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Research Article

Sea Surface Temperature Affects the Reproductive Biology of Female Pearl Perch (*Glaucosoma scapulare* Macleay, 1881) in Queensland, Australia

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Pearl perch (*Glaucosoma scapulare*) are endemic to the east coast of Australia and have a long history of exploitation. Recent stock assessments indicate that the current rate of fishing mortality is unsustainable in the long term. To better inform the management of the pearl perch stock and to address gaps in our understanding of their reproductive biology, we investigated patterns in gonad development and estimated length- and age-at-maturity and batch fecundity from females collected from southern and central Queensland waters between 2018 and 2022. The mean gonadosomatic index (GSI) varied both temporally and spatially, with maxima in the austral autumn in southern Queensland and in summer in central Queensland, coinciding with sea surface temperatures between 25.26 and 26.32°C. The length- and age-at-maturity of females were 353 mm (fork length, FL) and 4.42 years, respectively, and batch fecundity (B) was correlated to FL such that $\mathrm{Ln}(B) = 2.45 \times \mathrm{Ln}(\mathrm{FL}) + 3.90$. Our results will inform a management strategy to recover the stock to acceptable levels of exploitation.

1. Introduction

Pearl perch (*Glaucosoma scapulare*) are endemic to the east coast of Australia between Port Jackson, New South Wales (~34°S) and Rockhampton, Queensland (~23°S) [1]. This limited distribution means that the pearl perch population has been considered a single biological stock [1]. They occur in schools at depths from 10 m to >200 m, close to submerged reefs, rocky seabeds, and pinnacles [2]. Pearl perch are a member of the family Glaucosomatidae, which includes three other species: *G. magnificum* (Ogilby, 1915), *G. hebraicum* (Richardson, 1845), and *G. buergeri* (Richardson, 1845). Pearl perch grow to 700 mm (total length, TL) and 7.3 kg [3] and have a maximum age of at least 27 years [4]. While this reported longevity is consistent with that of *G. buergeri* and *G. hebraicum*, 26 and 39 years, respectively [5, 6], recent research indicates that pearl perch reach asymptotic size faster than either of these species [4].

Pearl perch are caught as part of Queensland's rocky reef fishery (RRF), which is accessed by commercial, recreational, and charter fishers using rod and reel. Rocky reef fishers target a range of species, primarily snapper (*Chrysophrys auratus*, Forster, 1801), pearl perch, and teraglin (*Atractoscion aequidens*, Cuvier, 1830) [7]. The annual commercial catch of pearl perch peaked at 96 t in 2005 before decreasing to a mean of 10.6 t for the period 2018–2022 [8]. Queensland's fisheries management agency, Fisheries Queensland (FQ), has been collecting biological information on RRF species since 2006 as part of its routine fishery monitoring program [7]. Filleted fish frames, donated by commercial fishers and recreational anglers on an opportunistic basis, provide information such as length and age for use in quantitative stock assessments [8].

Since the peak in commercial pearl perch catch in 2005, commercial catch rates have declined significantly [9], and Lovett et al. [8] estimated that, in 2019, the spawning biomass ratio (SBR) of the pearl perch biological stock was 22% of prefishing levels. A previous stock assessment indicated that knowledge of the reproductive biology of pearl perch would be beneficial for managing the species in Queensland [10]. In some instances, spawning closures have been shown to benefit other overexploited demersal species [11] such as red hind (*Epinephelus guttatus*, Linnaeus, 1758) [12, 13], mutton snapper (*Lutjanus analis*, Cuvier, 1828) [14], and Nassau grouper (*Epinephelus striatus*, Bloch, 1792) [15]. However, the efficacy of spatial and temporal closures is contingent on adequate knowledge of when and where fish spawn. The reproductive strategies of pearl perch are poorly understood and the lack of spawning animals in fishery-dependent samples prompted Stewart et al. [1] to hypothesise that pearl perch undertake spawning migrations. This hypothesis is yet to be confirmed.

Despite the lack of spawning females in fishery-dependent samples, previous research indicates that SST is likely to affect the intra-annular development of pearl perch ovaries. Temperature-driven ovary development is common and has been demonstrated in a number of demersal fish species including red snapper (*Lutjanus campechanus*, Poey, 1860) [16] and five-lined snapper (*Lutjanus quinquelineatus*, Bloch 1790) [17]. For example, the development of *C. auratus* ovaries in Western Australia is related to SST, with maximum GSI occurring between 19 and 21°C across a wide latitudinal (25.5°S–35.5°S) distribution [18]. Similarly, ovary development in *G. herbraicum* is influenced by SST, with reproductive development commencing when SST rises in November [19].

The aim of this study was to investigate the reproductive biology of pearl perch to better inform the management of the species in Queensland. Specifically, gonadosomatic index, length- and age-at-maturity, and batch fecundity were quantified using samples collected in central and southern Queensland between 2018 and 2022. The effect of sea surface temperature on ovary development was also assessed.

