Population dynamics of kawakawa (*Euthynnus affinis* (Cantor, 1849)) in Sri Lankan waters

Dalpathadu K.R*., Balawardhana D.G.T.C., Haputhantri S.S.K.

Marine Biological Resource Division, National Aquatic Resources Research and Development Agency (NARA), Colombo 15, Sri Lanka

***kasun.randikad@gmail.com**

Abstract

Neritic tuna species play an important role in the tuna fishery conduct in Sri Lankan waters. Kawakawa (*Euthynnus affinis* (Cantor, 1849)) is the third dominant species in this group in the commercial catch contributing around 20.8 % of the total neritic tuna landings in Sri Lankan waters during the 2020-2021 period. Kawakawa in Sri Lankan waters is mainly caught by gillnets, handlines, coastal longlines, and ring nets. Despite its significance, very few studies have been conducted on kawaka in Sri Lankan waters. This study attempts to estimate the von Bertalanffy growth parameters and mortality parameters of kawakawa by length-based population dynamic models. The length frequency data collected in 2020/2021 by measuring the Fork Length (FL) of kawakawa in Sri Lankan waters were made used for this study. Accordingly, monthly length frequency data of kawakawa were analyzed by the Electronic LEngth Frequency ANalysis (ELEFAN) of the R package "TropFishR". A total of 2049 FL data were used for the analysis. The estimated growth parameters were L_∞ = 62.98 cm (FL); K = 0.70 yr^{-1}; Ø = 3.44. The estimated values of total mortality (Z), natural mortality (M) and fishing mortality (F) were 1.60 yr^{-1}, 0.81 yr^{-1} and 0.79 yr^{-1} respectively. The Exploitation ratio (E) was estimated at 0.50. The fishing mortality that led to the maximum yield per recruit (F_{max}) was estimated at 1.22 yr^{-1}. The estimated target reference points of $F_{0.1}$ and $F_{0.5}$ were 0.63 yr^{-1} and 0.45 yr^{-1} respectively, which were lower than the current F. Based on the findings it was fair to conclude that the current exploitation level of kawakawa in Sri Lanka is sustainable. However, there is a risk of growth overfishing of the kawakawa stock in Sri Lankan waters. The estimated values for the abovementioned parameters could be made used when stock assessments are conducted.

Keywords: *Euthynnus affinis*, Kawakawa, Growth parameters, TropFishR. Growth overfishing

Introduction

Sri Lanka is an Island located between the latitudes 5º 30' and 10º 00' North and longitudes 70º 30’ and 82º 00’ East in the Indian Ocean. It has a shoreline of 1585 km long and an Exclusive Economic Zone (EEZ) extending up to 200 nautical miles (Samaranayake, 2003; Wijayaratne, 2001). As a result of the strategic location in the Indian Ocean, Sri Lanka is privileged to have productive ocean terrain enriched with fishery resources. As an Island, the fisheries sector in the country plays a vital role in providing direct and indirect employment. More importantly, it accomplishes about 50% of animal protein requirements in the country. According to recent statistics, the marine fisheries sector plays a significant role in the national economy contributing 1.1% to the Gross Domestic Production (GDP) of the country (Ministry of Fisheries, 2020). In 2019, the estimated total production in the marine fisheries sector was 415,490 Mt which accounted for about 82% of the total fish production in the country (Ministry of Fisheries, 2020).

Sri Lanka has a long history of tuna fishery (Dissanayake et al., 2008). Since then the pelagic fishery of Sri Lanka primarily targeting tuna species that have a valuable percentage contribution to coastal and offshore fishery production. Yellowfin tuna (*Thunnus albacares* (Bonnaterre, 1788)), big eye tuna (*Thunnus obesus* (Lowe, 1839)), skipjack tuna (*Katsuwonus pelamis* (Linnaeus, 1758)) are main contributors of the large pelagic fishery while kawakawa (*Euthynnus affinis* (Cantor, 1849)), frigate tuna (*Auxis thazard* (Lacepède, 1800)) and bullet tuna (*Auxis rochei* (Risso, 1810)) are the three dominant neritic tuna species which mainly contribute to the coastal fishery in Sri Lanka (Maldeniya et al., 1988; Haputhantri and Bandaranayake, 2013). In 2020-2021, kawakawa was the third dominant neritic tuna species by weight in the commercial catch in Sri Lanka. It contributed 20.8% of the total neritic tuna landings in Sri Lankan waters (2,489 t). Kawakawa in Sri Lankan waters is mainly caught by gillnets, handlines, coastal longlines, and ring nets.

