Abstract—The narrow-barred Spanish mackerel (*Scomberomorus commerson*) is widespread throughout the Indo-West Pacific region. This study describes the reproductive biology of *S. commerson* along the west coast of Australia, where it is targeted for food consumption and sports fishing. Development of testes occurred at a smaller body size than for ovaries, and more than 90% of males were sexually mature by the minimum legal length of 900 mm TL compared to 50% of females. Females dominated overall catches although sex ratios within daily catches vary considerably and females were rarely caught when spawning. *Scomberomorus commerson* are seasonally abundant in coastal waters and most of the commercial catch is taken prior to the reproductive season. Spawning occurs between about August and November in the Kimberley region and between October and January in the Pilbara region. No spawning activity was recorded in the more southerly West Coast region, and only in the north Kimberley region were large numbers of fish with spawning gonads collected. Catches dropped to a minimum when spawning began in the Pilbara region, when fish became less abundant in inshore waters and inclement weather conditions limited fishing on still productive offshore reefs. Final maturation and ovulation of oocytes took place within a 24-hour period, and females spawned in the afternoon-evening every three days. A third of these spawning females released batches of eggs on consecutive days. Relationships between length, weight, and batch fecundity are presented.

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Variability in spawning frequency and reproductive development of the narrow-barred Spanish mackerel (*Scomberomorus commerson*) along the west coast of Australia

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The narrow-barred Spanish mackerel (*Scomberomorus commerson*) is a prized food fish targeted by fishermen throughout its range in the Indo-West Pacific region (Collette and Nauen, 1983). Reaching over 2.4 m in length and 45 kg in weight, this pelagic species is seasonally abundant in coastal waters where it often schools in large numbers. In Australian waters, the commercial mackerel fishery targets these schools using trolling methods, and 2362 metric tons were caught in 2001–02 for domestic and overseas markets (ABARE, 2003).

Scomberomorus commerson is also a premier sport fishing species, targeted by an increasing number of recreational anglers throughout its broad Australian distribution. The combined commercial and recreation take of *S. commerson* has put significant pressure on stocks in Queensland (QLD) waters, leading to a possible decline in the spawning stock abundance (McPherson and Williams, 2002). The biology of *S. commerson* in these waters has been well studied (e.g., Munro, 1942; McPherson, 1981, 1992, 1993). Biological information is also available for *S. commerson* in waters of the Northern Territory (NT; Buckworth[1]), where stocks are still recovering from a prolonged period of exploitation by foreign gill-net operators that ended in 1986. In contrast, little is known about the stock status and biology of *S. commerson* in Western Australian (WA) waters, despite the fact that catches are similar to those taken in QLD and the NT, and commercial fishermen have expressed concern about increasing fishing pressure on this species in WA. Recent moves to overhaul management of the mackerel fishery in WA (in which *S. commerson* is the dominant species) have further highlighted the need for more information on the biology and stock status of *S. commerson* along the WA coast.

Research to enable a stock assessment of *S. commerson* in WA waters was therefore commenced in 1999. Description of reproductive biology was a key focus of this study, since this information is required for stock assessment models and for management controls such as minimum legal lengths, which were previously set with little knowledge of the biology of *S. commerson* in WA. Information on other reproductive parameters, such as batch fecundity and spawning behavior, which are also required for

[1] Buckworth, R. C. 1999. Age structure of the commercial catch of Northern Territory narrow-barred Spanish mackerel. Final Report to the Fisheries Research and Development Corporation (FRDC) on project no. 1998/159. Fishery report 42, 27 p. Department of Business Industry and Resource Development, Darwin, Northern Territory, 0800, Australia.

stock assessments, is unavailable or insufficiently described in the literature for this species. The objective of our study was, therefore, to provide a comprehensive description of the reproductive biology of *S. commerson* in Western Australian waters.

Material and methods

Collection and processing of samples

Scomberomorus commerson were collected onboard vessels operating from a number of locations along the WA coast between 1998 and 2002 (Fig. 1). These locations were pooled into three regions to reflect differences in fishing methods within the mackerel fishery (Kimberley—east of 120°E, Pilbara—north of 23°S to the Kimberley border, and West Coast—south of 23°S; Fig. 1). *Scomberomorus commerson* are seasonally abundant in coastal waters although low numbers are caught in the Pilbara region during the "off-season." Samples were therefore collected throughout the year from this region only.

Fresh *S. commerson* collected from commercial and recreational fishermen were measured (total length [TL] and fork length [FL] in mm) and, where possible, weighed to 0.1 kg (whole weight [WW] and clean weight [viscera and gonads removed]). Heads were removed and measured from tip of the mouth to firm edge of the operculum (mm), and weighed with gills intact (±0.1 gm). Gonads were removed from the fish within hours of capture, macroscopically staged (see below), weighed where possible (±0.01 g), and preserved in 10% formalin and seawater solution. Frozen head and viscera obtained from commercial and recreational fishermen were also measured and weighed as above. The thawed gonads were macroscopically staged by using a simplified staging system (see below) that is used in less detailed reproductive analyses.