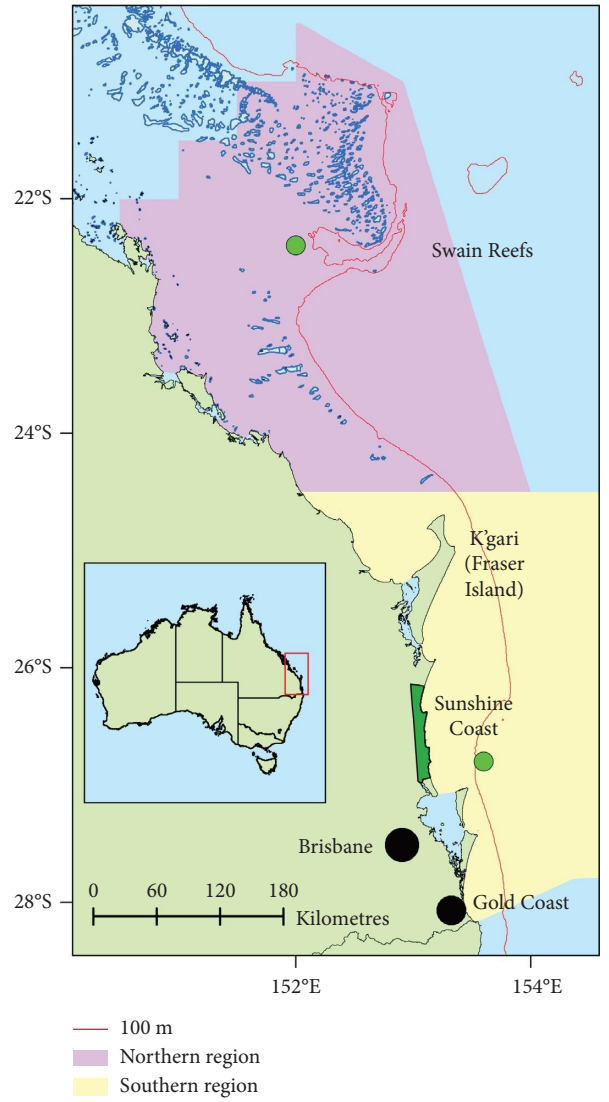

Figure 1: Spatial extent of the northern and southern regions from which pearl perch were caught between July 2018 and June 2022. The two green dots represent the locations used to assess the effect of sea surface temperature (SST, °C) on gonad development and are the approximate midpoint of locations from which pearl perch were sampled from the northern (22.4°S, 152°E) and southern (26.8°S, 153.6°E) regions.

2. Materials and Methods

2.1. Sampling. Pearl perch samples were collected from a combination of fishery-dependent and fishery-independent sources. Most samples were collected as part of FQ's routine fishery-dependent monitoring program between July 2018 and June 2022. Fish frames were either donated to FQ by commercial and recreational fishers or obtained from fish processors and wholesalers as filleted frames. The pearl perch examined were caught between central Queensland (Swain Reefs) and the Gold Coast in southern Queensland (Figure 1). Samples were frozen until processed by the FQ staff. These samples were supplemented by fishery-independent sampling conducted as part of the current study, which included the collection of fish under the minimum legal size (MLS) to reduce bias when estimating length- and age-at-maturity.

2.2. Laboratory Processing. In the laboratory, all pearl perch were thawed, sexed, weighed (±0.01 g, for whole fish only), and measured (fork length, FL, ±1 mm). After sagittal otolith pairs were removed to determine age and growth (see [4]), female ovary pairs were then removed, staged macroscopically (Table 1), and weighed (±0.0001 g). A section of some ovaries, classified as developed (Stage 4) and spawning (Stage 5), was removed and fixed in 10% neutral buffered formalin for estimates of batch fecundity.

2.3. Gonadosomatic Index. Gonadosomatic index (GSI) was calculated for females identified as stage 2 or higher using the equation $GSI = [W_o/W_t] * 100$, where W_o is the total weight (g) of both ovaries and W_t is the total weight (g) of the

Table 1: Macroscopic stages of pearl perch ovaries, adapted from the six macroscopic stages outlined by Mackie et al. [20] to include separate spawning (5) and spent (6) stages.

Stage	Classification	Description of ovaries
0	Unknown sex	Small translucent ribbons, sex indistinguishable
1	Immature	Ovaries thin and firm, pale or translucent pink
2	Resting	Ovaries more rounded, pale pink or red. No oocytes visible. Approximately 1/4–1/3 length of the body cavity
3	Developing	Ovaries enlarged, pale orange or pink, blood vessels noticeable. Oocytes visible, small. Approximately 1/3–2/3 length of the body cavity
4	Developed	Ovaries enlarged, orange or yellow but not speckled. Oocytes large and clearly visible
5	Spawning	Ovaries much enlarged, translucent pale orange. Hydrated clear oocytes visible giving speckled appearance. Blood vessels prominent
6	Spent	Ovaries bloody and flaccid

animal. For filleted fish collected from fishers and wholesalers, W_t was estimated from fork length using the equation $W_t = 0.04 + FL^{2.787} + \sigma$, where FL is the fork length (mm) and σ is the error from the regression [21].