Studying the population dynamics of the kawakawa is important in understanding how the fishery trend changes the stock as well as to estimate the optimum harvesting rates. Furthermore, findings of the population dynamics analysis are the key inputs for different stock assessment models used to evaluate the status of the stocks of kawakawa in different regions (Wilderbuer and Zhang, 1999). Indian Ocean Tuna Commission (IOTC) conducted a stock assessment of the kawakawa in the Indian Ocean in 2022 (Geng, 2022). Besides that, several sub-regional studies have been conducted to understand the population dynamics of kawakawa: Indian waters (Khan, 2004; Kumar et al., 2018; Mudumala et al., 2018), Indonesian waters (Lelono and Bintoro, 2019), Thai waters (Yasaki, 1989) and Yemen waters (Shaher Saeed, 1995). However, studies on the population dynamics of kawakawa in Sri Lankan waters are extremely scarce. Therefore, the present study was undertaken to estimate the population parameters of the kawakawa in Sri Lankan waters. The findings of this study will facilitate fishery managers to understand the current trends in the fishery for the kawakawa in Sri Lankan waters and ultimately the estimated parameters that can be used for assessing the stock of kawakawa.

Methodology

The length frequency data collected in 2020/2021 by measuring the Fork Length (FL) of kawakawa in Sri Lankan waters were used for this study. The length measurements comprise fish caught by gillnets, handlines, coastal longlines, and ring nets in Sri Lankan waters. The FL was measured to the nearest 1.0 cm. The monthly FL data for the pooled sexes were grouped into 3.0 cm length class intervals for the estimation of growth parameters. Growth parameters were estimated for the pooled sexes through the von Bertalanffy growth function (VBGF) (von Bertalanffy, 1938) using monthly length-frequency data, by the electronic length frequency analysis (ELEFAN) of R package "TropFishR" (Mildenberger et al., 2017). The growth curve fitting and estimation of the asymptotic length (L_∞), growth coefficient (K) and growth performance (Ø') was done by the electronic length-frequency analysis using a bootstrapped method with a genetic algorithm within the TropFishR (Mildenberger et al., 2017; Taylor & Mildenberger, 2017). The von Bertalanffy growth equation was defined as follows (Sparre and Venema, 1998):

$$L_t = L_\infty \left(1 - e^{(-K(t-t_0))}\right)$$

Where; L_t is the folk length (cm) at age t (year), L_∞ is the asymptotic length (cm), K is the growth coefficient and t_0 is the theoretical age at zero length ($year^{-1}$).

The growth performance index (Ø’) was estimated by the following equation (Pauly and Munro, 1984)

$$\emptyset' = Log(K) + 2Log\ (L_{\infty})$$

The total mortality rate (Z; year^{-1}) was calculated based on the linearized length–converted catch curve (Ricker, 1975) within the TropFishR R package (Mildenberger et al., 2017; Taylor & Mildenberger, 2017). The natural mortality (M; year^{-1}) was calculated by Then’s growth formula (Then et al., 2015), in the TropFishR R package (Mildenberger et al., 2017; Taylor & Mildenberger, 2017) as follows:

$$M = 4.118K^{0.73}L\infty^{-0.33}$$

Fishing mortality (F; year^{-1}) was obtained from the following relationship as described by Sparre and Venema, 1998:

$$F = Z - M$$

The stock status was based on current F relative to biological reference points, such as F_{max}, $F_{0.1}$ and $F_{0.5.}$ F_{max} is defined as the fishing mortality (F) leading to the maximum yield per recruit. $F_{0.1}$ (Gulland and Boerema 1973) corresponds to F where the slope of the yield per recruit curve is equal to 10% of the slope in the origin. $F_{0.5}$ corresponds to F where the biomass per recruit is equal to 50% of the biomass per recruit without fishing. Backwards extrapolation of the length converted catch curve was used to estimate the probability of capture data (Pauly and Munro, 1984). The Thompson and Bell yield per recruit (YPR) model was used to estimate yield and biomass per recruit.

