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Improving estimates of growth for pearl perch (*Glaucosoma scapulare*) in Queensland, Australia

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Abstract

The pearl perch (*Glaucosoma scapulare*) is endemic to the east coast of Australia in depths to 150 m. The species has a long history of exploitation, and the stock is currently depleted. Previous research indicated the species is long lived and slow growing based on fishery-dependent sampling undertaken in the late 1990s and early 2000s on traditional fishing grounds at the southern end of the species' range. Increasing fishing power has facilitated the expansion of the fishery to areas to the north and east of traditional grounds, which has resulted in the appearance of older fish (>10 yr) in fishery-dependent samples not previously observed. The current study estimated the growth parameters using 1153 length-at-age observations from fish collected in Queensland between January 2020 and December 2021. The lack of significant numbers of individuals at either end of the age frequency distribution necessitated the estimation of growth in a Bayesian framework with informative priors for length-at-age-zero and maximum length using a multi-model approach. The von Bertalanffy growth function (VBGF) was found to best fit the observed length-at-age data and the estimated VBGF parameters were $L_\infty = 562$ mm FL, $L_0 = 2.02$ mm FL and $k = 0.295$ yr^{-1}. The high proportion of older fish in samples, combined with prior information on relevant parameters, improves growth parameter estimation by reducing bias and facilitating improved model fits to observed length-at-age data.

KEYWORDS
Bayesian framework, *Glaucosoma scapulare*, growth, length-at-age, life history, pearl perch

1 | INTRODUCTION

The pearl perch (*Glaucosoma scapulare*) is endemic to the east coast of Australia between Rockhampton (23°20′S) and Port Jackson (33°50′S) (McKay, 1997. Along with three other species (*G. hebraicum*, *G. magnificum* and *G. buergeri*), pearl perch are classified within the family Glaucosomatidae, all of which occur in the Indo-Pacific region (McKay, 1997). McKay (1997) stated pearl perch were found to depths of 90 m; however, Sumpton et al. (2013b) indicate that pearl perch are caught in depths to at least 150 m in Queensland. Apart from submerged rocky reef areas (McKay, 1997), the species is known to aggregate over shipwrecks, gravel substrates and adjacent areas, particularly those where gorgonian sea whips, colloquially known as 'wire weed', occur (Grant, 2004).

Pearl perch are considered excellent table fish (Grant, 2004; McKay, 1997) and, consequently, the species is a target for both commercial and recreational fishers. The species has a long history of exploitation (Stewart et al., 2013) and were likely caught incidentally by recreational anglers targeting snapper (*Chrysophrys auratus*) in southern Queensland in the late 1880s (Thurstan et al., 2016). Pearl perch are primarily caught by line fishers using rod-and-reel, and an increasing number of fishers are now using either electric or hydraulic reels in deeper offshore waters (Sumpton et al., 2013b). The line fishery accounts for most of the fishing mortality applied to the stock; however, an unknown amount of discard mortality results from the incidental capture of juveniles in trawl (Courtney et al., 2007; Rowsell & Davies, 2012) and crab (*Portunus armatus*) (Sumpton et al., 2003) fisheries.

Despite the long history of exploitation of pearl perch throughout its distribution, there is scant biological information on the species in the primary literature. Stewart et al. (2013) examined the growth of pearl perch using fishery-dependent samples, supplemented by samples of small fish collected by a research trawl vessel. These authors reported that pearl perch are long lived and slow growing, a life history strategy consistent with its congeners *G. hebraicum* (Hesp et al., 2002) and *G. buergeri* (Newman, 2002). Further, Stewart (2011) demonstrated that the age distributions of fishery-dependent samples of pearl perch were truncated, suggesting that exploitation had removed the older animals from the population. Finally, Campbell et al. (2014) quantified the post-release survival of line-caught pearl perch and, in contrast to results reported by St. John and Syers (2005) for *G. hebraicum*, found that pearl perch are resilient to catch-and-release.

The pearl perch stock is currently classified as depleted by the Status of Australian Fish Stocks report (SAFS, https://fish.gov.au/report/336-Pearl-Perch-2020), which states that fishing mortality exceeds sustainable levels. In Queensland, logbook data (available at https://qfish.fisheries.qld.gov.au/) indicate that commercial harvest has decreased from a peak of ~96 t in 2005 to ~14 t in 2019, a decrease of ~85%. In the same period, commercial harvest rates of pearl perch decreased from ~17.5 to ~6 kg boat^{-1} day^{-1} (Wortmann, 2020). Similarly, the number of pearl perch retained by recreational fishers in Queensland decreased from 54,000 in 2000–2001 to 15,000 in 2019–2020 (data available at: https://www.daf.qld.gov.au/business-priorities/fisheries/monitoring-research/monitoring-reporting/statewide-recreational-fishing-surveys/dashboard). A recent stock assessment (Lovett et al., 2022) indicated that these declines have coincided with a reduction in spawning biomass, compared with pre-fishing levels. This stock assessment used length and age data obtained as part of a routine monitoring program conducted by the Queensland government's fisheries management agency, Fisheries Queensland (FQ). Since 2006, FQ have collected biological information with which to assess stock status and develop future harvest strategies for a range of rocky reef-associated species in Queensland, including pearl perch. Biological samples for age determination are primarily in the form of filleted fish carcasses, donated by commercial and recreational fishers or collected at seafood wholesale outlets.