2.4. Statistical Analyses. Generalised additive modelling (GAM) was used to examine factors affecting the GSI in pearl perch. These analyses were guided by previous work which used GAMs to examine reproductive periodicity [22]. Models were fitted using R statistical software (Version 4.2.1, R Foundation for Statistical Computing, Vienna, Austria; see https://www.R-project.org/, accessed 15 August 2022) via the "FSSgam" package ([23], https://github.com/beckyfisher/FSSgam, accessed 15 August 2022), with GSI as the gamma-distributed response variable. The GAM quantified changes in pearl perch GSI between years and months, and within months (lunar scale), and allowed for the inclusion of a spatial component to assess variation in GSI across their distribution. Preliminary analysis indicated temporal and spatial differences in reproductive activity, and, as such, the fishery was divided into two regions at the 24.5°S line of latitude. The effect of month (1 : 12, examining seasonal periodicity in GSI) was assessed via cyclic cubic splines. Lunar phase, a measure of the moon's brightness (0 is the new moon and 1 is the full moon), was modelled with cubic regression splines, and region (north or south, Figure 1) was included as a categorical factor. All variable interactions were considered to identify potential differences in month and lunar periodicity within and between regions. As this study had a large sample size ($n = 897$) and two continuous predictors, a maximum of three predictors were included. The number of knots (k) was restricted in all GAM fits to reduce overfitting by including unnecessary splines and providing an optimal smoothed relationship [22]. The most appropriate model was selected according to the Akaike information criterion (AIC) value and the coefficient of determination (R^2).

Given the association between sea surface temperature (SST) and GSI in *G. hebraicum* [19], the effect of SST on pearl perch GSI was assessed. It should be noted that SST was not included in the analysis above due to its dependence on both month and region and the need to retain month in the model to inform potential management changes to protect spawning pearl perch. Daily SST data, derived from observations from the advanced very high resolution radiometers (AVHRR) on board National Oceanic and Atmospheric Administration (NOAA) polar-orbiting satellites, were downloaded from the Integrated Marine Observing System (IMOS, https://imos.org.au/data) via the Australian Ocean Data Network (AODN) portal. The SST at two sites, representing the approximate midpoint of locations from which pearl perch were sampled from the northern (22.4°S, 152°E) and southern (26.8°S, 153.6°E) regions during the current study (Figure 1), were used to assess the effect of SST on GSI. This approach was required as the exact location of each catch was not provided by fishers when donating samples. The effect of mean daily SST on GSI was assessed via a second GAM (hereafter referred to as the "reduced GAM") in R using the "mgcv" package [24], where GSI was the response variable and SST was added as a continuous explanatory variable with a cubic regression spline.

2.5. Maturity. The length-at-maturity (L_{50}) and age-at-maturity (t_{50}) of female pearl perch were quantified using generalised linear modelling (GLM) in R, via a binomial distribution with a logit link function. Maturity (0 = immature, 1 = mature) was the response variable, and FL (mm) or adjusted age (in years) were added as continuous explanatory variables. Ages assigned by Campbell et al. [4] were adjusted for growth beyond the last complete opaque zone according to the marginal increment ratio (MIR): ages were increased by 0.33 year for otolith sections with $0 < \text{MIR} < 0.66$ and 0.66 year for sections with $\text{MIR} \geq 0.66$ [25]. All immature fish were collected during fishery-independent sampling conducted offshore from Brisbane and the Sunshine Coast (Figure 1), and as such, maturity was assessed for fish only caught in these areas to minimise any bias in the estimates of t_{50} and L_{50} resulting from the undersampling of immature animals in other areas. The age and length at 95% maturity (L_{95} and t_{95}) were also estimated.

2.6. Batch Fecundity. To obtain estimates of batch fecundity, samples were removed from female ovaries categorised as developed (Stage 4) or spawning (Stage 5) (Table 1). After

each gonad pair was weighed, three small masses of eggs were removed from connective tissue and placed in separate labelled 8 mm × 120 mm petri dishes and weighed (±0.0001 g). Each sample was examined with a Leica M6Z stereo microscope at a magnification of 8x, under reflected light on a Matt black background. A digital image of each sample was acquired with a Leica IC90 E digital camera. The acquired images were uploaded into the ImageJ software ([26], accessed 17 June 2022) to facilitate egg counts. Batch fecundity (B) was calculated as $B = [E_n/W_s] \times W_o$, where E_n is the number of eggs; W_s is the sample weight (g); and W_o is the total weight of both ovaries (g). This resulted in three measures of B for each gonad pair, from which a point estimate and a standard error were derived. The mean batch fecundity, as a function of fork length, was estimated in R via linear regression, after the natural logarithm transformation of each variable.

3. Results

3.1. Gonadosomatic Index. During this study, a total of 962 female pearl perch were assessed for reproductive activity. Of these, 897 were assessed for GSI (Figure 2). The 442 individuals caught in the southern region had a mean FL of 480 mm (S.E. = 4.0, range = 265–670 mm), whereas the 455 individuals caught in the northern region had a mean fork length of 486 mm (S.E. = 3.6, range = 319–680 mm). Two-sample t-tests indicated that this difference was not significant at the 95% level of confidence ($t = 0.99$, d.f. = 883.84, $P = 0.32$, Figure 2). The GAM indicated that month, lunar phase, and region explained some of the variation surrounding GSI ($R^2 = 13.4\%$, Figure 3). The interaction between month and region was also found to have significantly affected GSI for both the northern ($F = 10.04$, e.d.f. = 1.76, $P < 0.001$) and southern ($F = 32.26$, e.d.f. = 1.94, $P < 0.001$) regions (Figure 3).

