No 19.84./56.....

FIRC .37....

- ☐ NEW PROPOSAL
- ☐ CONTINUING PROJECT
- ☒ FINAL REPORT
- ☐ PROGRESS REPORT

FISHING INDUSTRY RESEARCH TRUST ACCOUNT

TITLE OF PROPOSAL/PROJECT: STUDY OF THE REPRODUCTIVE BIOLOGY OF THE SOUTHERN BLUEFIN TUNA (THUNNUS MACCOYII (CASTLENAU)) OFF THE COAST OF AUSTRALIA.

ORGANISATION: ~~UNIV OF SYDNEY~~

PERSON(S) RESPONSIBLE: MR J THOROGOOD

FUNDS SOUGHT/GRANTED

YEAR	SOUGHT	GRANTED
1984/85 - 85/86		$32,275

RELATED APPLICATIONS:

RECEIVED ...../...../19....

DISTRIBUTED ...../..... 19...

Secretary
Fishing Industry Research Committee

F139 12/84

INTRODUCTION

The results of this project are detailed in the accompanying reprint 'Aspects of the reproductive biology of the southern bluefin tuna (Thunnus maccoyii); I would ask that at least the 'abstract' be read in conjunction with this report. I feel that within the constaints imposed by a one year study, this project has made significant progress towards achieving the objectives set out in the initial proposal. In summary it has been ascertained:

That a significant proportion of fish caught by the Australian fishery should be considered mature and a component of the spawning stock.

That a small number of fish sampled from the Bight appeared ready to spawn; though I doubt that the Bight is a spawning area.

That younger mature fish appear to spawn only once each year, and that fecundity is proportional to size.

PLANNING AND LOGISTICS

As this project has relied heavily on the co-operation of the catching and processing sectors of the industry, forward planning and liaison with fishermen, processors, and co-operating scientific agencies has been essential. Liaison with the Australian Fisheries Service, Department of Primary Industry has been excellent and invaluable; I particularly wish to thank Messrs Albert Caton and Neil Trainer. Mr Kevin Williams of W W Fisheries has also been most helpful in liaison with fishermen and with the industry in general. I thank Undine P/L and Port Lincoln Tuna Processors for their long-standing co-operation in allowing me to sample from their boats and processing plant respectively. Sampling, no matter how carefully and discreetly conducted, invariably causes inconvenience to the fishermen or plant operators, consequently I would be happy to see some tangible form of recognition available for their co-operation.

As sampling is largely dependant on access to freshly caught fish, it has been necessary to maintain close contact with fishermen, and to be able to be on a plane at literally an hours notice. A rigid sampling programme is not possible. With the exception of the first east coast season this liason has proved entirely satisfactory.

PLANNING AND LOGISTICS

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SAMPLING

Sampling was conducted over the duration of the South Australian season, from pole-and-liners, purse-seiners, and Japanese processing vessels and from fish unloaded on the wharf and at the P.L.T.P. processing plant. By far the most efficient sampling was achieved on board the Japanese processing vessel. Unfortunately, access to these vessels was restricted at the end of last season on the grounds that suitable accomodation was unavailable. P.L.T.P's Mr Casey has assured me that accomodation will be available on any of their four Japanese carriers this season as required.

A small quantity of samples were provided by Tasmanian Fisheries Development Authority observers Messrs Shaun Collins and Dave Strong, from Tasmanian / east coast Japanese longline cruises.

GENERAL COMMENTS

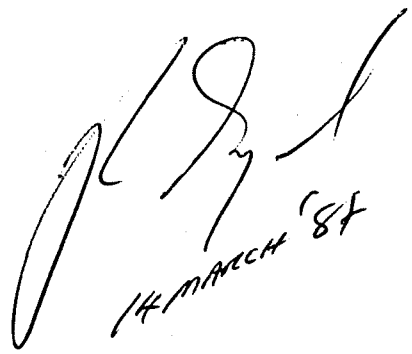
As principal investigator I am highly satisfied with the results achieved in this project. Through close liaison with The University of Sydney, the N.S.W. Department of Agriculture Fisheries Research Institute, the CSIRO Division of Fisheries Research, and the Department of Primary Industry I have enjoyed ready access to a comprehensive range of advice, information and services; I thank all those involved.

Since mid 1985 raw and processed data has been stored on floppy disc using the Apple Pro Dos 1.0.1 format. Earlier data is being transfered to disc as time permits.

Having attended and gained great benefit from international and inter-institutional southern bluefin tuna workshops, I was twice dissapointed in 1986 at being prevented from attending 'east coast tuna workshops'. These workshops, involving personnel from state and Commonwealth institutions and a private consulting firm, whilst dealing primarily with species other than southern bluefin would clearly be of benefit to my keeping abreast of the field. Further, having now been involved with tuna biology for five years I consider it likely that I may be able to make significant contributions at such workshops.

Although a minor point, for future projects I feel it would be of benefit if a tax number was available so that larger purchases could easily be made sales tax exempt.

Lastly, I cannot praise highly enough the assistance given to me by Mr Russel Neuman, as acting FIRC secretary.



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Fisheries Research, 4 (1986) 297–315
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Aspects of the Reproductive Biology of the Southern Bluefin Tuna (*Thunnus maccoyii*)

JOHN THOROGOOD

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(Accepted for publication 24 June 1986)

ABSTRACT

Thorogood, J., 1986. Aspects of the reproductive biology of the southern bluefin tuna (*Thunnus maccoyii*). *Fish. Res.*, 4: 297–315.

The development of southern bluefin tuna (*Thunnus maccoyii*) gonads, collected from waters off the south eastern and southern coasts of Australia during the period July 1984 to March 1985, was assessed by gross visual examination, histological examination which included measurement of ova diameter, and by Gonad Index. Histological examination, as a method for assessing gonad development, is shown to be the most sensitive, particularly at the time of onset of maturity. The homogeneous distribution of ova within and between ovaries of a pair was statistically demonstrated.

Age-at-first-maturity, as determined by histological examination, was shown to lie between 5 and 7 years, a decrease of approximately 1–2 years over previous studies. The larger fish (regardless of actual size) in each school sampled were found to be mature; that is whilst sexual development is related to size/age per se, it would appear to be mediated by the size-composition of the school.