Prior to 2010, the age frequencies of fish collected by FQ were truncated as described by Stewart (2011), with very few fish >10 yr in age (see Lovett et al., 2022, Figure D.7, p. 47), despite a lifespan of at least 19 yr (Stewart et al., 2013). In recent years, however, the routine monitoring undertaken by FQ has collected significant numbers of pearl perch at ages not previously observed in fishery-dependent samples. An increasing number of samples have come from waters >100 m depth in the area south of Fraser Island, particularly offshore of traditional fishing ports such as Mooloolaba on the Sunshine Coast (Figure 1). The presence of these older fish in samples is likely to affect the estimates of the growth parameters used in stock assessments and, therefore, the aim of the current study was to update the growth estimates of pearl perch in Queensland previously reported by Stewart et al. (2013) and Sumpton et al. (2013a). To overcome bias resulting from the under-sampling of individuals at either end of the age distribution, growth parameters were estimated in a Bayesian framework using prior information for length-at-age-zero and maximum length.

2 | MATERIALS AND METHODS

Specimens of pearl perch were collected as part of FQ's routine fishery monitoring program between January 2020 and December 2021. Samples were either donated by commercial and recreational fishers or collected at seafood wholesale outlets and stored in freezers located at the EcoSciences Precinct in Brisbane, Queensland. The objective of this sampling is to collect fish that are representative of total harvest and samples are collected throughout the pearl perch distribution in Queensland, between the Swain Reefs in the north and the Queensland/New South Wales border (Figure 1). This sampling was supplemented by fishery-independent samples collected in the same time period. As part of this fishery-independent sampling, sub-legal fish were collected under permit in an attempt to inform the lower end of the growth function herein.

2.1 | Laboratory processing

All pearl perch individuals were thawed, sexed and measured (fork length, FL, ±0.1 cm). Sagittal otolith pairs were removed from each individual, cleaned, wiped dry and placed into labelled vials. After drying, the left otolith was embedded in polyester resin and sectioned with a Buehler IsoMet Low Speed cutting saw (www.buehler.com/isoMet-low-speed-cutter.php), at a width of 350 μm, and mounted on a microscope slide. Each otolith section was examined with a Leica M6Z stereo microscope (www.leica-microsystems.com/products/stereo-microscopes-macroscopes/p/ leica-mz6/) at a magnification of 8×, under reflected light on a matt black background. A digital image of the section was acquired with a Leica IC90 E digital camera (www.leica-microsystems.com/products/microscopecameras/p/leica-ic90-e/).