Preserved gonads were blotted dry with a paper towel and weighed. A 4-mm slice from the mid-region was processed by using standard histological techniques and stained with Harris's haematoxylin and eosin for microscopic examination. Full details of methods used in the collection and analysis of *S. commerson* gonads are provided in Mackie and Lewis.[2]

Biological analyses

Gonads were staged macroscopically and microscopically. Macroscopic staging employed five developmental steps that were compatible with the microscopic staging system (Mackie and Lewis[2]):

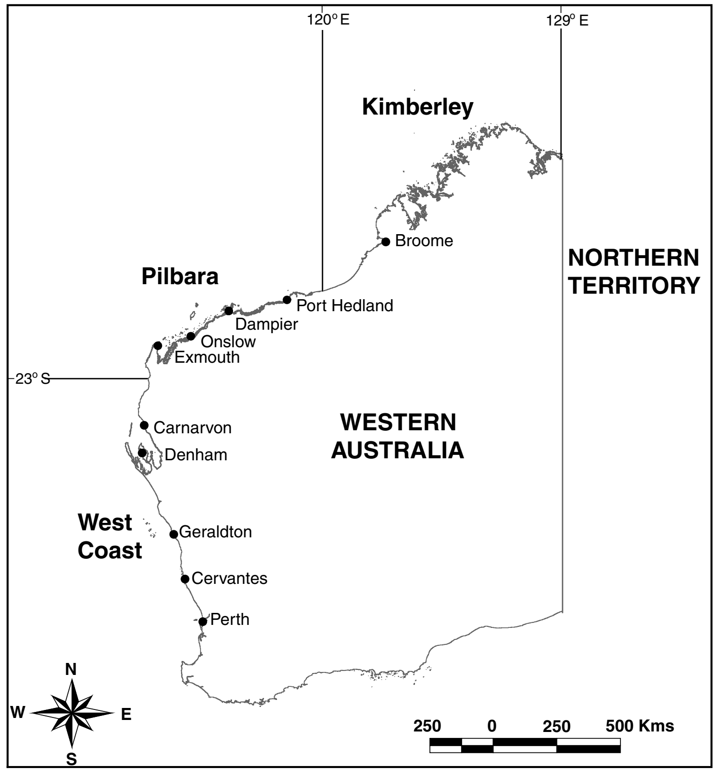

Figure 1

Sampling locations used in the study of the narrow-barred Spanish mackerel (*Scomberomorus commerson*) reproductive biology.

Juvenile (J)	undifferentiated.
Females	
stage 1	immature ("virgin" in other studies);
stages 2–3	mature, resting;
stage 4	reproductively developed;
stage 5	spawning ("running, ripe" in other studies).
Males	
stage 1	immature ("virgin" in other studies);
stage 2	mature resting;
stage 3	reproductively developed, ripe;
stage 4	spawning ("running, ripe" in other studies).

The microscopic staging system had more stages and allowed a more detailed description of spawning:

Juvenile (J)	undifferentiated.
Females	
stage 1	immature ("virgin" in other studies);
stage 1a	immature, developing;
stage 2	mature, resting;
stage 3	mature, developing;
stage 4	reproductively developed;
stage 5a	prespawning;
stage 5b	spawning ("running, ripe" in other studies);
stage 5c	postspawning;
stage 6	spent.

[2] Mackie, M. C., and P. D. Lewis. 2001. Assessment of gonad staging systems and other methods used in the study of the reproductive biology of narrow-barred Spanish mackerel, *Scomberomorus commerson*, in Western Australia. Fisheries Research Report 136, 25 p. Department of Fisheries, Perth, Western Australia 6020, Australia. http://www.fish.wa.gov.au/res/broc/frr/frr136/index.html. [Accessed January 15 2002.]

Males

stage 1	immature ("virgin" in other studies);
stage 1a	immature, developing;
stage 2	mature, resting;
stage 3	reproductively developed, ripe;
stage 4	spawning.

The immature, developing stage identified females that were immature and unlikely to spawn but had ovaries containing cortical alveoli stage oocytes (which otherwise identified mature, developing females).

Division of the microscopic staging system for ovaries into three spawning stages was based on the presence of migratory nucleus stage or hydrated oocytes within the ovarian lamellae (stage 5a), the presence of hydrated oocytes within the ovarian lumen (stage 5b), and the presence of postovulatory follicles (POFs) in the lamellae (stage 5c). In tropical fish species POFs may remain up to 24 hours in the ovaries before being resorbed (West, 1990), and there is evidence suggesting this is the case for *S. commerson* in Queensland waters (McPherson, 1993). In the present study POFs observed in the ovaries of females were categorized as either "new" or "old" based on their degree of degeneration (Mackie and Lewis[2]).

Gonadosomatic indices (GSIs) were calculated by using ratios of gonad weight to whole body weight, head weight, and head length. The latter two ratios were used to assess the usefulness of head and viscera samples in future monitoring of *S. commerson*.

Scomberomorus commerson is a serial-spawning species (Munro, 1942). Estimates of batch fecundity were made for preserved prespawning (stage 5a) ovaries from counts of hydrated oocytes within three samples taken from the anterior, middle, and posterior region of one lobe (each 130–200 mg). A section of each ovary was also processed by using histological methods to confirm suitability for estimation of fecundity. Some ovaries were subsequently rejected for fecundity estimates because the most mature batch of oocytes had not fully hydrated and were less easy to distinguish from earlier stage oocytes. These ovaries tended to provide an overestimate of batch fecundity (Mackie et al.[3]).

