Population dynamics of the white spotted rabbitfish (Siganus canaliculatus Park, 1797) in Makassar Strait and Gulf of Bone, Indonesia

Suwarni 1, J Tresnati 2, S B A Omar 2 and A Tuwo 2
1Student, Postgraduate Program, Universitas Hasanuddin, Makassar, South Sulawesi, Indonesia.
2Faculty of Fisheries and Marine Science, Universitas Hasanuddin, Makassar, South Sulawesi, Indonesia.

E-mail: suwarniliger17@gmail.com

Abstract. The white spotted rabbitfish (Siganus canaliculatus Park, 1797) is a locally important foodfish across much of Indonesia. This study aimed to support population dynamics-based fisheries management of white spotted rabbitfish stocks in the Makassar Strait and Gulf of Bone through providing data on age classes (cohorts), growth, mortality, and exploitation rate. Field data were collected over the year from February 2017 to January 2018. A total of 2248 white spotted rabbitfish (1810 males and 438 females) were collected from the Makassar Strait and 1686 (1277 males and 409 females) from the Gulf of Bone. The fish were measured (L = total length in mm), and all analyses were implemented in FISAT II. Cohorts were determined by sex based on monthly length-frequency data using the Bhattacharya method. The growth factor K and asymptotic length L∞ of white spotted rabbitfish in the Makassar Strait were K = 0.42/yr and L∞ = 211.98 mm with t0 = -0.250 yr for males and K = 0.43/yr, L∞ = 215.00 mm and t0 = -0.386 yr for females. In the Gulf of Bone the values were K = 0.42/yr, L∞ = 211.98 cm and t0 = -0.250 yr for males and K = 0.43 /yr, L∞ = 215.00 mm and t0 = -0.386 yr for females. Mortality parameters of white spotted rabbitfish in the Makassar Strait were total mortality Z = 1.70/yr, natural mortality M = 0.76/yr, F = 0.94/yr giving an exploitation rate of E = 0.55 for males, while for females Z = 1.77/yr, M = 0.84/yr, F = 0.93/yr and E = 0.53. In the Gulf of Bone, for male white spotted rabbitfish Z = 1.78/yr, M = 0.60/yr, F = 1.18 /yr and E = 0.67, while for females Z = 2.42/yr, M = 0.60/yr, F = 1.82/yr and E = 0.75/yr. These data indicate heavy fishing of both stocks, most likely at unsustainable levels.

1. Introduction
The Makassar Strait and Gulf of Bone are known for their reef-associated fisheries. The rabbitfishes (Family Siganidae), such as Siganus javus, Siganus virgatus, and Siganus canaliculatus, are popular foodfishes in this region of Indonesia [1]. Within the genus Siganus, the white spotted rabbitfish (S. canaliculatus) is one of the most commonly caught species.

The fisheries statistics produced by the South Sulawesi Province Marine and Fisheries Service for the period 2010 to 2015 show large annual fluctuations in the reported S. canaliculatus catch. In 2010 the reported catch was 274.4 metric tonnes, with 62.3 metric tonnes in 2011, 420 metric tonnes in 2012, 471.7 metric tonnes in 2013, 450 metric tonnes in 2014, and 382.9 metric tonnes in 2015. A preliminary study revealed declining production volumes; furthermore, around 90% of white spotted
rabbitfish being landed were males, and the average size was becoming smaller. The white spotted rabbitfish catch observed during this preliminary study ranged from 70-210 mm total length (TL), considerably smaller than the dominant catch size of 250-350 mm TL reported by an earlier study [2].

These data show cause for concern over the sustainability of the rabbitfish fisheries. Sustainable fisheries management policies should be based on reliable scientific data, in particular regarding the population dynamics of fished stocks (e.g. age-based cohorts, growth and mortality parameters, recruitment, exploitation levels, and relative yield per recruit). However, in practice, such data are rarely available, and it is still rare for fisheries policies to be underpinned by a strong scientific basis.

This research aimed to determine a number of key population dynamics parameters for white spotted rabbitfish (S. canaliculatus) stocks in the Makassar Strait and Gulf of Bone, in particular age-based cohorts, growth and mortality parameters, and exploitation rate. The wider goal of the research was to contribute to sustainable management of fisheries resources through supporting the development of science-based fisheries management for white spotted rabbitfish in the Makassar Strait and Gulf of Bone.