The values for the constant (*a*) and the slope (*b*) of the length–weight relationship of the kawakawa in Sri Lankan waters were obtained from the recent research work of Herath et al., (2019) (*a* = 0.132; *b* = 3.115).

Results

Length frequency distribution

In this study, a total of 2049 FL data of kawakawa from commercial landings around the Sri Lankan coast were analyzed. Mid values of the length classes of FL ranged from 25.0 cm to 58.0 cm and the majority of the catch was composed of individuals with 25.0 – 40.0 cm FL (Figure 1). The mean FL of the kawakawa in the commercial catch during 2020-2021 was estimated at 38.1 ± 7.5 cm wherein 47.6% of the catch was higher than the mean FL. In terms of the number of individuals, catch from gillnets, handlines, coastal longlines, and ring nets respectively represented 37.9%; 12.5%; 5.0% and 44.6% in the total catch during the study period.

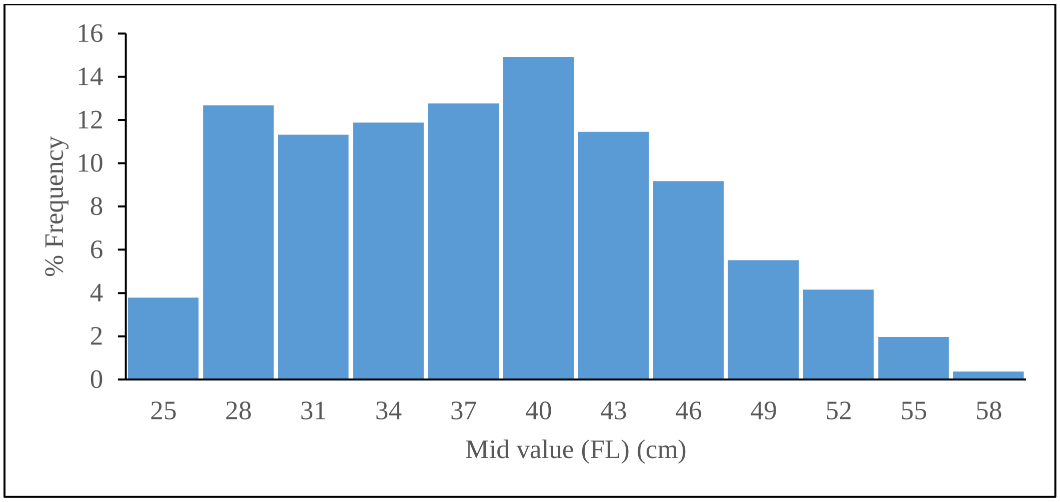

Figure 1. Percentage frequency of length *E. affinis* in Sri Lankan waters during 2020-2021.

Population parameters and Mortality rates

The Von Bertalanffy growth function was fitted to the restructured length frequency data of the kawakawa in Sri Lankan waters for 2020-2021 (Figure 2).