Gonad Index was highest during the period January–March; combined results of this study and of Shingu (1978) provide strong evidence for a single period of spawning. Ova size-frequency distribution indicates a synchronous mode of spawning. However, as Kikawa (1964b) reported evidence of serial spawning for significantly older fish, a varied strategy is suggested.

Mean fecundity for fish of between 115 cm FL (approximately 6 years of age) and 130 cm FL (approximately 7.5 years of age) was estimated at between 870 000 and 2 200 000, respectively. With the addition of Kikawa's (1964b) estimate for a 158-cm FL fish (approximately 12 years old), a fecundity regression was developed: Fecundity = Fork Length (cm)$^{8.832} \times (8.526 \times 10^{-13})$. A population fecundity of between 1.07×10^{13} and 2.31×10^{13} was calculated, based on population age-structure estimates provided by X. Hampton (personal communication, 19xx).

INTRODUCTION

The southern bluefin tuna, *Thunnus maccoyii*, is distributed throughout the southern temperate oceans and is a resource of high economic value to Australia, Japan and New Zealand. The critical biological state of the population

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has been identified by Australian (Murphy and Majkowski, 1981) and Japanese (Shingu et al., 1981) scientists. Rational and responsible management of the fishery is dependent upon a reliable and up-to-date biological data-base, which accommodates information on reproductive biology.

Age-to-first-maturity is an imporant parameter of the equation by which the CSIRO Division of Fisheries Research currently estimates the maximum catch which will allow the stock parental biomass to remain stable. The currently accepted estimate of age-at-first-maturity was derived from Gonad Index calculations (Shingu, 1970) and length/age estimates (Murphy and Majkowski, 1981). Gonad Index and length/age give indirect estimates of age-at-first-maturity; imprecision and inaccuracy may threaten the validity of derived estimates of stock production and recruitment.

Numerous accounts in the literature (e.g. Lett and Doubleday, 1976; Healey, 1980; Jensen, 1981; Beacham, 1982, 1983a,b,c) relating to age-at-first-maturity report a decrease in the age-at-first-maturity coincidental with a decrease in stock numbers, usually related to increased fishing pressure. Accounts in the literature deal with demersal stocks, but it was felt that a similar effect might be seen in a pelagic stock such as southern bluefin tuna, parental biomass having been reduced from 450 000 to 250 000 tonnes during the period 1959–1978 (Murphy and Majkowski, 1981).

Gross measurements of maturity, such as visual examination of the gonads and Gonad Indices, have been reported as being unreliable for tuna (e.g. Bunag, 1956; Yoshida, 1964; X. Everett, personal communication, 19xx). Microscopic and histological examination of gonad material is necessary to provide detailed and reliable information.

Current management policy aims at stabilising the southern bluefin tuna's parental biomass in order to ensure continued adequate levels of recruitment. However, a more direct and desirable approach would be to stabilise stock egg production levels (J. Majkowski, personal communication, 19xx). Such an approach would rely heavily on accurate fecundity estimates. The fecundity of a single southern bluefin tuna of 158 cm FL was estimated by Kikawa (1964b) to be between 14 000 000 and 15 000 000.

MATERIALS AND METHODS

Japanese and Australian commercial catches of southern bluefin tuna off the Australian east coast and in the Great Australian Bight (Fig. 1) were sampled during the period from June 1984 to March 1985. Length, weight and reproductive condition were recorded for 734 fish, ranging in fork length from 45 to 180 cm.

Fork length was measured on a centimeter-offset measuring board or, where this was impractical because of the size of the fish and the restricted work area (on Japanese processing vessels), with a measuring rule. Whole weight was

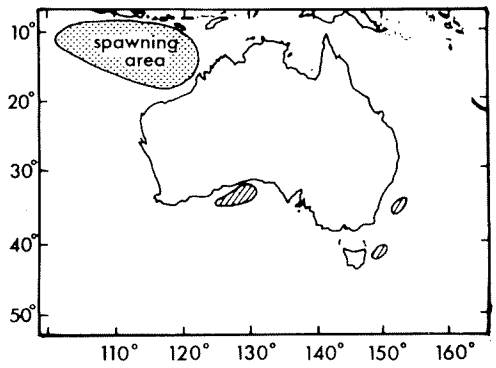


Fig. 1. Areas (hatched) from which samples for this study were obtained.

recorded in kilograms to one decimal point. In instances where it was impossible to record either weight or length, functional regressions (Shingu, 1978) were used to estimate the missing measurement.

The original plan for this work proposed the collection of sagittal otoliths for the determination of the age of the fish from which gonads were sampled. However, the recent change to supplying the Japanese sashimi markets precluded this. Fish were assigned an age by reference to the length–age relationship reported by Murphy and Majkowski (1981).

The sex of tunas is not shown by external characteristics (Schaefer and Orange, 1956). Ovaries and testes were sampled, chiefly from freshly caught fish, at sea, although a few samples were collected at shore-based canneries, the fish having been frozen. Gonads were preserved and stored in 7% formalin. In the laboratory, gonads were blotted dry and weighed (in grams). The weights of left and right gonads were statistically compared by analysis of variance. Before dissection, the gonads were "field-staged" by the method of Schaefer and Orange (1956) as applied to yellowfin (*Thunnus albacares*) and skipjack (*Katsuwonus pelamis*) tuna. Gonad Index (G.I.) was calculated for all fish sampled, in a manner similar to that used for yellowfin (June, 1953; Schaefer and Orange, 1956), big-eye (Yuen, 1955), albacore (Otsu and Uchida, 1959) and skipjack (Yoshida, 1964).

A detailed examination of gonads was made by histological techniques. Gonads were sectioned at 9 μm and stained with Mayer's haematoxylin and eosin (Ham and Leeson, 1961). Ovaries were staged according to the most developed ova present, using the six-stage classification system of Cyrus and Blaber (1984). From each prepared slide, measurements of ova diameter were taken from the most developed stage of ova present. Diameters of ova (which are not perfectly spherical) were measured along whichever axis fell parallel to the scale of the micrometer (June, 1953; Schaefer and Orange, 1956).

In order to test for heterogeniety of ova size distribution, cross-sections were

taken from the anterior, middle and posterior of an ovary of a mature female. Each section was divided into sub-samples of the centre, mid-region and periphery of the ovary. Ova diameters were then measured and the size distribution for the different regions was compared by analysis of variance.

