Abstract.—The spawning seasonality of albacore, *Thunnus alalunga*, in the South Pacific was studied by examining ovaries and testes collected from longline vessels operating in the waters off New Caledonia (21°–23°S, 164°–166°E) and Tonga (16°–29°S, 171°–177°W), January 1990 to February 1992. The monthly change in GSI values and mean oocyte diameters indicated that albacore are annual spawners, with most spawning limited to the austral summer months from November to February. Asymmetry in weight of, but not in the reproductive development of, the left and right gonad pairs was apparent in samples from the two collection sites; most right ovaries and testes were heavier and larger than those on the left side.

Spawning seasonality of albacore, *Thunnus alalunga*, in the South Pacific Ocean

Darlene Ramon

Southwest Fisheries Science Center
National Marine Fisheries Service, NOAA
La Jolla, California 92038
e-mail address: darlene@pooh.ucsd.edu

Kevin Bailey*

South Pacific Commission
Tuna and Billfish Assessment Programme
B.P. D5, Noumea Cedex, New Caledonia

Albacore, *Thunnus alalunga*, are distributed throughout the Pacific in temperate and tropical waters. The North and South Pacific populations are considered to be separate stocks because 1) catch rates for these two populations are extremely low in the equatorial region, 2) the two populations have nonoverlapping spawning areas and different spawning seasons, and 3) there is no evidence that albacore tagged in the North Pacific move to the South Pacific (Lewis[1]). In the South Pacific, albacore are found from the Equator to 50°S latitude and from the surface to depths of 300 m (Yoneta and Saito, 1973). South Pacific albacore generally are considered to reach sexual maturity in the size range of 85 to 90 cm fork length [FL] (Ueyanagi, 1957; Otsu and Hansen, 1962), when they are usually between 6 and 8 years old (Labelle et al., 1993).

Two major fisheries target albacore in the South Pacific: a longline fishery concentrating on adult fish (80–110 cm) in tropical and subtropical waters (10°–30°S) throughout the year and a surface troll fishery targeting subadults (50–80 cm) in temperate waters (30°–40°S) during the austral summer (Lewis[1]; Rensink[2]). An area of research that was recognized by the second South Pacific Albacore Research (SPAR) workshop as needing further work was delineation of the spawning seasonality of albacore in the South Pacific. A sampling and histological project was organized by the Tuna and Billfish Assessment Programme (TBAP) of the South Pacific Commission (SPC) and the Southwest Fisheries Science Center (SWFSC) to provide a better understanding of albacore reproduction in the South Pacific. Because adult albacore at various stages of reproductive development were needed, sampling was limited to the longline fishery.

The purpose of our study is to report on the spawning seasonality of albacore in the South Pacific Ocean by using oocyte development and gonadosomatic indices as indicators of spawning activity.

Manuscript accepted 1 July 1996.
Fishery Bulletin 94:725–733 (1996).

* Deceased.

[1] Lewis, A. D. 1990. South Pacific albacore stock structure: a review of available information. Third South Pacific albacore research workshop; Noumea, New Caledonia, 9–12 October 1990, Working Paper 5, 13 p. South Pacific Commission, B.P. D5, Noumea Cedex, New Caledonia.

[2] Rensink, G. 1991. Summary of the 1989–90 U.S. South Pacific albacore fisheries data. Southwest Fish. Sci. Center, National Marine Fisheries Service, P.O. Box 271, La Jolla, CA 92038. Admin. Rep.14:1–21.

Materials and methods

Albacore were sampled from the catches of two longline vessels: a Japanese–New Caledonia joint-venture with longliners fishing in New Caledonia waters (21°–23°S, 164°–166°E) and unloading in Noumea, and 2) the Tonga government-owned longliner, MV *Lofa*, operating in Tonga waters (16°–29°S, 171°–177°W) (Fig.1). These sampling arrangements were selected because these vessels fished throughout the year in known spawning areas. Fishing operations took place during daylight and standard commercial longline gear was used.

Sampling was designed to cause minimum disturbance to commercial operations while providing adequate samples and data. For both sampling operations, sex, fork length (to the nearest centimeter), and gonad weight (to the nearest g, New Caledonia [females]; or to the nearest 5 g, Tonga [females and males]) were measured. In waters near New Caledonia, ovaries from each 10-cm size class (70–79 cm, 80–89 cm, 90–99 cm, and 100–110 cm) were collected each collection day, but actual quantities were dependent on the landings from the commercial operation. However, in waters near Tonga, ovaries were collected only from albacore in the 80–89 cm size class because of sampling limitations. Sampling in waters near New Caledonia was done once a week, May 1990 to February 1992, whereas sampling near Tonga occurred on every second set of the longline during January 1990 to February 1992.