2. Research Methods

This research took place over one year, from February 2017 to January 2018. White spotted rabbitfish (S. canaliculatus) samples were collected each month (12 months) from the Makassar Strait and Gulf of Bone. Analysis of the specimens was carried out at the Fisheries Laboratory and the Physiology Laboratory of the Faculty of Marine Science and Fisheries, Universitas Hasanuddin.

White spotted rabbitfish were selected randomly from the catch of local fishermen using a local type of semi-permanent set net (sero) in the Makassar Strait and Gulf of Bone. The fish were placed in an insulated coolbox with crushed ice to keep them fresh. On arrival at the laboratory, the fish were taken out of the coolbox and cleaned. The fish were then spread out on a clean slate and labelled. Each fish was measured. The total length (L) of each fish was measured (from the anterior tip of the snout to the posterior tip of the tail) using a fish ruler with 1mm precision. Each specimen was then dissected using surgical scissors and a scalpel in order to examine the gonads and thus determine the sex of the individual. Males had white gonads, while females had yellow gonads.

All data analysis was implemented in the FAO-ICLARM Fish Stock Assessment Tools II (FISAT II) software package Version 1.1.0. The data analysis comprised the following stages.

2.1. Cohort analysis

The length-frequency data were converted into cohort data using the Bhattacharya’s method module in FISAT II [3]. This method is based on the division of the data into a number of normal distributions. Each cohort, representing fish of the same age group, is indicated by the presence of a peak in the histogram. In order to run this analysis, the length-frequency data were first divided into a number of length intervals or classes.

2.2. Growth parameter estimation

The growth parameters were estimated using the von Bertalanffy growth equation [4] as follows:

\[ L_t = L_\infty (1 - e^{-K(t-t_0)}) \]

where \( L_\infty \) is the asymptotic length of the fish (mm), \( K \) is the growth coefficient (yr\(^{-1}\)), \( t_0 \) is the theoretical age at which the length of the fish would be zero (yr), \( t \) is the age (yr) at which the length \( L_t \) (mm) is measured.

The Response Surface Analysis routine within the ELEFAN I module of FISAT II was used to obtain an estimate of the asymptotic length (\( L_\infty \)) and growth coefficient (K). The estimated value of \( t_0 \) was obtained from the empirical equation in [5]:

\[ \log (-t_0) = -0.3922 - 0.2752 \log L_\infty - 1.038 \log K \]

where \( t_0 \) is the theoretical age at which the length of the fish would be zero (yr), \( L_\infty \) is the asymptotic length of the fish (mm), and K is the growth coefficient (yr\(^{-1}\)).
2.3. Mortality and exploitation rate
Total mortality $Z$ was estimated using the Beverton and Holt equation [4]:

$$Z = K \frac{L_\infty - \bar{L}}{\bar{L} - L'}$$

Where: $Z$ = total mortality (yr$^{-1}$), $K$ = growth coefficient (/yr), $L_\infty$ = asymptotic length of the fish (mm), $\bar{L}$ = is the mean length of fish of length $L'$ and longer (mm), and $L'$ is some length for which all fish of that length and longer are under full exploitation.

Natural mortality can be estimated using the empirical approach described in Pauly [5], based on annual average sea surface temperatures. The average seawater temperature for each seaway was 29°C, based on primary data.

Total mortality $Z$ is based on the linearized catch curve constructed from the length–frequency data with the assumption that the age structure of the population is stable [4]. Fishing mortality $F$ is obtained as $F = Z - M$.