The daily timing and frequency of spawning were determined for females captured in the Kimberley region during September 1999 when 94% of ovaries were retained for histological analysis (n=344). Spawning frequency was determined as the inverse of the spawning fraction (the number of ovaries with hydrated or migratory nucleus stage (MNS) oocytes divided by the total number of mature ovaries in the catch). These data were compared with estimates made by using the number of ovaries macroscopically identified as having hydrated oocytes. Analyses of sex ratios were based on data where the whole catch or a known random sample of the catch was processed.

Results

The gonads of 5128 male, female, and juvenile *S. commerson* were macroscopically staged during this study. Of these, 1624 were also processed with histological techniques for more detailed analyses.

Biological analyses

Body lengths ranged from 58 to 1720 mm FL (62 to 1840 mm TL), and whole weights ranged from 0.0015 to 40.6 kg. Regression analyses incorporating step-wise reduction (using analysis of variance) of a fully parameterized model indicated that differences in length and weight relationships between regions and sex were minor compared to measurement error. Thus, the simplest models which adequately explain the pooled data were

$$\textit{Whole weight}\ (\text{kg}) = 3.40e - 9 \times FL\ (\text{mm})^{3.12} \quad (n{=}2842)$$
$$(\text{SE of constants: } a{=}2.78e{-}10,\ b{=}0.01)$$

$$TL\ (\text{mm}) = 42.74 + (1.06 \times FL\ (\text{mm}))$$
$$(n{=}1679,\ r^2{=}0.996).$$

Overall sex ratios were biased towards females, with the M:F ratio varying between 1:1.2 and 1:1.6 in the three regions. However, there was considerable variation between samples, from a peak M:F ratio of 1:2.6 for samples obtained in the nonreproductive period, to a male bias of 1.1:1 in pooled samples obtained during the peak spawning period. This slight male bias during the spawning period occurred in successive years; the sex bias, however, was variable between daily samples. Sex ratios also changed over from a male to female bias with increasing size class, with a 1:1 ratio occurring at about 1000–1050 mm FL.

Ovarian weight ranged from 2.00 to 1908.30 g and testes from 0.84 to 840.10 g. Gonads of juvenile *S. commerson* were small and contained no recognizable germ tissue. The smallest fish with differentiated gonads was a 301-mm-FL male. The smallest female was 396 mm FL. Two abnormally large juveniles (1170 and 1251 mm FL) were captured whose gonads had remained unusually small and undifferentiated. Body lengths of immature females (largest=1195 mm FL [13.8 kg WW]) overlapped substantially with those of mature females (smallest=641 mm FL [2.3 kg WW]).

Estimates of the size at which 50% of females were mature were calculated by using all available data as well as data taken only during the reproductive season (October to April). Data for each area were pooled to provide sufficient samples (virtually all samples of immature fish were obtained from the Pilbara region). Both data sets provided similar estimates; 809 mm FL, ±9.8 SE (898 mm TL) for all data, and 788 mm

[3] Mackie, M. C., D. J., Gaughan, and R. C. Buckworth. 2003. Stock assessment of narrow-barred Spanish mackerel (*Scomberomorus commerson*) in Western Australia. Final report to the Fisheries Research and Development Corporation (FRDC) on project no. 1999/151, 242 p. Department of Fisheries, Perth, Western Australia, 6020.