In New Caledonia and aboard *Lofa*, gonads were removed from the gut cavity of albacore and identified as male or female. Each pair was separated into a left and right section and weighed fresh to the nearest 1 g in New Caledonia and to the nearest 5 g on *Lofa* for size comparison. Weights of fresh gonads included the weight of the associated fatbody.

A total of 1,105 albacore were examined and measured (300 females, 799 males, 6 undetermined); of this number, 246 pairs of ovaries and 444 pairs of testes were weighed fresh (Table 1). A subset of 150 ovaries were collected from female albacore in various stages of development for histology. A greater percentage of the ovaries collected came from New Caledonia because ovary collections from waters near Tonga were limited to ovaries from albacore in the 80–89 cm FL size range. In the laboratory, the ovary was removed from a formalin fixative, patted dry, and weighed to the nearest 0.1 g. The associated fatbody was then removed and the ovary reweighed without the fatbody; these values were then used to calculate the gonadosomatic index (GSI). Male albacore testes were not collected for histological study from either site.

Histological processing was done by staff at the Maas Diagnostic Laboratories who followed the

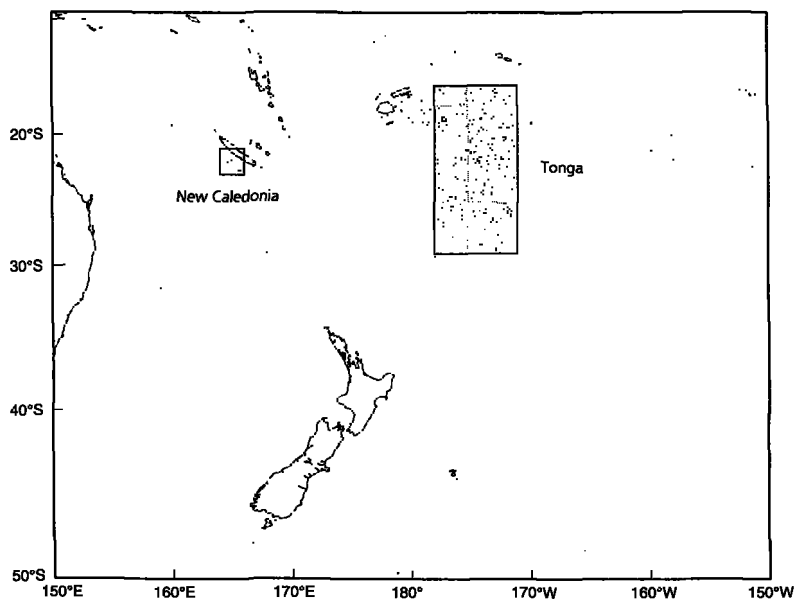

Figure 1

Sampling areas for albacore, *Thunnus alalunga*, in the South Pacific Ocean near New Caledonia and Tonga from 1990 to 1992.

Table 1

Summary of albacore gonads sampled in the South Pacific, January 1990–February 1992. Undeter. = undetermined.

Site	Sampling period	Sex	Number of albacore examined	Number of gonads weighed	Number of ovaries collected
New Caledonia	May 1990–February 1992	Female	108	104	105
		Male	239	0	0
		Undeter.	6	0	0
Tonga	January 1990–February 1992	Female	192	142	45
		Male	560	444	0

methods described in Hunter et al. (1986). A cross section of the ovary was taken from the middle region of the ovary, dehydrated, embedded in paraffin, sectioned at 7 μm, and stained with Harris's hematoxylin followed by eosin counterstain. The slides were examined with a compound microscope to determine the stage of ovarian development (as characterized by the presence or absence of yolk, lipid vesicles, hydrated oocytes, and postovulatory follicles) and were classified as early developing (unyolked), late developing (partially yolked), or advanced (fully yolked) (Schaefer, 1987). A second cross section of ovarian tissue was taken from the outer edge of the ovary to the lumen. This sample was placed in 33% glycerol for 10 to 20 minutes to separate the oocytes from the ovarian connective tissue (Hunter et al., 1986). The separated oocytes were then measured to 0.01 mm to determine the average size of the most developed stage of oocytes in each ovary; this was done by measuring the diameter of 20 oocytes in the sample as described by Schaefer (1987). The mean diameter of the most advanced stage of oocytes was plotted against months to examine the seasonal trend of maturity (Fig. 2). Oocyte diameter and developmental stage of the ovaries were examined to see if differences in weight between the right and left sides of the ovary were associated with differences in the reproductive state.

