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Abstract

Pacific yellowtail emperor, *Lethrinus atkinsoni*, is one of the most targeted reef fish species in Southern Sulawesi, Indonesia. Assessing its stock is important to understand the condition of the population, providing valuable inputs for sustainable fisheries management in the area. Here we assess stock condition of *L. atkinsoni* in Southern Sulawesi, Indonesia, by using the Length-Based Spawning Potential Ratio (LBSPR) model. A total of 952 individuals were collected from commercially small-scale fishers from January to May 2022. Total length, sex, and gonad maturity of the individuals were examined. We observed that the fish' length was ranged from 14 to 37 cm, with an average length of 23.8 cm. Sex ratio was found equal (1:1.2) between male and female individuals, respectively. Length at first maturity (Lm) and length at first capture (Lc) were 22.9 and 21.9 cm, respectively. We observed growth coefficient (k) of 0.4/year, with asymptotic length ($L\infty$) of 40.5 cm and natural mortality (M) of 0.5/year. Based on these life history parameters, we observed the spawning potential ratio (SPR) value of 14%, indicating an unsustainable fishery level (SPR of <30%). Further concerns related to sustainability of the species, strategy to rebuild stock of the *L. atkinsoni* in the Southern Sulawesi is utmost important.

Keywords (3 to 5): *Lethrinus atkinsoni*, Fisheries Management, Length-Based Spawning Potential Ratio, Southern Sulawesi

Introduction

Indonesia is the second world's largest fisheries producer (FAO, 2020), with coral reef fisheries contributing to Indonesian fisheries productivity, estimated to reach a total of 800 thousand tons annually (MMAF, 2022). Coral reef fishes are economically important commodities in Indonesia, demanded not only by domestic market but also by international market, such as to Singapore and Hong Kong (Rizal & Jaliadi, 2018). Due to its high demand, populations of some reef fish species are threatened across the country (Campbell et al., 2013; Hawkins et al., 2000; McManus, 1997).

Reef fish of the family Lethrinidae (emperors) are abundant in tropical and subtropical regions where coral reefs, seagrass beds, and mangrove forest areas are their habitats (Kulmiye et al., 2002; Young & Martin, 1982). Fishes within the family are one of significant food resources in the western Pacific Ocean and Indian Ocean due to their high catch amount (Larson et al., 1992). Among the lethrinids, the *Lethrinus atkinsoni*, known as pacific yellowtail emperors, is one of highly targeted fish by local fishers in Indonesia (Damayanti, 2005; Mayunar, 1996), including in the Southern Sulawesi region (Agustina et al., 2021).

About 90-95% of fishers in Indonesia are small-scale yet generating important contributions for coastal communities (Pusdatin, 2022; Sari et al., 2021). Small-scale fisheries, or often referred to as artisanal fisheries, is a traditional fishery that involves fishing households, and uses relatively small fishing vessels, short fishing trips, and the catch is mainly for local consumption. Most fishers in the Southern Sulawesi are small-scale, contributing significantly to social and economic conditions in the area, as the main source of livelihood, providing food for the community. The fishers and the local community are dependent on fish resources. Accordingly, they are vulnerable to any change that disrupts their harvest (Wiyono, 2011). Effective management of the small-scale fisheries in the area is crucial for the community.

The Southern Sulawesi is one of the important regions for coral reef fisheries in Indonesia, where the world's 3rd largest coral reef atoll found (Malik et al., 2018) and the coral reefs are home for more than 500 reef fish species, including the highly demanded reef fish emperors of the family Lethrinidae (Muhidin et al., 2019). However, the coral reefs there are being threatened due to destructive fishing activities by explosives and cyanide (Panuluh et al., 2020). Despite being one of the most important fishery commodities in Indonesia, the potential of lethrinid fish and its utilization status are still poorly understood (Restiangsih & Muchlis, 2019). In addition, the impact of fishing activities in the Southern Sulawesi is not yet fully known due to limited data (Agustina et al., 2021). This certainly affects fishery management, hampering its resources to be sustainably managed (Rizal & Jaliadi, 2018). In this context, identifying biological characteristics and assessing the stock condition of lethrinid fish is necessary to improve fisheries management in the area. This study aims to assess the stock status of *L. atkinsoni* in Southern Sulawesi, Indonesia. Biological characteristics and stock conditions of the species were investigated by using the length-based stock assessment approach.

Materials and Methods

Study site and sample collection

This study was conducted in the Southern Sulawesi, Indonesia (Fig. 1), from January to May 2022. A total of 952 individuals of *Lethrinus atkinsoni* (Fig. 2) were collected from three landing sites; the Tarupa Besar, Rajuni Kecil, and Latondu Besar. The samples were commercially caught by small-scale handline and speargun fishers. The samples were measured to the nearest millimeter in total length (TL).

From those total samples, in April and May 2022, a total of 152 individuals of *L. atkinsoni* were examined for their sex and gonad maturity following West (1990). The sex of each individual sample was determined through macroscopic examination after dissection, whereby the shape, the color of the testis and ovaries were used to assign sex and gonadal maturity of the fish.

Data analysis

Sex ratio of *L. atkinsoni* was estimated and tested for the significant differences in the proportion of males and females for a theoretical 1:1 relation using a Chi-square (X^2) equation (Kenney & Keeping, 1951). We assessed the fish stock using the Length-Based Spawning Potential Ratio (LBSPR) model (Hordyk et al., 2015). The life-history parameters and length frequency distribution data were examined as its input. The life-history parameters consist of growth coefficient (k), asymptotic length ($L\infty$), natural mortality (M), length at first capture (Lc) and length at first maturity (Lm). Growth parameters (i.e., k and $L\infty$) were estimated by von Bertalanffy growth model (Sparre & Venema, 1998) using the "TropFishR" package in Rstudio (Mildenberger et al., 2017). Natural mortality (M) was calculated following the Pauly empirical equation (Pauly, 1980). Length at first maturity (Lm) was analyzed following the formula of Spearman-Karber (Udupe, 1986), while the length at first capture (Lc) was analyzed based on the logistic curve from the selection ogive function (Sparre & Venema, 1998). The recruitment pattern was estimated by backward projection using length frequency distribution data based on the von Bertalanffy growth curve (Pauly, 1984; Mildenberger et al., 2017).

Results

Size frequency distribution

Length range of *L. atkinsoni* was from 14 to 37 cm, with most of individuals were observed within the 22-23 cm size class (Fig. 3). The average length of the species was 23.78 cm (±SD = 3.93).

Sex ratio

From 152 samples of *L. atkinsoni* that were collected for gonad investigation, we found 83 female and 69 male individuals. Sex ratio (M:F) was 1:1.2 with the observed proportion was statistically not significantly different (p >0,05).

Life history parameters and spawning potential ratio

We observed that the asymptotic length ($L\infty$) of *L. atkinsoni* was 40.5 cm (Table 1). Growth coefficient (k) of the species was 0.4/year, indicating a high growth rate (k >0.3; Froese, 2005). The natural mortality (M) of the species was 0.5/year, with theoretical age at length 0 cm (t0) was 0.38 year (Table 1). Length at first maturity (Lm) of the species was 23.40 cm, with the length at first capture (Lc) was 21.90 cm (Table 1; Fig 4). Based on the LBSPR model, we observed that the spawning potential ratio (SPR) of the *L. atkinsoni* in Southern Sulawesi was 14%, indicating unsustainable level of the stock condition (SPR <30%) (Ault et al., 2008).

Recruitment pattern

We observed that *L. atkinsoni* in Southern Sulawesi was a partial spawner, with the range of monthly recruitment of 2 - 15 % (Fig. 5). The peaks of recruitment were observed in April (15%), July (15%), and November (12%).

Discussion

This is the first study of the length-based stock assessment of *L. atkinsoni*, the pacific yellowtail emperor, in Southern Sulawesi, Indonesia. We provide scientific information regarding the biological characteristics of the species, providing valuable input for the fisheries management in the region. Based on the biological characteristics, we found that the population was harvested at an unsustainable level.

The length's range of the *L. atkinsoni* in Southern Sulawesi was from 14 to 37 cm. In other sites within Indonesia, the ranges of the conspecific were from 15.1 to 32.5 cm and from 12.0 to 37.7 cm in East Seram (Rumania et al., 2020) and in Wakatobi (Prihatiningsih et al., 2021), respectively. In the Great Barrier Reef, Australia, the maximum length reported was 48 cm (Currey et al., 2013). While the range was similar among sites within Indonesia, the length of the fish was relatively smaller compared to the conspecific in Australia (Currey et al., 2013). This discrepancy might be due to ecological and environmental conditions between Indonesia and Australia, such as water quality, genetics, catch rate, and food abundance (Nikolskii, 1963; Rahardjo & Simanjuntak, 2007), which can affect the biological condition of the fish.

In the present study, we found that sex ratio of the *L. atkinsoni* in Southern Sulawesi was equal between male and female individuals. Similarly, sex ratio of the conspecific in the Wakatobi was found equal (sex ratio M:F = 0.55:1.00; Prihatiningsih et al., 2021). Variations in the sex ratio can be affected by several factors, including behavior patterns, mortality, and growth rates between male and female individuals, spawning behavior, sexual maturity, length distribution due to its depth ranges, and length (or age) of the individuals (Effendie, 1997; Nikolskii, 1963). However, note should be taken into considerations that *L. atkinsoni* is protogynous hermaphroditism species, with the length of sexual transition was reported between 23.0 and 23.9 cm FL off Yaeyama and between 30.0 and 30.9 cm FL off Okinawa (Ebisawa, 1999). In protogynous species, the exact effect of fishing pressure on stock dynamics is complex (Alonzo & Mangel, 2004). In case of the present study, no data of sexual transition length was reported of the species from the area. Accordingly, further measures of the fishery management for the species might be challenging.

We observed that the growth coefficient (k) of the *L. atkinsoni* was 0.4/year, with the asymptotic length ($L\infty$) of 40.5 cm. Based on Froese (2005), the k values of higher growth rate is above 0.3/year. In areas close to the equator (i.e., tropical region), *L. atkinsoni* tends to have higher k values than the conspecific in higher latitudes (Table 2). Higher annual seawater temperature in the tropic might affect the higher growth rate of *L. atkinsoni* (Gislason et al., 2010).

Length at first maturity (Lm) of *L. atkinsoni* in Southern Sulawesi was 23.40 cm, at the age of approximately 1.8 years. The Lm at the present study was relatively lower compared to the conspecific in the Wakatobi (Lm for male = 30.7 cm; Lm for female = 27.18 cm; Prihatiningsih et al., 2021), but relatively higher in Japan (Ebisawa, 1999) with the Lm of 19 cm FL off Yaeyama and 21 cm FL off Okinawa. The Lm discrepancy was presumably due to the influence of environmental factors including nutrient conditions, seawater temperature, irradiation, as well as species feeding habits and physiological conditions of fish, and the location of fishing ground (Hagiryanto et al., 2013; Lagler et al., 1963; Sudarno et al., 2020; Udupe, 1986; Wootton, 1985). Latitudinal difference of more than 5° was thought to be the cause of differences in age and length at first gonad maturity (Effendie, 1997). Moreover, high fishing pressure could affect the length at first maturity, where rapid maturation was found as a strategy of fish populations to cope with high fishing pressure (Restiangsih & Amri, 2019). The rate of fishing pressure in Southern Sulawesi is relatively higher than in Wakatobi (Fatma et al., 2021). To maintain its population, *L. atkinsoni* in the Southern Sulawesi was likely to follow a similar strategy.

We observed that the average size of the first capture (Lc) of *L. atkinsoni* in Southern Sulawesi was 21.90 cm at the age of approximately 1.5 years. The Lc was lower than the Lm, indicating that local fishers in Southern Sulawesi also caught the proportion of immature individuals (Fig. 4). Based on the size frequency distribution (Fig. 3), about 49.8% of immature individuals were caught by the local fishers. In addition, we found that the peak of recruitment of *L. atkinsoni* occurred in April, July, and November. This information can be used to predict the spawning period of *L. atkinsoni* in Southern Sulawesi (Agustina et al., 2019), which can provide input to fisheries managers to apply temporary fishing closure.

Based on the LBSPR model, the SPR of *L. atkinsoni* in Southern Sulawesi was 14%, indicating that the population was harvested at an unsustainable level. The low SPR values (<30%) can reduce the ability of spawning stock biomass to produce adult stock in the structure of the population (Ault et al., 2008). This reflects a reduction in the number of young fish, thereby triggering a decrease in spawning stock, limiting the number of eggs produced. The SPR as the biological reference point is used to define safe levels of fishery harvesting and as benchmarks against which the actual status of a fish stock can be measured (Collie & Gislason, 2001). Management actions to rebuild stock of the species are needed to increase SPR above the threshold (>30%), in which can be achieved by reducing fishing intensity, temporary fishing closure, and regulating the harvest size limit. Further management actions are needed to rebuild stock of the species in the area, to ensure a sustainable fishery.