The gonadosomatic index was the highest on the new moon in the southern region, while lunar phase had no effect on GSI in the northern region. The mean GSI was found to increase in the spring in the northern region, reaching a peak in summer (December and January). In contrast, the mean GSI increased through summer in the southern region, with a peak in April.

The sea surface temperature was the highest in the northern region (Supplementary Figure 1). The mean daily SST at the northern point (Figure 1) over the period of interest was 25.0°C (S.D. = 2.36°C), compared to 23.6°C (S.D. = 2.22°C) at the southern point. Two-sample t-tests indicated that this difference was significant at the 95% level of confidence ($t = 16.81$, d.f. = 2927, $P < 0.001$). Throughout the sampling period, SST was lowest in August or September in both regions and highest in February, March, or April. The reduced GAM indicated that SST significantly affected GSI ($F = 52.04$, e.d.f. = 1.97, $P < 0.001$), with mean GSI >2% when SST was 25.26–26.32°C (Figure 4).

Peaks in mean GSI in each region coincided with a higher proportion of females with spawning and spent ovaries (Stages 5/6, Figure 5). Females with spawning ovaries were caught in April, May, June, and December in the southern region and in September, October, and November in the northern region. Female pearl perch with developing ovaries were observed in each month in the southern region, while females with developing ovaries were observed in all months in the northern region except April; however, the sample size was low in that month ($n = 7$, Figure 5).

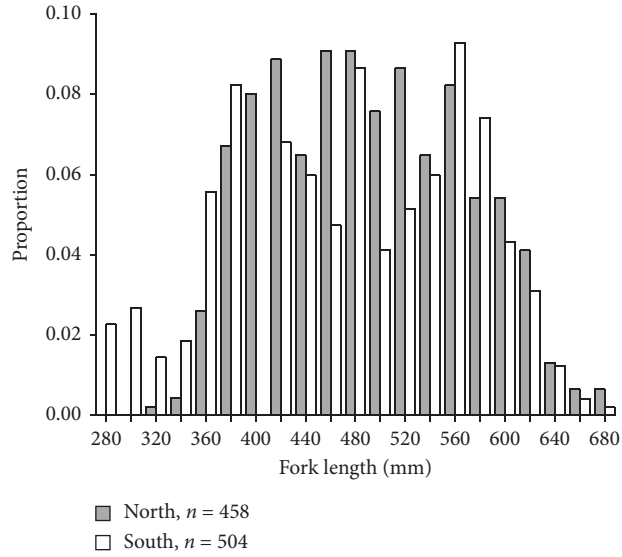

Figure 2: Length frequency (FL, mm) distribution of 962 female *Glaucosoma scapulare*, 458 from the northern region and 504 from the southern region (split at the 24.5° South line of latitude), assessed for their reproductive biology in Queensland, Australia.

3.2. Maturity. Of the 281 animals used to assess length- and age-at-maturity, 200 were mature and 81 were immature. The logistic regressions indicated the length- and age-at-maturity of female pearl perch were $L_{50} = 353$ mm FL ($CI_{\alpha=0.05} = 338$–366 mm FL) and $t_{50} = 4.42$ years ($CI_{\alpha=0.05} = 4.04$–4.77 years), respectively (Figure 6). Further, the length and age at which 95% of females were mature were $L_{95} = 427$ mm ($CI_{\alpha=0.05} = 408$–457 mm FL) and $t_{95} = 6.79$ years ($CI_{\alpha=0.05} = 6.25$–7.62 years), respectively.

3.3. Batch Fecundity. Batch fecundity was estimated from 41 females with a mean FL of 506 mm (S.E. = 16.2, range = 283–640 mm). Fecundity estimates ranged from ~99,694 eggs for a 293 mm FL female to ~3,057,836 eggs for a 540 mm FL female, with a mean of 893,020 (S.E. = 98,360) eggs per female. Batch fecundity (B) was positively correlated ($t = 6.574$, d.f. = 39, $P < 0.001$) to FL and this relationship was estimated to be $\ln(B) = 2.4462 \times \ln(\text{FL}) + 3.8951$ ($R^2 = 0.53$) (Figure 7).