The histological condition of the samples did not provide the resolution necessary to distinguish

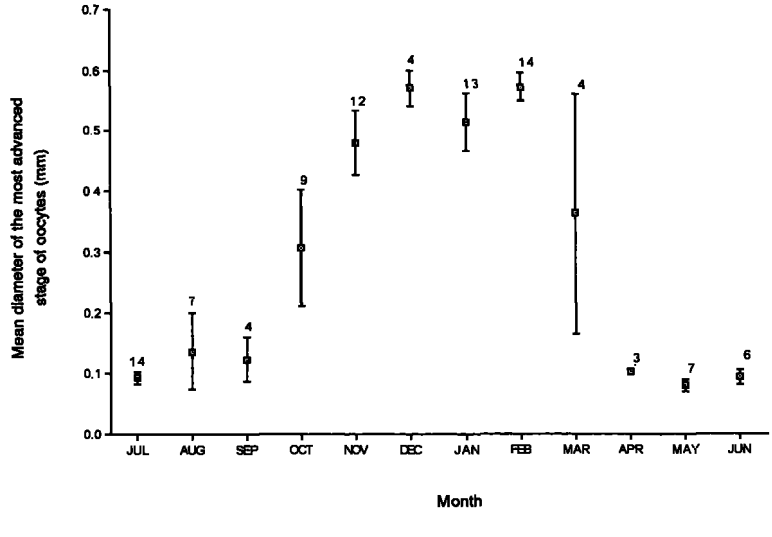

Figure 2

Monthly variation in mean diameter of the most advanced stage of oocytes for albacore, *Thunnus alalunga*, sampled from New Caledonia and Tonga, 1990 to 1992 (±2 standard errors; n=97). Numbers above error bars indicate the sample size for each month.

postovulatory follicles from preservation artifacts. Because of the time between capture and preservation, significant amounts of atresia occurred. The atresia limited the usefulness of the ovary sections because postovulatory follicles could not be distinguished from atretic conditions and histological materials.

Gonadosomatic indices (GSI) were calculated from the ovarian samples collected from New Caledonia and Tonga by using the formula of Kume and Joseph (1969):

$$GSI = 10^4 W/L^3,$$

where W = total gonad weight in grams minus fatbody and L = fork length in centimeters. The GSI was calculated only for those females whose ovaries were collected and processed in the laboratory. The critical GSI value was determined to be 1.7 according to the definition of maturity by Cayré and Farrugio (unpubl. data),[3] the value for which 100% of the females display an advanced mode of oocyte development (>0.3 mm) (Fig. 3).

[3] Cayré, P., and H. Farrugio. 1983. Biologie de la reproduction du listao *Katsuwonus pelamis* de l'Océan Atlantique. Doc. SKJ. Conf./83/12, présenté à la réunion de clôture du Programme International de Recherches sue le listro Atlantique, Teneriffe (Espagne), juin 1983, 62 p.

Results

Length-frequency distributions of sampled albacore

Length and sex data were collected on 1,105 albacore in the South Pacific. Size frequencies differed between males and females in both the New Caledonia and Tonga sites (Fig. 4, A and B). Male albacore had two size modes, 8–91 cm FL and 100–102 cm FL (Fig. 4, A and B). The relative strength of the modes differed at each sampling site. Female albacore from New Caledonia had a single mode, 86–92 cm FL (Fig. 4A), whereas females from Tonga possibly displayed two size modes, 87–89 cm FL and 92–96 cm FL (Fig. 4B). Few females over 100 cm FL were collected in either the New Caledonia or Tonga samples.

Male albacore were encountered more often than female albacore (Fig. 4, A and B). Male albacore accounted for 68.9% of the samples from New Caledonia and for 74.5% of the samples from Tonga (Table 1).

