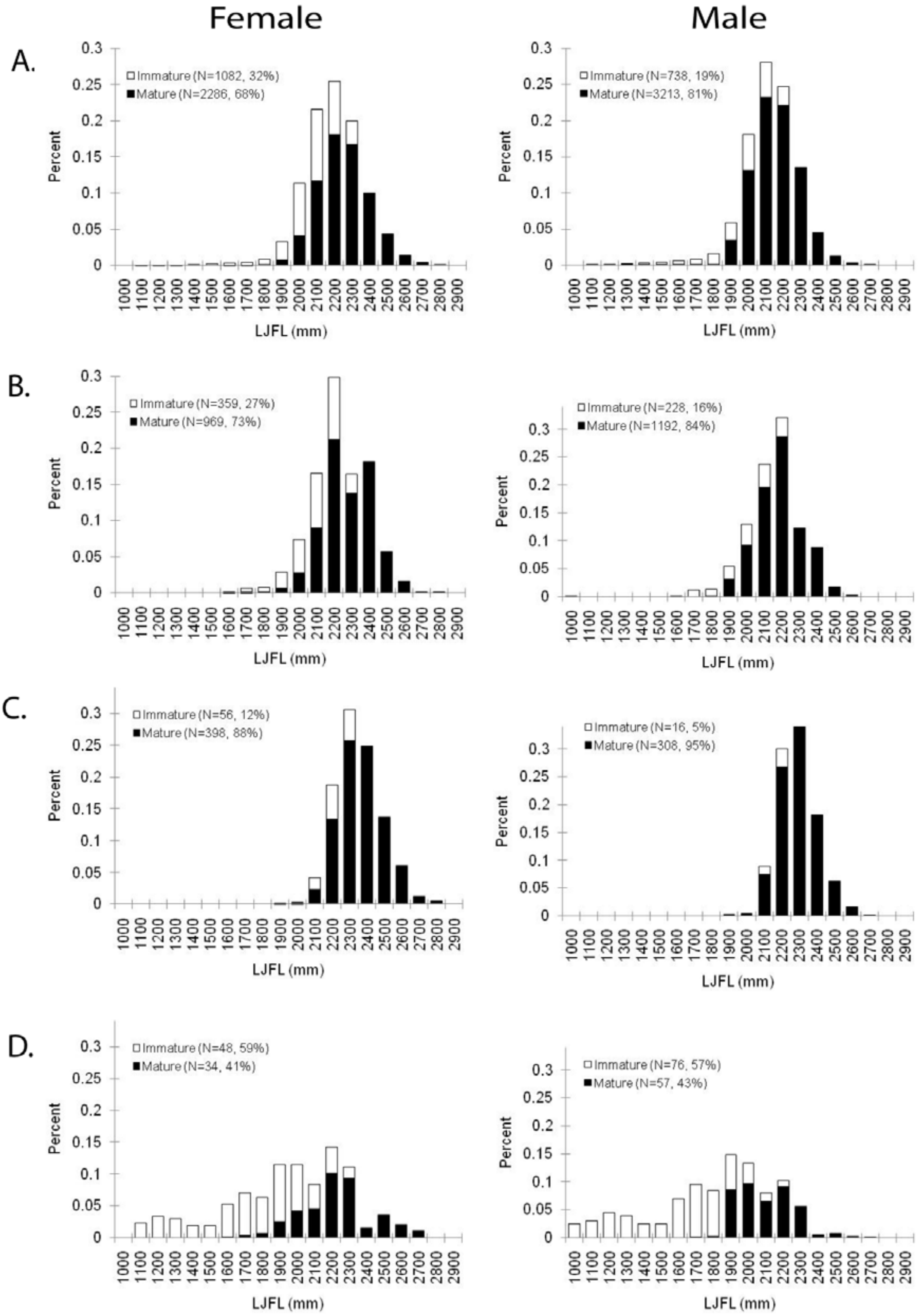


Figure 16. Percentage of female and male striped marlin immature and mature by length (LJFL,mm) class caught in fisheries in the southwest Pacific Ocean between 2006 and 2008 including the Australian commercial longline fishery (A.), Australian recreational (B.), New Zealand recreational (C.), and commercial longline fisheries from Pacific Island Countries and Territories (D.).