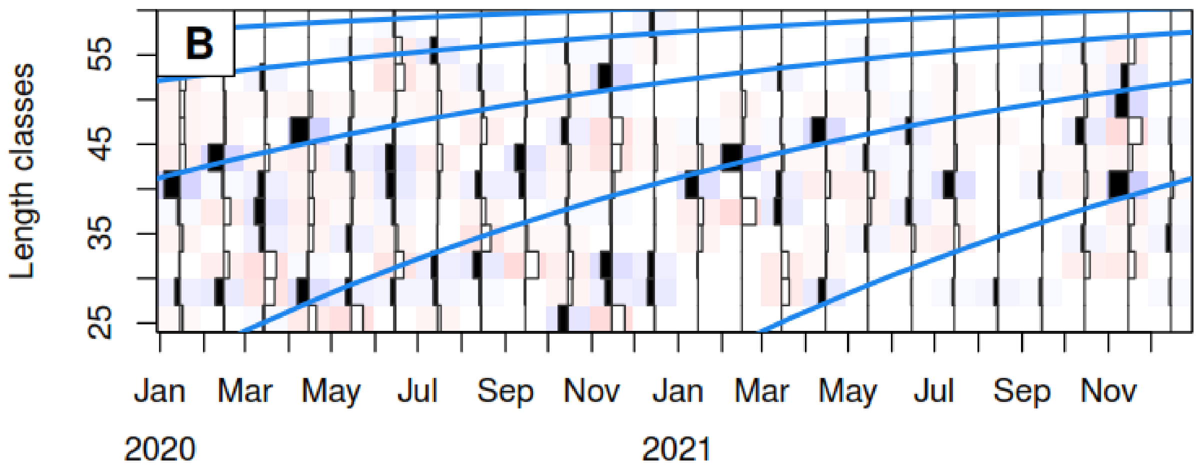

Figure 2. Restructured length-frequency data with overlaid von Bertalanffy growth (VBG) curves fitted by ELEFAN with genetic algorithm (Moving Average (MA) = 5; Bin size = 3).

The estimated growth parameters were: asymptotic length (L_∞) = 62.98 cm (FL); growth coefficient (K) = 0.70 yr^{-1} and the growth performance coefficient (Ø) = 3.44. The estimated values of total mortality (Z), natural mortality (M) and fishing mortality (F) were 1.60 yr^{-1}, 0.81 yr^{-1} and 0.79 yr^{-1} respectively. The Exploitation ratio (E) was estimated at 0.50. The estimated fishing mortality (F) based on reference points and the estimated stock status in terms of current fishing mortality (F) to reference points (F_{max}, $F_{0.1}$, $F_{0.5}$) are given in Table 1 and Yield per recruit and biomass per recruit for a range of fishing mortality rates are illustrated in Figure 3. The estimated F for the kawakawa in 2020-2021 was lower than the estimated F_{max} but greater than the target reference point of $F_{0.1}$ and $F_{0.5}$.

Table 1. The estimated fishing mortality (F) based on reference points and the estimated stock status in terms of current fishing mortality (F) to reference points.

F_{max} (yr^{-1})	**$F_{0.1}$ (yr^{-1})**	**$F_{0.5}$ (yr^{-1})**	**F/ F_{max}**	**F/ $F_{0.1}$**	**F/ $F_{0.5}$**
1.22	0.63	0.45	0.65	1.26	1.76

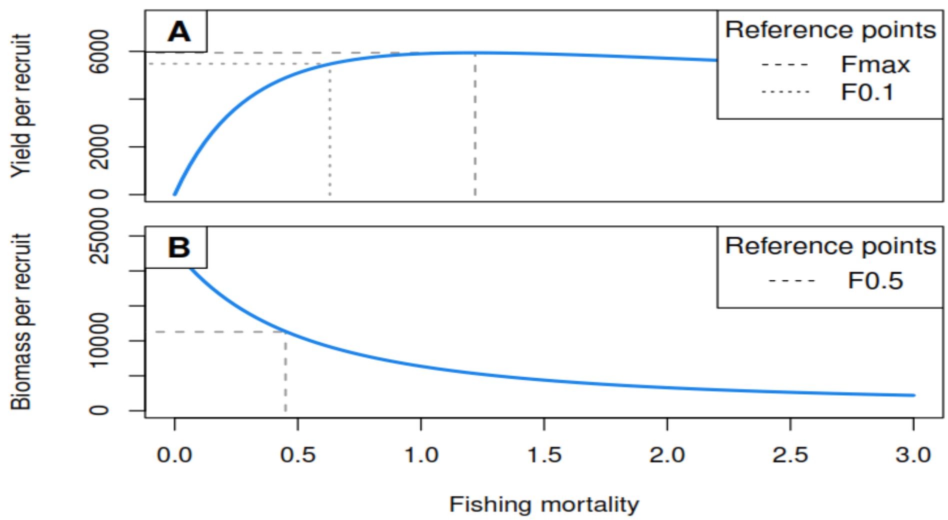

Figure 3. Yield per recruit (A) and biomass per recruit (B) of kawakawa in Sri Lankan waters for a range of fishing mortality rates (x-axis). Grey segments indicate various reference points.