Oocyte development

The most advanced stage of oocytes collected during the austral winter months was the unyolked oocytes

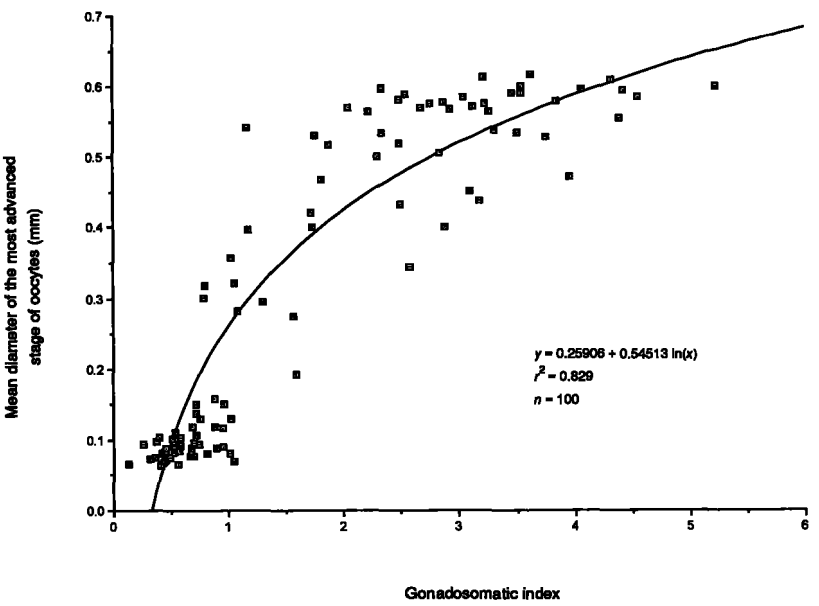

Figure 3

Relationship between the mean diameter of the most advanced stage of oocytes and the gonadosomatic index of female albacore, *Thunnus alalunga*, sampled from New Caledonia and Tonga, 1990 to 1992.