Fecundity, defined as the number of ova (greater than 0.3 mm, Stage III) which could be spawned during one reproductive season, was estimated using a Coulter Counter (Model ZB-I). Initially, samples were taken from the anterior, middle and posterior of each mature ovary. Later, only the middle of the ovary was sampled. The ova were separated from associated connective tissues using a Vibrotec vortex. Attempts to separate the ova from connective tissue using Gilson's fluid and the proteolytic enzymes protease and trypsin were unsuccessful.

Fecundity estimates were calculated using the equation

$$F = (NO/S)$$

where F is the number of mature ova,
N is the number of mature ova in the sub-sample,
O is the weight of both ovaries,
S is the weight of the sub-sample.

A fecundity–length regression was developed from a log–log transformation of the data. Population fecundity was calculated using the regression, the Murphy and Majkowski (1981) age–length key, and estimates of population age structure provided by X. Hampton (personal communication, 19xx).

RESULTS AND DISCUSSION

Description of the gonads

The testes are paired, elongate organs suspended by the mesorchium in the body cavity. They are thin and ribbon-like in immature fish, but with advance in maturity they develop into flattened, whitish-yellow organs which are relatively solid. Spermatozoa are collected by a a series of small ducts, vasa efferentia, leading posteriorly to a larger duct, the vas deferens, which opens to the exterior through the urogenital orifice.

The ovaries, like the testes, are paired elongate organs suspended from the dorsal wall of the body cavity by the mesovarium. In immature fish, the ovaries are ribbon-like, and closely resemble the immature testes in appearance. They become progressively enlarged in size as the fish attain sexual maturity, and with the final ripening of the eggs, may attain a diameter in excess of 80 mm. In the more advanced stages, the ovaries are nearly circular in cross-section with one ovary usually slightly larger than the other, although the difference in the weight of 150 pairs of measured ovaries was not statistically significant ($P < 0.005$). The ovary is a hollow structure, its lumen connecting posteriorly

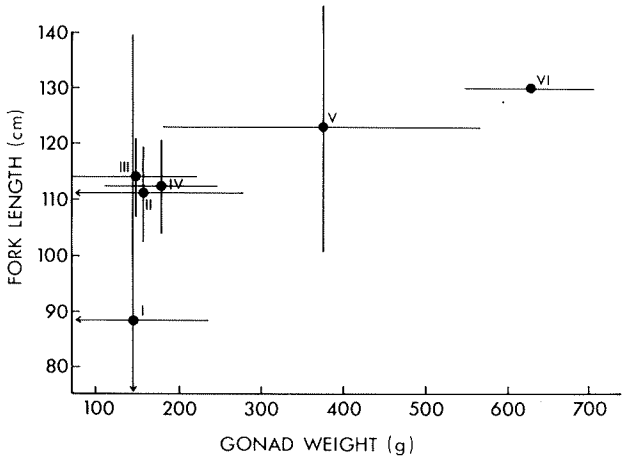


Fig. 2. Mean fork length plotted against mean gonad weight for fish of ovary histological Stages I–VI, sampled in January. Error bars represent one standard error from the mean for fork length (vertical) and gonad weight (horizontal), respectively.

to a thick-walled oviduct that opens as a slit on the urogenital papilla behind the anus. Numerous ovigerous lamellae project into the lumen.

Gonad Index: The relationship of ovary size to fish size as a measure of maturity.

Determination of the degree of maturity by gross examination of gonads has been shown to lack precision (Buang, 1956; Schaefer and Orange, 1956; Baglin, 1982). Distinction between Stage II and Stage III, depending on the visibility of ova to the naked eye, will vary with observers and with the physical condition of the ovaries after preserving or freezing. It is therefore desirable to employ a more precise and objective method of determining the stage of maturity of the gonads.

The relationship between fish length and ovary weight, in each histological stage, of fish sampled in January is shown in Fig. 2. Fish assigned to early developmental Stages (II, III, IV) are clumped and are indistinguishable by Gonad Indices.

The spawning season as indicated by Gonad Index

The Gonad Index for fish between 110 and 180 cm FL sampled over the study period is shown in Fig. 3. Gonad Indices calculated by Shingu (1978) for fish of a similar length caught off the Australian south-east coast are included for comparison and to show the seasonal pattern. The combined data provide further evidence of a single spawning season during the period January–March

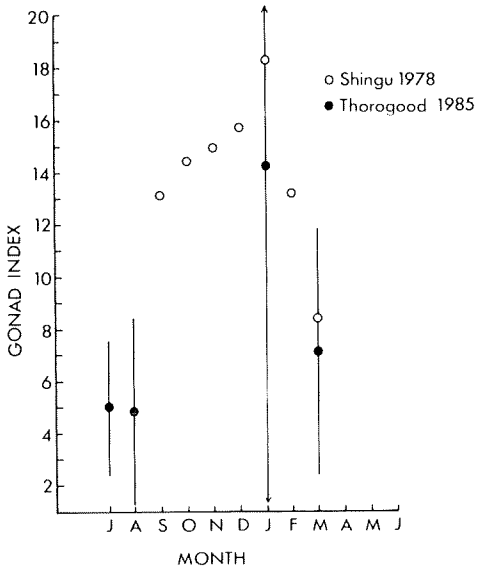


Fig. 3. Mean Gonad Index plotted by month for female southern bluefin tuna. Error bars represent one standard error from the mean.

(Kikawa, 1964a). Again, the large standard errors are indicative of the degree of variation in sexual maturity of fish in this size range.