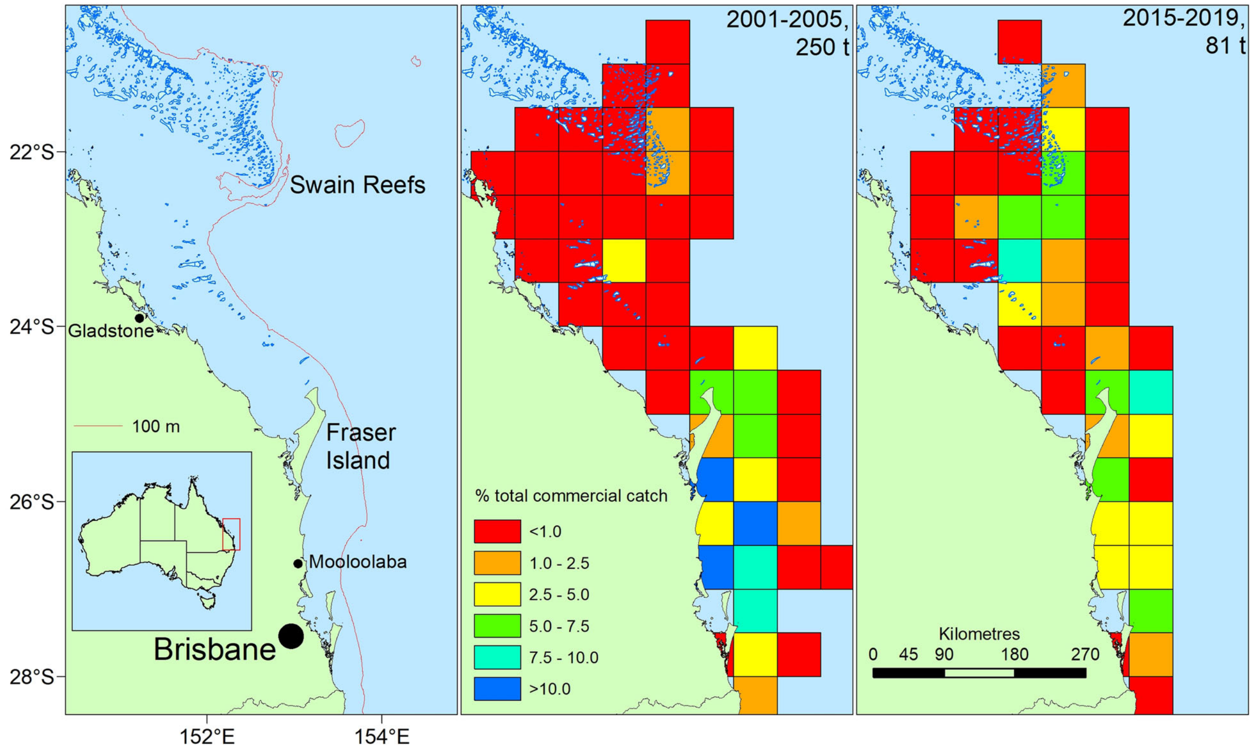

FIGURE 1 Spatial extent of the study area from which pearl perch were collected between January 2020 and December 2021. Also shown is the percentage of the commercial harvest in each 30-min × 30-min reporting grid for the periods 2001–2005 and 2015–2019.

2.2 | Ageing

The protocol used to interpret age for pearl perch was similar to that used by Stewart et al. (2013). The age of each individual was based on increment count, equal to the number of opaque zones visible along the dorsal sulcul ridge between the primordium and the otolith edge. Age was determined without prior knowledge of the length, sex or capture date of the individual. Readability of each section was based on a qualitative assessment of the reader's confidence in their interpretation, similar to the assessment described by Officer et al. (1996).

Prior to interpreting the otoliths in the current study, familiarisation of the incremental macrostructure of pearl perch was undertaken with the use of a reference collection. Subsequently, the reader's competency was tested with species-specific qualification criteria, which prevents long-term drift in interpretation of the otoliths ensuring consistency of age estimation over time by experienced readers. Once competency was achieved all otoliths were read. After the first read of all otoliths, a sub-sample of 500 was randomly selected and aged again by the same reader to provide a measure of consistency between reads. Bias and precision were tested using: (1) percent agreement, (2) average percent error (APE; Beamish & Fournier, 1981) and (3) average coefficient of variation (ACV; Chang, 1982). Further, Bowker's test of symmetry was used to assess bias between reads.

2.3 | Marginal increment ratio

To determine the periodicity of opaque zone formation, marginal increment ratio (MIR) was calculated following Natanson et al. (1995), who defined MIR as $MIR = (OR - OR_n)/(OR_n - OR_{n-1})$, where OR is the otolith radius, OR_n is the radius of the final complete opaque zone and OR_{n-1} is the radius of the penultimate complete opaque zone. In accord with Stewart et al. (2013), MIR was calculated only for animals aged ≥4 years. Following Simpfendorfer et al. (2000), MIR was compared between months using the Kruskal–Wallis one way analysis of variance on ranks.

Edge type was qualitatively assessed to provide further evidence of opaque zone formation periodicity (Cailliet et al., 2006) and was classified into three levels, namely, 'new', 'intermediate' and 'wide'. A 'new' edge was one where an opaque zone occurred at the distal edge of the sectioned otolith, irrespective of the width of the opaque band. The edge of an otolith section with a continuous band of translucent material visible beyond the last complete opaque zone was categorised as 'intermediate' (i.e., MIR > 0). An edge was classified as 'wide' where the width of the translucent zone beyond the last complete opaque zone was equal to or more than 2/3 of its expected width when fully complete (i.e., MIR ≥ 0.66). A chi-square test was used to compare the observed frequency of each edge type, as a function of month, with the expected frequencies. In this case, the null hypothesis of the test was that the frequency of edge type was not dependent on month of capture.

TABLE 1 Equations of the three candidate growth functions used to assess the growth of pearl perch ($n = 1153$)

Model	Growth function
Von Bertalanffy	$L_t = L_0 + (L_\infty - L_0)\left(1 - e^{-kt}\right)$
Gompertz function	$L_t = L_0 \times e^{\left(Ln\left(\frac{L_\infty}{L_0}\right)\left(1 - e^{-g_1 t}\right)\right)}$
Logistic function	$L_t = \frac{L_\infty \times L_0\left(e^{(g_2 t)}\right)}{L_\infty \times L_0\left(e^{(g_2 t - 1)}\right)}$

L_t is the length at age t (years); L_∞ is the asymptotic length (in mm); L_0 is the length at $t = 0$ (in mm); and k, g_1 and g_2 are coefficients (year^{-1}) of the respective growth functions to be estimated.