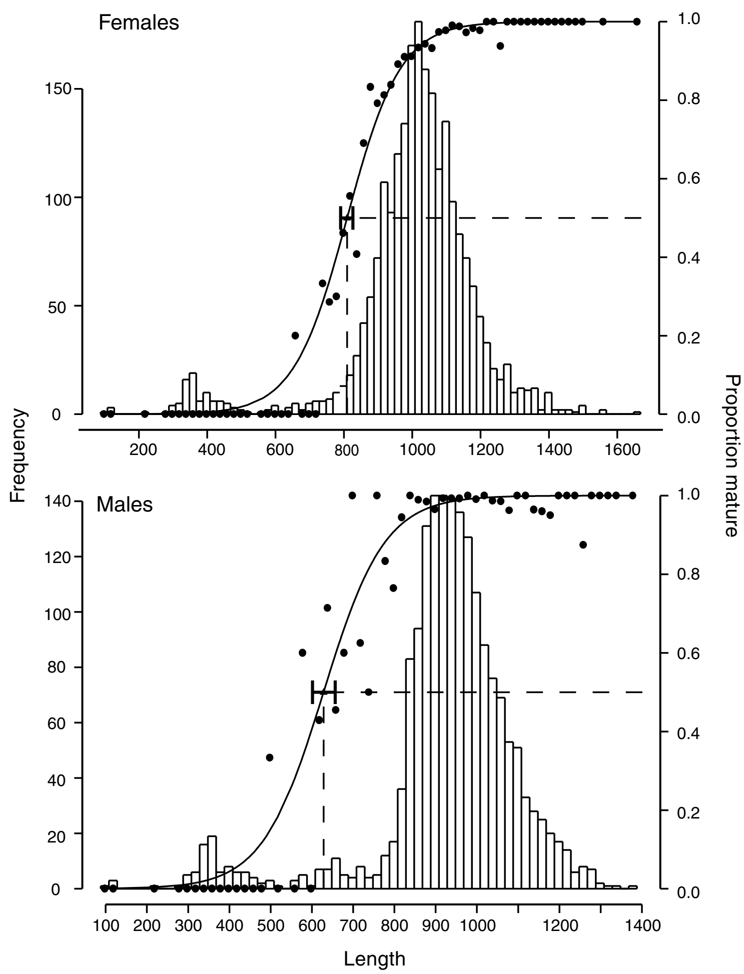

Figure 2

Proportion of mature female and male *S. commerson* within samples. The number of fish within each length class is indicated by the vertical bars and the left *y*-axis and the proportion of mature fish by the black circles and the right *y*-axis. The length at which 50% of fish within the samples were mature is indicated on the fitted maturity curve (±95% CI). Lengths are fork length in mm. Note that data for juvenile fish of undifferentiated sex are included in both graphs. The dashed lines indicate the length at 50% mature (P=0.5).

FL (±14.5 SE) for data taken during the reproductive period. The size at which 10% of females were mature was 638 mm FL (±19.6 SE), with 90% mature by 981 mm FL (±7.2 SE) (Fig. 2A).

There was also considerable overlap between the lengths of immature and mature males. The largest immature male was 1140 mm FL (11.3 kg WW), whereas the smallest mature male (stage 3) was 491 mm FL (1.0 kg WW). The size at which 10% of males were mature was 465 mm FL (±24.9 SE), the size at which 50% of males were mature was 628 mm FL (±13.8 SE) or 706 mm TL, and the size at which 90% were mature was 791 mm FL (±10.5 SE) (Fig. 2B).

Development of oocytes is asynchronous and all stages of oocytes are present at the same time within reproductively active ovaries. This reproductive feature, along with the maturation of multiple batches of oocytes (as evidenced by presence of both POFs and hydrated or MNS oocytes in spawning ovaries), confirms that female *S. commerson* are serial or partial spawners (Hunter et al., 1985).

Relationships between batch fecundity and body parameters were obtained from counts of hydrated oocytes within prespawning (stage 5a) ovaries. Size of females for which batch fecundity was determined ranged from 857 to 1143 mm FL and from 5.3 to

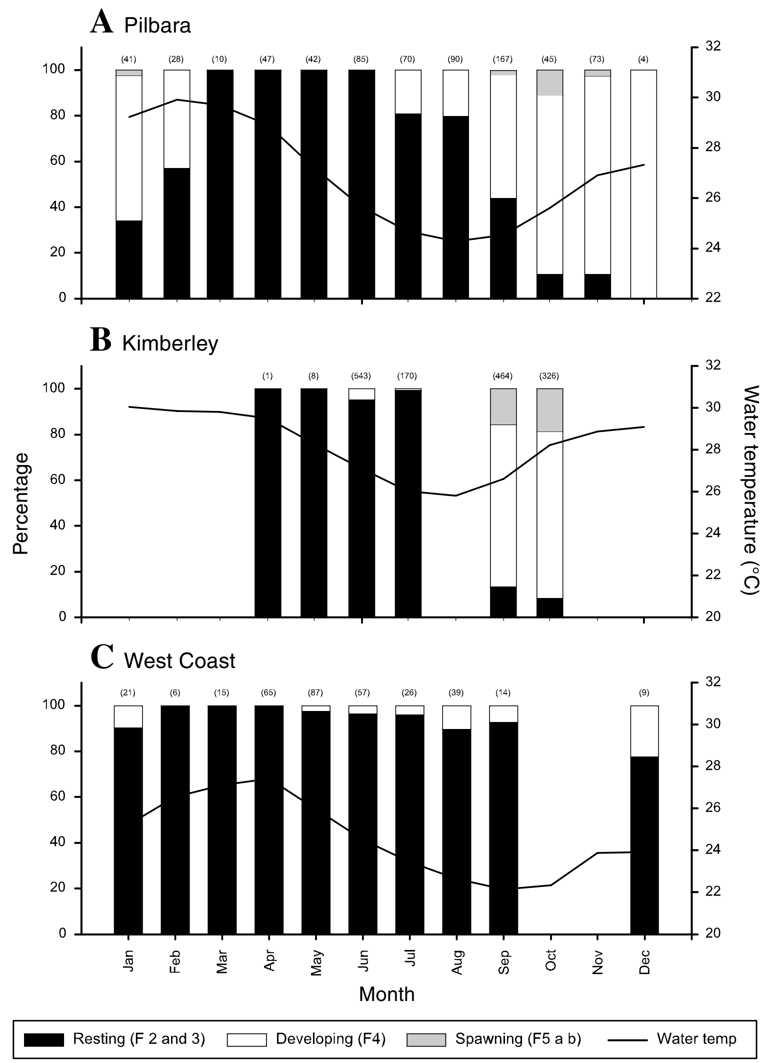

Figure 3

Annual cycle of *Scomberomorus commerson* reproduction within each region, as indicated by macroscopically staged ovaries. Mid-month sea surface temperatures are overlaid (solid line) and sample sizes are shown above each column.