Table 2. Comparison of growth parameters of kawakawa in the study with other studies conducted in the region.

Region	**K (year^{-1})**	**L_∞ (cm)**	**Ø**	**Reference**
Sri Lanka	0.61	63.0 (FL)		Joseph et al., 1987
Gujarat and Maharashtra: India	0.70	67.9 (FL)	3.51	Mudumala et al., 2018
Place Puger and Prigi coasts: Indonesia	0.11	72.5 (TL)	2.76	Lelono and Bintoro, 2019
Sassoon Dock, Maharashtra: India	0.79	81.7 (FL)	3.72	Khan, 2004
Thailand	0.96	76.0	8.62	Yasaki ,1989
Yemen	0.23	92.0	7.60	Shaher Saeed, 1995

Gulf of Mannar, Southwestern Bay of Bengal	0.63	70.0	Kumar et al., 2018

Selectivity and yield per recruit

Values of the sizes where the probability of capture was 50% (L_{50}) and 75% (L_{75}), were estimated to be 27.5 and 28.9 cm (FL), respectively (Figure 4). Accordingly, about 4% of the catch has lengths lower than the length at first capture (L_{50}).

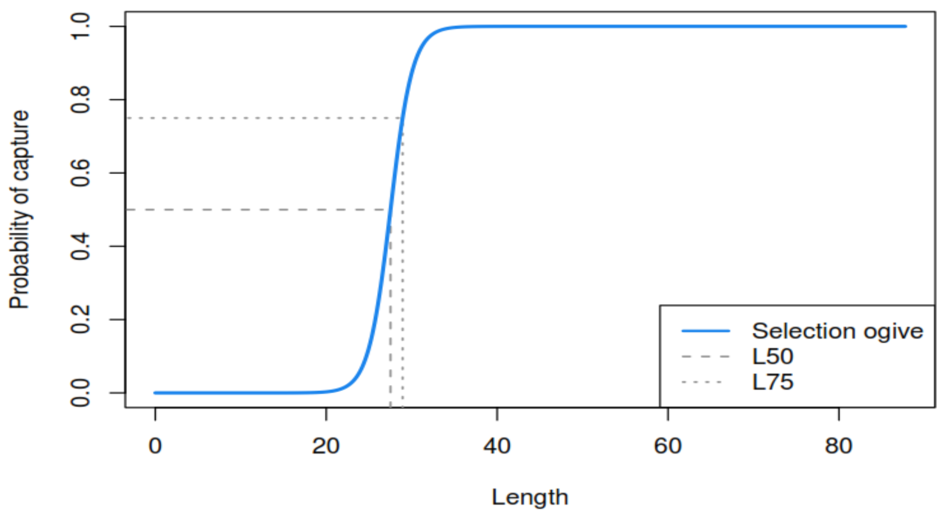

Figure 4. Estimated logistic gear selectivity as the probability of capture (y-axis) at length (x-axis) for the kawakawa in Sri Lankan waters.

Discussion

The selectivity of the fishing gear largely affects the size composition of the catch of a particular fish species (Mildenberger et al., 2017; Kumar et al., 2018). The estimated FL for the length at first capture (L_{50}) in this study was 27.5 cm. This value was smaller than some of the L_{50} values estimated in the region: 46.88 cm (FL) in the Persian Gulf and Sea of Oman (Taghavi et al., 2010) and 52.23 cm (FL) in Ternate Waters, Indonesia (Tangke et al., 2021). Considering the size composition in the commercial catch by gears, about 45% of the individuals have come from ring nets. Several studies have shown that the ring net catches a considerably large number of immature fish (Punyadeva, 2015; Bett et al., 2021). The higher representation of the ring net catch may be the reason for the comparatively smaller L_{50} value in this study.