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Tables and Figures

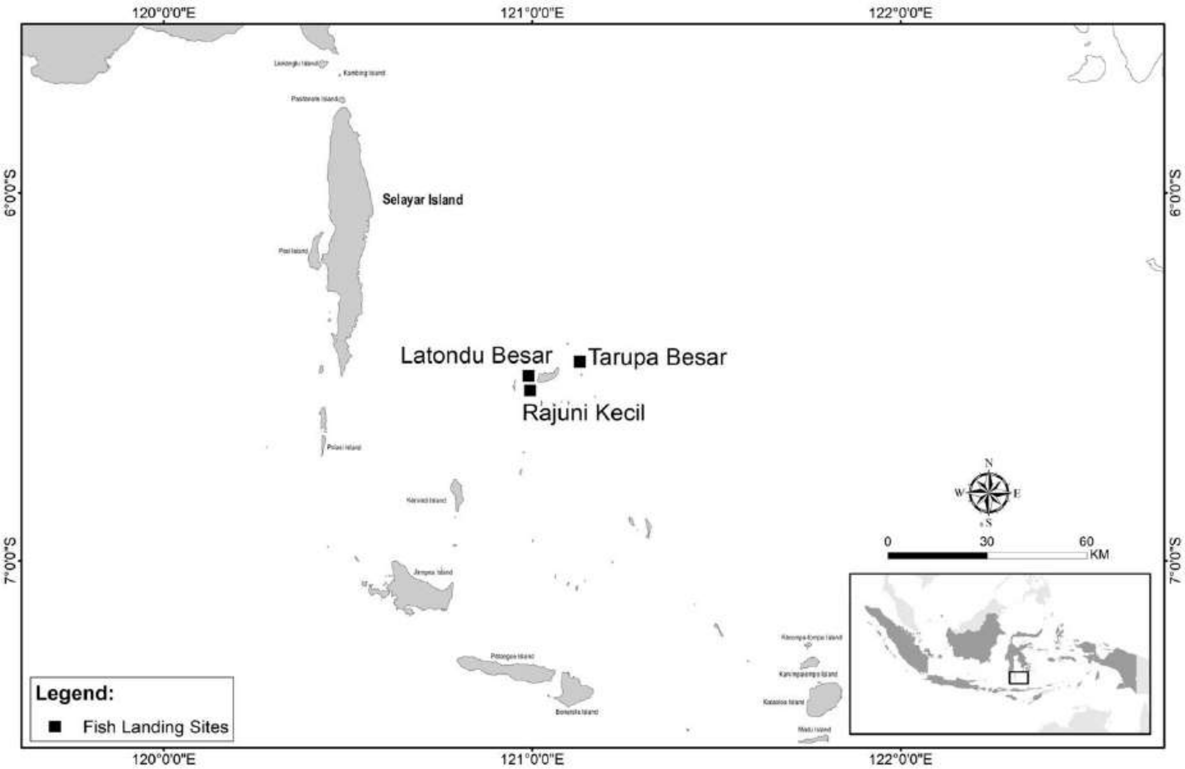

Fig 1. Map of the study area where data of *Lethrinus atkinsoni* were collected from three landing sites in Southern Sulawesi, Indonesia

Fig 2. A sample of *Lethrinus atkinsoni* caught from small-scale fishers in Southern Sulawesi, Indonesia

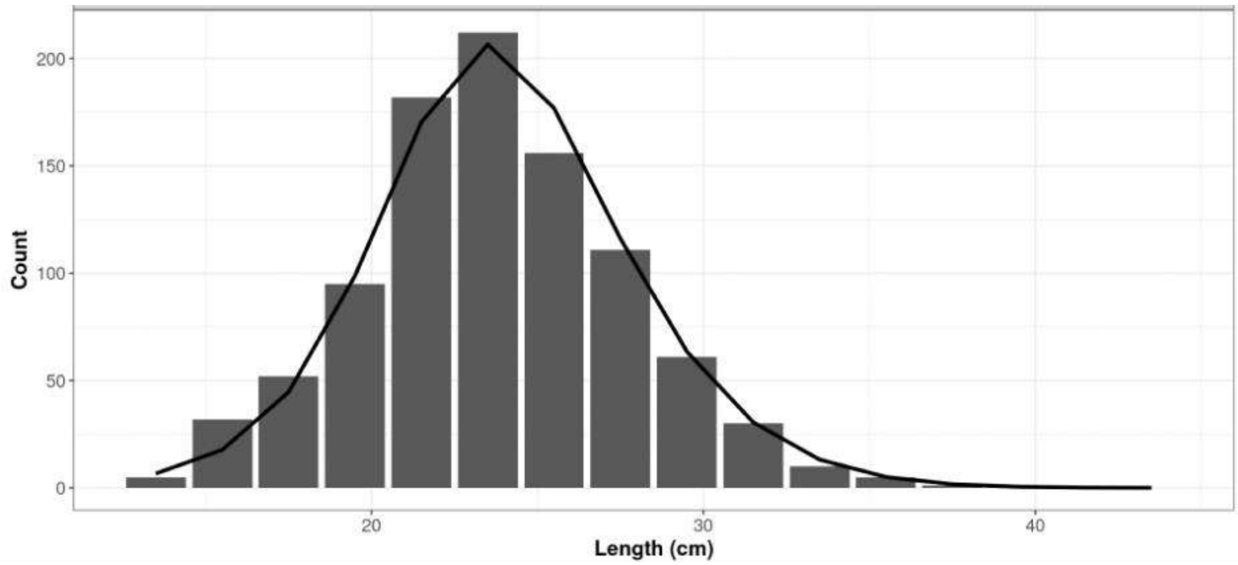

Fig 3. Length frequency distribution of *Lethrinus atkinsoni* that were collected from three landing sites in Southern Sulawesi, Indonesia

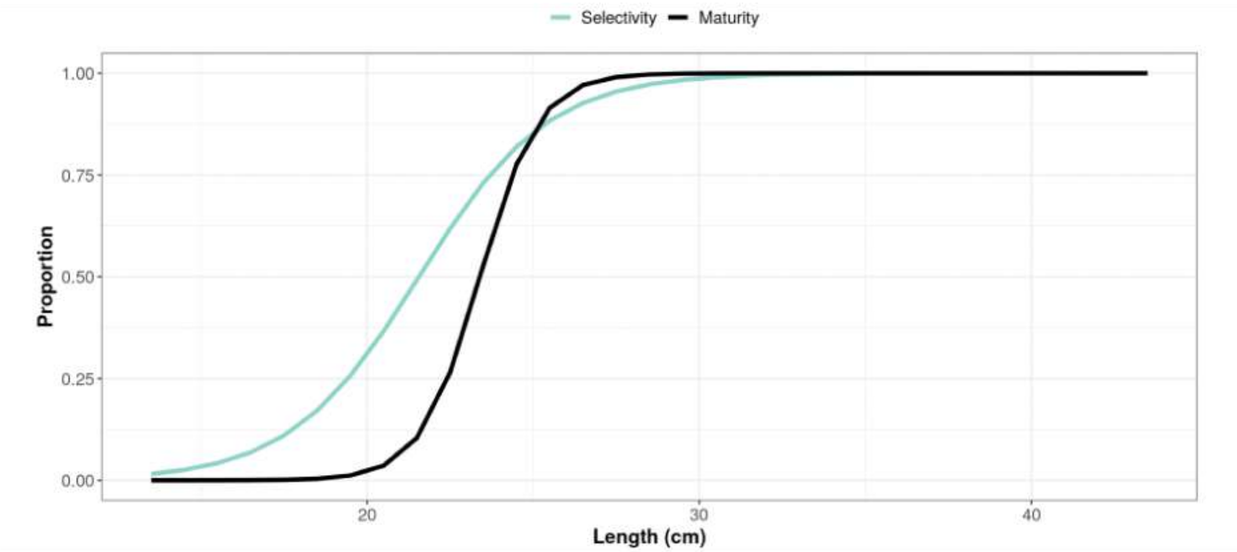

Fig 4. Maturity and selectivity curve of *Lethrinus atkinsoni* in Southern Sulawesi, Indonesia

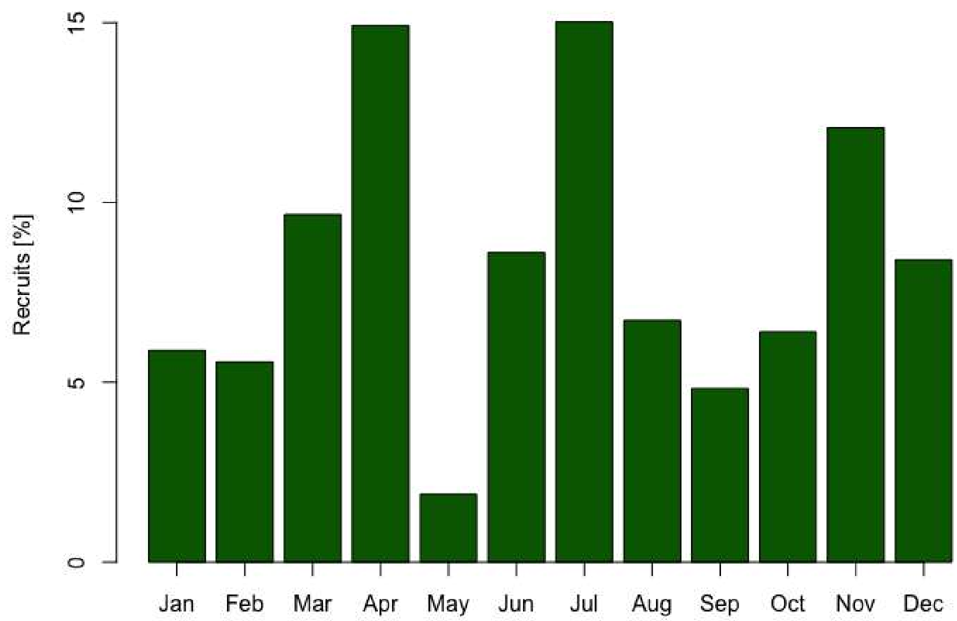

Fig 5. Recruitment pattern of *Lethrinus atkinsoni* in Southern Sulawesi, Indonesia

Table 1. Life history parameters and spawning potential ratio of *Lethrinus atkinsoni* in Southern Sulawesi, Indonesia

Parameter	**Unit**	**Value**
Asymptotic length (L∞)	cm	40.50
Growth coefficient (k)	Per year	0.40
The theoretical age at a length 0 cm (t0)	year	-0.38
Natural mortality (M)	Per year	0.50
Length at first maturity (Lm)	cm	23.40
Length at first capture (Lc)	cm	21.90
Spawning potential ratio (SPR)	%	14

Table 2. Growth parameters of *Lethrinus atkinsoni* in different locations

Location	**L∞ (cm)**	**k (/year)**	**References**
Yaeyama, Japan	30.9 (FL)	0.186	Fishbase (2022)
Great Barrier Reef and Eastern Torres Strait, Australia	32.5 (FL)	0.32	Fishbase (2022)
Northern coast, Fiji	42.8 (SL)	0.29	Fishbase (2022)
Okinawa, Japan	35.1 (SL)	0.26	Fishbase (2022)
Great Barrier Reef, Australia	32.2 (FL)	0.32	Currey et al., (2013)
Wakatobi, Indonesia	38.2 (FL)	0.44	Prihatiningsih et al., (2021)
East Seram, Indonesia	34.2 (TL)	0.42	Rumania et al., (2020)
Southern Sulawesi, Indonesia	*40.5 (TL)*	*0.40*	*This study*

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[Fast-track] New Manuscript is submitted (1st, Subarea: Ecology and Fisheries Resource Management) (fas-2022-0136)

Kotak Masuk

Fisheries and Aquatic Sciences

Manuscript ID : fas-2022-0136 (1st) Manuscript Type : Research Article Manuscript Subarea : Ecology and Fisheries Resource Management Manuscript Title : Length-

Sel, 29 Nov 2022 19.38

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Nyoman Suyasa

Dear Editorial Office, The Journal of Fisheries and Aquatic Sciences, May we check the status of that we had submitted on 29 November 2022 (email

Kam, 19 Des 2022 11.23

N

Nyoman Suyasa <soeyasa.aup@gmail.com>

Sel, 17 Jan 21.46

kepada Fisheries

Dear Editorial Office, Journal of Fisheries and Aquatic Sciences,

I am resending my email to check the status of the manuscript (manuscript ID: fas-2022-0136) that we have submitted in November 2022.

I really appreciate if you could give any information about the status of our manuscript.

Thank you very much.

Sincerely Yours,

Dr. I Nyoman Suyasa

[RE]Re: [Fast-track] New Manuscript is submitted (1st, Subarea: Ecologyand Fisheries Resource Management) (fas-2022-0136)

Kotak Masuk

(사)한국수산과학회 Dear Nyoman Suyasa Happy day to you. I apologize for the late reply. The reviewer review completed, so you will receive the first round of resu — Jum, 27 Jan 15.50

Nyoman Suyasa <soeyasa.aup@gmail.com> — Min, 29 Jan 08.01

kepada "(사)한국수산과학회"

Dear Yeonjoo Chae,

Thank you very much for your reply. We look forward for the next step process of review.

Best Wishes,

I Nyoman Suyasa

On Jan 27, 2023, at 3:50 PM, (사)한국수산과학회 <kosfas@kosfas.or.kr> wrote:

Dear Nyoman Suyasa

Happy day to you.

I apologize for the late reply.

The reviewer review process has been completed, so you will receive the first round of results soon.

I ask for your generous understanding.

Hope this answer was helpful.

Best regards,

Yeonjoo Chae

Journal Secretariat

N

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Posisi manuscript pada 25 Januari 2023 review completed

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Submission List

Action	Manuscript ID	Type (Urgency) (Category)	Title	Status (Date changed)	Author (Date submitted)
View Submission Letters	fas-2022-0136 (1st)	Research Article (**Fast-track**) (Ecology and Fisheries Resource Management)	Length-based stock assessment of the Pacific Yellowtail Emperor in the Southern Sulawesi, Indonesia	**Required review completed** (2023-01-25)	I Nyoman Suyasa (2022-11-29)

Manuscript ID : fas-2022-0136 (1st)
Manuscript Type : Research Article
Manuscript Subarea : Ecology and Fisheries Resource Management
Manuscript Title : Length-based stock assessment of the Pacific Yellowtail Emperor in the Southern Sulawesi, Indonesia

Dear Dr. I Nyoman Suyasa

This is Fisheries and Aquatic Sciences.

The examination of your manuscript has been completed.
The editor-in-chief had made a final decision that the revision were needed.
You can check the comments below by accessing the online submission system.
Even if there is some files attached by the reviewers, you can not check it in the e-mail, so please make sure to access the system.
After reflecting the correction in the manuscript, be sure to submit it again using the submission system.

Editor's comment to author:

Reviewer 1:

The manuscript is sufficient and accepted to be published. Some comment to strengthen the finding is suggested.

Reviewer 2:

This paper is thought to be useful in understanding the ecological characteristics and the stock status of Lethrinus atkinsoni, which should be managed effectively in the area. However, I think this paper should be revised or more samples should be taken for this study. Please see the attachment for specific comments.

Another comment is recommended to be submitted as a short communication rather than an article. This is because the sampling period of this study is too short and the results presented in the paper include only a part of the ecology of the species.

Editor-in-chief's comment to author:

Please do not reply to this e-mail message. If you have comments or questions, please use the contact information below.

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Best regards,
You-Jin Jeon, Jung Hwa Choi, Han Kyu Lim, and Suengmok Cho, Editors-in-Chief
Fisheries and Aquatic Sciences

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ARTICLE INFORMATION	Fill in information in each box below
Article Type	Research article
Article Title (within 20 words without abbreviations)	Length-based stock assessment of the Pacific Yellowtail Emperor in the Southern Sulawesi, Indonesia
Running Title (within 10 words)	Length-based stock assessment of the Pacific Yellowtail Emperor
Author	I Nyoman Suyasa[1], Alifah Fitam Rakhma Sari[1], Siska Agustina[2], Rian Prasetia[2], Ratna Suharti[1], Toni Ruchimat[1,2], Budy Wiryawan[2,3,4], Irfan Yulianto[2,3]
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Competing interests	No potential conflict of interest relevant to this article was reported.
Funding sources State funding sources (grants, funding sources, equipment, and supplies). Include name and number of grant if available.	Not applicable.
Acknowledgements (Anything that is grateful or helped, not support funding)	We thank local fishers and traders in the Tarupa, Rajuni, and Latondu villages in Southern Sulawesi, Indonesia, for their support in conducting data collection.
Availability of data and material	Upon reasonable request, the datasets of this study can be available from the corresponding author.
Ethics approval and consent to participate	Not applicable.