12.7 kg WW. Both relationships were explained with power curves:

$$Batch\ fecundity = 0.0011 \times FL^{2.896} \quad (r^2=0.441,\ n=21)$$
$$Batch\ fecundity = 31087 \times WW^{1.384} \quad (r^2=0.714,\ n=19).$$

Annual reproductive cycle

Female *S. commerson* within the Pilbara region were nonreproductive between March and June, during the downward cycle of water temperatures (Figs. 3 and 4). As water temperatures reached a minimum in July and August (around 24°C), a small proportion of mature ovaries had become reproductively developed (stage 4). The proportion of developed ovaries during September (the start of the upward cycle of water temperatures) varied noticeably between years in the Pilbara region, from 18.5% to 79% in 2001 and 2000, respectively. A small number of females were also actively spawning when sampled during September 2000. Peak reproductive activity extended from October to January, and spawning females were captured during this period in 1999 and 2000 when the sea surface temperature (SST) was rising from about 25.5° to 28.5°C. By February, when SST peaked at approximately 30°C, reproductive development was declining and the ovaries of most females were spent or resting.

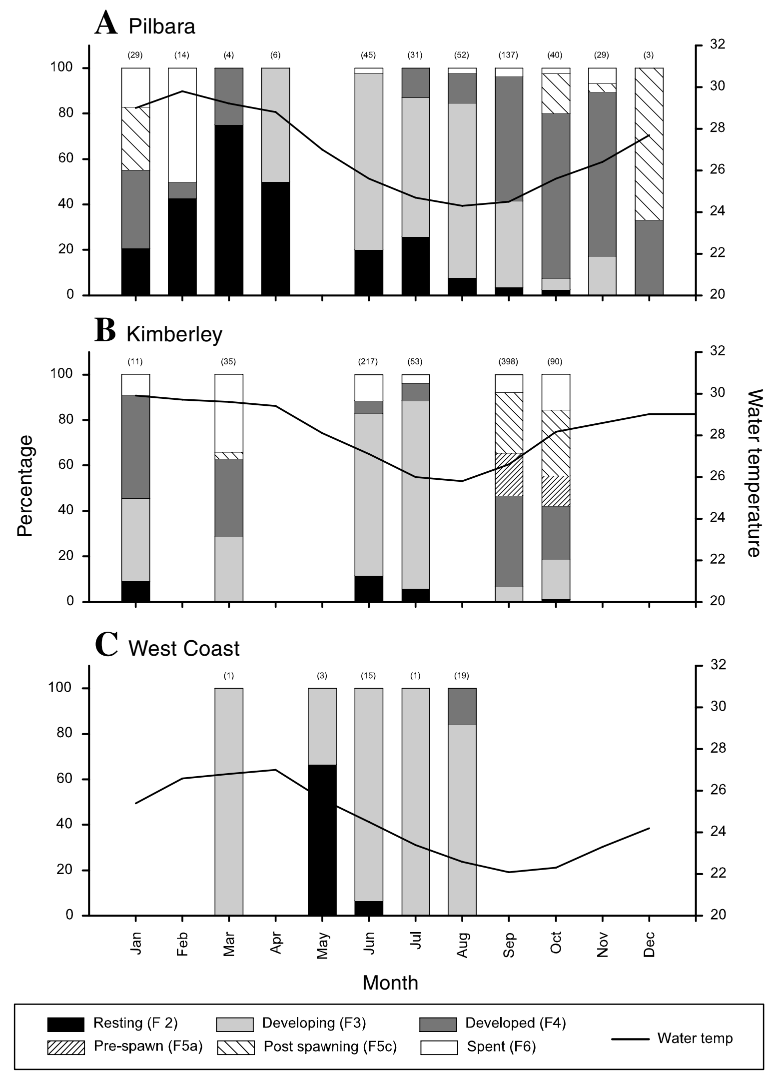

Figure 4

Annual cycle of *Scomberomorus commerson* reproduction in Western Australia for (**A**) Pilbara, (**B**) Kimberley, and (**C**) West Coast regions, as indicated by histologically staged ovaries. Mid-month sea surface temperatures are overlaid (solid line) and sample sizes are shown above each column.

The annual reproductive cycle of ovaries in the Kimberley region follows a similar pattern to that in the Pilbara region (Figs. 3 and 4). However, because 30–50% of females captured in Kimberley waters during September 1999 and 2000 were actively spawning, it appears that *S. commerson* commence spawning at least one month earlier in this region. About 60% of females were also spawning when sampled during October 1999 and 2000, although only 35% were spawning during this month in 2001. If spawning in the Kimberley region commenced in August and concluded in November (same duration as in the Pilbara region), the associated SST ranged from approximately 26.5–27°C to 29–30°C (annual maximum approx 30–31°C; Figs. 3 and 4). Sampling of developed ovaries in March also indicated that the reproductive period for *S. commerson* in the Kimberley region may be more protracted than in the Pilbara region.

