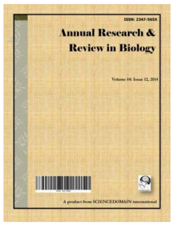

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Length-weight Relationships of Four Commercially Important Fish Species in Indonesia

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Authors' contributions

This work was carried out in collaboration between both authors. Author AK designed the study, wrote the protocols and improved the drafts of the manuscript. Author MB processed data and wrote the first draft of the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Length-frequencies and length-weight relationships of the four economically important fish species *Encrasicholina heteroloba* (Rüppel 1837), *E. punctifer* Fowler 1938, *Katsuwonus pelamis* (Linnaeus 1758) and *Rastrelliger kanagurta* (Cuvier 1816) were analysed to assess the condition of the respective stocks. Length-frequency data were analysed to estimate the theoretical maximum size of fish in a stock (L_∞) and the coefficient K, indicating how fast fish reach that size. A power model approach was used with length and weight data to estimate the condition factor a and allometry coefficient b. The two anchovy species (*Encrasicholina*) showed similar values with L_∞ = 9.45 cm, K = 1.10 year^{-1}, a = 0.00672 and b = 2.919 for *E. heteroloba* and L_∞ = 10.78 cm, K = 1.00 year^{-1}, a = 0.01031 and b = 2.871 for *E. punctifer*. For both species, the allometry coefficient was below 3, implying allometric growth. The estimated parameters for the skipjack tuna *K. pelamis* and the Indian mackerel *R. kanagurta* were L_∞ = 72.32 cm, K = 0.38, a = 0.0395 and b = 2.766 and L_∞ = 27.83 cm, K = 0.92, a = 0.00556 and b = 3.216, respectively. All data were collected in Pasir Kendang, Padang, West-Sumatra in 1993 and 1994.

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Keywords: Enchrasicholina heteroloba; Encrasicholina punctifer; Katsuwonus pelamis; Rastrelliger kanagurta; L/W data; LF data; Padang; West Sumatra; pelagic fisheries.

1. INTRODUCTION

As an archipelagic country, fishing resources play an important role in Indonesia's economy. Highly exploited pelagic fish stocks make up most of Indonesian catches. Bailey et al. [1] noted that some stocks, e.g. in eastern Indonesia, could support increased fishing pressure. The application of length-based methods such as in ELEFAN (and later FiSat) allow for preliminary assessments using a minimum of information, i.e. length-frequency data [2,3].

All species examined in this study are commercially important in South-East Asia. The two *Encrasicholina* species belong to the most frequently caught anchovy species and are often caught as baitfish [4]. *Katsuwonus pelamis* (Linnaeus 1758) belongs to the commercially most important tuna species and makes up considerable portions of the global tuna catch [5]. While 1.6 million tonnes of *K. pelamis* were caught globally in 1994, this catch had doubled to 3.1 million tonnes in 2014. Indonesia belongs to the most important countries to catch *K. pelamis* [6]. The Indian mackerel *Rastrelliger kanagurta* is especially important in the fisheries of Indonesia, Thailand, India, Malaysia and the Philippines [5]. The global catch increased slightly from 351 thousand tonnes in 1994 to 382 thousand tonnes in 2014 [6]. As Indonesia consists of over 17,500 islands, it is little surprising that over 6 million people worked in the fisheries sector in 2012. This sector contributes roughly 20% to the country's agricultural and 2.5% to the total Indonesian GDP. Although the amount of farmed fish has increased over the last decades, captured marine fish contributes the largest portion of fisheries [7].

The anchovy *E. heteroloba* commonly reaches sizes of 8 cm and has a maximum length of 12 cm. It has a cylindrical body shape, forms schools in pelagic waters and occurs inshore. It is found in the Indian Ocean and the Western Pacific Ocean [4]. Morphologically similar, *E. punctifer* has a cylindrical body shape, has a standard length of 8.5 cm and a maximum length of 13 cm. Much like *E. heteroloba*, its distribution ranges over the Indian Ocean and the Western Pacific Ocean, where it forms schools in pelagic waters. In contrast to *E. heteroloba*, it is found both inshore and offshore [4]. The skipjack tuna *K. pelamis* is a "fusiform, elongate and rounded" fish that commonly reaches lengths of 80 cm and has a maximum fork length of 108 cm. It has a silvery belly and a dark, purple back. As an oceanic and cosmopolitan species, it is found all around the world in tropical and warm-temperate waters, where it forms schools near the surface in epipelagic waters [5]. Lastly, the Indian mackerel *R. kanagurta* is a fish with a deep body shape, commonly reaching lengths of 25 cm and maximum lengths of 35 cm. It is found in epipelagic, neritic waters in the Indian Ocean and the Western Pacific Ocean [5].