4. Discussion

Pearl perch spawning varies temporally and spatially throughout their distribution in Queensland. The maximum mean GSI was found to coincide with SSTs of 25.26–26.32°C, which mainly occur between October and December in the northern region and between February and April in the

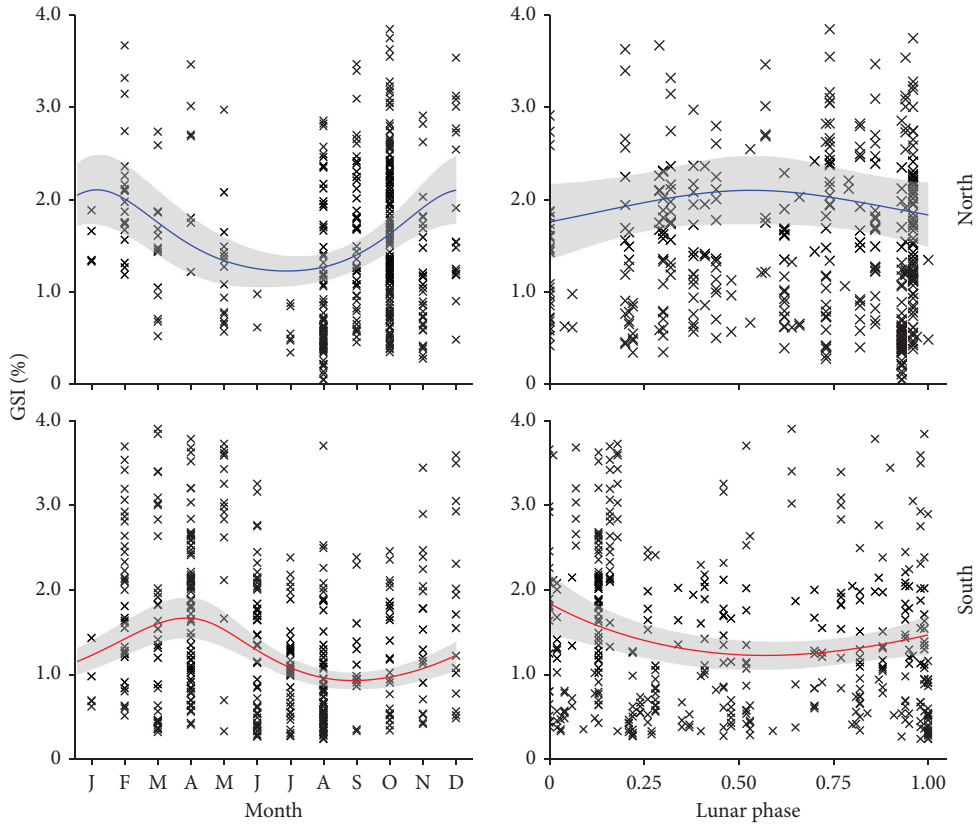

FIGURE 3: Mean monthly gonadosomatic index (GSI, %) for female *Glaucosoma scapulare* as a function of region, month, and lunar phase quantified using generalised additive modelling (GAM). The solid lines represent mean GSI from the GAM using the best model identified in the analyses. The grey ribbons are 95% confidence intervals. Observed values are shown as crosses. Note: GSI was examined for mature females (>Stage 2, Table 1) only.

southern region. The presence of female pearl perch with spawning ovaries in samples from the respective regions at these times is further evidence that SST influences spawning. This result is consistent with that of Lenanton et al. [19] who reported similar observations for *G. hebraicum*, with GSI increasing as SST increased during the austral spring. A female pearl perch with spawning ovaries caught in December 2021 in the southern region (Figure 5) was caught on a day where SST was 25.4°C. A SST of 25.26–26.32°C occurred between December 2021 and May 2022 (Supplementary Figure 1), indicating that spawning may have occurred over a protracted period.

While this study represents an important step in understanding the effects of SST on spawning periodicity in pearl perch, other environmental factors may also be influential (e.g., availability of spawning habitat). Further, social cues might influence the timing of spawning for pearl perch, as has been observed in *G. hebraicum* [27]. Thus, fish caught from a discrete pearl perch aggregation in any given month may not be representative of the spawning condition of fish in other aggregations located within that region. Considerable effort and expense would be required to test the presence of such complex interactions between environmental and behavioural factors affecting ovary development in pearl perch.

Similar to *G. hebraicum* [6, 19], female pearl perch with spawning (Stage 5) and spent (Stage 6) ovaries occurred over several months in both regions, although the number of females with spawning ovaries was low ($n = 13$). The presence of both hydrated eggs and postovulatory follicles in reproductively active ovaries indicates pearl perch are serial spawners, which is also consistent with *G. hebraicum* [6]. Female pearl perch with spawning ovaries were caught when mean monthly GSI was either increasing or decreasing, indicating that some portion of the spawning biomass was able to spawn outside of the period when mean GSI was at a maximum. This is consistent with results reported for *G. hebraicum* by Hesp et al. [6], who observed that some individuals spawned in November despite the mean GSI of female fish being well below its maximum. Furthermore, a high proportion of female pearl perch had non-reproductive ovaries (Stages 2 and 3) throughout the spawning period in the respective regions, a life history strategy that is also employed by *G. hebraicum* [19]. On completion of the spawning season, GSI decreased and was the lowest when SST was approximately 21°C. At this time, the proportion of resting (Stage 2) and developing (Stage 3) ovaries was highest. As SST increased from its minimun, GSI also increased, as did the proportion of developed (Stage 4) and spent (Stage 6) ovaries.