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Fax number	Not applicable.

Abstract

Pacific yellowtail emperor, *Lethrinus atkinsoni* *Seale, 1910*, is one of the most targeted reef fish species in Southern Sulawesi, Indonesia. ~~Assessing~~ Therefore, assessing its stock is important to understand the condition of the population, providing valuable inputs for sustainable fisheries management in the area. Here we assess the stock condition of *L. atkinsoni* in Southern Sulawesi, Indonesia, ~~by~~ using the Length-Based Spawning Potential Ratio (LBSPR) model. A total of 952 individuals were collected from commercially small-scale fishers from January to May 2022. The total length, sex, and gonad maturity of the individuals were examined. We observed that the fish~~'~~ length ~~was~~ ranged from 14 to 37 cm, with an average length of 23.8 cm. ~~Sex~~ The sex ratio was ~~found~~ equal (1:1.2) between male and female individuals~~, respectively.~~. Length at first maturity (Lm) and length at first capture (Lc) were 22.9 and 21.9 cm, respectively. ~~We~~ In addition, we observed a growth coefficient (k) of 0.4/year, with an asymptotic length ($L\infty$) of 40.5 cm and natural mortality (M) of 0.5/year. Based on these life history parameters, we observed the spawning potential ratio (SPR) value of 14%, indicating an unsustainable fishery level (SPR of <30%). Further concerns related to the sustainability of the species~~,~~ and strategy to rebuild stock of the *L. atkinsoni* in ~~the~~ Southern Sulawesi ~~is~~ are of utmost ~~important~~importance.

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Keywords (3 to 5): *Lethrinus atkinsoni*, Fisheries Management, Length-Based Spawning Potential Ratio, Southern Sulawesi

Introduction

Indonesia is the second world's largest fisheries producer (FAO, 2020), with coral reef fisheries contributing to Indonesian fisheries productivity, estimated to reach a total of 800 thousand tons annually (MMAF, 2022). ~~Coral~~ As a result, coral reef fishes are economically important commodities in Indonesia, demanded by domestic and international markets, such as Singapore and Hong Kong (Rizal & Jaliadi, 2018). ~~Due~~ However, due to its high demand, populations of some reef fish species are threatened across the country (Campbell et al., 2013).

Reef fish of the family Lethrinidae (emperors) are abundant in tropical and subtropical regions where coral reefs, seagrass beds, and mangrove forest areas are their habitats (Young & Martin, 1982). Fishes within the family are one of the significant food resources in the western Pacific ~~Ocean~~ and Indian Oceans due to their high catch amount (Larson et al., 1992). Among the lethrinids, the *Lethrinus atkinsoni*, known as pacific yellowtail emperors, is

~~one of~~a highly targeted fish by local fishers in Indonesia (Mayunar, 1996), including in the Southern Sulawesi region (Agustina et al., 2021).

About 90-95% of fishers in Indonesia are small-scale yet generating ~~important~~ significant contributions for coastal communities (Sari et al., 2021). Small-scale fisheries~~,~~ ~~or~~ often referred to as artisanal fisheries, is a traditional fishery that involves fishing households~~,~~ and uses relatively small fishing vessels~~,~~ and short fishing trips~~,~~ ~~and t~~. The catch is mainly for local consumption. Most fishers in ~~the~~ Southern Sulawesi are small-scale, contributing significantly to social and economic conditions in the area~~,~~ as the ~~main~~ primary source of livelihood, providing food for the community. The fishers and the local community are dependent on fish resources. Accordingly, they are vulnerable to any change that disrupts their harvest (Wiyono, 2011). ~~Effective~~ Therefore, effective management of ~~the~~ small-scale fisheries in the area is crucial for the community.

~~The~~ Southern Sulawesi is one of ~~the important regions for coral reef fisheries in Indonesia~~Indonesia's crucial regions for coral reef fisheries, where the world's 3rd ~~largest~~ most extensive coral reef atoll is found (Malik et al., 2018). T~~ and t~~he coral reefs are home ~~for~~ to more than 500 reef fish species, including the highly demanded reef fish emperors of the family Lethrinidae (Muhidin et al., 2019). However, the coral reefs there are being threatened due to destructive fishing activities by explosives and cyanide (Panuluh et al., 2020). Despite being one of the most important fishery commodities in Indonesia, the potential of lethrinid fish and its utilization status are still poorly understood (Restiangsih & Muchlis, 2019). In addition, the impact of fishing activities in ~~the~~ Southern Sulawesi is not yet fully known due to limited data (Agustina et al., 2021). This limited status and trend certainly affect~~s~~ fishery management, hampering its resources to be sustainably managed (Rizal & Jaliadi, 2018). In this context, identifying biological characteristics and assessing the stock condition of lethrinid fish is necessary to improve fisheries management in the area. This study aims to assess the stock status of *L. atkinsoni* in Southern Sulawesi, Indonesia. ~~Biological~~ The species' biological characteristics and stock conditions were investigated~~characteristics and stock conditions of the species were investigated by~~ using the length-based stock assessment approach.

Materials and Methods

Study site and sample collection

This study was conducted in ~~the~~ Southern Sulawesi, Indonesia (Fig. 1), from January to May 2022. A total of 952 individuals of *Lethrinus atkinsoni* (Fig. 2) were collected from three landing sites; the Tarupa Besar, Rajuni

Kecil, and Latondu Besar. The samples were commercially caught by small-scale handline and speargun fishers. The samples were measured to the nearest millimeter in total length (TL).

From those total samples, in April and May 2022, ~~a total of~~ 152 individuals of *L. atkinsoni* were examined for their sex and gonad maturity following West (1990). The sex of each ~~individual~~ sample was determined through macroscopic examination after dissection, whereby the shape~~,~~ and ~~the~~ color of the testis and ovaries were used to assign the ~~sex and~~ gonadal maturity of the fish.

Data analysis

~~Sex~~ The sex ratio of *L. atkinsoni* was estimated and tested for the significant differences in the proportion of males and females for a theoretical 1:1 relation using a Chi-square (X^2) equation (Kenney & Keeping, 1951). We assessed the fish stock using the Length-Based Spawning Potential Ratio (LBSPR) model (Hordyk et al., 2015). The life-history parameters and length frequency distribution data were examined as its input. The life-history parameters consist of growth coefficient (k), asymptotic length ($L\infty$), natural mortality (M), length at first capture (Lc) and length at first maturity (Lm). Growth parameters (i.e., k and $L\infty$) were estimated by the von Bertalanffy growth model (Sparre & Venema, 1998) using the "TropFishR" package in Rstudio (Mildenberger et al., 2017). Natural mortality (M) was calculated following the Pauly empirical equation (Pauly, 1980). Length at first maturity (Lm) was analyzed following the formula of Spearman-Karber (~~Udupe~~Udupe, 1986), while the length at first capture (Lc) was analyzed based on the logistic curve from the selection ogive function (Sparre & Venema, 1998). The recruitment pattern was estimated by backward projection using length frequency distribution data based on the von Bertalanffy growth curve (Pauly, 1984; Mildenberger et al., 2017).

Results

Size frequency distribution

The l~~L~~ength range of *L. atkinsoni* was from 14 to 37 cm, with most ~~of~~ individuals ~~were~~ observed within the 22-23 cm size class (Fig. 3~~).~~) with ~~The~~ an average length of ~~the species was~~ 23.78 ~~cm~~ (±~~SD =~~ 3.93 cm).

Sex ratio

From 152 samples of *L. atkinsoni* that were collected for gonad investigation, we found 83 female and 69 male individuals. The s~~S~~ex ratio (M : F) was 1:1.2, with the observed proportion was ~~was~~ statistically not significantly different (p >0,05).

Life history parameters and spawning potential ratio

We observed that the asymptotic length (L∞) of *L. atkinsoni* was 40.5 cm (Table 1). The g~~G~~rowth coefficient (k) of the species was 0.4/year, indicating a high growth rate (k >0.3; Froese, 2005). The natural mortality (M) of the species was 0.5/year, with theoretical age at length 0 cm (t0) was 0.38 years (Table 1). ~~L~~The length at first maturity (Lm) of the species was 23.40 cm, with the length at first capture (Lc) was 21.90 cm (Table 1; Fig 4). Based on the LBSPR model, we observed that the spawning potential ratio (SPR) of the *L. atkinsoni* in Southern Sulawesi was 14%, indicating an unsustainable level of the stock condition (SPR <30%) (Ault et al., 2008).

Recruitment pattern

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We observed that *L. atkinsoni* in Southern Sulawesi was a partial spawner, with ~~the~~ a range of monthly recruitment of 2 - 15 % (Fig. 5). The peaks of recruitment were observed in April (15%), July (15%)~~,~~ and November (12%).

Discussion

This study is the first ~~study~~ finding of the length-based stock assessment of *L. atkinsoni,* the pacific yellowtail emperor, in Southern Sulawesi, Indonesia. We provide scientific information regarding the biological characteristics of the species, providing valuable input for ~~the~~ fisheries management in the region. Based on the biological characteristics, we found that the population of this emperor was harvested at an unsustainable level.

The length~~'s~~ range of the *L. atkinsoni* in Southern Sulawesi was from 14 to 37 cm. In other sites within Indonesia, the ranges of the conspecific were from 15.1 to 32.5 cm and from 12.0 to 37.7 cm in East Seram (Rumania et al., 2020) and ~~in~~ Wakatobi (Prihatiningsih et al., 2021), respectively. In the Great Barrier Reef, Australia, the maximum length reported was 48 cm (Currey et al., 2013). While the range was similar among sites within Indonesia, the length of the fish was relatively smaller compared to the conspecific in Australia (Currey et al., 2013). This discrepancy might be due to ecological and environmental conditions between Indonesia and Australia, such as water quality, genetics, catch rate, and food abundance (Nikolskii, 1963), which can affect the biological condition of the fish.

In the present study, we found that the sex ratio of ~~the~~ *L. atkinsoni* in Southern Sulawesi was equal between male and female individuals. Similarly, the sex ratio of the conspecific in the Wakatobi was ~~found~~ equal (sex ratio M : F = 0.55:1.00; Prihatiningsih et al., 2021). Variations in the sex ratio can be affected by several factors, including behavior patterns, mortality, and growth rates between male and female individuals, spawning behavior, sexual maturity, length distribution due to its depth ranges, and length (or age) of the individuals (Effendie, 1997; Nikolskii, 1963). However, a note should be taken into consideration~~s~~ that *L. atkinsoni* is protogynous hermaphroditism species, with the length of sexual transition was reported between 23.0 and 23.9 cm FL off Yaeyama and between 30.0 and 30.9 cm FL off Okinawa (Ebisawa, 1999). In protogynous species, the exact effect of fishing pressure on stock dynamics is complex (Alonzo & Mangel, 2004). In the case of the present study, no data ~~of~~ on sexual transition length was reported ~~of~~ on the species from the area. Accordingly, further measures of ~~the~~ fishery management for the species might be challenging.

We observed that the growth coefficient (k) of ~~the~~ *L. atkinsoni* was 0.4/year, with ~~the~~ an asymptotic length (L∞) of 40.5 cm. Based on Froese (2005), the k value~~s~~ of a higher growth rate is above 0.3/year. In areas close to the equator (i.e., tropical region), *L. atkinsoni* tends to have higher k values than the conspecific in higher latitudes (Table 2). Higher annual seawater temperatures in the tropic might affect the higher growth rate of *L. atkinsoni* (Gislason et al., 2010).

The l~~L~~ength at first maturity (Lm) of *L. atkinsoni* in Southern Sulawesi was 23.40 cm~~,~~ at the age of approximately 1.8 years. The Lm ~~at~~ in the present study was relatively lower compared to the conspecific in the Wakatobi (Lm for male = 30.7 cm; Lm for female = 27.18 cm; Prihatiningsih et al., 2021)~~,~~ but relatively higher in Japan (Ebisawa, 1999) with the Lm of 19 cm FL off Yaeyama and 21 cm FL off Okinawa. The Lm discrepancy was presumably due to the influence of environmental factors, including nutrient conditions, seawater temperature, irradiation, as well as species feeding habits and physiological conditions of fish, and the location of the fishing ground (Lagler et al., 1963; Udupe, 1986; Wootton, 1985). Latitudinal difference of more than 5° was thought to ~~be the cause of~~cause differences in age and length at first gonad maturity (Effendie, 1997). Moreover, high fishing pressure could affect the length at first maturity, where rapid maturation was found as a strategy ~~of~~ for fish populations to cope with high fishing pressure (Restiangsih & Amri, 2019). The rate of fishing pressure in Southern

Sulawesi is relatively higher than in Wakatobi (Fatma et al., 2021). To maintain its population, *L. atkinsoni* in ~~the~~ Southern Sulawesi was likely to follow a similar strategy.

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We observed that the average size of the first capture (Lc) of *L. atkinsoni* in Southern Sulawesi was 21.90 cm at the age of approximately 1.5 years. The Lc was lower than the Lm, indicating that local fishers in Southern Sulawesi also caught ~~the~~ a proportion of immature individuals (Fig. 4). Based on the size frequency distribution (Fig. 3), about 49.8% of immature individuals were caught by the local fishers. In addition, we found that the peak of recruitment of *L. atkinsoni* occurred in April, July, and November. This information can ~~be used to~~ predict the spawning period of *L. atkinsoni* in Southern Sulawesi (Agustina et al., 2019), which can provide input to fisheries managers to apply temporary fishing closure.

Based on the LBSPR model, the SPR of *L. atkinsoni* in Southern Sulawesi was 14%, indicating that the population was harvested at an unsustainable level. The low SPR values (<30%) can reduce the ability of spawning stock biomass to produce adult stock in the structure of the population (Ault et al., 2008). This low SPR reflects a reduction in the number of young fish, thereby triggering a decrease in spawning stock~~,~~ and limiting the number of eggs produced. The SPR, as the biological reference point, is used to define safe levels of fishery harvesting and as benchmarks against which the actual status of a fish stock can be measured (Collie & Gislason, 2001). Management actions to rebuild the ~~stock~~ biomass of the species are needed to increase SPR above the threshold (>30%), ~~in~~ which can be achieved by reducing fishing intensity, temporary fishing closure, and regulating the harvest size limit. Further management actions are needed to rebuild the stock of the species in the area~~,~~ to ensure a sustainable fishery.

