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# Age-based population dynamics of the four-rayed rattail *Coryphaenoides subserrulatus* from the Chatham Rise, New Zealand

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**ABSTRACT**

This study explores the age-based population dynamics of the four-rayed rattail *Coryphaenoides subserrulatus,* a bycatch species from the Chatham Rise orange roughy (*Hoplostethus atlanticus*) fishery. Age and size distribution of *C. subserrulatus* ranged from 2 to 27 years, and 139 mm to 366 mm (TL), respectively. The sampled population was female-dominated, especially in the older and larger classes, with a sex ratio of 1.69 females per 1 male (F:M = 1.69:1). Von Bertalanffy growth function (VBGF) analysis showed asymptotic length of 337.02 mm for females and 312.84 mm for males. Likelihood Ratio Test (LRT), and 95% confidence ellipses conducted on VBGF parameters of $L\infty$ and K, confirmed female growth to be significantly different than male. Length–Weight relationship analysis showed this species to have a negatively allometric growth coefficient ($b = 2.69$), which indicates prioritisation of growth over condition. Annual mortality rate was estimated at 14.39% ($yr^{-1}$), indicating a stable population under unfished conditions. This study contributes to the understanding of the population dynamics of *C. subserrulatus* in New Zealand waters, adding to the existing knowledge on the ecology of this deep-sea bycatch species.

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## Introduction

Commercial bottom-trawl fisheries have substantially reduced the abundance of demersal fish species, impacting both target and non-target populations across diverse geographical regions (Priede et al. 2011). Despite this, the age and growth dynamics of many affected species remain inadequately studied. Rattails belong to the Macrouridae family and are prevalent in deep-sea environments along continental slopes and mid-ocean ridges (McMillan and Paulin 1993; Kelly et al. 1997). Consequently, macrourids are frequently caught as bycatch in deep-sea fisheries, such as the Orange Roughy

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(*Hoplostethus atlanticus*) fishery (Clark et al. 2000; Anderson and Clark 2003; Anderson and Finucci 2022).

Age and growth-based studies of New Zealand rattail species remain rare (Stevens et al. 2010; McMillan et al. 2021), primarily due to a lack of focused funding on bycatch fisheries research. The four-rayed rattail *Coryphaenoides subserrulatus* (Makushok 1976) is one of 12 *Coryphaenoides* species in New Zealand waters, and one of the most commonly captured rattail bycatch species in deepwater (800–1300 m) fisheries around the Chatham Islands and southern regions of New Zealand (Stevens et al. 2023). There is limited knowledge on the early ontogeny of *C. subserrulatus*, with Fukui et al. (2008) describing how the oil globule within macrourid fish eggs helps them ascend to the pelagic zone for hatching, after which the larvae will slowly descend to deeper waters for settlement.

As with most New Zealand rattails, *C. subserrulatus* is small and holds no commercial value. To date, McMillan et al. (2021) remains the only study that has provided some preliminary estimates of age and growth parameters for *C. subserrulatus* in New Zealand, although it was based on a relatively small sample size ($n = 89$). This study aims to contribute to a critical knowledge gap by offering a detailed analysis of the age and growth patterns of *C. subserrulatus* in New Zealand waters. By enhancing our understanding of this species' population dynamics, we aim to inform effective conservation and management strategies for deep-sea ecosystems and provide insight into bycatch dynamics of deep-sea fisheries.

## Materials and methods

### *Sample collection*

401 *C. subserrulatus* specimens were collected as bycatch from four trawl stations on northeastern Chatham Rise (Figure 1) by RV Tangaroa in July 2004 (TAN0408)