The present study provides parameters with relevance to fisheries management. Results are also discussed in the light of the already existing literature on the same fish species, both in South-East Asia and elsewhere [6,7].

2. MATERIALS AND METHODS

134,628 datasets on length-frequency and 42,768 datasets on length and weight were available for *Enchrasicholina heteroloba* (former name: *Stolephorus heterolobus*), *E. Punctifer* (former names: *Stoplephorus buccaneeri* and *Stolephorus punctifer*), *Katsuwonus pelamis* (Linnaeus 1758) and *Rastrelliger kanagurta* from various student surveys and own collections. Data for *E. heteroloba* were collected in December 1993 and January 1994 with 8,337 observations in total and 344 observations with weight measurements. *E. Punctifer* measurements were obtained from August to November 1993 and from June to July 1994 with a total of 88,536 observations, 13,225 of which had information on weight. There were 31,459 observations for *K. pelamis*, 30,199 of which also had weight information, collected from June to July 1994 and from April to Mai 1995. The 6,296 observations of *R. kanagurta* were collected from April to July 1994. All data were collected in Pasir Kandang, Padang, West-Sumatra using a wooden fish measurement board (total length TL, to the lower 0.5 cm) and a Satorius Acculab Atilon (Germany) scale (weight W, to the lower g).

Length-frequency analysis was performed with the ELEFAN procedure [8] within the FiSAT II program [9]. With this, the maximum theoretical length of the fish species (L_∞) and a measure of the rate at which a fish species reaches this size (K) were estimated as parts of the von Bertalanffy Growth Formula (VBGF). Analysis of length-weight relationships was done in the open-source program R version 3.2.3 [10]. A univariate linear model of total length over weight was fitted on the log-transformed data was fitted. Observation with studentised residuals more than two standard deviations from the mean were removed. The regression model had the form:

$$log_{10}(\mathrm{L}) = log_{10}(\mathrm{a}) + \mathrm{b} * log_{10}(\mathrm{W}),$$

where L is length and W is weight. The model was transformed to a power model of the form $\mathrm{L} = \mathrm{a} * \mathrm{W}^{\mathrm{b}}$.

Confidence intervals for the growth parameters and goodness of fit estimates were calculated for the linear model. The allometry coefficient describes how fast individuals gain weight when they grow. It generally assumes values around 3, which corresponds to isometric growth [11].

3. RESULTS

To estimate the allometry coefficient, a power model was fitted on those observations, where both length (L) and weight (W) information was available (see Table 1). Within the available LW data, *E. heteroloba* showed a size range of 3.3 – 9.3 cm (mean = 6.7 cm, SD = 1.4 cm), *E. punctifer* showed a size range of 4.0 – 9.3 cm (mean = 5.5 cm, SD = 1.0 cm), *K. pelamis* showed a size range of 26.0 – 70.0 cm (mean = 45.5 cm, SD = 9.0 cm) and *R. kanagurta* showed a size range of 6.1 – 26.2 cm (mean = 11.6 cm, SD = 2.9 cm). *E. heteroloba* showed a weight range of 0.2 – 4.6 g (mean = 1.9 g, SD = 1.2 g), while *E. punctifer* showed a weight range of 0.4 – 7.5 g (mean = 1.5 g, SD = 1.0 g). *K. pelamis* showed a weight range of 300.0 – 4900.0 g (mean = 1666.1 g, SD = 871.2 g). *R. kanagurta* showed a weight range of 1.7 – 204.8 g (mean = 18.4 g, SD = 20.3 g). Two of the examined species, namely *E. punctifer* and *K. pelamis* showed an allometry coefficient of below three. *R. kanagurta* and *E. heteroloba* had an allometry coefficient of over 3.

Length-frequency data were analysed to estimate L_∞ and K. The species with the smallest asymptotic size was *E. heteroloba*, followed by *E. punctifer*. Both had an estimated K near to 1 year^{-1}, speaking for a fast growth in these two species. The model fit was Rn = 0.719 for *E. heteroloba* and Rn = 0.732 for *E. punctifer*. The largest species analysed was *K. pelamis*, with an asymptotic length of 72.32 cm. The estimated K was 0.38 year^{-1}, indicating a considerably slower growth in relation to body size than in the other species. The model fit of the VBGF curve was only Rn = 0.277. The last species analysed was *R. kanagurta*. The estimated maximum size was 27.83 cm and the estimated K was 0.92 year^{-1}. The model fit in this case was Rn = 0.308. The results for all species are summarised in Table 1 and all analyses are illustrated in Fig. 1.