2.4 | Growth

Three growth functions were used to estimate mean length-at-age: von Bertalanffy growth function (VBGF), Logistic growth function and Gompertz growth function (Table 1) (Smart et al., 2016). In all cases, the length-at-age-zero (L_0) was estimated rather than the age-at-zero-length (t_0). Growth was estimated in a Bayesian framework using Markov chain Monte Carlo (MCMC) using the 'BayesGrowth' package (Smart, 2020, accessed 11 July 2022) in R statistical software (Version 4.0.2, R Foundation for Statistical Computing, Vienna, Austria, see https://www.R-project.org/, accessed 11 July 2022), in accord with methods described by Smart and Grammer (2021). Four MCMC chains with 10,000 simulations, with a burn in period of 5000 simulations, were used to determine parameter posterior distributions. Model convergence was assessed using the Gelman-Rubin test and diagnostic plots generated using the 'Bayesplot' package (Gabry, 2020, accessed 11 July 2022) in R.

Models were fit to length-at-age data for both sexes combined, females only and males only. Each model was fit with a normal residual error structure (σ). The prior distribution of the L_∞ parameter of each growth function was $L_\infty \sim N(700, 35)$ based on a maximum size of 700 mm TL (McKay, 1997). The prior distribution of the L_0 parameter was $L_0 \sim N(2, 0.02)$ in accord with Stewart et al. (2013). A non-informative prior was used for σ and a common non-informative prior was used for the growth coefficients of the three candidate models (k, g_1 and g_2; Table 1). An upper bound was nominated for the uniform distributions of σ and k of 150 and 0.8 yr $^{-1}$, respectively. The common non-informative prior for the growth coefficients allowed for comparison of the three candidate growth functions, each with identical priors. Leave-one-out-information-criterion weights (LOOICw), calculated within the 'BayesGrowth' package using the 'loo' R package (Vehtari et al., 2020), were used to determine the most appropriate candidate model. As with the Akaike weights in the frequentist approach, the candidate model with the highest LOOICw was considered the most appropriate. Credible intervals were calculated using the 'Calculate_MCMC_growth_curve' function within the 'BayesGrowth' package, based on the 95% MCMC parameter percentiles.

Differences in growth parameters between sexes were assessed by comparing 10,000 posterior estimates of L_∞, k and L_0 of each sex. A frequency histogram of a vector, representing the difference between the two vectors of interest (e.g., male L_∞ and female L_∞), was generated and a significant difference was detected if zero was not within the 95% confidence interval of the distribution of this vector (Campbell and Rigby, 2022).

3 | RESULTS

During the 2020 and 2021 calendar years, FQ collected 755 pearl perch with which to estimate growth and the fishery-independent sampling component provided a further 405 individuals. Of these, age could not be determined for seven individuals, resulting in a total of 1153 length-at-age observations (Table 2 and Figure 2). Two-sample t-tests indicated that there was no significant difference in either length ($t = -0.300$, d.f. = 951.82, $p = 0.764$) or age (on log scale, $t = -1.716$, d.f. = 963.14, $p < 0.086$) as a function of sex, at the 99% level of confidence. The sex of 91 animals was indeterminable because they were either immature or the gonads were absent when processed.

Of the 500 otoliths used to assess bias, three were classified as unreadable and were excluded from the analysis. Generally, ageing between reads was consistent ($n = 497$, agreement = 79.07%, APE = 1.95, ACV = 2.76), with the age bias plot showing little variation from the 1:1 line of equivalence (Figure 3). Further, Bowker's test of symmetry showed no between-reads bias ($\chi^2 = 41.82$, d.f. = 29, $p = 0.058$) at the 95% level of confidence. The oldest individual collected was a 27-yr-old female with a length of 620 mm FL and the oldest male was 19 yr old and 590 mm FL.

MIR was highest during the austral winter (Figure 4) and the Kruskal–Wallis test on ranks indicated that MIR varied significantly between months ($\chi^2 = 59.197$, d.f. = 11, $p < 0.001$). Mean MIR increased from February, peaked in the winter, before decreasing through the spring and early summer. The lowest mean MIR occurred in February. New edges were most likely to occur in summer and the frequency of edge type differed significantly as a function of month ($\chi^2 = 62.983$, d.f. = 11, $p < 0.001$).

The VBGF was found to best fit all length-at-age datasets (Table 3; LOOICw = 1). There was no support for either the Logistic (LOOICw = 0) or the Gompertz (LOOICw = 0) growth functions. The growth parameters did not differ significantly as a function of sex (Figure S1) and the estimated VBGF parameters were $L_\infty = 562$ mm FL, $L_0 = 2.02$ mm FL and $k = 0.295$ yr^{-1} (Figure 5).