Development of the ova

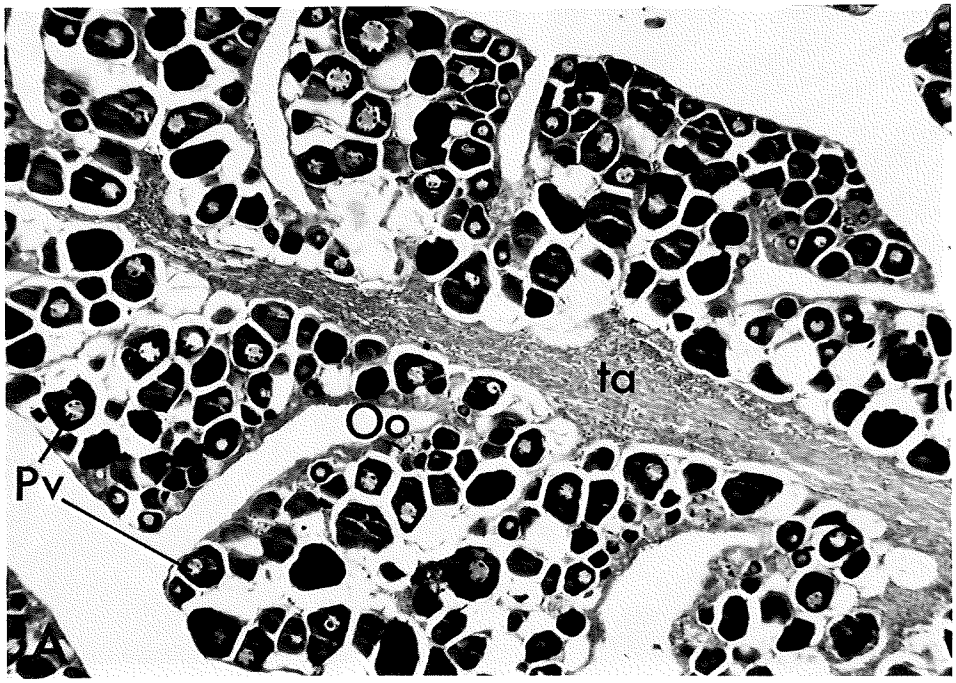
Histology of the ovary

The ovary walls consist of the tunica albuginea, a thick layer of connective tissue containing blood vessels, and smooth muscle fibres. The developing oocytes (oogonia) lie along the projecting folds of the tunica albuginea, embedded in the losse connective tissue, the stroma (Fig. 4A).

Stages of oogenesis

Stage I. Oogonia. Present in all developing and mature fish sampled, but frequently obscured by maturing ova. Oogonia are characterised by a large nucleus containing a single nucleolus (Fig. 4A).