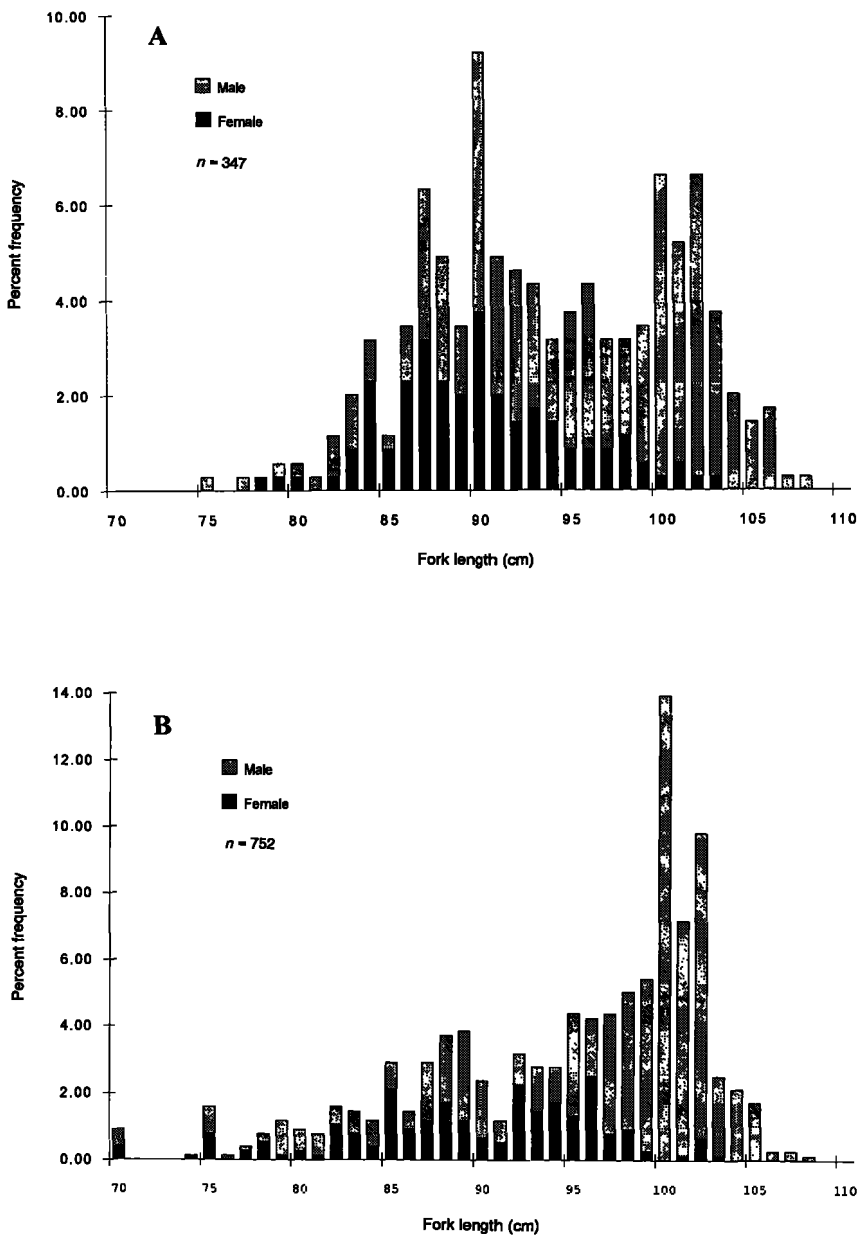

Figure 4

(**A**) Length-frequency distribution of albacore, *Thunnus alalunga*, sampled from New Caledonia, January 1990–February 1990; (**B**) Length-frequency distribution of albacore, *Thunnus alalunga*, sampled from Tonga, January 1990–February 1990.

with a mean diameter near 0.1 mm (Fig. 2). Between September and December, the number of albacore with partially yolked or fully yolked oocytes increased rapidly, and mean monthly oocyte diameters progressed from 0.12 mm to 0.57 mm (Fig. 2). Albacore with fully yolked oocytes were found from the summer months through March. No hydrated ovaries were observed in either the New Caledonia or the Tonga samples. By April, the most advanced-stage oocytes were resting-state oocytes with a mean diameter of 0.1 mm for all samples (Fig. 2).

A correlation exists between the most advanced stage of oocytes and GSI, as indicated by the positive coefficient of determination, $r^2 = 0.829$ (Fig. 3).

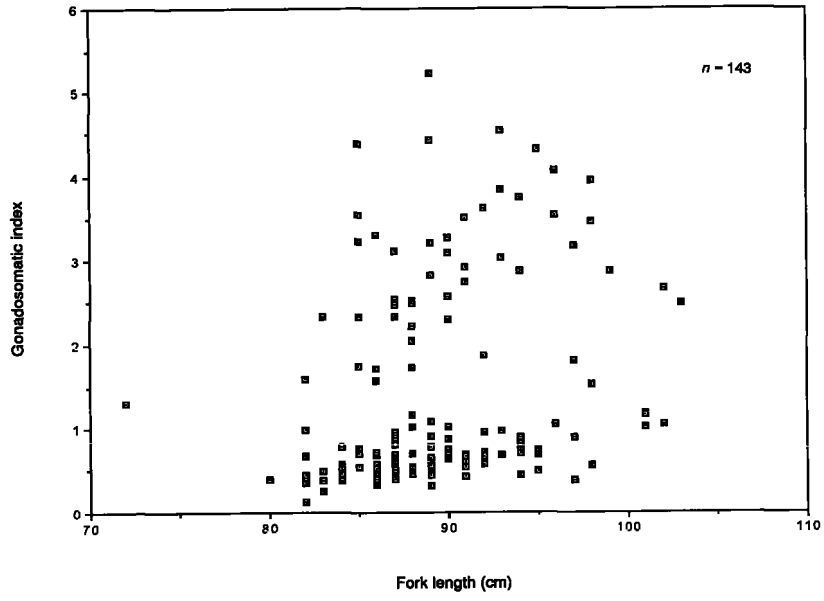

Figure 5

Gonadosomatic index values for female albacore, *Thunnus alalunga*, versus fork length, sampled from New Caledonia and Tonga from 1990 to 1992.

Gonadosomatic index

Because albacore gonads often have a fatbody attached, only those samples processed at the Southwest Fisheries Science Center (SWFSC), with the fatbody removed, were used in calculating GSI. The weight of the fatbody was found to compose an average of 4.4% of ovarian weight, from 0.0% to 31.6% in the samples sent to the SWFSC for processing. Because of the large variability in the weight of the fatbody, we decided not to attempt any corrections for fatbody presence but to use only the weight of ovaries measured in the laboratory. The relationship between GSI and fork length of sampled female albacore is shown in Figure 5.