3. Result and discussion
3.1. Result
3.1.1. Cohorts. The cohort analysis for white spotted rabbitfish in the Makassar Strait (figure 1) and Gulf of Bone (figure 2) are presented separately for male and female fishes. The months in which one or two cohorts were identified differed between males and females as well as between the two sites.
**Figure 1.** Cohort analysis by month for white spotted rabbitfish (*Siganus canaliculatus* Park, 1797) from Makassar Strait using the Bhattacharya [3] Model: (a) males and (b) females.

| Month     | Sample Size |
|-----------|-------------|
| April 2017  | n = 15       |
| May 2017    | n = 22       |
| June 2017   | n = 21       |
| July 2017   | n = 28       |
| October 2017 | n = 46      |
| November 2017 | n = 58    |
| December 2017 | n = 32   |

**Figure 2.** Cohort analysis by month for white spotted rabbitfish (*Siganus canaliculatus* Park, 1797) from the Gulf of Bone using the Bhattacharya [3] Model: (a) males and (b) females.

| Month     | Sample Size |
|-----------|-------------|
| February 2017 | n = 97     |
| March 2017   | n = 101     |
| April 2017   | n = 87      |
| May 2017     | n = 52      |
| June 2017    | n = 98      |
| July 2017    | n = 104     |
| August 2017  | n = 42      |
| September 2017 | n = 45   |
| October 2017 | n = 26      |
| November 2017 | n = 68    |
| December 2017 | n = 11    |
| January 2018 | n = 45      |
| February 2017 | n = 26     |
| March 2017   | n = 42      |
| April 2017   | n = 68      |
| May 2017     | n = 11      |
| June 2017    | n = 14      |
| July 2017    | n = 37      |
| August 2017  | n = 15      |
| September 2017 | n = 36   |
| October 2017 | n = 62      |
| November 2017 | n = 42    |
| December 2017 | n = 37    |
In the Makassar Strait (figure 1) the male white spotted rabbitfish catch appeared to come from two cohorts during 8 out of 12 months, from March to August 2017 as well as December 2017 and January 2018. During February 2017 and September to November 2017, only one cohort seemed to be present. Meanwhile two cohorts were only observed in female white spotted rabbitfish caught in this seaway during July, September, and October 2017, with a single cohort in the remaining 9 months.

In the Gulf of Bone (figure 2), two cohorts of male rabbit fish were also observed during 8 months, with a single cohort present in February, September, and October 2017 as well as January 2018. Two cohorts of female white spotted rabbitfish only appeared during two months (May and July 2017), with one cohort apparent in the remaining 10 months.

### 3.1.2. Growth parameter

The estimated growth parameters based on the analysis of length-frequency data for white spotted rabbitfish from the Makassar Strait and the Gulf of Bone (table 2) were similar for the two sites. However the parameters differed between male and female fish.

#### Table 2. Growth parameters of White spotted rabbitfish (*Siganus canaliculatus* Park, 1797) estimated using the Von Bertalanffy model.

| Seaway      | Sex     | n     | Parameter           |              |
|-------------|---------|-------|---------------------|--------------|
|             |         |       | **L∞** | **K** | **t₀** | **L₁** |
| Makassar Strait | Male   | 1795  | 211.98 | 0.42  | -0.250 | 211.98 (1 – e⁻^(0.42 (t – (-0.250))) |
|             | Female  | 453   | 215.00 | 0.43  | -0.386 | 215.00 (1 – e⁻^(0.43 (t – (-0.386))) |
| Gulf of Bone | Male    | 1277  | 211.98 | 0.42  | -0.250 | 211.98 (1 – e⁻^(0.42 (t – (-0.250))) |
|             | Female  | 409   | 215.00 | 0.43  | -0.386 | 215.00 (1 – e⁻^(0.43 (t – (-0.386))) |

### 3.1.3. Mortality and exploitation

The estimated mortality rates and exploitation rates for white spotted rabbitfish from the Makassar Strait and Gulf of Bone (table 3) differ between the two sites as well as between males and females. However the between site variation was greater than that between male and female fishes from each site.