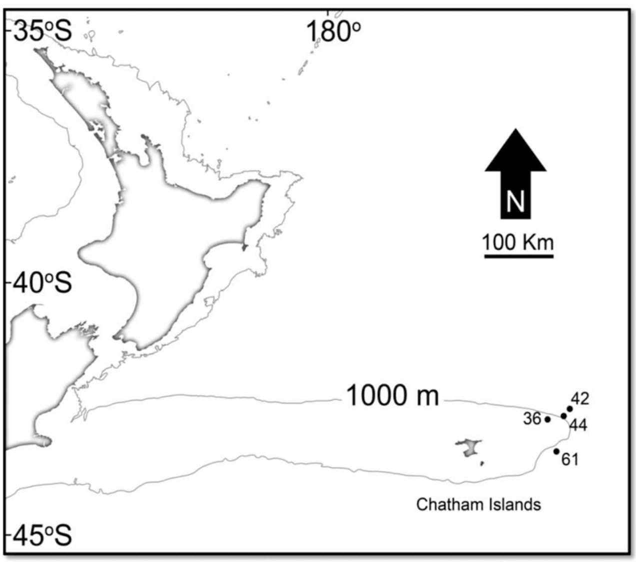


**Figure 1.** Map of the Chatham Islands, New Zealand, showing the trawl locations where the *Coryphaenoides subserrulatus* were collected from.

during an orange roughy (*H. atlanticus*) stock assessment. The location and depth of the trawls were as follows: station S 36, 43°20.43′S, 174°19.69′W, maximum gear depth (MGD) 901 m; S 42, 43°03.76′S, 174°04.56′W, MGD 1196 m; S 44, 44° 04.76′S, 174°37.56′W, MGD 1117 m; and S 61, 44°04.82′S, 174°37.78′W, MGD 1093 m. From each specimen, weight (g), total length (mm), and sex were determined macroscopically.

### *Age estimation*

After extraction, sagittal otoliths (Figure 2) were cleaned with distilled water, air-dried, weighed (g) and stored for subsequent age analysis. Age estimation was based on thin transverse sections (≈500 µm) of sagittal otoliths (Secor et al. 1995; Choat and Axe 1996). Annual age estimation was determined by counting opaque growth rings along a linear path from the core to the distal edge of each otolith (Figure 3), using a 20× magnification camera-mounted compound microscope. The assumption of annual periodicity of opaque and translucent zones in Macrourid otoliths has been proposed (Andrews et al. 1999; Swan and Gordon 2001), but remains to be definitively validated. Each sample was blind read by the corresponding author, allocating a readability score of 1–5; 1 representing very clear and 5 unreadable. If the two estimates matched, that age was recorded. If the estimates did not match, a third reading was conducted. If there was no consensus after three readings, that otolith was removed from analysis. Excluding readability scores of 5, 146 Males and 247 Females ($n = 393$) were confidently aged. A regression analysis of otolith age versus weight was carried out to examine their linear relationship. Since otolith accretion never stops throughout a fish's life, a strong correlation between otolith age and weight is expected (Labropoulou and Papaconstantinou 2000).