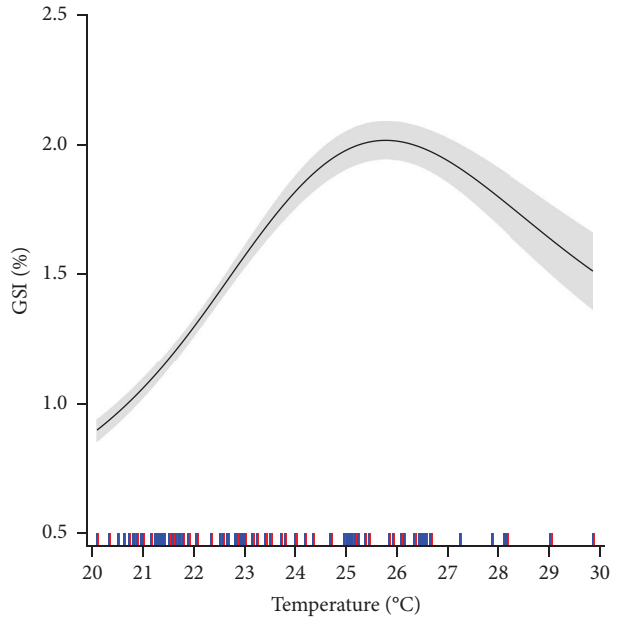

FIGURE 4: Mean gonadosomatic index (GSI, %) as a function of sea surface temperature quantified using a generalised additive model (GAM). GSI was the gamma-distributed response variable and daily sea surface temperature (SST) was added as a continuous explanatory variable with a cubic regression spline. The blue and red ticks along the *x*-axis represent the SST of GSI observations from the northern and southern regions, respectively, and the grey band represents the 95% confidence interval. Note: GSI was examined for mature females (>Stage 2, Table 1) only.

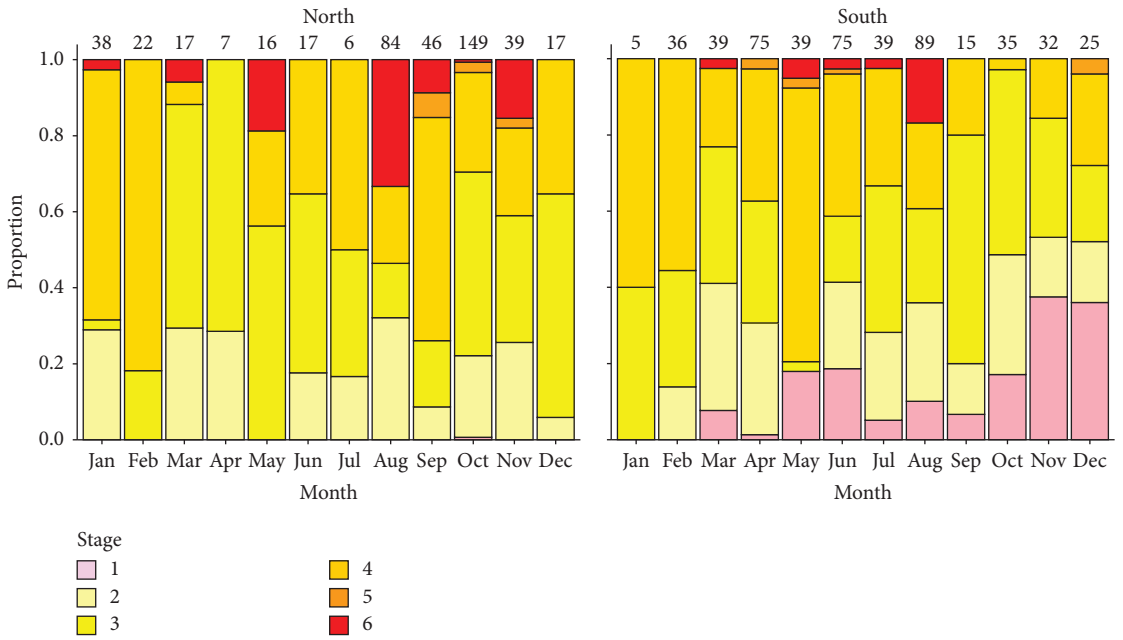

FIGURE 5: Gonad stage (Table 1) of female *Glaucosoma scapulare* as a function of month and region between June 2018 and June 2022. Numbers above each bar represent the number of females sampled in each month.

The low number of females with spawning ovaries observed in the current study is potentially a result of the opportunistic nature of the sampling undertaken. Samples were provided by fishers who were constrained by weather and market forces, including targeting other species, which may have prevented fishers from accessing the fishing grounds during peak spawning periods. Increasingly stringent management interventions have also prompted both commercial and recreational fishers to disengage with the FQ monitoring program, including some fishers who specialise in targeting pearl perch aggregations north of K'gari (A. Garland, Fisheries Queensland, pers. comm.).