4. DISCUSSION

In this paper 134,628 datasets on length-frequency and 42,768 datasets on length and weight for altogether four species of commercial importance were analysed to obtain fish stock relevant information such as length-weight relationships, allometric growth coefficients, asymptotic length L_∞ and growth factor K. For at least two fish species there are hints for a strong exploitation of the local fish populations.

4.1 *Encrasicholina heteroloba*

Of all species investigated, *E. heteroloba* had the lowest asymptotic length with L_∞ = 9.45 cm and the highest estimate for K with 1.10 year^{-1}, which indicates a relatively fast growth. The allometric coefficient was unusually high with 3.218, which is normally indicative of a “fat” body shape, but could be also due to a low sample size (n = 344). The asymptotic length reported here is lower than in four previous studies from Southeast Asia [2, 12, 13], but higher than in studies from elsewhere [14, 15]. The literature estimates of K vary greatly and range from 0.95 [2] to 2.6 [14]. Estimates of the allometric coefficient are, with the exception of [16], lower than 3, contrasting the findings reported here [17]. The smaller asymptotic length derived from this study could be a seasonal influence or maybe indicate high fisheries pressure especially on larger individuals.

4.2 *Encrasicholina punctifer*

The allometric coefficient of *E. punctifer* is close to 3, implying an almost isometric body shape. The estimates for the asymptotic length and the K value were similar to the values of *E. heteroloba*. All obtained results of the length-frequency analysis are lower than previously

Table 1. Results of length-weight and length frequency analysis; N = total number, n = number of samples with weight information, TL = total length [cm], weight in g, L_∞ in cm, K in year^{-1}. *Sampling* took place in 1993 and 1994

Species	n	n weight	TL range	Weight range	a	95% Cl a	b	95% Cl b	r^2	L_∞	K
Encrasicholina heteroloba (Rüppel 1937)	8,337	344	3.3 - 9.3	0.2 - 4.6	.0037	.0032 - .0042	3.22	3.15 - 3.29	.96	9.45	1.1
Encrasicholina punctifer Fowler 1938	88,536	13,225	4.0 - 9.3	0.4 - 7.5	.0082	.0078 - .0084	2.99	2.98 - 3.01	.93	9.98	0.9
Katsuwonus pelamis (Linnaeus 1758)	31,459	30,199	26.1 - 68.9	300.0 - 4900.0	.0379	.0376 - .0383	2.78	2.77 - 2.78	.99	72.32	0.38
Rastrelliger kanagurta (Cuvier 1816)	6,296	6,296	6.5 - 26.5	1.7 - 204.8	.0049	.0048 - .0051	3.26	3.25 - 3.27	.98	27.83	0.92