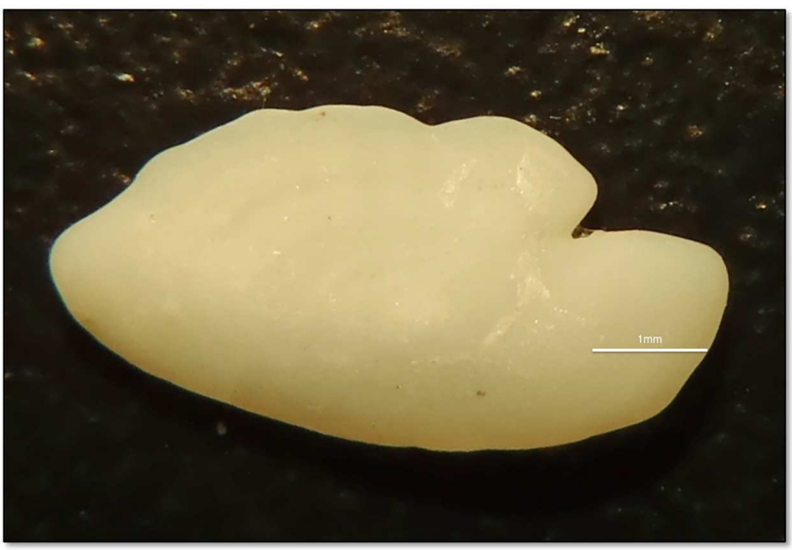


**Figure 2.** Sagittal otolith of *Coryphaenoides subserrulatus*.

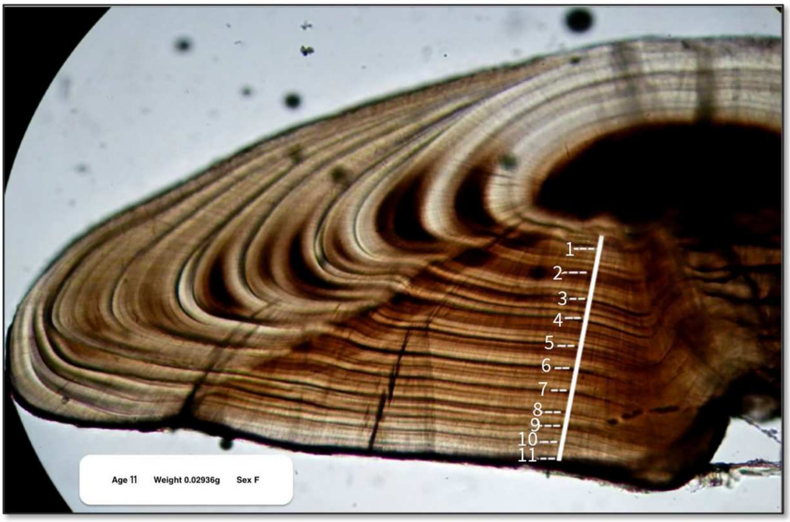


**Figure 3.** Sectioned otolith of *Coryphaenoides subserrulatus* viewed under a transmitted light. Distinctive opaque growth increments selected as annual rings are marked.

### *Population parameters*

Size and age class frequencies were analysed to assess the range of growth and longevity in this species. Rates of instantaneous total mortality (**Z**) for *C. subserrulatus* were derived from age-based catch curves. Mortality was then calculated as $\mathbf{Z = 100\text{-}}\boldsymbol{S}$, where $\boldsymbol{S}$ is the survivorship calculated as $\boldsymbol{S} = \mathbf{exp(\text{-}}\boldsymbol{a}\mathbf{)}$, with $\boldsymbol{a}$ corresponding to the absolute value of the slope of the line ($\mathbf{y} = \boldsymbol{a}\mathbf{x} + \boldsymbol{b}$) (Beverton and Holt 1957). The relationship between weight and length was described as $\boldsymbol{W = a\ x\ L^b}$ (Ricker 1973) where $\boldsymbol{W}$ represents the total weight (g), $\boldsymbol{L}$ is the total length (mm), $\boldsymbol{a}$ is the y-intercept or initial growth coefficient, and $\boldsymbol{b}$ is the slope or growth coefficient. In most fish species, growth is isometric, where $b$ is approximately 3.0. If $b$ is less than 3.0, it indicates negative allometric growth, while a $b$ value greater than 3.0 signifies positive allometric growth. The relationship between size and age of *C. subserrulatus* was modelled overall and individually for both sexes using the von Bertalanffy Growth Function (VBGF) (Kimura 1980) $\mathbf{L(t) = L_\infty\ [\ 1 - exp^{-K\ (t\ -\ t0)}\ ]}$, where $\mathbf{L(t)}$ is the mean length of the fish at age $\boldsymbol{t}$; $\mathbf{L_\infty}$ is the asymptotic length; **K** is the growth rate constant, which indicates how quickly the fish approaches its asymptotic length; and **t0** is the theoretical age at which the fish's length would be zero. Due to the lack of very young specimens and the unavailability of size at settlement for *C. subserrulatus* in the literature, we did not constrain our VBGF model to an arbitrary fixed t0. Comparison of von Bertalanffy growth parameters between males and females was tested using Likelihood Ratio Tests (LRT) (Kimura 1980; Cerrato 1990). The null hypothesis, which posited no growth difference between the sexes, was tested at an alpha level of 0.05, with $q$ (degrees of freedom) representing the number of parameters being constrained. Growth differences among sexes were further tested using 95% confidence ellipses around least squares estimates of $L_\infty$ and $K$ (Kimura 1980; Cerrato 1990). Non-overlapping confidence regions indicate significant difference in the examined growth parameters.