According to Beverton and Holt (1957), the reliability of the estimated natural mortality, M is ascertained by using the M/K ratio which is within the ranges of 1.12 to 2.5 for most fishes. The M/K ratio of 1.16 obtained in the present study was within this range and therefore suggests that the estimated natural mortality for this species was acceptable. The estimated K value in this study is greater than the previously estimated value of 0.61 year^{-1} by Joseph et al., (1987) for the kawakawa in Sri Lankan waters. Also, the estimated L_∞ in this study (62.98 cm (FL)) is almost similar to the value of the study of Joseph et al., (1987). Furthermore, the estimated K and L_∞ in this study are in concurrence with the values of kawakawa in the Indian Ocean estimated by Mudumala et al. (2018). Even though the estimated K and L_∞ in this study are considerably different to the values obtained for studies conducted in Indonesia, Thailand and Yemen (Table 2). The differences in the estimated K and L_∞ values could be attributed to sampling error or variation in fishing intensity or environmental conditions (Taghavi et al, 2010; Hunter et al., 2016; Lavin et al., 2022). The growth of kawakawa in different regions could be compared by respective growth performances (Ø) of kawakawa in those regions (Pauly and Munro, 1984). It was found that the growth performance of kawakawa in the Indian waters (Ø = 3.51) (Mudumala et al., 2018) was almost similar to the Ø of kawakawa in Sri Lankan waters. Even though, much higher Ø of kawakawa has been recorded in Thai and Yemen waters (Table 2). Ø is directly related to the metabolism and food consumption of the fish (Pauly and Munro, 1984) thus having higher Ø values in some regions (Table 2) may indicate the availability of better environmental conditions for kawakawa in such areas.

According to this study, the present Exploitation ratio (E) was estimated at 0.50 which indicates a sustainable level of exploitation of kawakawa in Sri Lankan waters (Gulland, 1971 & 1979). The target reference point (TRP) of F_{max} indicates the level of fishing mortality for a given size at first capture, which maximizes the average yield from each recruit entering the fishery. The estimated F in this study (0.79 yr^{-1}) was also less than the estimated F_{max} (1.22 yr^{-1}). It indicates that the existing fishing pressure on kawakawa in Sri Lankan waters was not at a harmful level.

Even though there are several arguments for taking F_{max} as a good target reference point (TRP) as it is usually greater than F_{msy}, and that fishing at this rate over an extended period is liable to deplete the spawning stock and reduce future recruitment (Clarke, 1991). Therefore, considering $F_{0.1}$ which is the fishing mortality rate at which the slope of the yield per recruit curve as a function of fishing mortality is 10% of its value at the origin, as a more conservative TRP (Gulland and Boerema, 1973), the present F is higher than the estimated TRP of $F_{0.1}$ (0.63 yr^{-1}). Accordingly, there is a possibility of experiencing growth overfishing on the kawakawa stock in Sri Lankan waters. Considering the $F_{0.5}$ which corresponds to F where the biomass per recruit is equal to 50% of the biomass per recruit without fishing, the resulting value in this study (0.79 yr^{-1}) was higher than the estimated $F_{0.5}$ (0.45 yr^{-1}) which could be resulted by catching the kawakawa stock before reaching the first maturity stage.

As there was a possibility of experiencing growth overfishing on the kawakawa stock in Sri Lankan waters, fisheries regulation of minimum escape gaps (mesh sizes) should be enforced to ensure that small-size kawakawa can escape when caught.

References

Bett, D.K., Tole, M., Mlewa, C.M. (2021). Impact of a ring net fishery in the inshore marine waters of Kilifi on the reproductive biology of six pelagic fish species. Western Indian Ocean Journal of Marine Science, 20(1): 1-10.