In this study, a GSI of 1.7 was used as the critical GSI value, delimiting the point at which 100% of the females in our sample displayed an advanced stage of oocyte development (>0.3 mm)(Fig. 3). GSI values of 1.6 (Kikawa, 1959, 1966), 2.0 (Shung, 1973; Koido and Suzuki, 1989), and 2.1 (Kikawa, 1962) have been used to indicate group maturity of different species of female tunas. Female albacore appear to be capable of achieving this level of ovarian maturity and therefore of spawning once they reach 82 cm FL (Fig. 5). Evidence of spawning, as indicated by the presence of residual hyaline oocytes, was found in an 85-cm-FL albacore with a GSI of 2.8 and a mean maximum oocyte diameter of 0.57 mm. The largest GSI measured was 5.2 for a 89-cm female captured in Tonga in November. The weight of its ovary was 368.3 g, and the mean oocyte diameter of its most advanced oocytes was 0.60 mm.

The mean monthly GSI's of females show that peak reproductive development (GSI>1.7) occurs in the austral summer months, November–February (Fig. 6). The first indication of maturation was observed in October, when three of 15 albacore sampled were found to have GSI's greater than 1.7. These three had partially and fully yolked oocytes in the 0.35–0.54 mm size range. The first large increase in mean monthly GSI value occurred in November, when the mean GSI increased to 3.2 (Fig. 6). The largest monthly GSI, a mean of 3.3, occurred in February (Fig. 6). In March, the mean GSI declined to 1.2, although a small number of females still exhibited some spawning activity as indicated by females with high GSI values and late developed ovaries with oocyte diameters greater than 0.3 mm. The mean GSI then dropped to a resting level, close to 0.5, for the austral autumn and winter months.

Gonadal asymmetry

The right gonad was found to be heavier than the left in 80.0% of the females examined, and in 98.6% of the males (Table 2). In terms of collection sites,

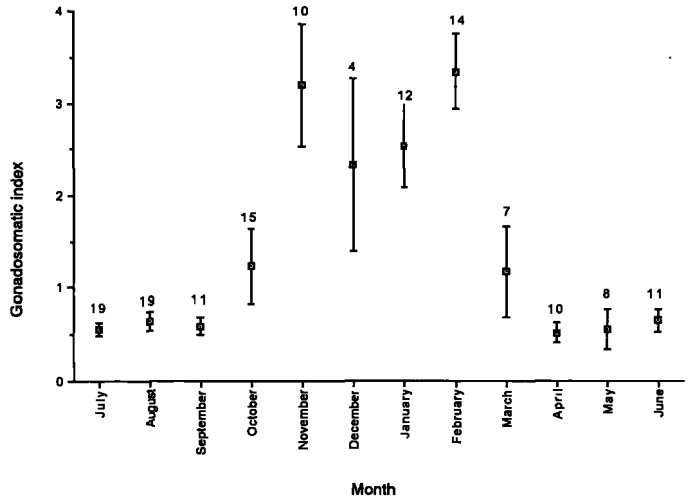

Figure 6

Mean monthly gonadosomatic index values for female albacore, *Thunnus alalunga*, by month, sampled from New Caledonia and Tonga from 1990 to 1992 (±2 standard errors; n=140). Numbers above error bars indicate sample size for each month.

the difference in females was less pronounced in New Caledonia (55.8%) than in Tonga (95.1%).

The left and right ovaries showed no significant difference in oocyte diameters between the left and right ovaries in the paired t-test ($T_{0.05(2),83}$=1.902). Only one of the 150 ovary pairs examined revealed a difference in maturity stages, with the left and smaller ovary being classified as developing and the right and larger as late developing.

Discussion

Our data indicate that albacore caught near New Caledonia and Tonga are seasonal spawners, spawning mainly during the austral summer months, November–February. This supports the work on albacore reproduction in the South Pacific by Otsu and Hansen (1962). Nishikawa et al. (1985) and Ueyanagi (1969) analyzed larval data and determined that spawning was greatest in spring and early summer (October–December). Few larval surveys, however, were undertaken later in the season, January–March in the spawning area (see Fig. 37 in Nishikawa et al., 1985). It should be noted that albacore larvae are reported to occur south of 10°S in the South Pacific for all months except July–September (Nishikawa et al., 1985), indicating that spawning may be protracted. Leis et al. (1991) found high concentrations of albacore larvae near the islands of French Polynesia (14°–17°S) in January and February, corresponding to the period of peak reproduction period observed in this study.

Table 2

Asymmetry in gonad weight of albacore sampled from New Caledonia and Tonga, 1990–92.