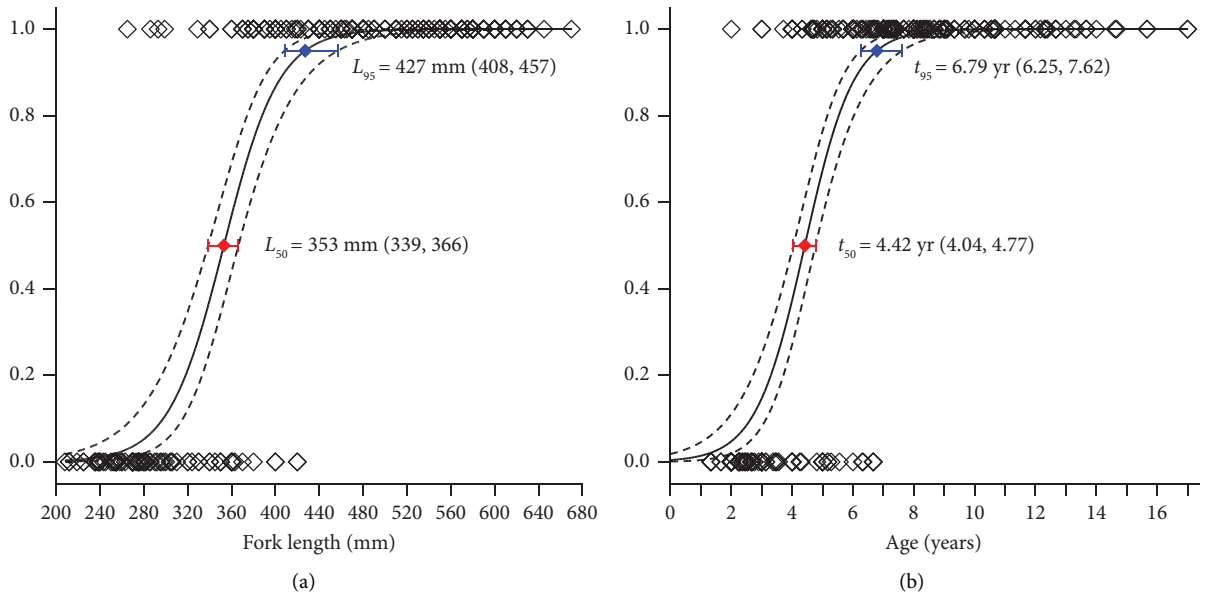

FIGURE 6: (a) Length-at-maturity (mm fork length) and (b) age-at-maturity (years) for 281 female *Glaucosoma scapulare* caught in southern Queensland. Dashed lines represent 95% confidence intervals. Hollow diamonds represent the observed data, where 0 = immature and 1 = mature. The red point represents the length at which 50% of females are mature (t_{50}, L_{50}) and the blue point represents the length at which 95% of females are mature (t_{95}, L_{95}). Horizontal error bars represent the 95% confidence intervals of the respective point estimates.

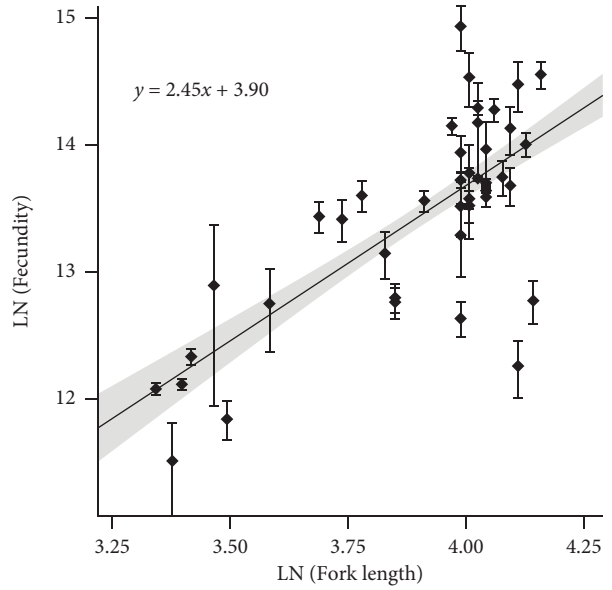

FIGURE 7: Batch fecundity as a function of fork length (in mm) for 41 *Glaucosoma scapulare*. The dashed lines represent 95% confidence intervals, and the error bars are the standard error around the mean of three measures of batch fecundity from each ovary.

This, combined with the effects of the COVID-19 pandemic, significantly restricted the number of samples with which to assess reproductive activity throughout the current study. In addition, the opportunistic nature of the fishery-dependent sampling herein likely introduced some sampling bias. For example, a single fisher may have contributed a large number of pearl perch, caught from a single location, which would bias both GSI and gonad stage proportion for the month in which the sample was caught.

Female pearl perch with spawning ovaries were found in samples collected to the east and north of the traditional fishing grounds in southern Queensland and northern New South Wales. Prior to 2008, no female pearl perch with spawning ovaries were observed in fishery-dependent samples [1], which led these authors to hypothesise that pearl perch migrate to spawn. However, at the time the study by Stewart et al. [1] was conducted, the MLS in Queensland and New South Wales was 300 mm TL

(286 mm FL). As a result, a high proportion of the fish sampled by these authors were smaller and younger than the length- and age-at-maturity, respectively, estimated herein. Further, the Queensland pearl perch sampled by Stewart et al. [1] were caught primarily by fishers targeting snapper on the heavily fished inshore (<100 m) grounds south of K'gari (Figure 1), during the snapper spawning season (June–September, [28]), when pearl perch GSI is at its lowest and SST is ~19–21°C. The results from our study indicate that female pearl perch with spawning ovaries were very unlikely to occur in the samples obtained by Stewart et al. [1].