## Results

Sex-based age distribution of *C. subserrulatus* ranged from 2 to 27 years (Figure 4). Age 6 was the modal class for both sexes, while the sex ratio was female-dominated (1.69 F:M 1.0), especially in the older age classes. The size distribution of *C. subserrulatus* ranged from 139 to 366 mm (TL), dominated by females in the larger size classes (Figure 5).

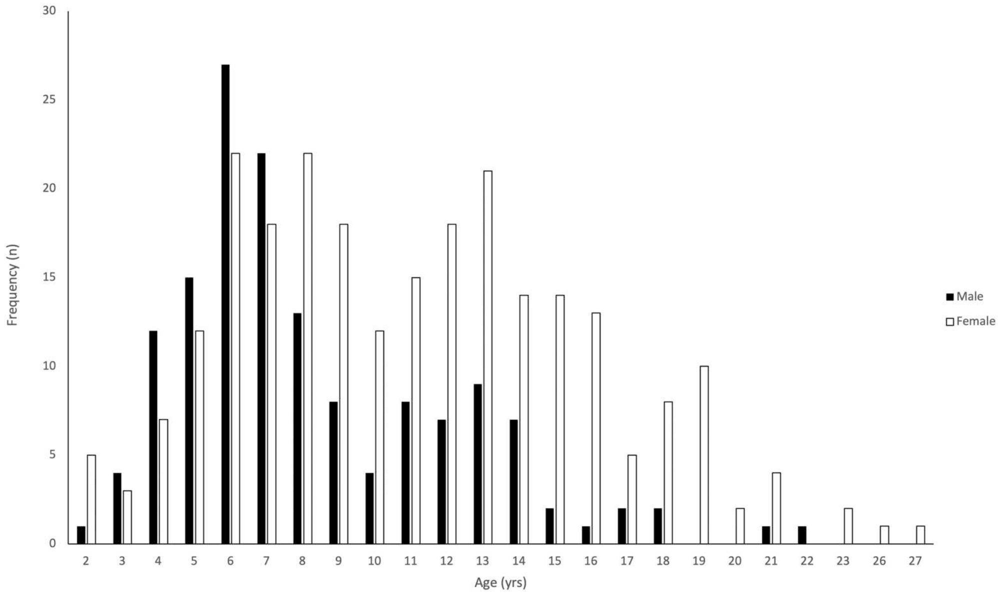


**Figure 4.** Age distribution of male and female *Coryphaenoides subserrulatus.*

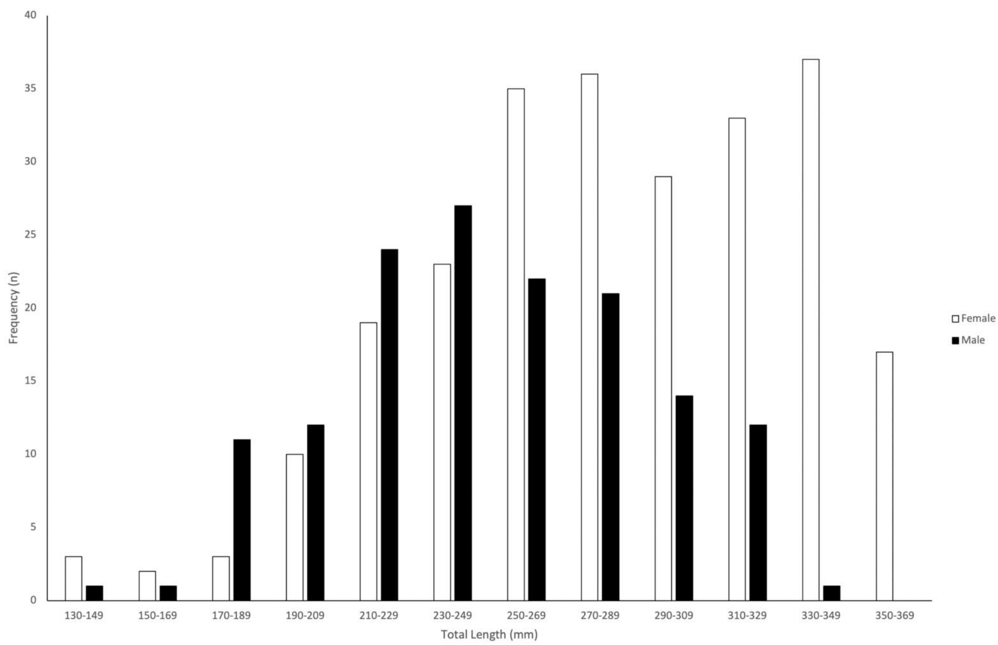


**Figure 5.** Size distribution of male and female *Coryphaenoides subserrulatus.*

**Table 1.** Population parameter values of best-fit models for Coryphaenoides subserrulatus; growth parameters of von Bertalanffy Growth Function (BVGF) showing sex-specific and overall growth trajectories, length-weight relationship fitted to a power curve, mortality estimates calculated from age-based catch curves, otolith weight-age relationship fitted to a linear regression, and sex ratio.

| Function | Parameters | C. subserrulatus |