Fig. 4. Oocyte development in *Thunnus maccoyii*. A. Oogonia (Oo) and pre-vitellogenic oocytes (Pv) lying within ovigerous folds, the tunica albuginea (ta). 126×. FL 78 cm. B. Pre-vitellogenic (Pv), yolk precursor (Yp), primary yolk (Py), and secondary yolk (Sy) oocytes. 126×. FL 129 cm. C. Pre-vitellogenic (Pv), yolk precursor (Yp), primary yolk (Py), and secondary yolk (Sy) oocytes. 320×. FL 129 cm. D. A secondary yolk oocyte (Sy) showing the granulosa (gr) and zona radiata (zr) which together comprise the chorion. 500×. FL 134 cm. E. Two ripe eggs (Re) showing the aggregated oil globules (og). 320×. FL 134 cm. F. Atretic oocytes, peripheral yolk granules liquefy. 320×. FL 120 cm.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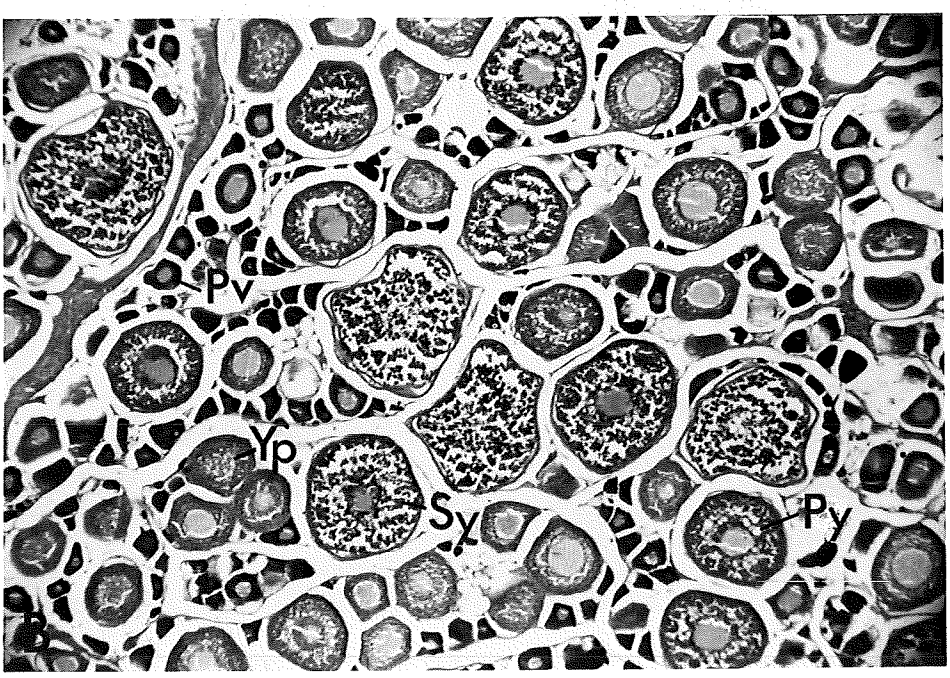
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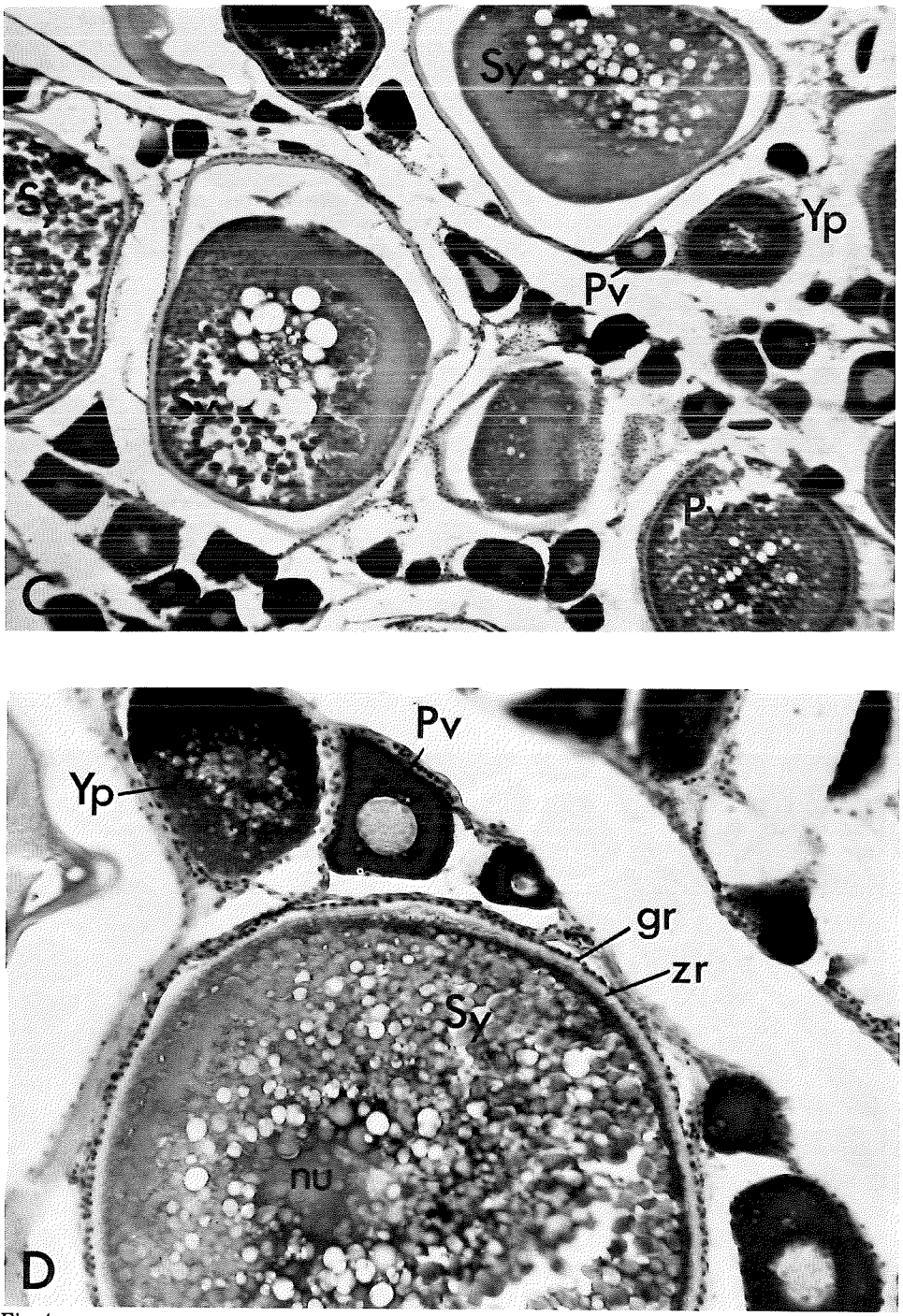
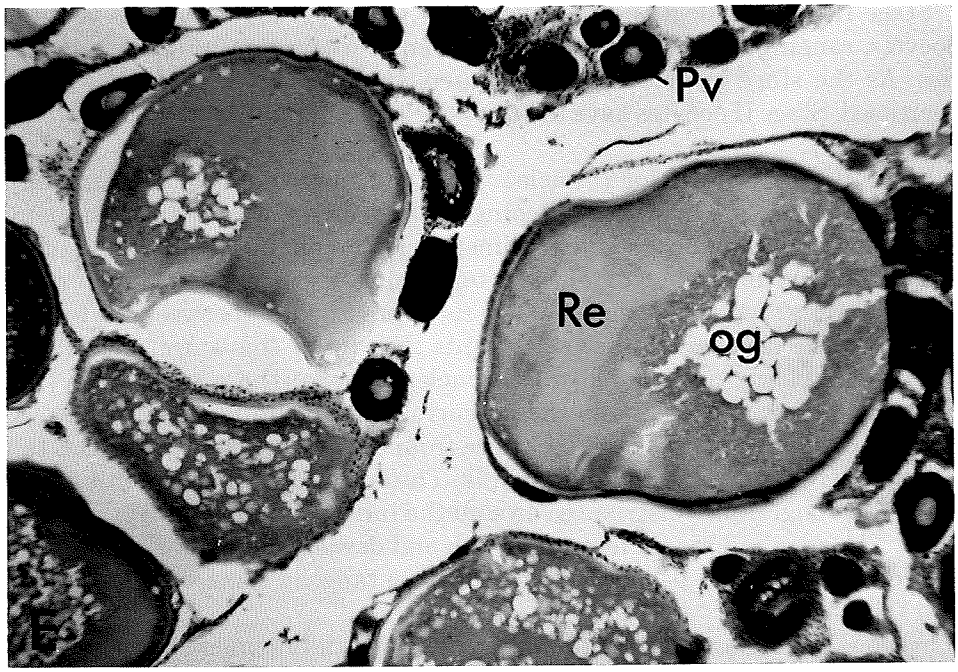


Fig. 4.



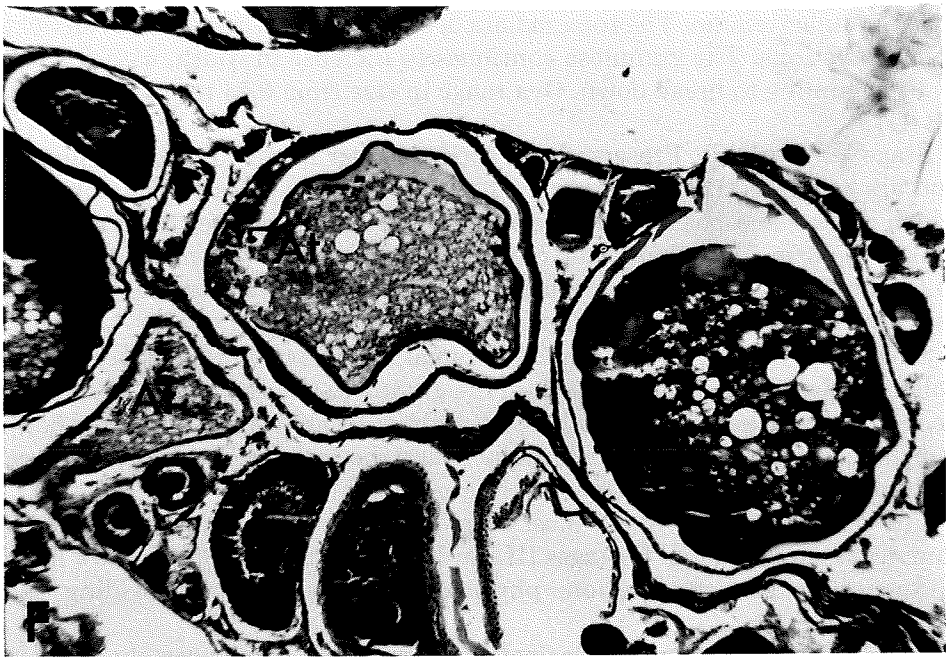


Fig. 4.