#### Table 3. Estimated Mortality (Total = Z, Natural = M, Fishing = F) and Exploitation Rate (E) for male and female white spotted rabbitfishes (*Siganus canaliculatus* Park, 1797) from two seaways.

| Seaway      | Sex     | Parameter | Z | M | F | E |
|-------------|---------|-----------|---|---|---|---|
|             | Male    |           | 1.70 | 0.76 | 0.94 | 0.55 |
|             | Female  |           | 1.77 | 0.84 | 0.93 | 0.53 |
|             | Male    |           | 1.78 | 0.60 | 1.18 | 0.67 |
|             | Female  |           | 2.42 | 0.60 | 1.82 | 0.75 |

### 3.2. Discussion

#### 3.2.1. White spotted rabbitfish (*Siganus canaliculatus* Park, 1797) Cohorts based on length-frequency distributions

The smallest and largest class mid-lengths for male white spotted rabbitfish were 64.50 mm and 214.27 mm in the Gulf of Bone mm, considerably lower than those in the Makassar Strait (105.00 mm and 304.35 mm). A similar pattern was observed for female white spotted rabbitfish, with smallest and largest class mid-lengths of 71.00 mm and 217.02 mm in the Gulf of Bone, as against 113.00 mm and 330.51 mm in the Makassar Strait.

King [6] said that the sample taken is based on the same time interval. Sample species collected were used to determine growth parameters by single sample analysis using the Ford-Walford plot method. Spare and Venema state that sampling is used to determine the characteristics of a group of individuals without having to carry out overall identification of the individual members of the group.
White spotted rabbitfish samples were taken from all the catches landed by fishermen, so that each white spotted rabbitfish had an equal chance of being selected as a sample in order to reduce the likelihood of bias.

The presence of more than one cohort in the catch both in the Makassar Strait and Gulf of Bone during several months of the year is thought to be due to the recruitment of individuals produced by several rabbitfish spawning events over the previous months. Thus, in the following months, more than one cohort could be present in the catch. The mode of the length of each group of white spotted rabbitfish sampled (monthly sample) tended to vary between 129.25 mm and 193.92 mm, indicating a preponderance of young (juvenile) fish. One reason for this phenomenon could be the faster growth of young rabbitfish compared to older individuals [7]. Younger white spotted rabbitfish would generally have faster growth rates, while older white spotted rabbitfish still keep growing but their growth slows down as they become older [8] and approach their asymptotic length [9]. In general, a rabbitfish population comprises more small fishes than large individuals, one reason being the accumulated mortality within a population over time [10].

The length-frequency analysis of fishing data for one year based on the Bhattacharya [3] model shows that in general two cohorts are present in the catch. This indicates that the fishing gear used at the study sites is not particularly selective for size. This gives rise to fears that many white spotted rabbitfish are being caught at smaller sizes, before they have had a chance to reproduce. Rochet and Trenkel and Shutter and Koonce state that unselective fishing has been shown to reduce the relative abundance of species or individuals in an aquatic community, with negative impacts on ecosystem productivity, and in particular on fish biomass, age structure, and size at first maturity, as well as food chains [11-12]. According to Neala et al [13] there is a need for fisheries to apply the precautionary principle, and in particular size selectivity, on both biological and economic grounds.

3.2.2. Growth pattern. Using the ELEFAN I routine in FISAT II on data aggregated by site, the analysis of length-frequency data for white spotted rabbitfish fish (male and female combined) caught in the Makassar Strait and Gulf of Bone yielded the following equations: \( L_t = 313.99 \left(1 - e^{-0.69 (t - (0.215))}\right) \) and \( L_t = 225.89 \left(1 - e^{-0.66 (t - (0.175))}\right) \), respectively. The analysis of length-frequency data using the ELEFAN I routine in FISAT II applied to sex-segregated white spotted rabbitfish caught in the Makassar Strait and Gulf of Bone yielded the equations \( L_t = 211.98(1 - e^{-0.42(t - (0.210))}) \) and \( L_t = 211.98(1 - e^{-0.43(t - (0.250))}) \), respectively, for males. For female white spotted rabbitfish, the respective equations were \( L_t = 215.00 \left(1 - e^{-0.43 (t - (0.386))}\right) \) and \( L_t = 215.00 \left(1 - e^{-0.43 (t - (0.386))}\right) \). Although the equations for female rabbitfish indicate a tendency to slightly faster growth compared to males, at each site the growth factors were not significantly different between male and female rabbitfishes.

The resultant growth curves show that male white spotted rabbitfish in the Gulf of Bone tend to reach their maximum size at around 10 years of age. With a theoretical maximum length of 259.38 mm, fish older than 10 years should have reached their asymptotic length. The growth curve for female white spotted rabbitfish using the Von Bertalanffy method gives a theoretical length of 215.00 mm at 10 years of age, indicating that females over 10 years of age should have attained their asymptotic length \( (L_{\infty}) \).