4 | DISCUSSION

The results from the current study demonstrate that pearl perch are a relatively long-lived species. The longevity of pearl perch (~27 yr) is similar to that reported for *G. buergeri* (Newman, 2002) but shorter

TABLE 2 Summary statistics for the 1153 pearl perch collected between January 2020 and December 2021 in Queensland to determine growth

Sex	*n*	Fork length (mm)			Age (years)		
		Mean	S.D.	Range	Mean	S.D.	Range
All	1153	455	99	208–680	6.89	3.46	1–27
Females	615	460	96	208–680	7.17	3.55	1–27
Males	447	459	98	208–680	6.78	3.29	1–19
Unknown	91	404	110	210–650	5.52	3.37	1–20

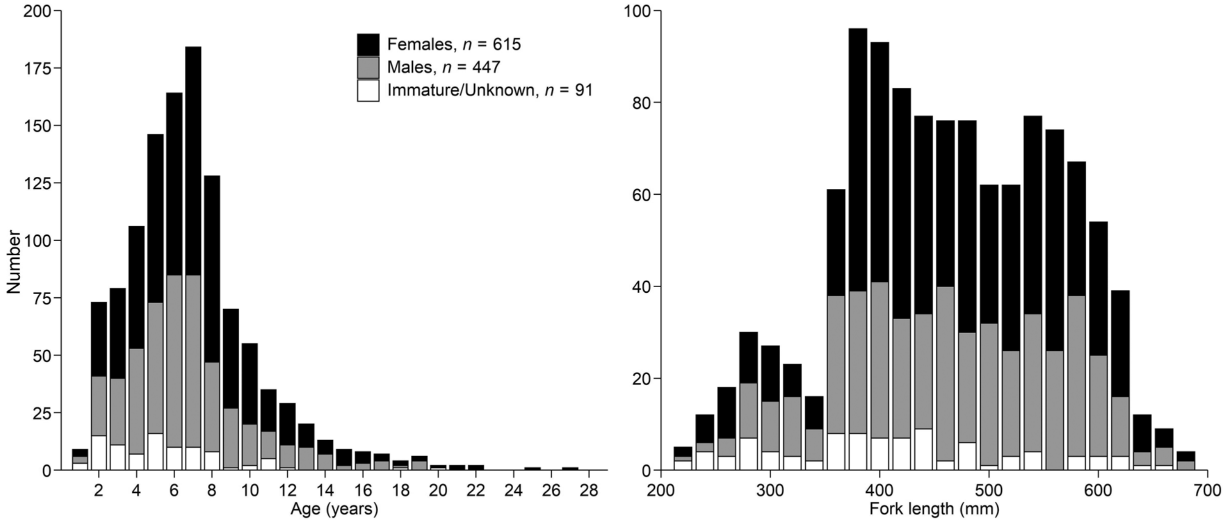

FIGURE 2 Age frequency and length frequency of the 1153 pearl perch collected between January 2020 and December 2021 in Queensland to determine growth

TABLE 3 Parameter estimates representing the mean values of the posterior distributions of the respective parameters

Growth function	LOOIC	LOOICw	L_∞ (mm)	k/g (yr^{-1})	L_0 (mm)	σ
von Bertalanffy	12,866	1	562	0.29	2.02	64.05
			(551–572)	(0.28–0.31)	(1.63–2.41)	(61.49–66.77)
Gompertz	13,852	0	499	0.89	2.41	75.36
			(493–505)	(0.85–0.93)	(2.05–2.79)	(72.32–78.54)
Logistic	19,630	0	763	0.50	11.29	79.93
			(741–777)	(0.48–0.52)	(11.03–11.56)	(72.99–86.93)

Numbers in parentheses are the 95% credible intervals from their posterior distributions generated by the 'BayesGrowth' package via R statistical software.
Note: LOOIC is the leave-one-out-information-criterion; LOOICw is the LOOIC weights; L_∞ is the asymptotic length; L_0 is the length at $t = 0$; k/g is the growth coefficient of the respective functions (Table 1); and σ is the estimated residual error.

than the largest glaucosomatid, *G. hebraicum*, at 41 yr (Hesp et al., 2002). However, the results also indicate that pearl perch reach asymptotic size faster than previously assumed and the growth coefficient (k) derived herein is the highest reported for any glaucosomatid. Stewart et al. (2013) reported $k = 0.24\ \text{yr}^{-1}$ for *G. scapulare* caught in Queensland, Hesp et al. (2002) reported $k = 0.111\ \text{yr}^{-1}$ for *G. hebraicum* caught in southern Western Australia and Newman (2002) reported $k = 0.139\ \text{yr}^{-1}$ for *G. buergeri* from north-western Australia. However, the growth curve reported by Newman (2002) resulted in a $L_0 = {\sim}60$ mm, despite the transition from larvae to juvenile stage occurring at 8 mm total length for this species (Pironet and Neira, 1998), indicating a poor fit of the VBGF at younger ages. The under-sampling of younger fish is a common source of bias when assessing growth and has been shown to result in the under-estimation of k (Gwinn et al., 2010). Although younger fish were under-represented in the current study, due to issues relating to the selectivity of the gear used to obtain