In the West Coast region few reproductively developed ovaries and no spawning ovaries were obtained; *S. commerson* are rarely captured in this region during the peak spawning period observed in the northern regions. The maximum sea surface temperature (SST) in this region of around 28°C is above the lower temperature range of spawning in the two northern regions. Reproductively developed ovaries obtained from the

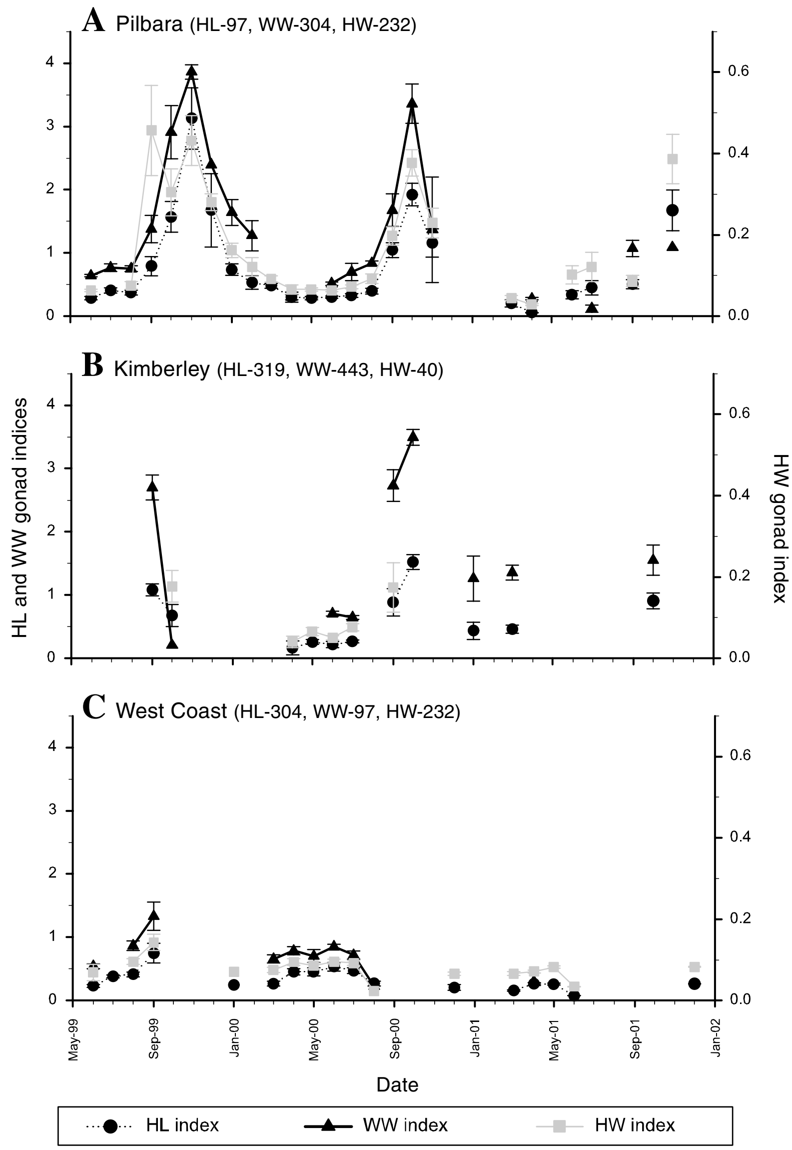

Figure 5

Annual cycle of gonad indices for *Scomberomorus commerson* in Western Australia for (**A**) Pilbara, (**B**) Kimberley, and (**C**) West Coast regions. Sample sizes are given for each index, where HL=head length index, WW=whole weight index, and HW=head weight index.

West Coast region were collected over a range of SSTs, including when it was at a minimum (Figs. 3 and 4).

Gonadosomatic indices calculated from whole weight, head weight, and head length exhibited similar patterns and confirmed the spawning cycle determined from examination of ovaries (Fig. 5). The most complete data set was for females from the Pilbara region. In this region indices were minimal between March and August and increased considerably during September as ovaries became reproductively developed. Peak indices occurred in November 1999 and October 2000, coinciding with peaks in the proportion of spawning (stage 5) ovaries in the samples. The drop in gonad indices during December 1999 showed that the supplies of vitellogenic oocytes within the ovaries were reduced by this time, even though many females were still spawning (Fig. 4). This drop continued until March when all the ovaries in the samples were in the resting stage. Data for 2001 indicate that decreased GSIs during the reproductive season were comparable to data from the previous two

Table 1

Ovarian development of *Scomberomorus commerson* sampled in the Kimberley region during the spawning season. POFs= postovulatory follicles. Ovaries in prespawning, spawning, postspawning, and spent stages of development are indicated by 5a, 5b, 5c, and 6, respectively. Note that data for stage 5c includes only females that had spawned on the day of capture (i.e., excluding ovaries containing old POFs only). Data for "Old POFs" includes all ovaries containing old POFs as well as other evidence of recent or imminent spawning.

		Histological analysis		Morning					Afternoon				
Year	Total caught	Total	Number mature	Total	5a	5b	5c	Old POFs	Total	5a	5b	5c	Old POFs
1999	344	325	306	171	59	0	0	70	135	1	1	23	51
2000	406	115	103	59	22	0	0	21	44	0	0	15	13

years. Data for the Kimberley and West Coast regions were limited but concurred with gonad staging data and also confirmed the low reproductive status of *S. commerson* within the West Coast region.