Stage II. Pre-vitellogenic (perinucleolar) oocytes. Large numbers of these oocytes, ranging in size from 0.13 to 0.39 mm, were present in immature ovaries. As the stage of maturation increased, the number of Stage II oocytes decreased. Stage II oocytes have relatively large nuclei; several nucleoli develop (Fig. 4A–F).

Stage III. Yolk precursor (vesicle). With the onset of gonad development, the oocytes increase in size, developing to the yolk precursor stage. In many cases the nuclei show an irregular outline; nucleoli remain visible. Yolk vesicles form in the peripheral region of the cytoplasm. They increase in number and size extending towards the nucleus. The zona radiata forms between the follicle layer and the developing oocyte. Towards the end of this stage, the follicle thickens and forms a layer of distinctly nucleated cells (the granulosa). A thin layer of connective tissue (the theca) surrounds the granulosa. Oocytes are nearly spherical in shape, ranging in size from 0.23 to 0.68 mm (Fig. 4B,C).

Stage IV. Primary (non-staining) yolk. The oocyte contains numerous non-staining yolk granules distributed around the inner margin of the yolk vesicle layer. The zona radiata increases in width and develops radial striations. The cells of the granulosa also increase in size. Ova range in size from 0.23 to 0.68 mm (Fig. 4B,C).

Stage V. Secondary (eosin-staining) yolk. Early development of the secondary yolk stage is characterised by the appearance of small red-stained yolk granules. Development continues until the yolk vesicles become obliterated by the secondary yolk granules, completely filling the cytoplasm; only a few primary granules remain. The zona radiata decreases in width and shows distinct radial striations. The granulosa continues to increase in width, with the cell walls beginning to break down. Ova range in size from 0.54 to 1.09 mm (Fig. 4B–D).

Stage VI. Ripe egg. Preserved ova appear amber in colour, are translucent and are separated from the theca. The syncytial granulosa forms a chorion which is clear and has a rough surface. Yolk granules coalesce to form a pale pink cytoplasm. Numerous small oil globules form in the yolk mass and merge to form one or two large oil globules. The mature ovum is irregular in shape, ranging in size from 0.75 to 1.10 mm (Fig. 4C).

Stage VII. Atresia. Initially the zona radiata begins to erode, the peripheral yolk liquefies and begins to pass into the granulosa. As the yolk continues to be re-absorbed, the granulosa collapses until finally an irregularly shaped body remains consisting of vacuolated granulosa and theca. A small number of atretic mature ova were shown to persist well into winter (Fig. 4F).

The size distribution of the most development stage of ova for the ovaries sampled is shown in Fig. 5. Stages III and IV, and Stages V and VI, show little difference in size distribution; physiological development providing the distinction.

Shrinkage as a result of histological preparation was approximately 45%; far

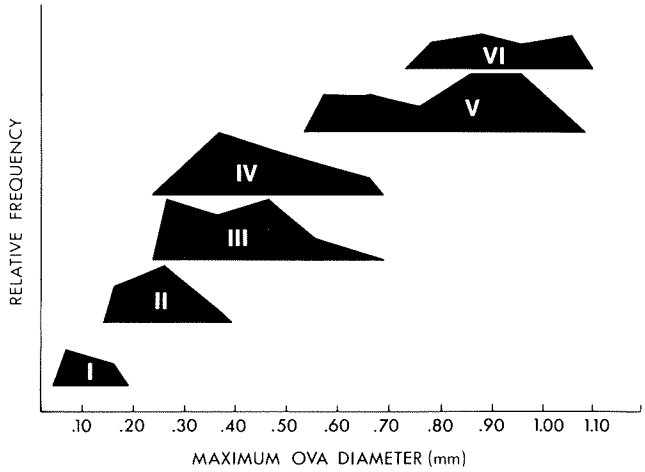


Fig. 5. Relative frequency of maximum ova diameters plotted by histological stage. Frequency is relative only within histological stages. Ova diameter has been transformed to account for histological shrinkage.

greater than that reported by Schaefer and Orange (1956). Gonads sampled from frozen fish showed considerable distortion, but this did not prevent accurate staging.

The size distribution of ova within ovaries of histological Stages I–V is shown in Fig. 6. Inherent to the use of the Coulter Counter is the phenomenon of double or triple passing, where two or three smaller ova may occasionally pass through the Counter orifice simultaneously and be interpreted by the Counter as one large ovum. This results in a degree of "noise", preventing a clean portrayal of ova distribution. However, the basic distribution profile remains reliable.

Distribution of mature ova within the ovary

Analysis of variance indicated no significant difference in the size ($P<0.01$) or number ($P<0.001$) of mature ova from sections taken from the anterior, middle and posterior regions of the ovary (Fig. 7). A non-significant difference ($P<0.25$) was indicated in the size of mature ova between centre, middle and peripheral sub-sections. Therefore, a representative section may be obtained from any region of the ovary, provided the sample is taken across the radius of the ovary.