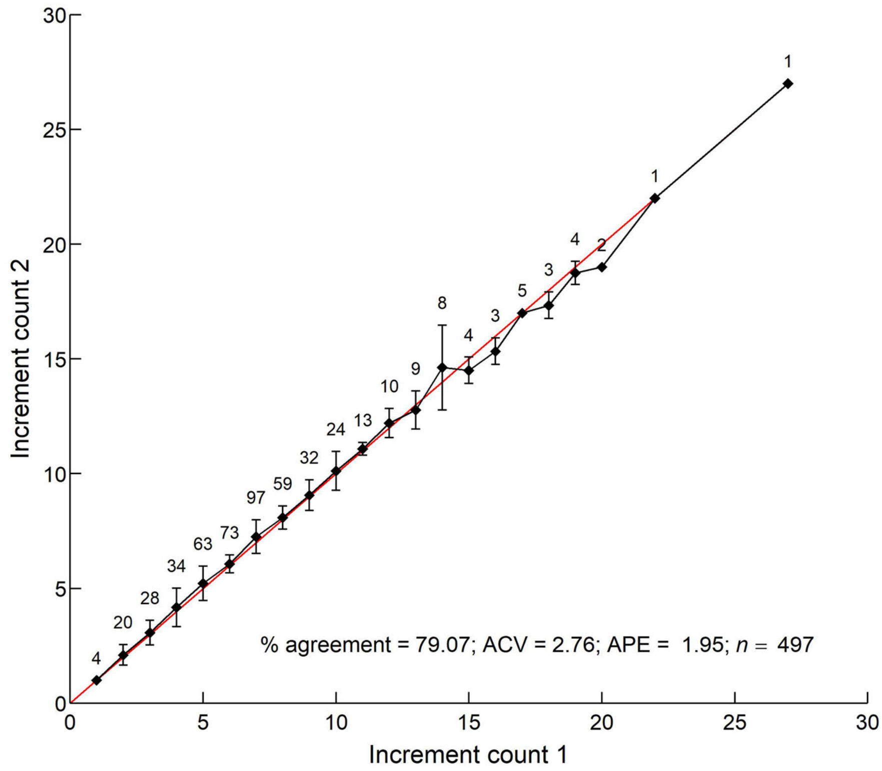

FIGURE 3 Age bias plot for 497 pearl perch. Error bars represent one standard deviation from the mean. Also shown are relevant indices of agreement between the two reads. The red line represents the line of equivalence. Numbers atop each point are the number of animals assigned the respective increment counts.

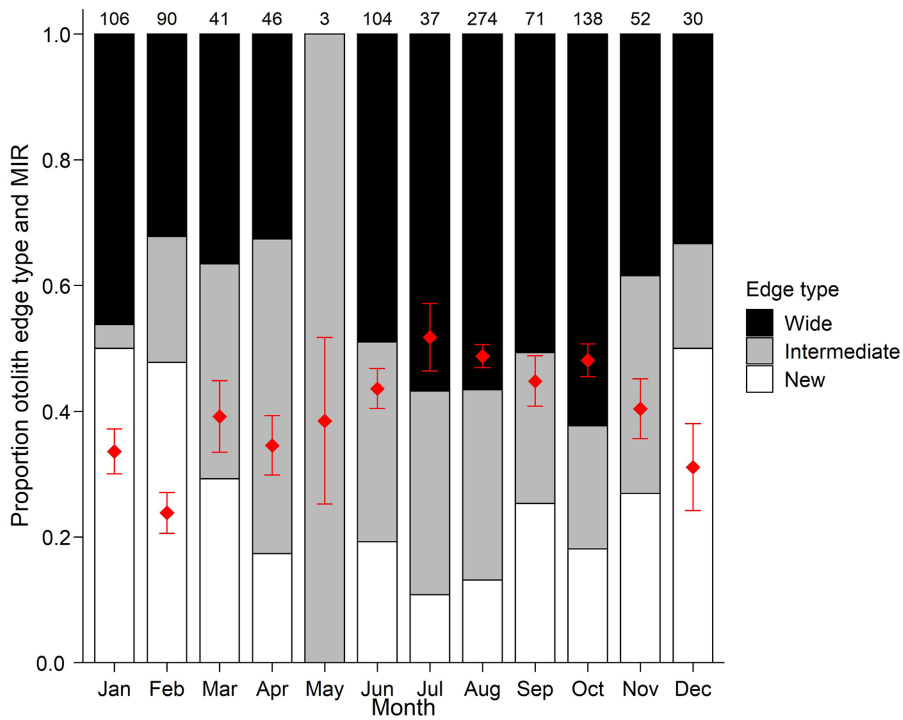

FIGURE 4 Variation in mean marginal increment ratio (red diamonds ± S.E.) and edge type as a function of month for region for pearl perch ≥4 yr caught between January 2020 and December 2021 in Queensland, Australia. The number above each bar is the sample size.