|---|---|---|
| VBGF | $L\infty$ | 335.50 (mm) |
| | $K$ | 0.17 |
| | $t_0$ | −1.21 |
| VBGF (male) | $L\infty$ | 312.84 (mm) |
| | $K$ | 0.17 |
| | $t_0$ | −1.64 |
| VBGF (female) | $L\infty$ | 337.02 (mm) |
| | $K$ | 0.17 |
| | $t_0$ | −1.02 |
| Length-Weight relationship | $n$ | 393 |
| | $b$ | 2.69 |
| | $R^2$ | 0.79 |
| Length-Weight relationship (male) | $n$ | 146 |
| | $b$ | 2.41 |
| | $R^2$ | 0.74 |
| Length-Weight relationship (female) | $n$ | 247 |
| | $b$ | 2.68 |
| | $R^2$ | 0.76 |
| Morality ($yr^{-1}$) – | $Z$(%) | 14.39 |
| Morality (male $yr^{-1}$) | $Z$(%) | 19.60 |
| Morality (female $yr^{-1}$) | $Z$(%) | 10.85 |
| Otolith weight-age relationship | $R^2$ | 0.81 |
| Sex ratio | F:M | 1.69:1.0 |

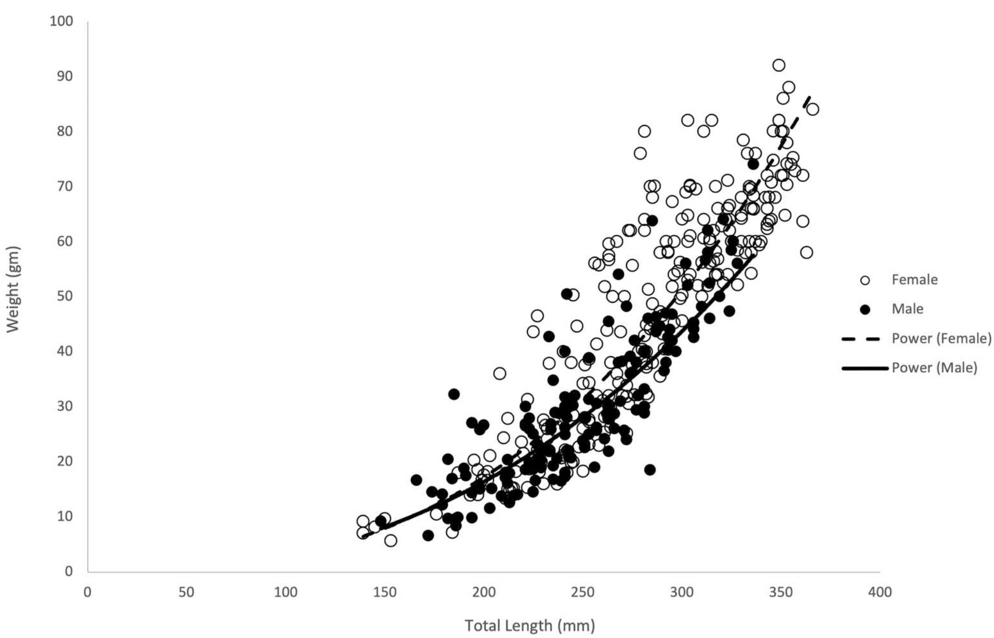


**Figure 6.** Weight-at-length of *Coryphaenoides subserrulatus*. Regression lines fitted are power curves for each sex (parameters are presented in Table 1).