Maximum ova diameter vs. mean ova diameter

The correlation coefficient (r) calculated for the maximum ovum diameter and the mean diameter of ova of the most advanced stage, calculated for a

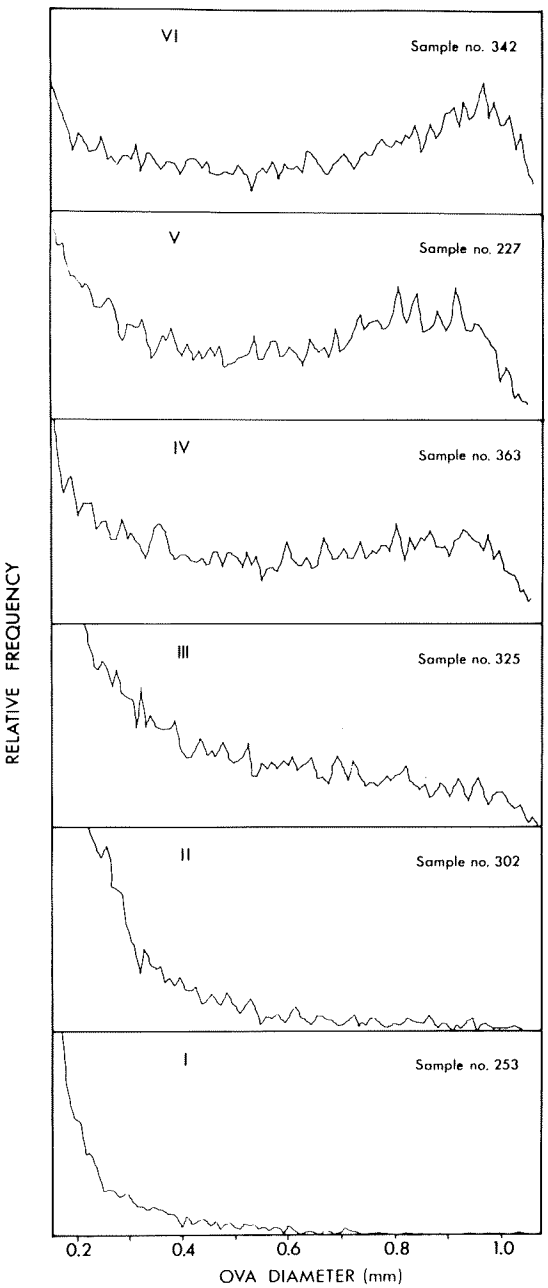


Fig. 6. Relative frequency of size distribution of ova within ovaries representative of histological Stages I–VI, showing a high proportion of eggs measuring > 0.7 mm in Stages IV and V.

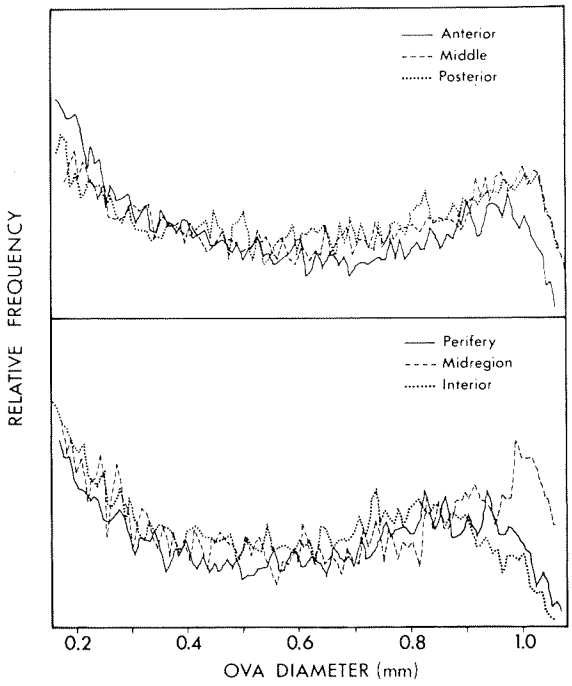


Fig. 7. Size frequency distribution of ova from regions within the ovary of a 140-cm southern bluefin tuna, of histological Stage V.

combined sample of Stage IV and V fish, was 0.9031. This strongly suggests that a single measurement of the largest ovum is adequate to indicate the size distribution of the most advanced stage of ova of the sample.

Age at first maturity

As determined by histological staging, the age-at-first-maturity of females varied between 5 and 7 years (110–125 cm FL). The criterion of maturity was the presence of ova of Stage III or more advanced, indicating the onset of vitellogenesis and consequent potential for spawning in the coming season (e.g. Yamamoto, 1956; Bara, 1960; Htun-Han, 1978). These results suggest a decrease in the age-at-first-maturity when compared with Shingu's (1978) estimates of 6–7 years of age. Shingu's determination was based on the Gonad Indices calculated by Kikawa (1961); Shingu proposed that females with a Gonad Index of 2 or greater were fully mature and capable of spawning. Since fish with Stage III + gonads, considered by the present author to be capable of spawning in the coming season, had a G.I. between 6 and 36, the difference between the age-at-first-maturity as determined by Shingu and that found in this study may be greater than indicated.

A decline in the age and length at first maturity may occur for two reasons. If it is assumed that size at maturity has a genetic component (Alm, 1959), then selective fishing (as the result of geographic location and characteristics of gear used) may remove genotypes that mature at larger lengths. Another explanation is that size at maturity is related to stock biomass. Growth rate has been shown to be inversely related to stock biomass for Atlantic cod (Lett and Doubleday, 1976; Beacham, 1980) and haddock (Templeman and Bishop, 1979). Under such circumstances, a decline in median size at maturity may result from a decline in stock biomass.

Maturity and school composition

Although only a relatively small number of schools were sampled, a consistent trend regarding the sexual development of females and the size composition of the schools was evident. The largest females of each school were the most developed, being at least Stage V in January and March. However, the size composition of the schools varied considerably (Fig. 8), suggesting that although sexual maturity is shown to be related to size per se, the presence of larger females may inhibit the maturation of smaller females within a school. If this concept were extrapolated to the stock as a whole, it would provide an argument for the decrease in age-at-first-maturity with decreasing stock numbers.

Fecundity and mode of spawning

Individual fecundity

Fecundity estimates were derived for 127 southern bluefin tuna, between 115 and 135 cm FL (6–8 years of age), and the regression was developed.

$$\text{Fecundity} = \text{Fork Length (cm)}^{8.832} \times (5.236 \times 10^{-13}).$$

Mean fecundity of each size-group, together with Kikawa's (1964b) estimate of fecundity for a 158-cm FL (approximately 12 years of age) fish, is shown in Fig. 9.

A high degree of variation was found in the fecundity of fish of a similar size, the correlation coefficient for the regression being 0.53.

Table I compares fecundity as determined by this study, with that obtained for other similar species.