Gonad weight (g)	New Caledonia female	Tonga female	Tonga male
Right> Left	55.77%	95.10%	98.60%
Right = Left	17.31%	4.90%	1.10%
Right < Left	26.92	0.00%	0.20%
n	104	142	444
$\bar{x}$	9.5	19.3	12.9
SD	41.6	13.7	12.8
Range	–130, +160	0–100	–30, +105

From the distribution of larval and juvenile albacore, various authors have shown that the spawning area of South Pacific albacore lies between 10° and 25°S (Otsu and Hansen, 1962; Nishikawa et al., 1985; Ishii and Inoue, 1956; Ueyanagi, 1969). In this study, most maturing albacore (i.e. with GSI's above 1.7) were taken between 20° and 23°S.

Both the New Caledonia and the Tonga GSI data support the view that female albacore reach maturity at a minimum length of around 82 cm (Fig. 5). Although, GSI values alone may not present a full

picture of gonadal activity, the similarity in trends of monthly values of GSI's and oocyte diameters (Figs. 2 and 6) suggests that either method can be used to determine spawning season for the samples as a group.

The length frequencies of male and female samples from New Caledonia and Tonga indicate sexually dimorphic size differences. Such dimorphism had previously been reported by Otsu and Sumida (1968). In yellowfin tuna, sexually dimorphic growth has been age verified, and males were found to represent the largest mode in fork lengths (Wild, 1986).

Gonadal asymmetry has been recorded in several fish species (Ovchinnikov, 1971; Sanwal and Khana, 1972) and was documented previously in albacore by Otsu and Uchida (1959) and Ueyanagi (1955). The former compared oocyte diameters from different areas of one pair of ovaries and found that differences existed between anterior and posterior regions of a single ovary but not between the sides. In contrast, Ratty et al. (1990) found that the smaller left testis of males from the temperate troll fishery was consistently more active than the larger right testis. We found no significant difference in the diameters of oocytes in left and right ovaries.

The absence of advanced and fully ripe ovaries in our samples is similar to the state of reproductive development of ovaries in other studies of albacore reproduction in the Pacific that have relied on longline fisheries as the main source of samples (Otsu and Uchida, 1959; Otsu and Hansen, 1962). As these authors have noted, albacore in, or close to, spawning condition are generally unavailable to the fishery, either because they have stopped feeding and will not take hooks or because they have moved beyond the range of gear. In order to capture the latter category of fish, both the New Caledonia longliners and the MV *Lofa* crew set and hauled their gear during daylight hours; it is possible, however, that albacore, like some other tunas, spawn at night (Hunter et al., 1986; Schaefer, 1996). In addition, albacore may pass rapidly through the mature and spawned stages of the cycle, as Hunter et al. (1986) found with skipjack tuna, and McPherson with yellowfin tuna (1991). Thus, there remain a number of key aspects of the reproduction of South Pacific albacore, such as spawning frequency, batch fecundity and length at 50% maturity, that require further investigation.

Acknowledgments

We are grateful to the many South Pacific Commission TBAP and Fisheries Programme staff who assisted in the collection of gonads and related data in New Caledonia. Special thanks are due to the radio operators and crew of MV *Lofa*, who, in the course of their normal duties, collected and weighed a considerable number of gonads. We also thank Tevita Finau Latu, Tongan Ministry of Fisheries, for coordinating sampling on *Lofa*. This paper has benefitted from discussions with colleagues at the Southwest Fisheries Science Center and South Pacific Commission, notably John Hampton and Marc Labelle of the South Pacific Commission and Norman Bartoo and David Au of the Southwest Fisheries Science Center.

Literature cited

Hunter, J. R., B. J. Macewicz, and J. R. Sibert.
1986. The spawning frequency of skipjack tuna, *Katsuwonus pelamis*, from the South Pacific. Fish. Bull. 84:895–903.

Ishii, K., and M. Inoue.
1956. Some notes on the ovary of albacore tuna, *Germo germo*, taken from the Coral Sea. Bull. Jpn. Soc. Sci. Fish. 22:89–93.

Kikawa, S.
1959. Notes on the regional differences of spawning season of Pacific yellowfin tuna. Rep. Nankai Reg. Fish. Res. Lab. 11:59–76.
1962. Studies on the spawning activity of the Pacific tunas, *Parathunnus mebachi* and *Neothunnus macropterus*, by the gonad index examination. Nankai Reg. Fish. Res. Lab., Occasional Rep. 1:43–56.
1966. The distribution of maturing bigeye and yellowfin and an evaluation of their spawning potential in different areas in the tuna longline grounds in the Pacific. Rep. Nankai Reg. Fish. Res. Lab. 23:131–208.