There was a positive linear correlation between otolith weight and estimated age ($R^2 = 0.81$), indicating that heavier otoliths correlate strongly with older estimates of age. Mortality estimates for *C. subserrulatus* based on age-based catch curves revealed an annual

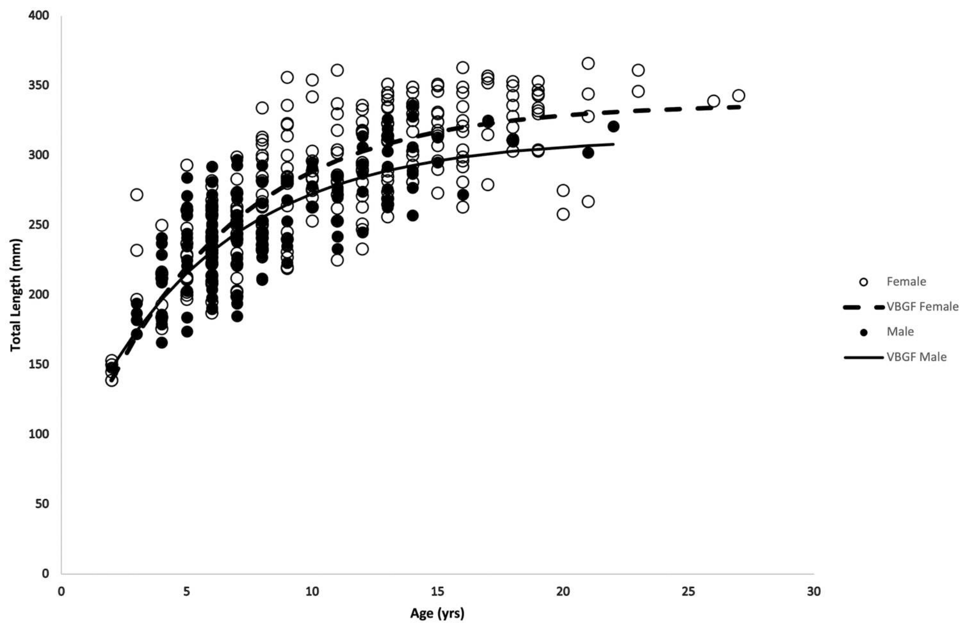


**Figure 7.** Sex-specific von Bertalanffy growth trajectories of male and female *Coryphaenoides subserrulatus*. Overall and sex-specific parameters are presented in Table 1.