Spawning

Evidence of spawning was found in 237 of the histologically processed ovaries. Thirty-eight percent (n=90) of these were about to spawn when captured (stage 5a), 62% (n=147) had recently spawned (stage 5c), and one was running, ripe (stage 5b). The ovaries of only two macroscopically staged females were also running, ripe. Most of these spawning fish (n=219) were captured in the north Kimberley region (eighteen from the Pilbara region). The most southern location from which a spawning female was obtained was Exmouth (one recently spawned fish), and no females captured in the West Coast or more southern regions showed histological (or macroscopic) evidence of spawning.

Spawning females collected during 1999 and 2000 were either prespawning (stage 5a) and caught in the morning, or had recently spawned (stage 5c) and were caught in the afternoon (Table 1). The absence of hydrated oocytes in the afternoon and new POFs in the morning showed that the entire cycle of oocyte maturation, ovulation, and spawning is completed within a 24-hour period. Because no new POFs were present in ovaries sampled during the morning the transition from new to old POFs occurs during the night, within about 12 hours of spawning. The lack of evidence to show that females spawned on more than two consecutive days indicates that old POFs are unrecognizable after 24 hours.

Spawning fraction was estimated by using data obtained in the Kimberley region during September 1999 when 95% (n=344) of ovaries were examined by using histological methods. Analyses were based on the number of prespawning (stage 5a) ovaries sampled during the morning (usually between 0600–0900 h). Afternoon samples (usually 1500–1800 h) were not used because the number of spawning fish was likely to be underestimated because of the low catchability of running, ripe (stage 5b) females. Thirty-five percent (n=59) of mature females in the morning samples were about to spawn (stage 5a). Spawning frequency was therefore 2.9 days. Comparison of spawning fractions in samples of at least ten females showed higher spawning fractions (33–56%) for the Kimberley region compared with the Pilbara region (4–28%).

Spawning fraction was also estimated for the morning samples as the proportion of macroscopically staged mature ovaries that contained hydrated oocytes. Thirty-one of the 180 mature females were identified as such, providing an estimated spawning fraction of 17.2%, and a spawning frequency of 5.8 days.

Thirty-six percent (n=54) of spawning females (stages 5, a–c) had spawned on two consecutive days. For example, 39 ovaries contained oocytes in the MNS or hydrated stage of development (i.e., spawning was imminent when fish were captured) and also contained old POFs. Another 15 ovaries had both old and new POFs.

Discussion

Scomberomorus commerson has a gonochoristic life history in which the gonad differentiates into an ovary or testis at around 300–400 mm FL. Males differentiate and reach sexual maturity at a smaller body size than females, as is the case with the congeneric species *S. maculatus* and *S. cavalla* (Beamariage, 1973; Schmidt et al., 1993). Consequently, more than 90% are sexually mature by the time the minimum legal length of 900 mm TL is reached in the fishery. In contrast only 50% of females are mature at 898 mm TL. Although mortality of released undersize fish may be high because of difficulties in removing fishing hooks, this size limit deters fishermen from targeting small fish and relatively few are captured (Mackie et al.[3]).

Biases in sex ratios have been observed in several species of *Scomberomorus* (e.g. Trent et al., 1981; Sturm and Salter, 1990; Begg, 1998). In the case of *S. commerson*, females usually dominate size classes above the MLL because they grow faster and reach a larger maximum size (McPherson, 1992; Mackie et al.[3]). However, they are rarely caught when actively spawning, despite observations by fishermen of leaping fish that might indicate that they are still present on the fishing grounds. Regional differences in fishing gear can also affect catchability. The lighter monofilament and reel outfits used in the Pilbara and West Coast regions likely catch larger fish than the heavier rope and thick monofilament hand-hauled rigs used by Kimberley fishermen that do not allow the fish to be "played" (i.e. do not allow the fish to swim) and may result in more gear failure.

The spring-summer spawning pattern observed in our study is similar to that of *S. commerson* along the east coast of Australia (McPherson, 1981). Water temperature may influence spawning in fish by affecting gametogenesis, gonad atresia, and spawning behavior (Lam, 1983). In WA waters *S. commerson* spawn as water temperatures are rising and, as found in Queensland, may compensate for latitudinal differences in temperatures by spawning earlier in northern waters (McPherson, 1981). No evidence of spawning activity was found within the West Coast region although the annual range of water temperatures overlap with those in which spawning occurs farther north. Restricted spawning by *S. commerson* on the east coast occurs at similar latitudes to northern parts of the West Coast region, and anecdotal evidence suggests that spawning may be restricted in some years in this region.