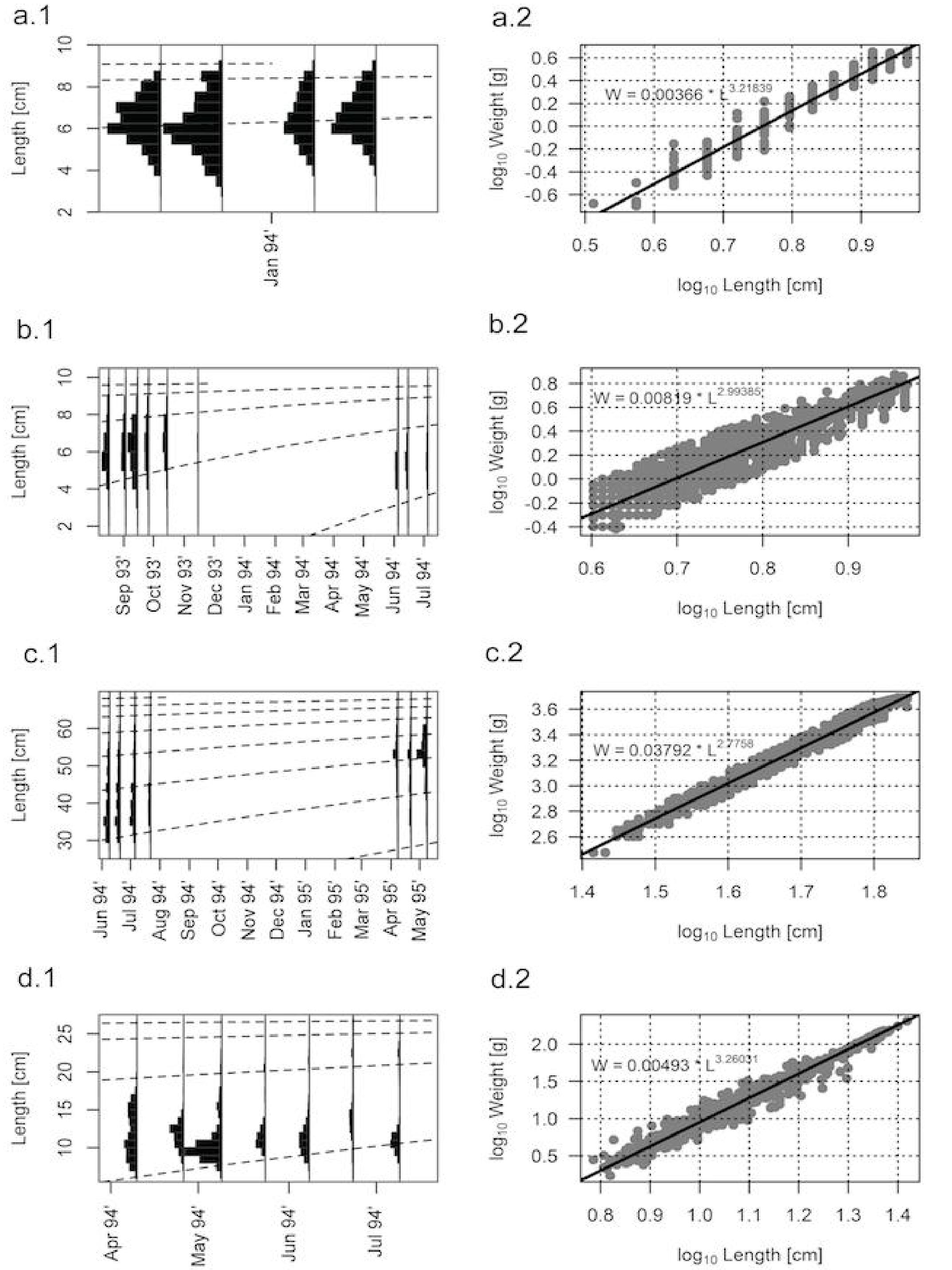

Fig. 1. Graphic illustration of length-frequency (LF) analyses and length-weight models. Length is given as TL. LF plots were created with the FiSAT II software. The length weight models were plotted over log-transformed axes. Plots a.1 and a.2 show data for E. heteroloba, plots b.1 and b.2 show data for E. punctifer, plots c.1 and c.2 show data for K. pelamis and plots d.1 and d.2 show data for R. kanagurta

reported estimates for this species, both in Southeast Asia [13] and from elsewhere [18,19,20]. The allometric coefficient was lower than in another study in Southeast Asia [21]. There were two studies with higher [16,22] and two studies with lower allometric coefficients from other regions in the world [19,20]. The variations may be due to differences in fish feeding, habitat or sex, as was also shown for other species.

4.3 *Katsuwonus pelamis*

The estimate of *K. pelamis'* growth coefficient was lower than in three studies in Southeast Asia [23,24,25]. Of those three studies, Amir et al. [24] and Vinh [23] described a lower coefficient K than described here. Considering studies from other regions, there was only one previous study with a L_∞ below the one described here [26], but nine with higher estimates [27-34]. Regarding the estimated K value, only three of these studies had a lower estimate [27,34,35]. The allometric coefficient of *K. pelamis* was lower than any previously described estimate, both within Southeast Asia [23,36,37] and in other regions [11,26,31,32,38-46]. The observed low growth and allometric coefficients are unusual and could potentially hint at strong exploitation of the local fish populations at the time of sampling.

4.4 *Rastrelliger kanagurta*

Growth parameter estimates were found in four previous studies in Southeast Asia [2,3,47,48]. With the exception of Guanco [47] these authors report similar values for L_∞ . However, the estimates for K are considerably higher in the other three studies. Considering studies from other regions as well, the estimates for L_∞ fall in the range of 25.8 – 38 cm, with most values being close to 29 cm [2,3,20,47-58]. The allometric coefficient for *R. kanagurta* is fairly similar in most published studies and usually lies around 3.2) [49-53,55-58] with the only exception being Mustafa and Ali [54]. With a mean of 3.235, these previous reports align well with the estimate of 3.26 described here.

5. CONCLUSION

The current study presents fisheries related parameters for four economically relevant fish species in South-East Asia. The presented data set expands the available literature and thereby supports the assessment of the development of the examined fish stocks. In comparison to previous studies, both in the same region and elsewhere in the world, the current study hints at a strong fishing pressure and high degree of exploitation.

ETHICAL APPROVAL

As per international standard or university standard written ethical approval has been collected and preserved by the authors.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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