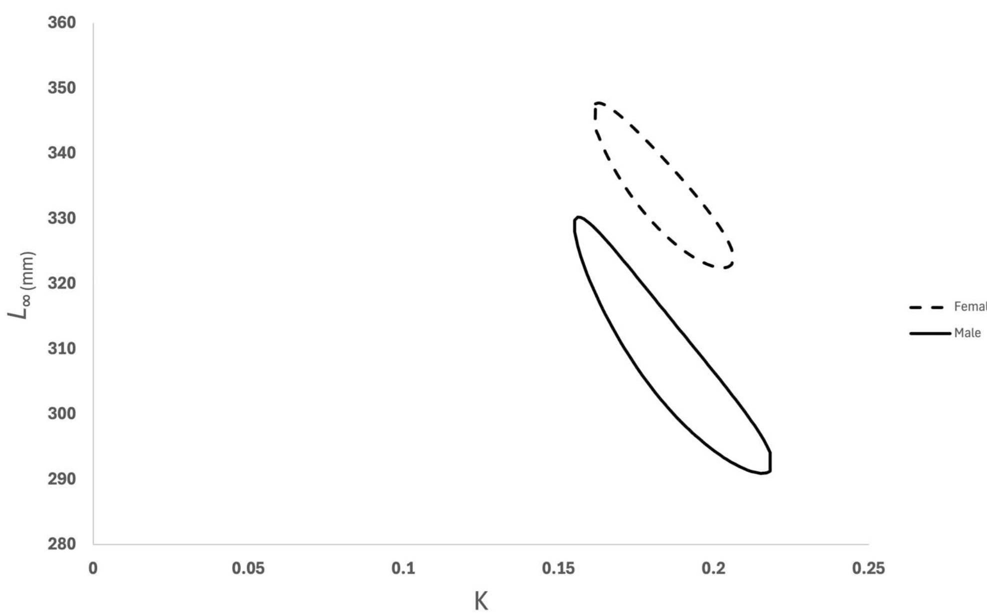


**Figure 8.** Comparison of VBGF parameters for male and female *Coryphaenoides subserrulatus* depicting 95% confidence regions around least squares estimate of K and L∞.

survivorship rate of 85.61%, which means the population experiences a natural mortality rate of approximately 14.39% per year (see Table 1). Analysis of the length (L) and weight (W) relationship for *C. subserrulatus* revealed a negatively allometric L-W growth coefficient of 2.69, which indicates a species that prioritises somatic growth over condition (Figure 6). Further insight into the growth characteristics of this species was gained through VBGF analysis. The two key VBGF parameters of $L_{\infty}$ and $K$ revealed that mean asymptotic length for the whole population was reached at 335.50 mm(TL), with a growth coefficient of 0.17 (see Table 1). However, females reached a higher asymptotic length (337.02 mm) compared to males (312.84 mm) (Figure 7). LRT conducted to compare growth parameters between males and females revealed statistically significant difference ($P < 0.05$). Confidence ellipses (Figure 8) conducted around $L_{\infty}$ and $K$ for both sexes also revealed non-overlapping regions, confirming significant growth difference between males and females.

## Discussion

This study contributes to the understanding of bycatch deep-sea fish population dynamics. Our estimated maximum age of 27 years closely aligns with the 28 years reported by McMillan et al. (2021) for *C. subserrulatus*. Although Stevens et al. (2010) did not provide male/female frequency distributions for their studied rattails, their data indicate that females outnumber males, which is consistent with our female-biased sex ratio of 1.69 females for every male. The overall instantaneous total mortality (Z) for *C. subserrulatus* was estimated at 14.39% pe year ($yr-^{1}$). This is lower than the 23.1% reported by McMillan et al. (2021), but likely to be more accurate given our larger sample size. The relationship between weight and length was negatively allometric overall ($b = 2.69$), as well as by sex (male $b = 2.41$, and female $b = 2.68$), indicating a strategy that prioritises somatic growth over condition. The weight–length relationships reported for the four rattails in Stevens et al. (2010) were either isometric or slightly positively allometric, except for female *M. carinatus,* which showed a negatively allometric $b$ value of 2.81. von Bertalanffy growth analysis of *C. subserrulatus* revealed asymptotic length of 333.50 (mm) with a growth coefficient of 0.17. Our L∞ estimate was smaller than that of McMillan et al. (2021), who reported an asymptotic length of 359 mm, with a growth coefficient of 0.14. Analysis also showed that females reach a much higher asymptotic length (337.02 mm) than males (312.84 mm). The pattern of larger female size at equivalent age was reported for all four rattail species studied by Stevens et al. (2010). LRT and 95% confidence ellipses on VBGF growth parameters confirmed significant difference between males and females.

Population parameters of deep-sea fishes remain relatively unexplored, especially if they are of little or no commercial value. While *C. subserrulatus* is not a target species for commercial fisheries, its status as bycatch in the deep-sea trawl fisheries necessitates careful consideration in fishery management plans. By gaining insights into their age and growth dynamics, we enhance our understanding of deep-sea ecosystems, which are among the least explored and most vulnerable habitats (Paulus 2021). In terms of the ecology of *C. subserrulatus* in New Zealand waters, this study has extracted robust population dynamics information from a dataset that has, to date, provided comprehensive information on the diet of this species (Jones 2008b, 2008a). However, future research should focus on long-term monitoring to better understand the full population trends of New Zealand *C. subserrulatus* in order to detect changes over time, particularly in response to fishing or environmental pressures.

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## Disclosure statement

No potential conflict of interest was reported by the author(s).

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