Mode of spawning

Kikawa (1961) showed strong evidence, in the form of modes of developing ova in mature ovaries, for serial spawning. He suggested that individual *T. maccoyii* spawn two or possibly three times during the spawning season, the first spawning releasing the greatest number of ova. Ova size-frequency distri-

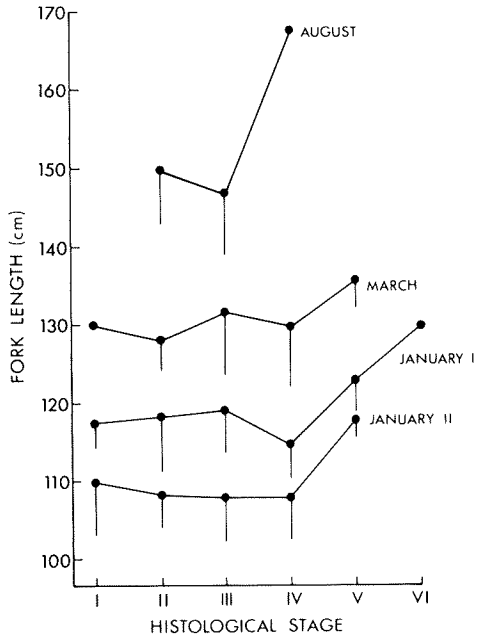


Fig. 8. Mean fork length of females from four different schools plotted against histological stage, sampled in January, March and August. Error bars (plotted below each point only, for clarity) represent one standard error from the mean.

butions derived for 180 mature (greater than Stage III) southern bluefin tuna showed no evidence of multi-modal development, with the exception of one individual. This fish was not the largest or most mature sampled. It may be possible that younger southern bluefin spawn only once during the spawning season, whilst older, more mature individuals are capable of serial spawning.

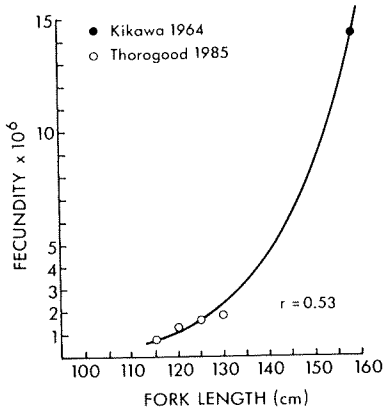


Fig. 9. Mean fecundity of southern bluefin tuna plotted by size class.

TABLE I

Fecundity estimates for five species of *Thunnus*

Species	Size-range	Fecundity	Author
Albacore (*T. alalunga*)	18- 25 kg	900 000- 2 100 000	Otsu and Uchida, 1959
Bigeye (*T. obesus*)	39-107 kg	2 900 000- 6 300 000	Yuen, 1955
Yellofin (*T. albacares*)	47- 88 kg	2 300 000- 8 600 000	June, 1953
Southern bluefin	115-158 cm	900 000-14 300 000	Thorogood, 1985
(*T. maccoyii*)	(30- 84 kg)		Kikawa, 1964b
Northern bluefin (*T. thynnus*)	205-269 cm	>60 300 000	Baglin, 1982

Serial spawning has been recorded for the northern bluefin (*T. thynnus*) (Baglin, 1982), the albacore (*T. alalunga*) (Otsu and Uchida, 1959) and the skipjack (*Katsuwonus pelamis*) (Yoshida, 1964).

A possible alternate to serial spawning is that the ova of less developed batches may not continue development to spawning, but may be held over to the next spawning season or resorbed. Fecundity estimates would need modification to take such a strategy into account. Beaumariage (1973) reported that king mackerel, *Scomberomorus cavalla*, showed developing vitellogenic (Stage III–IV) ova in their first year. Such ova were not numerous, were smaller than equivalent ova from older fish, and were securely retained within the compact lamellae. These ova were found not to develop fully, but rather to "rejuvenilize", to become the reserve fund for the following season. Such a phenomenon, if biologically possible, was not noted in this study.

Population fecundity

A population fecundity of between 1.07×10^{13} and 2.31×10^{13} was calculated, based on the fecundity-at-age regression and population breakdown estimates provided by X. Hamptom (personal communication).

CONCLUSIONS

The results presented in this paper differ in several respects from those presented by earlier workers. Whilst it may be concluded that populations undergo changes in age at first maturity in response to a changing population structure related to exploitation, this is only one of several possible explanations. Baglin (1982) summarises the results of several workers engaged in determining the age-at-first-maturity of the northern bluefin tuna, *Thunnus thynnus*. For fish from eastern Atlantic waters, age at first maturity was determined to be 3 (Sella, 1929), 3 onwards (Rodriguez-Roda, 1967) and 6 (Cort et al., 1976), and from western Atlantic waters, 6 (Baglin, 1982). The factors related to this variation are likely to be geographic location and related environmental con-

ditions and, possibly, the level of interaction with other members of a school of tuna.

During the seasons of 1982 and 1983, southern bluefin tuna caught by the Japanese in the vicinity of the spawning ground south of Java during the months October–March ranged between 84 and 190 cm FL. Therefore, it is quite possible that further study may find mature fish of less than 110 cm FL.

From the comparative results of the methods of assessing maturity, it is clear that for the southern bluefin tuna, histological staging is the only method of sufficient sensitivy to detect the onset of maturity (ova developing from Stage II to Stage III). The high degree of variation in maturity shown by fish of a similar size sampled from different schools is indicative both of the size-range of fish sampled (being those fish in transition between the juvenile and mature condition), and the apparent variation in age at first maturity. To determine the extent of variation in age at first maturity, a study ranging over several seasons and sampling from a large number of schools is necessary.

Possibly the most interesting question remaining is why tuna in a condition apparently close to spawning are found in the western part of the Great Australian Bight during months considered to be within the spawning season. Are these tuna about to spawn in the temperate waters of the Bight? Although evidence is lacking, I feel this is doubtful. It seems that a species only known to spawn in a restricted region within the tropics has a second spawning area in an environmentally different region. I feel an hypothesis suggested to me by a South Australian fisherman more likely to be correct. He considered these tuna to be "feeding up" in the "rich temperate waters of the Bight" before migrating to the tropical spawning grounds. The abundance of "bait-fish" in the Bight over the summer months is readily confirmed. Aerial spotters frequently rely on schools "rippling" or feeding at the surface in order to detect fish. The distance from the Western Bight, where tuna were sampled for this study, to the known spawning grounds in the Java Sea is approximately 3600 km. Such a distance could be covered in a month with the fish swimming 120 km/day (5 km/h).

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