Beverton, R.J.H., Holt, S.J. (1957). On the Dynamics of Exploited Fish Populations. Fisheries Investment Ministry, Agriculture Fish Food. Series II, Vol. 19. HMSO. London, 533 p.

Clarke, W.G. (1991). Groundfish exploitation rates based on life history parameters. Can. J. Fish. Aquat. Sci., 48: 734–750.

Dissanayake, D.C.T., Samaraweera, E.K.V. and Amarasiri, C. (2008). Fishery and feeding habits of yellowfin tuna (*Thunnus albacares*) targeted by coastal tuna longlining in the northwestern and north eastern coasts of Sri Lanka, Sri Lanka. J. Aquat. Sci.13:1-21.

Geng, Z. (2022). A preliminary stock assessment of Kawakawa (*Euthynnus affinis*) in the Indian Ocean: Document #: IOTC–2022–WPNT12–13_Rev1.

Gulland, J.A. (1971). The fish resources of the ocean. West By fleet, Surrey. Fishing News (Books), Ltd., for FAO, 255 p.

Gulland, J.A., Boerema, L.K. (1973). Scientific advice on catch levels. Fish. Bull. 71(2): 325–335.

Gulland, J.A., (1979). Report of FAO/IOP workshop on the fishery resources of the western Indian Ocean South of the Equator. FAO, IOFC/DEV/79/45 Rome, pp. 1-37.

Haputhantri, S.S.K., Bandaranayake, K.H.K. (2013). Analysis of Kawakawa (*Euthynnis affinis*) landings in Sri Lanka and estimation of the length-weight and length-length relationships. IOTC—2013—WPNT03—34 Rev l.

Herath, D., Perera, C., Hettiarachchi, C., Murphy, B. (2019). Length-weight and length-length relationships of three neritic tuna species of Sri Lankan coastal waters. International Journal of Fisheries and Aquatic Studies, 7(2): 129-133.

Hunter, A., Speirs, D.C., Heath, M.R. (2016). Investigating trends in the growth of five demersal fish species from the Firth of Clyde and the wider western shelf of Scotland. Fisheries Research, 177: 71-81.

Joseph, L., Maldeniya, R., Van der Knapp, M. (1987). Fishery and age and growth of Kawakawa (*E. affinis*) and Frigate tuna (*A.thazard*). In: Collective Volume of Working Documents presented at the Expert Consultation on stock assessment of tunas in the Indian Ocean, Colombo, Sri Lanka, 4-8 December 1986. Indo-pac. Tuna Dev. Mgt. Programme, Vol.2: pp. 113-23.

Khan, M.Z. (2004). Age and growth, mortality and stock assessment of *Euthynnus affinis* (Cantor) from Maharashtra waters. Indian J. Fish. 51(2): 209-213.

Kumar, R., Sundaramoorthy, B., Neethiselvan, N., Athithan, S., Kumar, R., Rahangdale, S. (2019). Fishery and length-based population parameters of little tuna, *Euthynnus affinis* (Cantor, 1849) from Gulf of Mannar, Southwestern Bay of Bengal. Indian Journal of Geo Marine Sciences, 48 (11): 1708-1714.

Lavin, C.P., Gordo-Vilaseca, C., Stephenson, F., Shi, Z., Costello, M.J. (2022). Warmer temperature decreases the maximum length of six species of marine fishes, crustacean, and squid in New Zealand. Environmental Biology of Fishes, 105(10): 1431-1446.

Lelono, T.D., Bintoro, G. (2019). Population dynamics and feeding habits of *Euthynnus affinis*, Auxis thazard, and Auxis rochei in South Coast of East Java waters. IOP Conf. Series: Earth and Environmental Science, 370:012054.

Maldeniya, R., Moyiadeen, N.M., Amarasiri, C. (1988). Present status of the fishery for small tuna species, billfish and seer fish in Sri Lanka, Report of workshop on small tuna, seer fish and bill fish in the Indian Ocean, pp. 24-37.