During the spawning period the average female *S. commerson* may spawn every three days and about one third of fish spawn on consecutive days. Female fish similarly spawn every 2–6 days and possibly on consecutive days in Queensland waters (McPherson, 1993). Our study showed that estimates based on the fraction of histologically staged prespawning (stage 5a) ovaries provided the best estimate of spawning frequency. However, only samples taken during the morning can be used for this analysis because of decreased catchability of running, ripe females in the afternoon. In comparison, macroscopic staging of ovaries with hydrated oocytes underestimated spawning frequency because migratory nucleus oocytes (which comprised 54% of histologically staged, prespawning [stage 5a] ovaries) cannot be identified. It is also impossible to identify fish that have spawned on more than one occasion with macroscopic criteria, resulting in a further underestimate of spawning activity (by 25% for *S. commerson*).

Maturation, ovulation, and spawning of oocytes by female *S. commerson* was completed within a 24-h cycle in the Kimberley region compared to 24–36 hours in Queensland waters (McPherson, 1993). Maturation of the oocytes is underway by sunrise and probably completed in all spawning ovaries by mid to late morning to allow for ovulation prior to spawning in the afternoon. Few samples were obtained at or after dusk because fish are generally not catchable, indicating that a high incidence of spawning at this time because only one spawning fish was obtained during the study. Dusk spawning is prominent among pelagic spawning species that inhabit tropical reefs (Thresher, 1984). However, spawning in the afternoon is less common and may be linked to large tidal cycles and strong currents in the north of WA, as indicated for the brown stripe snapper (*Lutjanus vitta*) that also spawns in the afternoon in the Pilbara region (Davis and West, 1993).

Batch fecundity of *S. commerson* has not previously been recorded and such data are rare for other *Scomberomorus* species. Fecundity estimates for *S. commerson* from the Indian Peninsula (Devaraj, 1983) were not comparable because those data appeared to be obtained from counts of both vitellogenic and previtellogenic oocytes. Although the current study provided fecundity estimates only for females up to 13 kg whole weight, it shows that *S. commerson* is highly fecund (the highest estimated batch fecundity of 1.2 million eggs was obtained from an ovary that was less than half the weight of the heaviest ovary sampled). This study highlighted the need to histologically check that oocytes in the spawning batch are fully hydrated because fecundity may otherwise be over-estimated. Similarly, fecundity will be under-estimated if ovulation has commenced. The best time to collect gonad samples so that these biases are minimized is during the mid to late afternoon for this species.

Fishing activity is also regulated by the reproductive cycle. About 3–6 months prior to the spawning season catches of *S. commerson* by commercial fishermen increase as large numbers of smaller *S. commerson* appear on offshore reefs sometime between March and May, and soon after throughout the coastal waters of WA (Mackie[4]). By the time reproductive development in ovaries begins (approximately August and September in the Kimberley and Pilbara regions, respectively) catches have peaked or are declining. In the Pilbara region commercial catches have dropped to a minimum when spawning begins, as fish become less abundant in inshore waters and inclement weather conditions limit fishing on still productive offshore reefs. Because *S. commerson* generally do not make substantial longshore movements (Buckworth et al.[5]), it is likely that most spawning activity occurs at offshore locations in this region (e.g., in mid to outer areas of the continental shelf), although anecdotal evidence indicates that

[4] Mackie, M. C. 2001. Spanish mackerel stock status report. *In* State of the fisheries report 1999/2000 (J. W. Penn, W. J. Fletcher, and F. Head, eds.), p. 71–75. Department of Fisheries, Perth, Western Australia, 6020. http://www.fish.wa.gov.au/sof/1999/comm/nc/commnc26.html, Accessed 10/2/2001.

[5] Buckworth, R. C., S. J. Newman, J. R. Ovenden, R. J. G. Lester, and G. R. McPherson. 2004. In prep. The stock structure of northern and western Australian spanish mackerel. Final report to the Fisheries Research and Development Corporation (FRDC) on project no. 1998/159. Department of Business Industry and Resource Development, Darwin, Northern Territory, 0800, Australia.

large, more solitary individuals may spawn in inshore waters.

Catches of *S. commerson* peak and decline rapidly along the Kimberley coast during the main spawning period because of declining fish abundance and weather conditions. As in the Pilbara region, few *S. commerson* are caught at this time in southern or midsections of the Kimberley coast. Fishermen must therefore undertake extensive trips north to the remaining productive grounds located between 12.5° and 15°S latitude where the majority of *S. commerson* spawning activity was encountered in the present study. Although it is possible that *S. commerson* in other areas of the Kimberley region may move offshore to spawn, it is also possible that some move northward, mixing and spawning with otherwise temporally and spatially discrete northern populations, in a similar manner to *S. cavalla* in U.S. waters (Broughton et al., 2002).

Monitoring of the WA fishery for *S. commerson* is likely to be based on the collection of head and gonad samples because limited funding and large distances will restrict future research trips. Onboard storage of filleted frames for research purposes is also prohibited by the large body size of *S. commerson*. In contrast, the head of this species is relatively small and easy to store, and as shown in the present study, provides a general measure of reproductive activity through calculation of head-to-gonad ratios. These ratios can also be supplemented by staging the gonads by using the macroscopic staging system developed for this species (Mackie and Lewis[2]). Head length can also be used to estimate body length of *S. commerson* (Mackie et al.[3]) and the otoliths contained in the head can be used to determine age. Although data gathered by such means is less accurate than that obtained from whole, fresh samples, it presents the best option for gathering ongoing data in sufficient quantities for meaningful analyses.

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