Koido, T., and Z. Suzuki.
1989. Main spawning season of yellowfin tuna, *Thunnus albacares*, in the western tropical Pacific Ocean based on gonad index. Bull. Far Seas Fish. Res. Lab. 26:153–163.

Kume, S., and J. Joseph.
1969. Size composition and sexual maturity of billfish caught by the Japanese longline fishery in the Pacific Ocean east of 139° W. Bull. Far Seas Fish. Lab. 2:115–162.

Labelle, M., J. Hampton, K. Bailey, T. Murray, D. A. Fournier, and J. R. Sibert.
1993. Determination of age and growth of South Pacific albacore (*Thunnus alalunga*) using three methodologies. Fish Bull. 91:649–663

Leis, J. M., T. Trnski, M. Harmelin-Vivien, J.-P. Renon, V. Dufour, M. K. El Moudni, and R. Galzin.
1991. High concentrations of tuna larvae (Pisces: Scombridae) in near-reef waters of French Polynesia (Society and Tuamotu Islands). Bull. Mar. Sci. 48:150–158.

McPherson, G. R.
1991. Reproductive biology of yellowfin tuna in the eastern Australian Fishing Zone, with special reference to the north-western Coral sea. Aust. J. Mar. Freshwater Res. 42:465–477.

Nishikawa, Y., M. Honma, S. Ueyanagi, and S. Kikawa.
1985. Average distribution of larvae of oceanic species of scombroid fishes, 1965–1981. Far Seas Fish, Res. Lab., S Series 12, 99 p.

Otsu, T., and R. Hansen.
1962. Sexual maturity and spawning of the albacore in the central South Pacific Ocean. U.S. Fish Wild. Serv., Fish. Bull. 62(204):151–162.

Otsu, T., and R. F. Sumida.
1968. Distribution, apparent abundance, and size composition of albacore, *Thunnus alalunga*, taken in the longline fishery based in American Samoa, 1954–65. Fish. Bull. 67:47–69.

Otsu, T., and R. N. Uchida.
1959. Sexual maturity and spawning of albacore in the Pacific Ocean. U.S. Fish. Wild. Serv., Fish. Bull. 59(148): 287–305.

Ovchinnikov, V.
1971. Swordfishes and billfishes in the Atlantic Ocean; ecology and functional morphology. [Translated from Russian by H. Mills, Jerusalem, Israel Prog. for Sci. Trans.] [Available from the U.S. Dep. Commer., Natl. Tech. Inf. Serv.]

Ratty, F., R. Kelly, and M. Laurs.
1990. Gonad morphology, histology and spermatogenesis in the South Pacific albacore tuna, *Thunnus alalunga* (Scombridae). Fish. Bull. 88:207–216.

Sanwal, R., and S. Khanna.
1972. Seasonal changes in the testes of a freshwater fish, *Channa gachua*. Acta Anat. 83:139-148.

Schaefer, K. M.
1987. Reproductive biology of black skipjack, *Euthynnus lineatus*, an eastern Pacific tuna. Inter-Am. Trop. Tuna Comm. Bull. 19(2):169–259.

1996. Spawning time, frequency, and batch fecundity of yellowfin tuna, *Thunnus albacares*, near Clipperton Atoll in the eastern tropical Pacific. Fish. Bull. 94:98–112.

Shung, S.
1973. The sexual activity of yellowfin tuna caught by the longline fishery in the Indian Ocean, based on examination of ovaries. Bull. Far. Seas Fish. Res. Lab. 9:123–142.

Ueyanagi, S.
1955. On the ripe ovary of the albacore, *Germo germo* (Lacepède), taken from the Indian Ocean. Jpn. Soc. Sci. Fish. Bull. 20(12):1050–1053.
1957. Spawning of the albacore in the western Pacific. Nankai Reg. Fish. Res. Lab. Rep. 6:113–124.
1969. Observations on the distribution of tuna larvae in the Indo-Pacific Ocean with emphasis on the delineation of the spawning ares of albacore, *Thunnus alalunga*. Far Seas Fish. Res. Lab. Bull. 2:177–256.

Yoneta, K., and S. Saito.
1973. Studies on the large-sized albacore and its vertical distribution in the western south Pacific Ocean. Bull. Jpn. Soc. Scient. Fish. 39:617–624.

Wild, A.
1986. Growth of yellowfin tuna, *Thunnus albcares*, in the eastern Pacific Ocean based on otolith increments. Inter-Am. Trop. Tuna Comm., Bull.18(6):421-482.