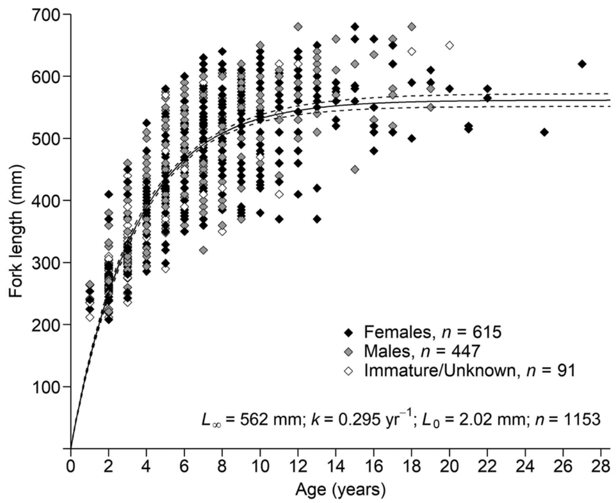

FIGURE 5 Mean length-at-age of pearl perch, derived using the von Bertalanffy growth function in a Bayesian framework. The dashed lines represent the 95% credible intervals around the growth curve and the diamonds represent the observed lengths-at-age. Priors were set at $L_\infty \sim N(700, 35)$ and $L_0 \sim N(2, 0.02)$ for both sexes. A non-informative prior was used for the growth coefficient (k, Table 1) with a maximum value of 0.8 yr^{-1}.

samples, using a prior for L_0 within a Bayesian framework minimises bias in the estimation of growth parameters (Smart and Grammer, 2021).

Young (<1 yr) pearl perch are typically associated with the sandy substrates utilised by penaeid prawns (Stewart et al., 2013) and are found in the discarded portion of penaeid-trawl discards in south-east Queensland (Courtney et al., 2007). These young fish likely avoid habitats favoured by adults to avoid predators such as samsonfish (*Seriola hippos*) and snapper, a strategy also observed in *G. hebraicum* (Hesp et al., 2002). In an effort to produce a more realistic mean length-at-age, in the absence of significant numbers of young fish, Stewart et al. (2013) constrained the age at zero length parameter to $t_0 = -0.02$ yr. However, fixing one parameter of the VBGF is known to result in substantially biased growth estimates (Pardo et al., 2013) and this may have contributed to differences between the growth parameter estimates obtained by Stewart et al. (2013) and those from the current study. No significant difference in growth between the sexes was detected for fish collected in the current study. This result is consistent with the results reported by Newman (2002) for *G. buergeri* and by Stewart et al. (2013) for pearl perch. In contrast, Hesp et al. (2002) found that female *G. hebraicum* had a higher L_∞ and lower k than did males.

Stewart et al. (2013) estimated the growth of pearl perch in Queensland and New South Wales from fish largely <10 yr old (see Figure 1 in that study). In the current study, growth was assessed from 1153 individuals, including 392 individuals aged ≥7 yr (~34%), in contrast to the 34 (14%) fish sampled in Queensland and 11 (~5%) of the fish sampled from New South Wales at these ages by Stewart et al. (2013). There were no fish in the New South Wales samples >10 yr, despite a lifespan of at least 19 yr (Stewart, 2011). The presence of these older animals in the current study enables improved model fitting at the upper end of the age range, reducing bias in the estimation of the VBGF parameters. Although the estimated L_∞ parameters presented here are lower than the maximum length (680 mm FL) of fish in the current study, the model produced reasonable fits to the observed length-at-age data for older fish.

The higher representation of ages ≥7 yr in the current study is a direct result of the expansion of the fishery that occurred throughout the early 2000s. Until the early 1990s, fishers were mostly limited to fishing areas close to the coast for ease of locating reefs via landmarks. At this time, pearl perch were caught incidentally by fishers targeting snapper on inshore grounds (<100 m) south of Fraser Island (see Figure 1), the area from which Stewart et al. (2013) collected the Queensland samples during their study. Both snapper and pearl perch have a long history of exploitation in this area such that the low spawning biomass of these species in the late 1990s (Sumpton et al., 2017; Wortmann et al., 2018; Lovett et al., 2022) forced commercial fishers to move to offshore fishing areas to the east and north of the traditional fishing grounds. The expansion of the fishery was facilitated by the availability of modern electronic fishing aids including colour sounders and global positioning systems. These changes occurred concurrently with increases in vessel size and range, resulting from the uptake of four-stroke outboard engines, along with the use of electronic and hydraulic reels (Sumpton et al., 2013b). This increase in fishing power allows fishers to target pearl perch in deeper (>100–200 m) waters offshore from the Sunshine Coast and Fraser Island (see Figure 1), and in waters adjacent to the Swain Reefs. In these more remote areas, fishers have located substantial aggregations of large pearl perch, which are now regularly accessed by both commercial and recreational fishers.