Mildenberger, T.K., Taylor, M.H., Wolff, M. (2017). TropFishR: an R package for fisheries analysis with length-frequency data. Methods in Ecology and Evolution, 8: 1520-1527. DOI 10.1111/2041-210X.12791.

Ministry of Fisheries. (2020). Fisheries Statistics 2020. Ministry of Fisheries, Colombo, 70pp.

Mudumala, V.K., Farejiya, M.K., Mali, K.S., Rao, K.R., Ankush, P.S., Anandhan, S. (2018). Investigations on the age, growth and mortality parameters of Kawakawa, *Euthynnus affinis* (Cantor, 1849) from the North west coast of India. Int. J. Aquat. Biol. 6(1): 21-24.

Pauly, D., Munro, J. (1984) Once more on the comparison of growth in fish and invertebrates. Fishbyte 2(1): 1-25

Pauly, D., Munro, J. (1984). A simple method for comparing growth of fishes and invertebrates. Fishbyte 1(1): 5-6

Punyadeva, N.B.P. (2015). Ring Nets (Kandan Kose) Fisheries associated with floating objects in the offshore waters of Sri Lanka and their possible impacts on the pelagic Tuna fish stocks. In: Proceedings of the National Aquatic Resources Research and Development Agency (NARA). Scientific Sessions 2015, NARA. pp. 11- 14.

Ricker, W.E. (1975). Computation and Interpretation of Biological Statistics of Fish Populations. Bull. Fish. Res. Bd. Can. 191: 1–382.

Samaranayake, R., A., D., B. (2003). Review of national fisheries situation in Sri Lanka. In: G. Silvestre, L. Garces, I. Stobutzki, M. Ahmed, R. A. Valmonte-Santos, C. Luna, L. Lachica Aliño, Munro, P., Christensen, V. & Pauly, D. (eds.). Assessment, Management and Future Directions of Coastal Fisheries in Asian Countries. World Fish Center Conference Proceedings 67, 1-120 p.

Sparre, P., Venema, S.C. (1998). Introduction to tropical fish stock assessment. Part 1. Manual. FAO Fisheries Technical Paper No. 306.1. Rev.*1*. FAO. Rome, 407 pp.

Taghavi, M.S.A., Hashemi, S.A., Kochanian, P. (2010). Population biology and assessment of kawakawa (*Euthynnus affinis*) in Coastal Waters of the Persian Gulf and Sea of Oman (Hormozgan Province). Iranian Journal of Fisheries Sciences, 9(2): 315-326.

Tangke, U., Laisouw, R., Talib, A., Husen, A., Kota, R., Umagap, W.A.Z. (2021). Population dynamics of eastern little tuna (*Euthynnus affinis*) in Ternate Waters. In: IOP Conference Series: Earth and Environmental Science, 890(1), IOP Publishing.

Taylor, M, Mildenberger, T.K. (2017). Extending electronic length frequency analysis in R. Fisheries Management and Ecology 24:330338DOI 10.1111/fme.12232.

Then, A.Y., Hoenig, J.M., Hall, N.G., Hewitt, D.A. (2015). Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species, ICES Journal of Marine Science, 72(1): 82–92, https://doi.org/10.1093/icesjms/fsu136

von Bertalanffy, L. (1938) A quantitative theory of organic growth. Human Biology, 10: 181–213.

Wijayaratne, B. (2001). Coastal fisheries in Sri Lanka: some recommendations for future management. United Nations University, Fisheries Training Programme, Reykjavik, Iceland.

Wilderbuer, T. K., Zhang, C. I. (1999). Evaluation of the population dynamics and yield characteristics of Alaska plaice, *Pleuronectes quadrituberculatus*, in the eastern Bering Sea. Fisheries Research. 41(2): 183–200. doi:10.1016/S0165-7836(99)00012-0.

Yasaki, M. (1989). Estimates of age and growth of kawakawa (*E. affinis*), longtail tuna (*Thunnus tonggol*) and frigate tuna (*Auxis thazard*) from the Gulf Thailand based on length data. Indo-Pac. Tuna Dev. Mgt. Programme, IPTP/89/GEN/17: 94-108.