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If a DOI (digital object identifier) is available for an article, always include it.

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Tables and Figures

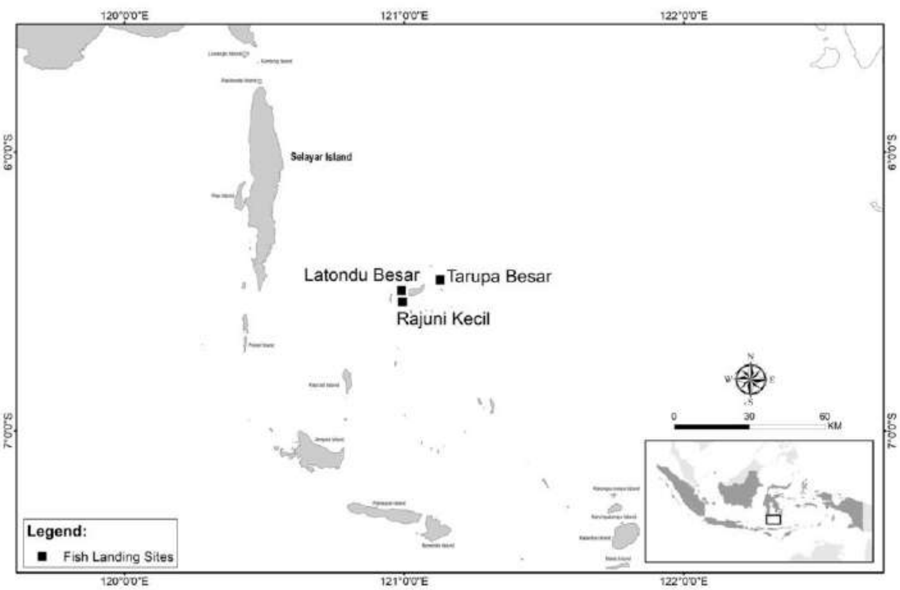

Fig 1. Map of the study area where data of *Lethrinus atkinsoni* were collected from three landing sites in Southern Sulawesi, Indonesia

Fig 2. A sample of *Lethrinus atkinsoni* caught from small-scale fishers in Southern Sulawesi, Indonesia

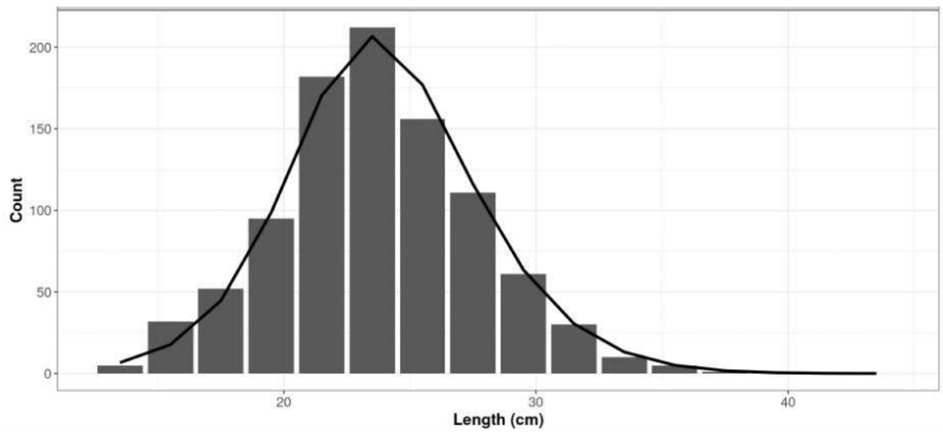

Fig 3. Length frequency distribution of *Lethrinus atkinsoni* that were collected from three landing sites in Southern Sulawesi, Indonesia

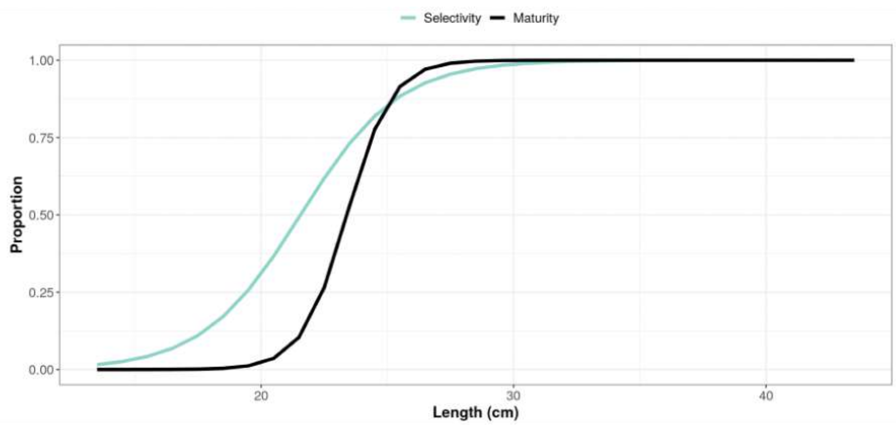

Fig 4. Maturity and selectivity curve of *Lethrinus atkinsoni* in Southern Sulawesi, Indonesia

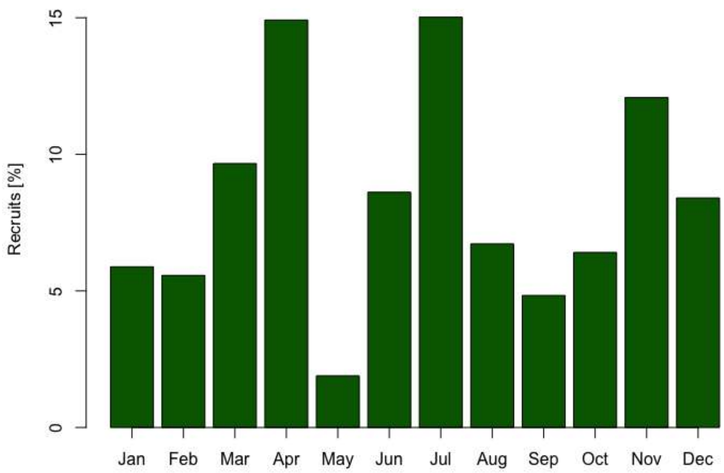

Fig 5. Recruitment pattern of *Lethrinus atkinsoni* in Southern Sulawesi, Indonesia

Table 1. Life history parameters and spawning potential ratio of *Lethrinus atkinsoni* in Southern Sulawesi, Indonesia

Parameter	**Unit**	**Value**
Asymptotic length ($L\infty$)	cm	40.50
Growth coefficient (k)	Per year	0.40
The theoretical age at a length 0 cm (t0)	year	-0.38
Natural mortality (M)	Per year	0.50
Length at first maturity (Lm)	cm	23.40
Length at first capture (Lc)	cm	21.90
Spawning potential ratio (SPR)	%	14

Table 2. Growth parameters of *Lethrinus atkinsoni* in different locations

Location	**L∞ (cm)**	**k (/year)**	**References**
Yaeyama, Japan	30.9 (FL)	0.186	Fishbase (2022)
Great Barrier Reef and Eastern Torres Strait, Australia	32.5 (FL)	0.32	Fishbase (2022)
Northern coast, Fiji	42.8 (SL)	0.29	Fishbase (2022)
Okinawa, Japan	35.1 (SL)	0.26	Fishbase (2022)
Great Barrier Reef, Australia	32.2 (FL)	0.32	Currey et al., (2013)
Wakatobi, Indonesia	38.2 (FL)	0.44	Prihatiningsih et al., (2021)
East Seram, Indonesia	34.2 (TL)	0.42	Rumania et al., (2020)
Southern Sulawesi, Indonesia	*40.5 (TL)*	*0.40*	*This study*

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Journal Title:	Fisheries and Aquatic Sciences
Manuscript ID:	fas-2022-0136
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Manuscript Title:	Length-based stock assessment of the Pacific Yellowtail Emperor in the Southern Sulawesi, Indonesia
Running Title:	Length-based stock assessment of the Pacific Yellowtail Emperor
Urgency:	Fast-track Manuscript
Type:	Research Article
Category:	Ecology and Fisheries Resource Management;
Respond to review:	Response to reviewer's comments

We thank the editor and reviewers for their fruitful comments on our manuscript. Below is the detailed (point-by-point) response to the reviewers for each comment.

Editor comments

The examination of your manuscript has been completed. The editor-in-chief had made a final decision that the revision were needed.
You can check the comments below by accessing the online submission system.
Even if there is some files attached by the reviewers, you cannot check it in the e-mail, so please make sure to access the system.
After reflecting the correction in the manuscript, be sure to submit it again using the submission system.

Response: Thank you very much for the final decision made. We have checked the comments from the Reviewer #1 and Reviewer #2 from your journal system. We have also addressed each of the comments and suggestion of both reviewers (point-by-point) below.

Reviewer #1

General comments:

The manuscript is sufficient and accepted to be published. Some comment to strengthen the finding is suggested.

Response: Thank you very much for your fruitful comments and suggestion in our manuscript. Please see our responses in addressing each of your comment and suggestion in detail below.

Comments in the manuscript text:

Line 159: It is suggested add more explanation on why the peaks occurred during those months

Response: We have added the explanation in the text about the recruitment model.

Lines 213-214: Not clear, please rewrite the sentence

Response: We have modified the sentence to make it clearer.

Line 247: +/- 30% journal international with 80% published more than 10 years. If a DOI (digital object identifier) is available for an article, always include it.

Response: We have added journal international references in the manuscript. However, we could not add significant number of the journal international references, as we found that sufficient studies related to the species are only in the Indonesian Journal. Hence, our manuscript will contribute to enhance exposure of the study of this species internationally. We have added the DOI (Digital Object Identifier) that is available for any article cited in the reference list.

Line 290: Year?

Response: Thank you. We have modified the references to add the year.

Suggestions of text and syntaxes in the manuscript:

Line 9: Add “Seale, 1910”

Response: We agree to add the text suggested.

Line 10: Add “Therefore”

Response: Agree to add the text suggested.

Line 11: Add “the”

Response: Agree to add the text suggested.

Line 12: Remove “by”

Response: Agree to remove the text suggested.

Line 14: Add “the”

Response: Agree to add the text suggested.

Line 15: Remove “was”

Response: Agree to remove the text suggested.

Line 15: Add “the” and remove “found”

Response: Agree to add and remove the texts suggested.

Line 16: Remove “respectively”

Response: Agree to remove the text suggested

Line 17: Add “In addition”, “a”, “an”

Response: Agree to add the texts suggested.

Line 20: Add “the”, “and”,

Response: We agree to modify the texts suggested.

Line 21: Replace “is” with “are of” and replace “important” with “importance”

Response: We agree to modify the texts suggested.

Lines 28-29: Add “As a result,”

Response: We agree to add the texts suggested.

Lines 29-30: Add “and international markets, such as”

Response: Agree to add the texts suggested.

Line 30: Add “However”

Response: Agree to add the text suggested.

Line 34: Add “the”, remove “ocean, add “s” in the word “ocean”

Response: Agree to add the text suggested.

Line 35: Replace “one of” with “a”

Response: We agree to modify the text suggested.

Line 36: Replace “one of” with a

Response: We agree to modify the text suggested

Line 38: Replace “important” with “significant”

Response: We agree to modify the text suggested.

Line 39: Remove “,” and “or”

Response: We agree to remove the text suggested.

Line 40: Remove “,” “,” add “and”

Response: We agree to modify the text suggested.

Line 41: Remove “and” “the” and add “The”

Response: modify the text suggested.

Line 42: Remove”,” and “main” add “primary”

Response: We agree to modify the text suggested.

Line 44: Replace “Effective” with “Therefore, effective”

Response: We agree to modify the text suggested

Line 45: Remove “the”

Response: Agree to remove the text suggested

Line 46-47: Remove “The” and replace “the important regions for coral reef fisheries in Indonesia” to “Indonesia’s crucial regions for coral reef fisheries”

Response: Agree to modify the text suggested

Line 47: Remove “largest” add “most extensive” “is”

Response: Agree to modify the text suggested

Line 8: Add “.” “The” “to” and remove “and” “for”

Response: Agree to modify the text suggested

Line 52: Remove “the”

Response: Agree to remove the text suggested

Line 53: Add “limited status and trend” replace “affects” to “affect”

Response: Agree to modify the text suggested

Line 57-58: Replace “Biological investigated characteristics and stock conditions of the species were investigated by” with “The species' biological characteristics and stock conditions were investigated”

Response: Agree to modify the text suggested

Line 62: Remove “the”

Response: We agree to remove the text suggested

Line 66: Remove “a total of”

Response: We agree to remove the text suggested

Line 67: Remove “individual”

Response: We agree to remove the text suggested

Line 68: Remove “,” and replace “the” to “and”

Response: We agree to modify the text suggested

Line 69: Add “the” and remove “sex and”

Response: We agree to modify the text suggested

Line 72: Add “The sex” and remove “Sex”

Response: We agree to modify the text suggested

Line 77: Add “the”

Response: We agree to add the text suggested

Line 80: Replace “Udupa” to “Udupe”

Response: We agree to modify the text suggested

Line 87: Replace “Length” to “The length” and remove “of” “were”

Response: We agree to modify the text suggested

Line 88: Remove “).” “The” “the species was” “cm” “SD =” and add “) with an” “cm”

Response: We agree to modify the text suggested

Line 92: Replace “Sex” to “The sex”

Response: We agree to modify the text suggested

Line 96: Replace “Growth” to “the growth”

Response: We agree to modify the text suggested

Line 98: Replace “year” to “years” and “Length” to “The length”

Response: We agree to modify the text suggested

Line 101: Add “an”

Response: We agree to add the text suggested

Line 104: Remove “the” add “a”

Response: We agree to modify the text suggested

Line 109: Add “study” and replace “study” to “finding”

Response: We agree to modify the text suggested

Line 111: Remove “the”

Response: We agree to remove the text suggested

Line 112: Add “of this emperor”

Response: We agree to add the text suggested

Line 113: Remove “’s”

Response: We agree to remove the text suggested

Line 115: Remove “in”

Response: We agree to remove the text suggested

Line 121: Add “the” to “the sex” and remove “the” from “the L. atkinsoni”

Response: We agree to modify the text suggested

Line 122: Add “the” to “the sex” and remove”found”

Response: We agree to modify the text suggested

Line 126: Add “a” and remove “s” from “considerations”

Response: We agree to modify the text suggested

Line 129: Add “the”

Response: We agree to add the text suggested

Line 130: Replace “of” to “on” and remove “the”

Response: We agree to modify the text suggested

Line 132: Remove “the” and replace “the” to “an”

Response: We agree to modify the text suggested

Line 133: Replace “s” from “values” and add “a”

Response: We agree to modify the text suggested

Line 135: Add “s” in “temperature”

Response: We agree to add the text suggested

Line 137: Add “The” to “Length”

Response: We agree to add the text suggested

Line 138: Replace “at” to “in”

Response: We agree to replace the text suggested

Line 142: Add “The”

Response: We agree to add the text suggested

Line 143-144: Replace “be the cause of” to “cause”

Response: We agree to replace the text suggested

Line 145: Replace “of” to “for”

Response: We agree to replace the text suggested

Line 151: Remove “the” add “a”

Response: We agree to modify the text suggested

Line 153: Remove “be used to”

Response: We agree to remove the text suggested

Line 158: Add “low SPR”

Response: We agree to add the text suggested

Line 159: Remove “,” add “and”

Response: We agree to modify the text suggested

Line 162: Replace “stock” with “biomass” and remove “in”

Response: We agree to modify the text suggested

Line 164: Add “the”

Response: We agree to add the text suggested

Line 174: Remove “of”

Response: We agree to remove the text suggested

Reviewer #2

General comments:

This paper is thought to be useful in understanding the ecological characteristics and the stock status of Lethrinus atkinsoni, which should be managed effectively in the area. However, I think this paper should be revised or more samples should be taken for this study, and the major things to be revised are as follows.