Sumpton et al. [7] were the first to observe female pearl perch with spawning ovaries, which were caught by fishers operating in the area between the Swain Reefs and K'gari, and in the deeper waters offshore of the Sunshine Coast (Figure 1). Fishers operating in these areas in the early 2000s located aggregations of pearl perch of a size and age not previously observed in fishery-dependent samples, some of which were females with spawning ovaries. These areas had received low levels of fishing effort prior to 2000, compared to areas in southern Queensland adjacent to the Sunshine Coast, Brisbane and the Gold Coast (Figure 1). Increasing effort in areas that were previously lightly fished has resulted in a higher proportion of larger fish (>500 mm FL) in commercial catch samples obtained by the FQ monitoring program (see Figure D3, [8]) and the length frequency of fish herein.

Our results indicate that pearl perch mature at a larger size than previously assumed. Sumpton et al. [7] reported that L_{50} was 250–275 mm TL; however, their estimate was based primarily on fishery-dependent sampling that precluded the collection of smaller, immature pearl perch, resulting in a biased estimate of L_{50}. Similarly [6], estimated the L_{50} of *G. hebraicum* based primarily on samples provided by commercial and recreational fishers and estimated a L_{50} for females and males of 301 mm TL and 320 mm, respectively, with only 16 of the 552 (3%) individuals <300 mm TL. Such bias was somewhat overcome in our study as we estimated L_{50} from the 281 individuals caught offshore from Brisbane and the Sunshine Coast, which included 81 immature fish (~29%) caught in the current study under permit.

Batch fecundity of female pearl perch increases with fork length; larger individuals produce more eggs, which is consistent with *G. hebraicum* [19]. Maximum estimates of batch fecundity derived herein exceed previously published estimates for any glaucosomatid. Maximum batch fecundity for pearl perch was estimated at ~720,000 eggs [21] and at 533,900 eggs for *G. hebraicum* [19]. The results presented here indicate that larger females produce more eggs than do smaller fish, and protections for these larger animals during spawning may be beneficial to increasing egg production [29]. The introduction of a maximum legal size may benefit the pearl perch stock given the species' high post-release survival [30]. This strategy is currently used in Queensland for commercially and recreationally important species such as dusky flathead (*Platycephalus fuscus*) and barramundi (*Lates calcarifer*).

The pearl perch spawning biomass is currently estimated to be 22%, compared to prefishing levels [8]. In response to declining spawning biomass, Fisheries Queensland introduced management changes in 2019, designed to prevent further declines and decrease fishing mortality. These changes included an annual total allowable commercial catch (TACC) of 15 t, a small increase in the MLS from 350 mm TL to 380 mm TL, a decrease in the recreational in-possession limit from five to four, and an annual closure for all sectors between July 15 and August 15. Our results indicate the current annual closure is unlikely to protect spawning pearl perch: this closure was primarily implemented to reduce the fishing mortality of snapper during its peak spawning period of July and August [28], when aggregations of spawning fish are targeted due to increased catchability, and large catches are possible [27, 31]. The retention of pearl perch during this period was also prohibited to minimise the incidental capture of snapper by fishers targeting pearl perch on grounds where both species occur. Most stakeholders understand the need for protection during spawning and, in Queensland, species such as tailor (*Pomatomus saltatrix*), barramundi (*Lates calcarifer*) and coral trout (*Plectropomus* spp.) have spatial and/or temporal spawning closures in place as protection from overexploitation during spawning periods. However, fishers are likely to question the benefits of a spawning closure if the species spawns at times outside the temporal closure as is the case currently for peal perch. Our results indicate that an effective spawning closure for pearl perch would need to vary in both time and space.

5. Conclusions

Pearl perch are a commercially and recreationally important species caught by rod and reel in Queensland. Improvements in fishing power in the early 2000s facilitated the expansion of the pearl perch fishery to the north and east of traditional fishing grounds south of K'gari. This expansion resulted in the presence of female pearl perch in fishery-dependent samples that were older and larger than those previously sampled. Pearl perch collected between 2018 and 2022 indicated that spawning varies spatially and temporally and is influenced by sea surface temperature: the mean gonadosomatic index was the highest when SST was 25.26–26.32°C. Pearl perch were found to mature at around 4.4 years of age and 353 mm FL. These results suggest that potential management changes to protect spawning pearl perch include altering the current annual closure to coincide with spawning across their distribution or introducing a maximum legal size.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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Supplementary Materials

Supplementary Figure 1: Daily sea surface temperature (SST, open diamonds) at two sites, representing the approximate midpoint of locations from which pearl perch were sampled from the northern (22.4°S, 152°E) and southern (26.8°S, 153.6°E) regions (see Figure 1), for the period 1 January 2018 to 29 November 2022. The semitransparent green bands represent the SST range 25.26–26.32°C, when GSI was >2%. The blue lines are loess smoothing curves, and the red vertical lines represent the first day of each year. (*Supplementary Materials*)

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