White spotted rabbitfish in Makassar Strait could attain a maximum length of 313.99 mm at ages of 8 years and over, thus growing larger than in the Gulf of Bone, indicating that white spotted rabbitfish are long-lived fishes. Once white spotted rabbitfish reach their maximum length, natural mortality will occur. Sparre and Venema found that some long-lived species take more than 5 years to reach their maximum length, and have high \( K \) values [4]. According to Frisch, reaching sexual maturity could take 3 years, with 10-12 years to reach maximum size [14]. The largest recorded size is 40 cm TL, although most adults are less than 30 cm long [15].

As mentioned above, although young individuals grow faster than older fishes, rabbitfishes will continue to grow albeit more and more slowly as they approach their asymptotic length. According to Welcomme state, as body size increases, growth is slower, while factors influencing growth can be divided into internal and external factors [8]. Internal factors include genetic factors [9], sex, age and...
health or disease [16-18]. External factors include environmental factors such as water quality [16] as well as the quantity and quality of food available [18-20]. One factor which can make it difficult to predict growth rates accurately is the effect of exploitation, especially if overfishing occurs [21].

3.2.3. Mortality. The mortality rate is a measurement of the likelihood that a fish will die within a given interval of time. Although it is not possible to know the number of fish that will actually die, predictions can be made based on repeated measurements [22]. Information on mortality rates is crucial to the analysis of the population dynamics of an exploited fish stock [23-24] and forms the basis for stock management [10]. The mortality parameters to be estimated include natural mortality (M), fishing mortality (F) and total mortality Z. Natural mortality was estimated using the empirical approach described in Pauly [5], based on annual average sea surface temperatures. Total mortality Z was based on the linearized catch curve constructed from the length-frequency data with the assumption that the age structure of the population is stable [4]. Fishing mortality F was obtained as F = Z - M.

The respective aggregated Z values for the two study sites were 2.09/yr and 2.99/yr, indicating higher mortality (from a combination of natural processes and fishing pressure) in the Gulf of Bone than in the Makassar Strait. Mortality rates tend to be high in white spotted rabbitfish of around 1 and 2 years of age, which are more commonly found in the Gulf of Bone than in the Flores Sea. At this age the fish may not be fully adapted to their environment and are subject to relatively high predation from carnivorous fish. With respect to fishing mortality, young (juvenile) and older (adult) rabbitfishes are both caught. If natural and fishing mortality are both high, white spotted rabbitfish populations will continue to decline. According to Pitcher and Hart, total mortality of a given species can vary greatly between year classes (by a factor of up to 400 times) [25].

The estimated natural mortality (M) of white spotted rabbitfish (based on Pauly’s empirical equations in FISAT II) was 0.74/yr in the Makassar Strait and somewhat higher at 0.79/yr in the Gulf of Bone. Both these M values are relatively low, compared to the 1.5/yr which considers as being high [5]. High levels of natural mortality are generally due to one or more of the following factors: high temperatures, pests and diseases, predation [8,26,27], low dissolved oxygen levels [27], and low pH [26,28]. According to Dodds, the mortality rate in each size/age class is correlated with environmental factors, and can be used to estimate the influence of these factors [10]. The low natural mortality indicates that current environmental conditions and dynamics in the two seaways seem to be suitable for maintaining healthy rabbitfish populations.

Pauly suggested that optimum catch levels should in general be reached when fishing mortality is equal to natural mortality (Fopt. = M) [5]. However, at both study sites fishing mortality was greater than natural mortality (F > M). According to Gulland, if F > M then a stock can be considered overexploited [23]. Unless such overexploitation is controlled, it will affect the relative species abundance within the aquatic community [11,29] and cause the decline of the target fish stock [30-31].