Another comment is recommended to be submitted as a short communication rather than an article. This is because the sampling period of this study is too short and the results presented in the paper include only a part of the ecology of the species.

Response: Thank you very much for your fruitful comments and suggestion in our manuscript. We have revised the manuscript text thoroughly based on your comments as well as comment from the Reviewer #1. Please see our responses (point by point) to your comments below.

Unfortunately, we disagree with your suggestion that our manuscript to be submitted as a short communication rather than an article. We thought that we have now a quite robust data (now added more period of samples, from 5 months to 10 months based on your comment). Also, the number of individuals sampled now increasing significantly from 952 to 4,887 individuals.

Line 34) pacific ⊠ Pacific: “P” should be uppercase

Response: Thank you. Agreed. We have modified the text as suggested.

In “Introduction”: Previous studies on Lethrinus atkinsoni should be introduced/described, and the purpose and necessity of this study should be further strengthened.

Response: Agreed. We have now added texts explaining the previous studies of the species (L. atkinsoni) in the introduction. We have also added context the necessity of this study to be conducted (i.e., L. atkinsoni stock assessment in Indonesia, particularly in the studied site). Please see the added text in the 2nd paragraph of the Introduction section.

line 60) This study collected samples from January to May 2022, but I can't see how these samples are used in this study. And I wonder why the samples were collected for 5 months. Generally, samples are collected for at least for one year for ecological studies.

Response: The samples include the fish length (total samples of 952 individuals) that were collected from January to May 2022. Of those 952 individuals, there were 152 samples that were collected in April and May 2022 to examine reproductive information (sex examination (male/female) and gonad maturity). As stated in the "Data analysis" section, both the fish' length and reproductive information were used to examine 1) size frequency distribution of the fish; 2) sex ratio; 3) the fish stock status using the Length-Based Spawning Potential Ratio (LBSPR) model; and 4) recruitment pattern. We modified the text in the methods to make it clearer, especially adding the formulae on how to calculate/estimate the results. Please see also our response to your comment No. 5 below related to "Data Analysis".

We agree to add the data from 5 months to 10 months (almost 1 year). We have reanalyzed the data and made the necessary changes, including modifying the text and the figures. We initially have continued data for 10 months (from January to October 2022). However, at the time we submitted our manuscript in the journal, we have only data of fish' length for 5 months (Jan - May 2022), as the other data from June to October 2022 were not ready yet (not compiled and not cleaned).

line 64) Why did you use only the samples from April to May for examining sex ratio?

Response: To examine individual reproductive biology (examining sex of the fish and examining gonad maturity) required high efforts and resources. We have limited resources (enumerators) and logistical constraints to conduct reproductive examination for longer term. Based on these constraints, we could only conduct this only for 2 months (April to May 2022).

The "Data Analysis" section does not specifically address how to calculate/estimate the results such as growth parameters, lengths at first maturity and at first capture, recruitment, etc. For example, to estimate gear selectivity (length at first capture), authors assumed the curve shape as the logistic function, but the shape differs depending on the gear characteristics. In addition, recruitment pattern analysis would be key results in this study, so it needs to describe the method and results in detail.

Response: We have modified the Data Analysis section to specifically address on how to calculate/estimate the results, including specifically address how to calculate the growth parameters, lengths at first maturity and at first capture, recruitment. We inserted the formulae of the data in the manuscript text.

line 96) 0.38 year → -0.38 years : it differs from Table 1.

Response: The value of T0 supposed to be in negative format. However, as we added the data, the T0 changed from -0.38 year to -0.33 year. We have modified the value throughout the manuscript text.

FAS (Fisheries and Aquatic Sciences) TITLE PAGE

Upload this completed form to website with submission

ARTICLE INFORMATION	Fill in information in each box below
Article Type	Research article
Article Title (within 20 words without abbreviations)	Length-based stock assessment of the Pacific Yellowtail Emperor in the Southern Sulawesi, Indonesia
Running Title (within 10 words)	Length-based stock assessment of the Pacific Yellowtail Emperor
Author	I Nyoman Suyasa[1], Alifah Fitam Rakhma Sari[1], Siska Agustina[2], Rian Prasetia[2], Ratna Suharti[1], Toni Ruchimat[1,2], Budy Wiryawan[2,3,4], Irfan Yulianto[2,3]
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Competing interests	No potential conflict of interest relevant to this article was reported.
Funding sources State funding sources (grants, funding sources, equipment, and supplies). Include name and number of grant if available.	Not applicable.
Acknowledgements (Anything that is grateful or helped, not support funding)	We thank local fishers and traders in the Tarupa, Rajuni, and Latondu villages in Southern Sulawesi, Indonesia, for their support in conducting data collection.
Availability of data and material	Upon reasonable request, the datasets of this study can be available from the corresponding author.
Ethics approval and consent to participate	Not applicable.

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Abstract

Pacific yellowtail emperor, *Lethrinus atkinsoni Seale, 1910*, is one of the most targeted reef fish species in Southern Sulawesi, Indonesia. Therefore, assessing its stock is important to understand the condition of the population, providing valuable inputs for sustainable fisheries management in the area. Here we assess the stock condition of *L. atkinsoni* in Southern Sulawesi, Indonesia, using the Length-Based Spawning Potential Ratio (LBSPR) model. A total of 4,887 individuals were collected from commercially small-scale fishers from January to October 2022. The total length, sex, and gonad maturity of the individuals were examined. We observed that the fish length ranged from 10.5 to 39.5 cm, with an average length of 23.3 cm. The sex ratio was equal (1:1.2) between male and female individuals. Length at first maturity (Lm) and length at first capture (Lc) were 23.4 and 19.6 cm, respectively. In addition, we observed a growth coefficient (k) of 0.45/year, with an asymptotic length ($L\infty$) of 41.14 cm and natural mortality (M) of 0.6/year. Based on these life history parameters, we observed the spawning potential ratio (SPR) value of 12%, indicating an unsustainable fishery level (SPR of <30%). Further concerns related to the sustainability of the species and strategy to rebuild stock of the *L. atkinsoni* in Southern Sulawesi are of utmost importance.

Keywords (3 to 5): *Lethrinus atkinsoni*, Fisheries Management, Length-Based Spawning Potential Ratio, Southern Sulawesi

Introduction

Indonesia is the second world's largest fisheries producer (FAO, 2020), with coral reef fisheries contributing to Indonesian fisheries productivity, estimated to reach a total of 800 thousand tons annually (MMAF, 2022). As a result, coral reef fishes are economically important commodities in Indonesia, demanded by domestic and international markets, such as Singapore and Hong Kong (Rizal & Jaliadi, 2018). However, due to its high demand, populations of some reef fish species are threatened across the country (Campbell et al., 2013).

Reef fish of the family Lethrinidae (emperors) are abundant in tropical and subtropical regions where coral reefs, seagrass beds, and mangrove forest areas are their habitats (Young & Martin, 1982). Fishes within the family are one of the significant food resources in the western Pacific and Indian Oceans due to their high catch amount (Larson et al., 1992). Among the lethrinids, the *Lethrinus atkinsoni*, known as pacific yellowtail emperors, is a highly targeted fish by local fishers in Indonesia (Mayunar, 1996), including in the Southern Sulawesi region (Agustina et al., 2021). There are numerous studies concerning the growth and biological parameters of the *L. atkisoni* (Rumania et al., 2020;

Prihatiningsih et al., 2021; Currey et al., 2013; Ebisawa, 1999), while no studies yet about the status of its stock in Indonesia, particularly in the Southern Sulawesi region.

About 90-95% of fishers in Indonesia are small-scale yet generating significant contributions for coastal communities (Sari et al., 2021). Small-scale fisheries often referred to as artisanal fisheries, is a traditional fishery that involves fishing households and uses relatively small fishing vessels and short fishing trips. The catch is mainly for local consumption. Most fishers in Southern Sulawesi are small-scale, contributing significantly to social and economic conditions in the area as the primary source of livelihood, providing food for the community. The fishers and the local community are dependent on fish resources. Accordingly, they are vulnerable to any change that disrupts their harvest (Wiyono, 2011). Therefore, effective management of small-scale fisheries in the area is crucial for the community.

Southern Sulawesi is one of Indonesia's crucial regions for coral reef fisheries, where the world's 3rd most extensive coral reef atoll is found (Malik et al., 2018). The coral reefs are home to more than 500 reef fish species, including the highly demanded reef fish emperors of the family Lethrinidae (Muhidin et al., 2019). However, the coral reefs there are being threatened due to destructive fishing activities by explosives and cyanide (Panuluh et al., 2020). Despite being one of the most important fishery commodities in Indonesia, the potential of lethrinid fish and its utilization status are still poorly understood (Restiangsih & Muchlis, 2019). In addition, the impact of fishing activities in Southern Sulawesi is not yet fully known due to limited data (Agustina et al., 2021). This limited status and trend certainly affect fishery management, hampering its resources to be sustainably managed (Rizal & Jaliadi, 2018). In this context, identifying biological characteristics and assessing the stock condition of lethrinid fish is necessary to improve fisheries management in the area. This study aims to assess the stock status of *L. atkinsoni* in Southern Sulawesi, Indonesia. The species' biological characteristics and stock conditions were investigated using the length-based stock assessment approach.

Materials and Methods

Study site and sample collection

This study was conducted in Southern Sulawesi, Indonesia (Fig. 1), from January to October 2022. A total of 4,887 individuals of *Lethrinus atkinsoni* (Fig. 2) were collected from three landing sites; the Tarupa Besar, Rajuni Kecil, and Latondu Besar. The samples were commercially caught by small-scale handline and speargun fishers. The samples were measured to the nearest millimeter in total length (TL).

From those total samples, in April and May 2022, 152 individuals of *L. atkinsoni* were examined for their sex and gonad maturity following West (1990). The sex of each sample was determined through macroscopic examination after dissection, whereby the shape and color of the testis and ovaries were used to assign the gonadal maturity of the fish.

Data analysis

The sex ratio of *L. atkinsoni* was estimated and tested for the significant differences in the proportion of males and females for a theoretical 1:1 relation using a Chi-square (X^2) equation (Kenney & Keeping, 1951) following the formula:

$$X^2 = \sum \frac{(O - E)^2}{E}$$

Where O is the observed number of males and females; E is the expected number of males and females.

We assessed the fish stock using the Length-Based Spawning Potential Ratio (LBSPR) model (Hordyk et al., 2015). The life-history parameters and length frequency distribution data were examined as its input. The life-history parameters consist of growth coefficient (k), asymptotic length (L∞), natural mortality (M), length at first capture (Lc) and length at first maturity (Lm). Growth parameters (i.e., k and L∞) were estimated by the von Bertalanffy growth model (Sparre & Venema, 1998) using the "TropFishR" package in Rstudio (Mildenberger et al., 2017), following the formula:

$$Lt = L\infty\left[1 - e^{-K(t - t0)}\right]$$

Where L∞ is the mean maximum length, k is a growth coefficient, and t_0 is the theoretical age at a size 0.

Natural mortality (M) was calculated following the Pauly empirical equation (Pauly, 1980):

$$Log(-t_0) = -0.3922 - 0.2752\log(L\infty) - 1.038\log(K)$$

Length at first maturity (Lm) was analyzed following the formula of Spearman-Karber (Udupe, 1986):

$$m = \left[Xk + \frac{X}{2}\right] - (X \sum pi)$$

with 95% confidence interval, it was calculated as:

$$Lm = antilog(m \pm 1.96 \times \sqrt{X^2 \sum \frac{pi \times qi}{ni - 1}}$$

where: m = Log of fish length at first mature gonad; Xk = Log of mean length value at first mature gonad; X = Log of median of last length at first mature gonad; X = Log of increased length of the fish at the median; Pi = The proportion of mature gonad at the interval of ith with the number of fish at the interval of ith; ni = Number of mature gonad at the interval of ith; qi = 1 - pi; M = Antilog m of the length of first matured gonad

The length at first capture (Lc) was analyzed based on the logistic curve from the selection ogive function (Sparre & Venema, 1998). The recruitment pattern was estimated by backward projection using length frequency distribution data based on the von Bertalanffy growth curve (Pauly, 1984; Mildenberger et al., 2017).

Results

Size frequency distribution

The length range of *L. atkinsoni* was from 10.5 to 39.5 cm, with most individuals observed within the 22-24 cm size class (Fig. 3) with an average length of 23.25 (±3.93 cm).

Sex ratio

From 152 samples of *L. atkinsoni* that were collected for gonad investigation, we found 83 female and 69 male individuals. The sex ratio (M : F) was 1:1.2, with the observed proportion was statistically not significantly different (p >0,05).

Life history parameters and spawning potential ratio

We observed that the asymptotic length ($L\infty$) of *L. atkinsoni* was 41.14 cm (Table 1). The growth coefficient (k) of the species was 0.45/year, indicating a high growth rate (k >0.3; Froese, 2005). The natural mortality (M) of the species was 0.6/year, with theoretical age at length 0 cm (t0) was -0.33 years (Table 1). The length at first maturity (Lm) of the species was 23.40 cm, with the length at first capture (Lc) was 19.59 cm (Table 1; Fig 4). Based on the LBSPR model, we observed that the spawning potential ratio (SPR) of the *L. atkinsoni* in Southern Sulawesi was 12%, indicating an unsustainable level of the stock condition (SPR <30%) (Ault et al., 2008).