The absence of older fish in age frequencies (termed 'age truncation') has been linked to over-exploitation (Siskey et al., 2016). The lack of older fish in the samples collected by Stewart et al. (2013) demonstrates the effect of fishing on pearl perch in areas close to ports such as Mooloolaba (Figure 1), on traditional fishing grounds. The age truncation observed has been shown to cause changes in fished populations that inhibit recovery (Hixon et al., 2013). In contrast, older fish are now found on remote offshore fishing grounds that have received relatively low levels of fishing effort. Stewart et al. (2013) hypothesised the lack of older fish was a result of fish migrating northward to spawn, a life history strategy used by species such as sea mullet (*Mugil cephalus*) and tailor (*Pomatomus saltatrix*). However, this hypothesis has yet to be supported by empirical evidence. Sexually mature females with ripened ovaries were collected during the current study in the area between Fraser Island and the Swain Reef complex (Figure 1), and in deep (~180 m) water, offshore of the Sunshine Coast (M. Campbell, unpublished data). From these areas, larvae are carried southward by the East Australian Current (EAC, Stewart et al., 2013), a western boundary current in the southwest Pacific Ocean (Ridgway and Dunn, 2003). The increasing access to offshore fishing grounds is of concern: the lack of spawning animals found on traditional grounds indicates that the pearl perch stock is heavily reliant on spawning animals inhabiting these remote areas.

Sea surface temperature (SST) increased at ~1°C decade^{-1} in the period 1993–2016 in south-eastern Australia (Pattiaratchi, 2020). Wang et al. (2020) demonstrated that a warming trend drives an increase in the growth coefficient (k) and decreases in L_∞ over time, and increasing SST may partly explain the differences between the k and L_∞ estimates presented herein and those reported by Stewart et al. (2013). Climate-driven increases in SST have been shown to cause poleward shifts in species distributions (Champion et al., 2021; Hu et al., 2022) and anecdotal reports suggest pearl perch have been caught by recreational fishers as far south as Montague Island in southern New South Wales (36°15′S) in recent years. This poleward shift is a result of the EAC strengthening and penetrating further south (Ridgway, 2007) and these changes are likely to influence the dispersal of pearl perch larvae. Along with the poleward movement commonly associated with climate-driven increases in SST, there is also evidence that some species respond to increasing temperatures by moving into deeper waters (Perry et al., 2005). Pearl perch are now primarily caught in commercial quantities in deeper (>150 m) offshore waters in southern Queensland. The increasing harvest of these fish is more likely a result of increased fishing power in recent years rather than a distributional shift: significant numbers of pearl perch are still caught in shallower waters (80–100 m) north of Fraser Island where fishing effort is low, compared with areas of similar depths close to southern Queensland ports such as Mooloolaba (Figure 1). Further research is required to determine the effects of climate-driven changes to SST and other environmental variables on the biology of pearl perch across its distribution.

In 2019, management changes were introduced to halt the decline of the pearl perch spawning biomass including a 1-month closure (July 15–August 15, annually), an increase in the minimum legal size from 35 cm TL to 38 cm TL, a reduction in the recreational bag limit from five to four, and a total allowable harvest of 15 t for commercial fishers. The efficacy of these changes has yet to be assessed. As a result of these changes, the number of commercial and recreational fishers providing samples for routine monitoring has decreased. A combination of both fishery-dependent and fishery-independent monitoring is optimal to ensure samples are representative of the population; however, fishery-independent monitoring of pearl perch is financially unviable. As such, the derivation of growth parameters from biased length-at-age sampling is unavoidable. These issues can be overcome by estimating growth parameters in a Bayesian framework, using prior information for length-at-age-zero and maximum length to reduce bias, and the 'BayesPlot' R package offers researchers a simple, user-friendly option for this task. It would be prudent to reanalyse the data collected by Stewart et al. (2013), using this method to reduce bias in growth parameters and improve the accuracy of future stock assessment outputs. This is of particular importance if the pearl perch stock is assessed regionally (e.g. New South Wales, Queensland south and Queensland north) in future, rather than as a single stock. Further, the higher k and lower L_∞ derived herein indicates that pearl perch may be more resilient to fishing pressure than previously assumed, given the correlation between these parameters and natural mortality (e.g., Then et al., 2015). Future stock assessments should, therefore, include natural mortality calculated from the growth parameters estimated here.

In conclusion, pearl perch are endemic to the east coast of Australia and have been subject to a long history of exploitation in the southern part of its distribution. In the early 2000s, increasing fishing power allowed fishers to access offshore areas to the east and north of traditional fishing grounds, where fishers located older fish not previously observed during fishery-dependent sampling. Growth parameters estimated in a Bayesian framework, using prior information for maximum length and length-at-age-zero, did not differ significantly as a function of sex. This research provides improved estimates of growth for use in future stock assessments which will result in greater confidence in stock assessment outputs.

AUTHOR CONTRIBUTION

Conceptualisation; formal analysis; investigation; methodology; supervision; validation; visualisation; writing – original draft: Matthew J. Campbell. *Investigation; writing – original draft*: Mark F. McLennan. *Data curation; investigation; writing – original draft*: Jamie R. Nicolson. *Methodology; supervision; validation; writing – original draft*: Anna Garland. *Methodology; Supervision; Validation; Writing – original draft*: Robert M. Prosser. *Investigation; writing – original draft*: Ricky F. Midgley.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

DATA AVAILABILITY STATEMENT

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

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PEER REVIEW

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ETHICS STATEMENT

This research was undertaken with Animal Ethics approval CA 2019/07/1297 and CA 2022/04/1597.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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