The status of the white spotted rabbitfish fishery in each seaway can be evaluated based on the exploitation rate (E). In the Gulf of Bone, the high value of E (0.74) shows that this white spotted rabbitfish stock is overfished, with 74% of total mortality due to fishing. Based on the optimum fishing level concept developed by Pauly and Gulland[5,23], under which Eopt = 0.5, exploitation of white spotted rabbitfish stocks has already exceeded the upper limit recommended for sustainability at both sites. There is a need to reduce fishing pressure, for example through reducing the number of fishing units operating in these waters.

The total mortality of female white spotted rabbitfish in the Gulf of Bone was considerably higher than that of males (2.42/yr compared to 1.78/yr), largely due to the difference in fishing mortality. The natural mortality rates were similar for males and females (0.85/yr and 0.84/yr), both well below the 1.5/yr considered as high by Pauly [5]. However the fishing mortality (F) of female white spotted rabbitfish (1.84/yr) was higher than that of males (1.18/yr). Female rabbitfishes seem to have suffered higher fishing mortality than males (Fmale < Ffemale).
4. Conclusion
4.1. Growth parameters of white spotted rabbitfish in the Makassar Strait were \( K = 0.42 \) /yr, \( L_\infty = 211.98 \) cm and \( t_0 = -0.250 \) /yr for males, while for females \( K = 0.43 \) /yr, \( L_\infty = 215.00 \) cm and \( t_0 = -0.386 \) yr. For male and female fish combined, \( K = 0.42 \) yr, \( L_\infty = 211.98 \) cm and \( t_0 = -0.250 \) yr for males, while for females \( K = 0.43 \) /yr, \( L_\infty = 215.00 \) cm and \( t_0 = -0.386 \) yr. For male and female fish combined, \( K = 0.66 \) /yr, \( L_\infty = 225.89 \) and \( t_0 = -0.175 \) yr.

4.2. The mortality parameters for white spotted rabbitfish from the Makassar Strait were \( Z = 1.70 \) /yr, \( M = 0.76 \) /yr, \( F = 0.94 \) per and \( E = 0.55 \) for males, while for females \( Z = 1.77 \) /yr, \( M = 0.84 \) /yr, \( F = 0.93 \) per and \( E = 0.53 \). In the Gulf of Bone, mortality parameters for male white spotted rabbitfish were \( Z = 1.78 \) /yr, \( M = 0.60 \) /yr, \( F = 1.18 \) /yr and \( E = 0.67 \), while for females \( Z = 2.42 \) /yr, \( M = 0.60 \) /yr, \( F = 1.82 \) /yr and \( E = 0.75 \).

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References
[1] Mallawa A 2006 Pengelolaan Sumberdaya Ikan Berkelanjutan dan Berbasis Masyarakat (Lokakarya Agenda Penelitian Program COREMANP II Kabupaten Selayar) 9-10 September 2006
[2] Malik A 2012 Studi Beberapa Parameter Dinamika Populasi dan Tingkat Eksplotasi Ikan Baronang Lingkis (Siganus canaliculatus) di Perairan Kabupaten Barru Skripsi (Makassar: Universitas Hasanuddin)
[3] Bhattacharyya C G 1967 A simple method of resolution of a distribution into Gaussian components. Biometrics 115-35
[4] Sparre P and Venema S C 1989 Introduction to Tropical Fish Stock Assessment Part I Manual FAO Fish Tech Pap (306/1)p 337
[5] Pauly D 1983 Some Simple Methods fot The Assesment of Tropical Fish Stocks FAO Fisheries Technical Paper 234 p 52
[6] King M 2013 Fisheries biology: assessment and management (new Jersey: John Wiley and Sons)
[7] Dina R 2008 Rencana Pengelolaan Sumberdaya Ikan Bada (Rasbora Argyrotaenia) Berdasarkan Analisis Frekuensi Panjang di Danau Maninjau Sumatera Barat Bachelor’s Thesis (Bogor: Institut Pertanian Bogor) p 76.
[8] Welcombe R L 2001 Inland Fisheries, Ecology, and Management (London; Fishing News Book, A division of Blackwell Science)
[9] Lagler K F, Bardach J E, Miller R R and Passino D R 1977 Ichthyology (USA: John Wiley and Sons) p 506
[10] Dodds W K 2002 Freshwater Ecology Concepts and Environmental Applications (San Diego: Academy Press, An Elsvier Science Imprint) p 569
[11] Rochet M-J and Trenkel V 2003 Which community indicators can measure the impact of fishing? A review and proposals Can. J. Fish Aquat. Sci. 60 86-99
[12] Shutter B J and Koonce J F 1977 A dynamic model of the western lake erie walleye (Stizostedion vitreum vitreum) population J. Fish Res. Board Can. 34 1972-82
[13] Kendall N W, Hard J J and Quinn T P 2009 Quantifying six decades of fishery selection for size and age at maturity in sockeye salmon Evolution. Appl. 2(4) 523-36
[14] Frisch A J 2007 Short-term and long-term movements of painted lobster (Panulirus versicolor) on a coral reef at Northwest Island, Australia Coral ree 26(2) 311–17
[15] Holthuis L B 1991 FAO Species catalogue Marine Lobster of World FAO Fisheries Synopsis 3 (125) 151-52
[16] Tsoumani M, Liasko R, Moutsaki P, Kagalou I and Leonardus I 2006 Length-weight relationship
of an invasive cyprinid fish (*Carasius gibelio*) from 12 Greek lakes in relation to their trophic states. *J. Appl. Ichthyol.* 22 281-84