Recruitment pattern

We observed that *L. atkinsoni* in Southern Sulawesi was a partial spawner, with a range of monthly recruitment of 2 - 15 % (Fig. 5). The peaks of recruitment were observed in April (15%), July (15%) and November (12%). The recruitment patern occurring in these months is likely influenced by the annual upwelling event in the respective area (Utama et al., 2017). According to Klein et al., (2018), the recruitment pattern revealed a strong relationship with the upwelling.

Discussion

This study is the first finding of the length-based stock assessment of *L. atkinsoni*, the pacific yellowtail emperor, in Southern Sulawesi, Indonesia. We provide scientific information regarding the biological characteristics of the species, providing valuable input for fisheries management in the region. Based on the biological characteristics, we found that the population of this emperor was harvested at an unsustainable level.

The length range of the *L. atkinsoni* in Southern Sulawesi was from 10.5 to 39.5 cm. In other sites within Indonesia, the ranges of the conspecific were from 15.1 to 32.5 cm and from 12.0 to 37.7 cm in East Seram (Rumania et al., 2020) and Wakatobi (Prihatiningsih et al., 2021), respectively. In the Great Barrier Reef, Australia, the maximum length reported was 48 cm (Currey et al., 2013). While the range was similar among sites within Indonesia, the length of the fish was relatively smaller compared to the conspecific in Australia (Currey et al., 2013). This discrepancy might be due to ecological and environmental conditions between Indonesia and Australia, such as water quality, genetics, catch rate, and food abundance (Nikolskii, 1963), which can affect the biological condition of the fish.

In the present study, we found that the sex ratio of *L. atkinsoni* in Southern Sulawesi was equal between male and female individuals. Similarly, the sex ratio of the conspecific in the Wakatobi was equal (sex ratio M : F = 0.55:1.00; Prihatiningsih et al., 2021). Variations in the sex ratio can be affected by several factors, including behavior patterns, mortality, and growth rates between male and female individuals, spawning behavior, sexual maturity, length distribution due to its depth ranges, and length (or age) of the individuals (Effendie, 1997; Nikolskii, 1963). However, a note should be taken into consideration that *L. atkinsoni* is protogynous hermaphroditism species, with the length of sexual transition was reported between 23.0 and 23.9 cm FL off Yaeyama and between 30.0 and 30.9 cm FL off Okinawa (Ebisawa, 1999). In protogynous species, the exact effect of fishing pressure on stock dynamics is complex (Alonzo & Mangel, 2004). In the case of the present study, no data on sexual transition length was reported on the species from the area. Accordingly, further measures of fishery management for the species might be challenging.

We observed that the growth coefficient (k) of *L. atkinsoni* was 0.46/year, with an asymptotic length (L∞) of 41.14 cm. Based on Froese (2005), the k value of a higher growth rate is above 0.3/year. In areas close to the equator (i.e., tropical region), *L. atkinsoni* tends to have higher k values than the conspecific in higher latitudes (Table 2). Higher annual seawater temperatures in the tropic might affect the higher growth rate of *L. atkinsoni* (Gislason et al., 2010).

The length at first maturity (Lm) of *L. atkinsoni* in Southern Sulawesi was 23.40 cm at the age of approximately 1.5 years. The Lm in the present study was relatively lower compared to the conspecific in the Wakatobi (Lm for male = 30.7 cm; Lm for female = 27.18 cm; Prihatiningsih et al., 2021) but relatively higher in Japan (Ebisawa, 1999) with the Lm of 19 cm FL off Yaeyama and 21 cm FL off Okinawa. The Lm discrepancy was presumably due to the influence of environmental factors, including nutrient conditions, seawater temperature, irradiation, as well as species feeding habits and physiological conditions of fish, and the location of the fishing ground (Lagler et al., 1963; Udupe, 1986; Wootton, 1985). Latitudinal difference of more than 5° was thought to cause differences in age and length at first gonad maturity (Effendie, 1997). Moreover, high fishing pressure could affect the length at first maturity, where rapid maturation was found as a strategy for fish populations to cope with high fishing pressure (Restiangsih & Amri, 2019). The rate of fishing pressure in Southern Sulawesi is relatively higher than in Wakatobi (Fatma et al., 2021). To maintain its population, *L. atkinsoni* in Southern Sulawesi was likely to follow a similar strategy where they tend to have rapid maturation to cope with high fishing pressure.

We observed that the average size of the first capture (Lc) of *L. atkinsoni* in Southern Sulawesi was 19.59 cm at the age of approximately 1.1 years. The Lc was lower than the Lm, indicating that local fishers in Southern Sulawesi also caught a proportion of immature individuals (Fig. 4). Based on the size frequency distribution (Fig. 3), about 53% of immature individuals were caught by the local fishers. In addition, we found that the peak of recruitment of *L. atkinsoni* occurred in April, July, and November. This information can predict the spawning period of *L. atkinsoni* in Southern Sulawesi (Agustina et al., 2019), which can provide input to fisheries managers to apply temporary fishing closure.

Based on the LBSPR model, the SPR of *L. atkinsoni* in Southern Sulawesi was 12%, indicating that the population was harvested at an unsustainable level. The low SPR values (<30%) can reduce the ability of spawning stock biomass to produce adult stock in the structure of the population (Ault et al., 2008). This low SPR reflects a reduction in the number of young fish, thereby triggering a decrease in spawning stock and limiting the number of eggs produced. The SPR, as the biological reference point, is used to define safe levels of fishery harvesting and as benchmarks against which the actual status of a fish stock can be measured (Collie & Gislason, 2001). Management actions to rebuild the biomass of the species are needed to increase SPR above the threshold (>30%), which can be achieved by reducing fishing intensity, temporary fishing closure, and regulating the harvest size limit. Further management actions are needed to rebuild the stock of the species in the area to ensure a sustainable fishery.

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Tables and Figures

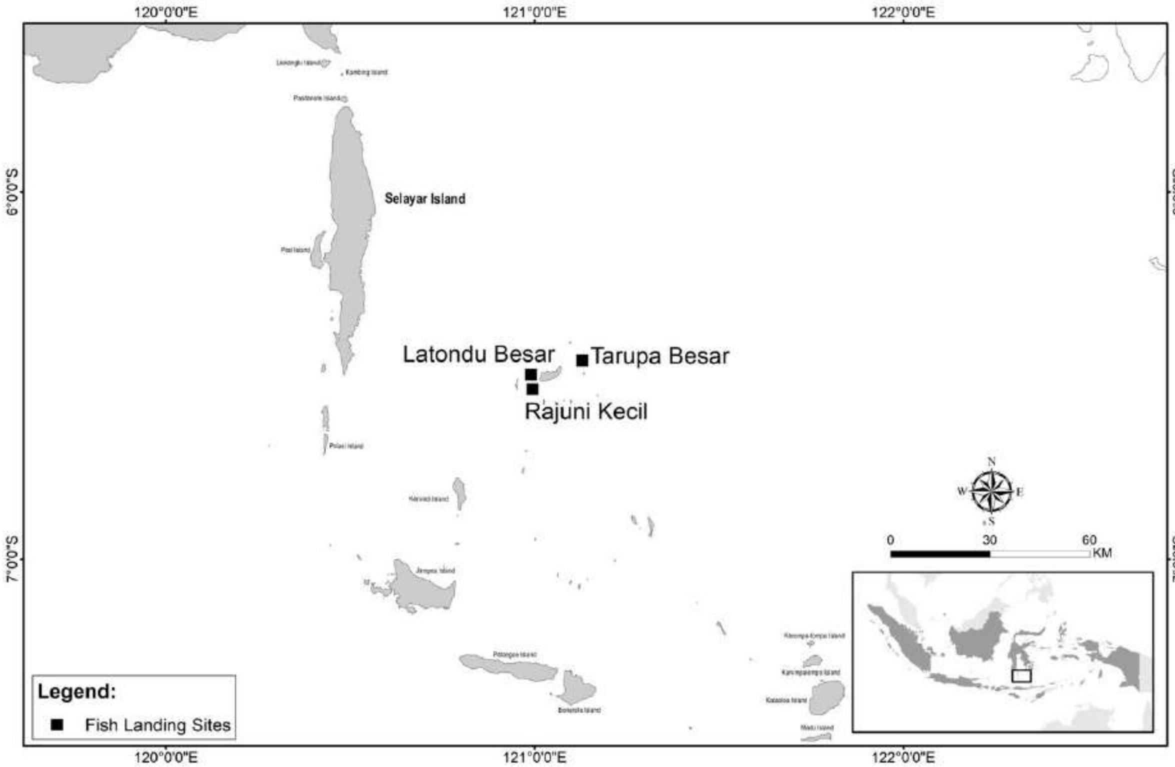

Fig 1. Map of the study area where data of *Lethrinus atkinsoni* were collected from three landing sites in Southern Sulawesi, Indonesia

Fig 2. A sample of *Lethrinus atkinsoni* caught from small-scale fishers in Southern Sulawesi, Indonesia

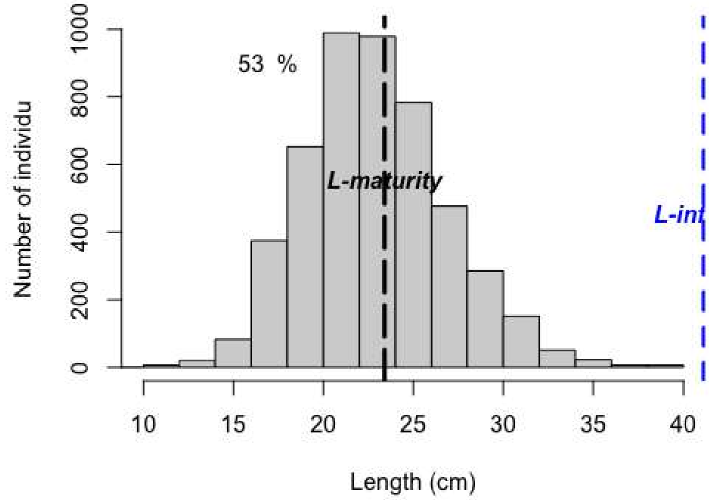

Fig 3. Length frequency distribution of *Lethrinus atkinsoni* that were collected from three landing sites in Southern Sulawesi, Indonesia

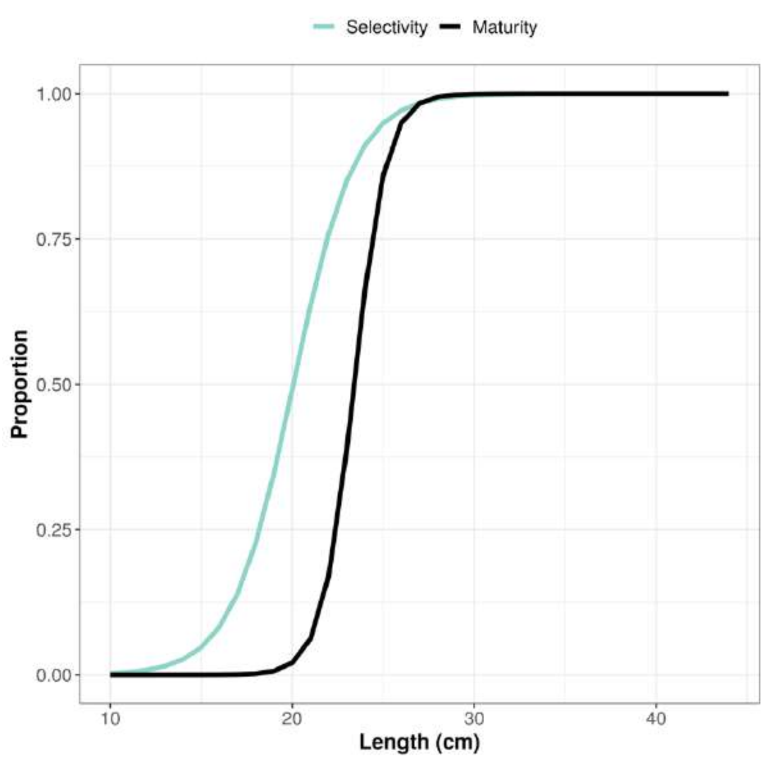

Fig 4. Maturity and selectivity curve of *Lethrinus atkinsoni* in Southern Sulawesi, Indonesia

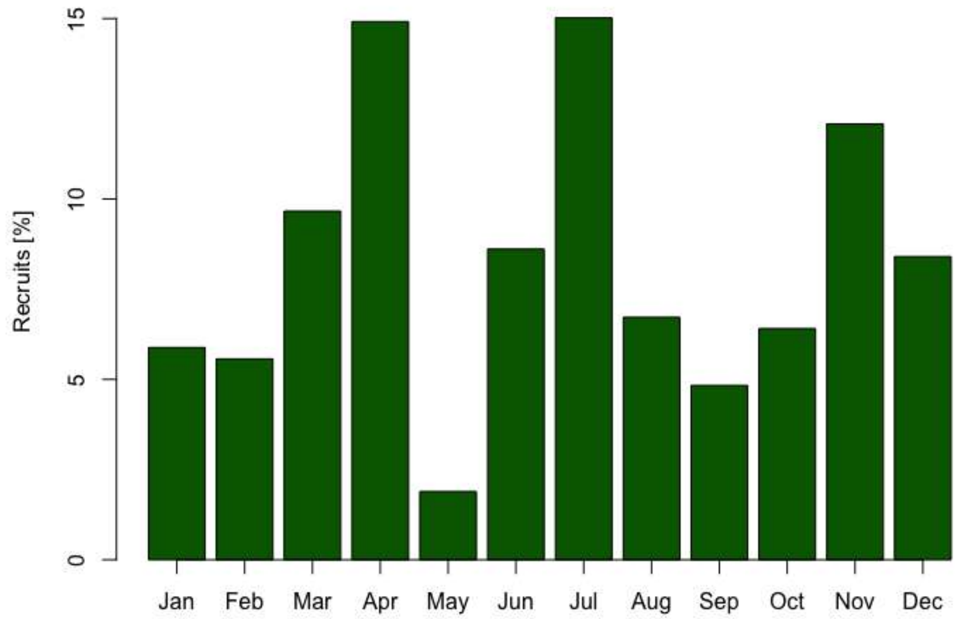

Fig 5. Recruitment pattern of *Lethrinus atkinsoni* in Southern Sulawesi, Indonesia

Table 1. Life history parameters and spawning potential ratio of *Lethrinus atkinsoni* in Southern Sulawesi, Indonesia

Parameter	**Unit**	**Value**
Asymptotic length (L_∞)	cm	41.14
Growth coefficient (k)	Per year	0.45
The theoretical age at a length 0 cm (t0)	year	-0.33
Natural mortality (M)	Per year	0.60
Length at first maturity (Lm)	cm	23.40
Length at first capture (Lc)	cm	19.59
Spawning potential ratio (SPR)	%	12

Table 2. Growth parameters of *Lethrinus atkinsoni* in different locations

Location	**L∞ (cm)**	**k (/year)**	**References**
Yaeyama, Japan	30.9 (FL)	0.186	Fishbase (2022)
Great Barrier Reef and Eastern Torres Strait, Australia	32.5 (FL)	0.32	Fishbase (2022)
Northern coast, Fiji	42.8 (SL)	0.29	Fishbase (2022)
Okinawa, Japan	35.1 (SL)	0.26	Fishbase (2022)
Great Barrier Reef, Australia	32.2 (FL)	0.32	Currey et al., (2013)
Wakatobi, Indonesia	38.2 (FL)	0.44	Prihatiningsih et al., (2021)
East Seram, Indonesia	34.2 (TL)	0.42	Rumania et al., (2020)
Southern Sulawesi, Indonesia	*40.5 (TL)*	*0.40*	*This study*

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ARTICLE INFORMATION	Fill in information in each box below
Article Type	Research article
Article Title (within 20 words without abbreviations)	Length-based stock assessment of the Pacific Yellowtail Emperor in the Southern Sulawesi, Indonesia
Running Title (within 10 words)	Length-based stock assessment of the Pacific Yellowtail Emperor
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Availability of data and material	Upon reasonable request, the datasets of this study can be available from the corresponding author.
Ethics approval and consent to participate	Not applicable.