[17] Miranda R, Oscoz J, Leunda P M and Escala C M 2006 Weight – length relationships of cyprinid fishes of the Iberian peninsula *J. Appl. Ichthyol.* 22 297-98

[18] Effendie M I 2002 *Biologi Perikanan Yogyakarta* (Jakarta: Yayasan Pustaka Nusatama)

[19] Christiansen J S and Jobling M 1990 The Behavioural and the Relationships Between Food Intake and Growth of Juvenile Arctic charr *Salvelinus alpinis* L. Subjected fo Sustained Exercise. *Can. J. Zoology* 68 2185-91

[20] Metcalfe N B, Huntingford F A and Thorpe J E 1988 Feeding intensity, growth rate and the Establishment of Life History Patterns in Juvenile Atlantic Salmon *Salmo salar* *J. Anim. Ecology* 57 463-74

[21] Hilbom R 1996 The development of scientific advice with incomplete information in the context of the precautionary approach. In *Technical Consultation on the Precautionary Approach to Capture Fisheries (Including Species Introductions)*, FAO Fisheries Technical Paper No. 350/2 (Rome: Food and Agriculture Organization of the United Nations) pp 77-101

[22] Azis 1989 *Pendugaan Stok Populasi Udang Karang Tropis*. (Bogor: Dirjen Pendidikan Tinggi Pusat Antara Universitas Ilmu Hayat, Institusi Pertanian Bogor)

[23] Gulland J A 1969 *Manual of Methods for Fish Stock Assessment Part I: Fish Population Analysis* (FAO Man Fish)

[24] Widodo J and Suadi 2006 *Management of Marine Fisheries Resources* (Yogyakarta: Gadjah Mada University Press)

[25] Pitcher T J and P J B Hart 1982 *Fisheries Ecology* (Avi, Westport CT)

[26] Naughton and Wolf 1990 *General Ecology – Second Edition* (Yogyakarta: Gadjah Mada University Press)

[27] Das S M and J Pande 1980 Pollution, Fish mortality and Environmental Parameters in Lake Nalnital *Journal Bombay Nat. Hist. Soc.* 79 100-09

[28] Feyrer F, Sommer T and Hanel W 2006 Managing Floodplain inundation for Native Fish: Production Dynamics of Age-0 splittait (*Pogonichthys macrolepidotus*) in California's Yoto Bypass *Hydrobiologia* 573(1) 213-26

[29] Jackson J B, et al 2001 Historical overfishing and the recent collapse of coastal ecosystem *Science* 293 1589-91

[30] Muchlisin Z A, Musman M, Azizah M S 2010 Spawning Season of *Rasbora tawarensis* (Pisces: Cyprinidae) in Lake Laut Tawar, Aceh Province, Indonesia *Reprod. Biol. Endocrinol.* 8 2-8

[31] Allan J D, Abell R, Hogan Z, Revenga C, Taylor B, Welcomme R L and Winemiller K O 2005 Overfishing of Inland Water *BioScience* 55 1041-51