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Abstract

Pacific yellowtail emperor, *Lethrinus atkinsoni Seale, 1910*, is one of the most targeted reef fish species in Southern Sulawesi, Indonesia. Therefore, assessing its stock is important to understand the condition of the population, providing valuable inputs for sustainable fisheries management in the area. Here we assess the stock condition of *L. atkinsoni* in Southern Sulawesi, Indonesia, using the Length-Based Spawning Potential Ratio (LBSPR) model. A total of 4,887 individuals were collected from commercially small-scale fishers from January to October 2022. The total length, sex, and gonad maturity of the individuals were examined. We observed that the fish length ranged from 10.5 to 39.5 cm, with an average length of 23.3 cm. The sex ratio was equal (1:1.2) between male and female individuals. Length at first maturity (Lm) and length at first capture (Lc) were 23.4 and 19.6 cm, respectively. In addition, we observed a growth coefficient (k) of 0.45/year, with an asymptotic length ($L\infty$) of 41.14 cm and natural mortality (M) of 0.6/year. Based on these life history parameters, we observed the spawning potential ratio (SPR) value of 12%, indicating an unsustainable fishery level (SPR of <30%). Further concerns related to the sustainability of the species and strategy to rebuild stock of the *L. atkinsoni* in Southern Sulawesi are of utmost importance.

Keywords (3 to 5): *Lethrinus atkinsoni*, Fisheries Management, Length-Based Spawning Potential Ratio, Southern Sulawesi

Introduction

Indonesia is the second world's largest fisheries producer (FAO, 2020), with coral reef fisheries contributing to Indonesian fisheries productivity, estimated to reach a total of 800 thousand tons annually (MMAF, 2022). As a result, coral reef fishes are economically important commodities in Indonesia, demanded by domestic and international markets, such as Singapore and Hong Kong (Rizal & Jaliadi, 2018). However, due to its high demand, populations of some reef fish species are threatened across the country (Campbell et al., 2013).

Reef fish of the family Lethrinidae (emperors) are abundant in tropical and subtropical regions where coral reefs, seagrass beds, and mangrove forest areas are their habitats (Young & Martin, 1982). Fishes within the family are one of the significant food resources in the western Pacific and Indian Oceans due to their high catch amount (Larson et al., 1992). Among the lethrinids, the *Lethrinus atkinsoni*, known as pacific yellowtail emperors, is a highly targeted fish by local fishers in Indonesia (Mayunar, 1996), including in the Southern Sulawesi region (Agustina et al., 2021). There are numerous studies concerning the growth and biological parameters of the *L. atkisoni* (Rumania et al., 2020;

Prihatiningsih et al., 2021; Currey et al., 2013; Ebisawa, 1999), while no studies yet about the status of its stock in Indonesia, particularly in the Southern Sulawesi region.

About 90-95% of fishers in Indonesia are small-scale yet generating significant contributions for coastal communities (Sari et al., 2021). Small-scale fisheries often referred to as artisanal fisheries, is a traditional fishery that involves fishing households and uses relatively small fishing vessels and short fishing trips. The catch is mainly for local consumption. Most fishers in Southern Sulawesi are small-scale, contributing significantly to social and economic conditions in the area as the primary source of livelihood, providing food for the community. The fishers and the local community are dependent on fish resources. Accordingly, they are vulnerable to any change that disrupts their harvest (Wiyono, 2011). Therefore, effective management of small-scale fisheries in the area is crucial for the community.

Southern Sulawesi is one of Indonesia's crucial regions for coral reef fisheries, where the world's 3rd most extensive coral reef atoll is found (Malik et al., 2018). The coral reefs are home to more than 500 reef fish species, including the highly demanded reef fish emperors of the family Lethrinidae (Muhidin et al., 2019). However, the coral reefs there are being threatened due to destructive fishing activities by explosives and cyanide (Panuluh et al., 2020). Despite being one of the most important fishery commodities in Indonesia, the potential of lethrinid fish and its utilization status are still poorly understood (Restiangsih & Muchlis, 2019). In addition, the impact of fishing activities in Southern Sulawesi is not yet fully known due to limited data (Agustina et al., 2021). This limited status and trend certainly affect fishery management, hampering its resources to be sustainably managed (Rizal & Jaliadi, 2018). In this context, identifying biological characteristics and assessing the stock condition of lethrinid fish is necessary to improve fisheries management in the area. This study aims to assess the stock status of *L. atkinsoni* in Southern Sulawesi, Indonesia. The species' biological characteristics and stock conditions were investigated using the length-based stock assessment approach.

Materials and Methods

Study site and sample collection

This study was conducted in Southern Sulawesi, Indonesia (Fig. 1), from January to October 2022. A total of 4,887 individuals of *Lethrinus atkinsoni* (Fig. 2) were collected from three landing sites; the Tarupa Besar, Rajuni Kecil, and Latondu Besar. The samples were commercially caught by small-scale handline and speargun fishers. The samples were measured to the nearest millimeter in total length (TL).

From those total samples, in April and May 2022, 152 individuals of *L. atkinsoni* were examined for their sex and gonad maturity following West (1990). The sex of each sample was determined through macroscopic examination after dissection, whereby the shape and color of the testis and ovaries were used to assign the gonadal maturity of the fish.

Data analysis

The sex ratio of *L. atkinsoni* was estimated and tested for the significant differences in the proportion of males and females for a theoretical 1:1 relation using a Chi-square (X^2) equation (Kenney & Keeping, 1951) following the formula:

$$X^2 = \sum \frac{(O - E)^2}{E}$$

Where O is the observed number of males and females; E is the expected number of males and females.

We assessed the fish stock using the Length-Based Spawning Potential Ratio (LBSPR) model (Hordyk et al., 2015). The life-history parameters and length frequency distribution data were examined as its input. The life-history parameters consist of growth coefficient (k), asymptotic length ($L\infty$), natural mortality (M), length at first capture (Lc) and length at first maturity (Lm). Growth parameters (i.e., k and $L\infty$) were estimated by the von Bertalanffy growth model (Sparre & Venema, 1998) using the “TropFishR” package in Rstudio (Mildenberger et al., 2017), following the formula:

$$Lt = L\infty\left[1 - e^{-K(t-t0)}\right]$$

Where $L\infty$ is the mean maximum length, k is a growth coefficient, and t_0 is the theoretical age at a size 0.

Natural mortality (M) was calculated following the Pauly empirical equation (Pauly, 1980):

$$Log(-t_0) = -0.3922 - 0.2752\log(L\infty) - 1.038\log(K)$$

Length at first maturity (Lm) was analyzed following the formula of Spearman-Karber (Udupe, 1986):

$$m = \left[Xk + \frac{X}{2}\right] - (X \sum pi)$$

with 95% confidence interval, it was calculated as:

$$Lm = antilog(m \pm 1.96 \times \sqrt{X^2 \sum \frac{pi \times qi}{ni - 1}}$$

where: m = Log of fish length at first mature gonad; Xk = Log of mean length value at first mature gonad; X = Log of median of last length at first mature gonad; X = Log of increased length of the fish at the median; Pi = The proportion of mature gonad at the interval of ith with the number of fish at the interval of ith; ni = Number of mature gonad at the interval of ith; qi = 1 - pi; M = Antilog m of the length of first matured gonad

The length at first capture (Lc) was analyzed based on the logistic curve from the selection ogive function (Sparre & Venema, 1998). The recruitment pattern was estimated by backward projection using length frequency distribution data based on the von Bertalanffy growth curve (Pauly, 1984; Mildenberger et al., 2017).

Results

Size frequency distribution

The length range of *L. atkinsoni* was from 10.5 to 39.5 cm, with most individuals observed within the 22-24 cm size class (Fig. 3) with an average length of 23.25 (±3.93 cm).

Sex ratio

From 152 samples of *L. atkinsoni* that were collected for gonad investigation, we found 83 female and 69 male individuals. The sex ratio (M : F) was 1:1.2, with the observed proportion was statistically not significantly different (p >0,05).

Life history parameters and spawning potential ratio

We observed that the asymptotic length (L_∞) of *L. atkinsoni* was 41.14 cm (Table 1). The growth coefficient (k) of the species was 0.45/year, indicating a high growth rate (k >0.3; Froese, 2005). The natural mortality (M) of the species was 0.6/year, with theoretical age at length 0 cm (t0) was -0.33 years (Table 1). The length at first maturity (Lm) of the species was 23.40 cm, with the length at first capture (Lc) was 19.59 cm (Table 1; Fig 4). Based on the LBSPR model, we observed that the spawning potential ratio (SPR) of the *L. atkinsoni* in Southern Sulawesi was 12%, indicating an unsustainable level of the stock condition (SPR <30%) (Ault et al., 2008).

Recruitment pattern

We observed that *L. atkinsoni* in Southern Sulawesi was a partial spawner, with a range of monthly recruitment of 2 - 15 % (Fig. 5). The peaks of recruitment were observed in April (15%), July (15%) and November (12%). The recruitment patern occurring in these months is likely influenced by the annual upwelling event in the respective area (Utama et al., 2017). According to Klein et al., (2018), the recruitment pattern revealed a strong relationship with the upwelling.

Discussion

This study is the first finding of the length-based stock assessment of *L. atkinsoni*, the pacific yellowtail emperor, in Southern Sulawesi, Indonesia. We provide scientific information regarding the biological characteristics of the species, providing valuable input for fisheries management in the region. Based on the biological characteristics, we found that the population of this emperor was harvested at an unsustainable level.

The length range of the *L. atkinsoni* in Southern Sulawesi was from 10.5 to 39.5 cm. In other sites within Indonesia, the ranges of the conspecific were from 15.1 to 32.5 cm and from 12.0 to 37.7 cm in East Seram (Rumania et al., 2020) and Wakatobi (Prihatiningsih et al., 2021), respectively. In the Great Barrier Reef, Australia, the maximum length reported was 48 cm (Currey et al., 2013). While the range was similar among sites within Indonesia, the length of the fish was relatively smaller compared to the conspecific in Australia (Currey et al., 2013). This discrepancy might be due to ecological and environmental conditions between Indonesia and Australia, such as water quality, genetics, catch rate, and food abundance (Nikolskii, 1963), which can affect the biological condition of the fish.

In the present study, we found that the sex ratio of *L. atkinsoni* in Southern Sulawesi was equal between male and female individuals. Similarly, the sex ratio of the conspecific in the Wakatobi was equal (sex ratio M : F = 0.55:1.00; Prihatiningsih et al., 2021). Variations in the sex ratio can be affected by several factors, including behavior patterns, mortality, and growth rates between male and female individuals, spawning behavior, sexual maturity, length distribution due to its depth ranges, and length (or age) of the individuals (Effendie, 1997; Nikolskii, 1963). However, a note should be taken into consideration that *L. atkinsoni* is protogynous hermaphroditism species, with the length of sexual transition was reported between 23.0 and 23.9 cm FL off Yaeyama and between 30.0 and 30.9 cm FL off Okinawa (Ebisawa, 1999). In protogynous species, the exact effect of fishing pressure on stock dynamics is complex (Alonzo & Mangel, 2004). In the case of the present study, no data on sexual transition length was reported on the species from the area. Accordingly, further measures of fishery management for the species might be challenging.

We observed that the growth coefficient (k) of *L. atkinsoni* was 0.46/year, with an asymptotic length (L∞) of 41.14 cm. Based on Froese (2005), the k value of a higher growth rate is above 0.3/year. In areas close to the equator (i.e., tropical region), *L. atkinsoni* tends to have higher k values than the conspecific in higher latitudes (Table 2). Higher annual seawater temperatures in the tropic might affect the higher growth rate of *L. atkinsoni* (Gislason et al., 2010).

The length at first maturity (Lm) of *L. atkinsoni* in Southern Sulawesi was 23.40 cm at the age of approximately 1.5 years. The Lm in the present study was relatively lower compared to the conspecific in the Wakatobi (Lm for male = 30.7 cm; Lm for female = 27.18 cm; Prihatiningsih et al., 2021) but relatively higher in Japan (Ebisawa, 1999) with the Lm of 19 cm FL off Yaeyama and 21 cm FL off Okinawa. The Lm discrepancy was presumably due to the influence of environmental factors, including nutrient conditions, seawater temperature, irradiation, as well as species feeding habits and physiological conditions of fish, and the location of the fishing ground (Lagler et al., 1963; Udupe, 1986; Wootton, 1985). Latitudinal difference of more than 5° was thought to cause differences in age and length at first gonad maturity (Effendie, 1997). Moreover, high fishing pressure could affect the length at first maturity, where rapid maturation was found as a strategy for fish populations to cope with high fishing pressure (Restiangsih & Amri, 2019). The rate of fishing pressure in Southern Sulawesi is relatively higher than in Wakatobi (Fatma et al., 2021). To maintain its population, *L. atkinsoni* in Southern Sulawesi was likely to follow a similar strategy where they tend to have rapid maturation to cope with high fishing pressure.

We observed that the average size of the first capture (Lc) of *L. atkinsoni* in Southern Sulawesi was 19.59 cm at the age of approximately 1.1 years. The Lc was lower than the Lm, indicating that local fishers in Southern Sulawesi also caught a proportion of immature individuals (Fig. 4). Based on the size frequency distribution (Fig. 3), about 53% of immature individuals were caught by the local fishers. In addition, we found that the peak of recruitment of *L. atkinsoni* occurred in April, July, and November. This information can predict the spawning period of *L. atkinsoni* in Southern Sulawesi (Agustina et al., 2019), which can provide input to fisheries managers to apply temporary fishing closure.

Based on the LBSPR model, the SPR of *L. atkinsoni* in Southern Sulawesi was 12%, indicating that the population was harvested at an unsustainable level. The low SPR values (<30%) can reduce the ability of spawning stock biomass to produce adult stock in the structure of the population (Ault et al., 2008). This low SPR reflects a reduction in the number of young fish, thereby triggering a decrease in spawning stock and limiting the number of eggs produced. The SPR, as the biological reference point, is used to define safe levels of fishery harvesting and as benchmarks against which the actual status of a fish stock can be measured (Collie & Gislason, 2001). Management actions to rebuild the biomass of the species are needed to increase SPR above the threshold (>30%), which can be achieved by reducing fishing intensity, temporary fishing closure, and regulating the harvest size limit. Further management actions are needed to rebuild the stock of the species in the area to ensure a sustainable fishery.

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Tables and Figures

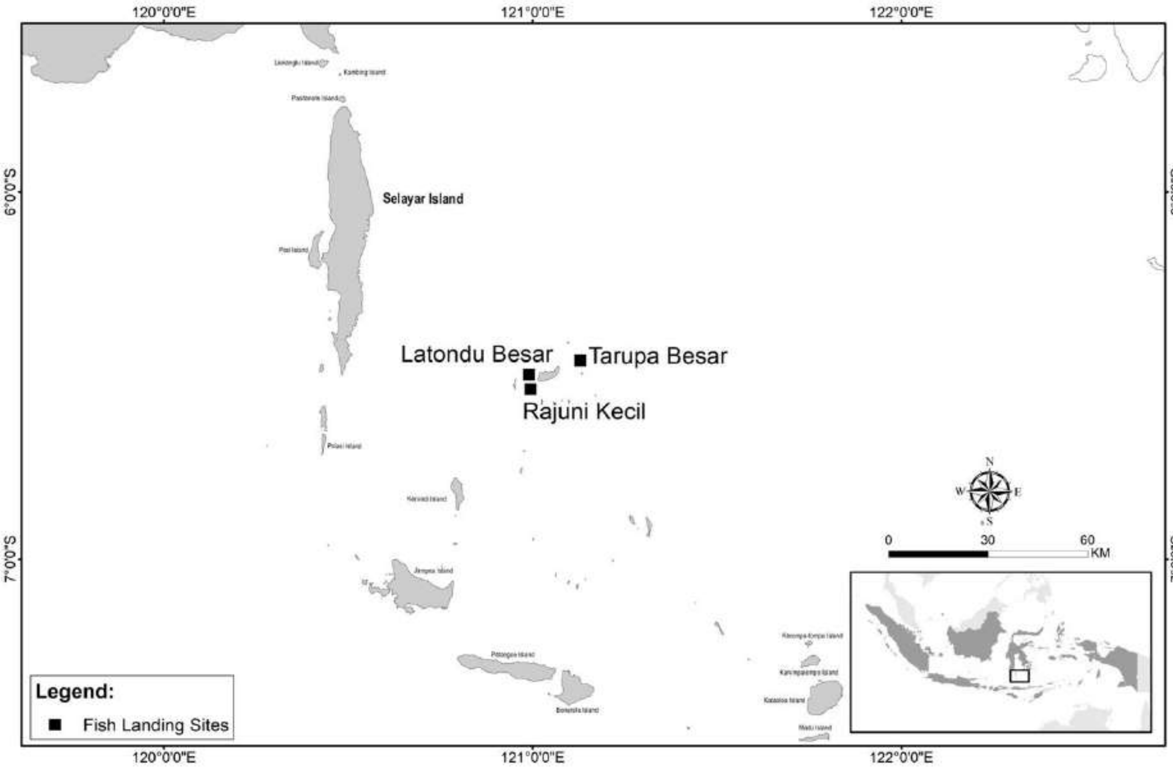


Fig 1. Map of the study area where data of *Lethrinus atkinsoni* were collected from three landing sites in Southern Sulawesi, Indonesia

Fig 2. A sample of *Lethrinus atkinsoni* caught from small-scale fishers in Southern Sulawesi, Indonesia

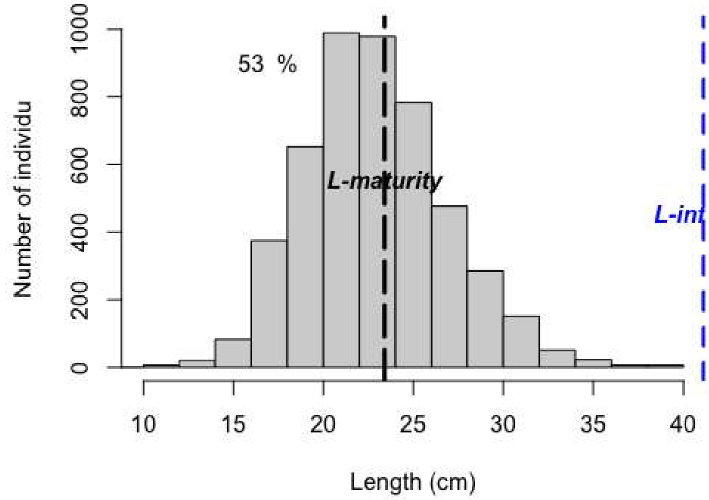


Fig 3. Length frequency distribution of *Lethrinus atkinsoni* that were collected from three landing sites in Southern Sulawesi, Indonesia

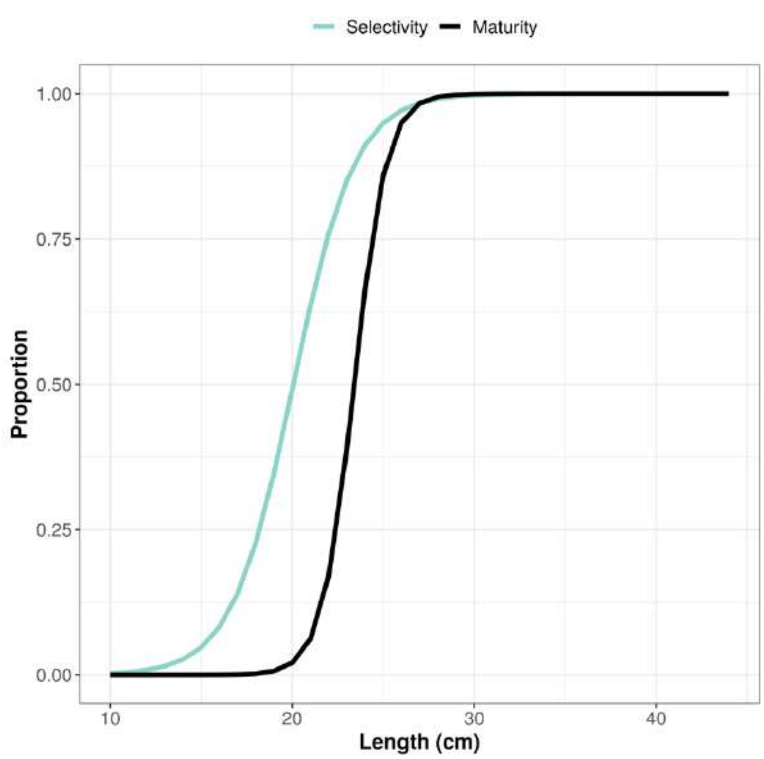


Fig 4. Maturity and selectivity curve of *Lethrinus atkinsoni* in Southern Sulawesi, Indonesia

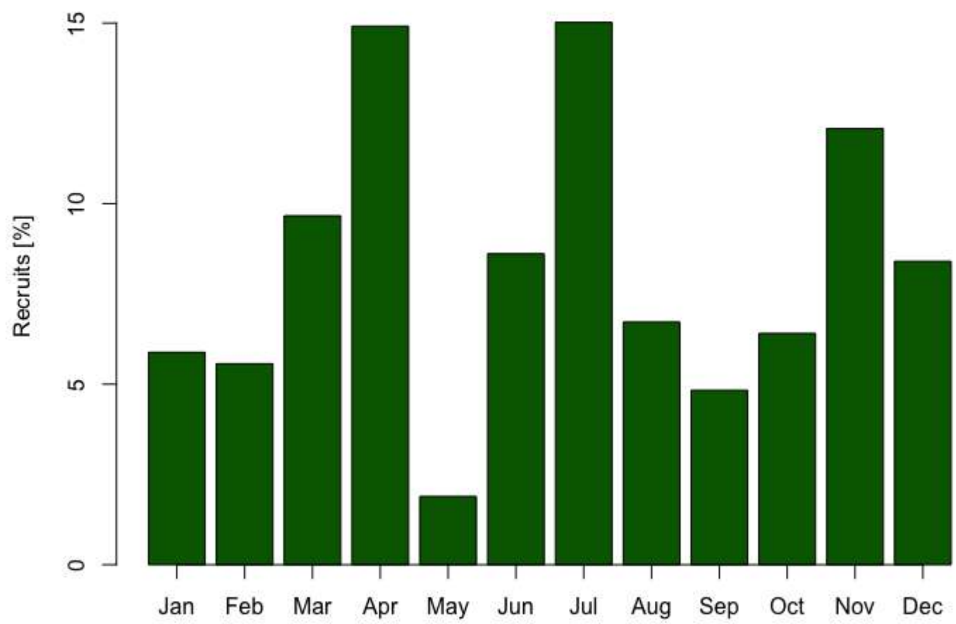


Fig 5. Recruitment pattern of *Lethrinus atkinsoni* in Southern Sulawesi, Indonesia

Table 1. Life history parameters and spawning potential ratio of *Lethrinus atkinsoni* in Southern Sulawesi, Indonesia

Parameter	**Unit**	**Value**
Asymptotic length (L∞)	cm	41.14
Growth coefficient (k)	Per year	0.45
The theoretical age at a length 0 cm (t0)	year	-0.33
Natural mortality (M)	Per year	0.60
Length at first maturity (Lm)	cm	23.40
Length at first capture (Lc)	cm	19.59
Spawning potential ratio (SPR)	%	12

Table 2. Growth parameters of *Lethrinus atkinsoni* in different locations

Location	**L∞ (cm)**	**k (/year)**	**References**
Yaeyama, Japan	30.9 (FL)	0.186	Fishbase (2022)
Great Barrier Reef and Eastern Torres Strait, Australia	32.5 (FL)	0.32	Fishbase (2022)
Northern coast, Fiji	42.8 (SL)	0.29	Fishbase (2022)
Okinawa, Japan	35.1 (SL)	0.26	Fishbase (2022)
Great Barrier Reef, Australia	32.2 (FL)	0.32	Currey et al., (2013)
Wakatobi, Indonesia	38.2 (FL)	0.44	Prihatiningsih et al., (2021)
East Seram, Indonesia	34.2 (TL)	0.42	Rumania et al., (2020)
Southern Sulawesi, Indonesia	*40.5 (TL)*	*0.40*	*This study*

Response to reviewer’s comments

We thank the editor and reviewers for their fruitful comments on our manuscript. Below is the detailed (point-by-point) response to the reviewers for each comment.

Editor comments
The examination of your manuscript has been completed.
The editor-in-chief had made a final decision that the revision were needed.
You can check the comments below by accessing the online submission system.
Even if there is some files attached by the reviewers, you cannot check it in the e-mail, so please make sure to access the system.
After reflecting the correction in the manuscript, be sure to submit it again using the submission system.

Response: Thank you very much for the final decision made. We have checked the comments from the Reviewer #1 and Reviewer #2 from your journal system. We have also addressed each of the comments and suggestion of both reviewers (point-by-point) below.

Reviewer #1

General comments:
The manuscript is sufficient and accepted to be published. Some comment to strengthen the finding is suggested.

Response: Thank you very much for your fruitful comments and suggestion in our manuscript. Please see our responses in addressing each of your comment and suggestion in detail below.

Comments in the manuscript text:

1. Line 159: It is suggested add more explanation on why the peaks occurred during those months

   Response: We have added the explanation in the text about the recruitment model.

2. Lines 213-214: Not clear, please rewrite the sentence

   Response: We have modified the sentence to make it clearer.

3. Line 247: +/- 30% journal international with 80% published more than 10 years. If a DOI (digital object identifier) is available for an article, always include it.

   Response: We have added journal international references in the manuscript. However, we could not add significant number of the journal international references, as we found that sufficient studies related to the species are only in the

Indonesian Journal. Hence, our manuscript will contribute to enhance exposure of the study of this species internationally.

We have added the DOI (Digital Object Identifier) that is available for any article cited in the reference list.

4. Line 290: Year?

   Response: Thank you. We have modified the references to add the year.

<u>Suggestions of text and syntaxes in the manuscript:</u>

5. Line 9: Add “Seale, 1910”

   Response: We agree to add the text suggested.

6. Line 10: Add “Therefore”

   Response: Agree to add the text suggested.

7. Line 11: Add “the”

   Response: Agree to add the text suggested.

8. Line 12: Remove “by”

   Response: Agree to remove the text suggested.

9. Line 14: Add “the”
   Response: Agree to add the text suggested.

10. Line 15: Remove “was”

    Response: Agree to remove the text suggested.

11. Line 15: Add “the” and remove “found”

    Response: Agree to add and remove the texts suggested.

12. Line 16: Remove “respectively”
    Response: Agree to remove the text suggested

13. Line 17: Add “In addition”, “a”, “an”

    Response: Agree to add the texts suggested.

14. Line 20: Add “the”, “and”,

Response: We agree to modify the texts suggested.

15. Line 21: Replace “is” with “are of” and replace “important” with “importance”

    Response: We agree to modify the texts suggested.

16. Lines 28-29: Add “As a result,”

    Response: We agree to add the texts suggested.

17. Lines 29-30: Add “and international markets, such as”

    Response: Agree to add the texts suggested.

18. Line 30: Add “However”

    Response: Agree to add the text suggested.

19. Line 34: Add “the”, remove “ocean, add “s” in the word “ocean”

    Response: Agree to add the text suggested.

20. Line 35: Replace “one of” with “a”

    Response: We agree to modify the text suggested.

21. Line 36: Replace “one of” with a

    Response: We agree to modify the text suggested

22. Line 38: Replace “important” with “significant”

    Response: We agree to modify the text suggested.

23. Line 39: Remove “,” and “or”

    Response: We agree to remove the text suggested.

24. Line 40: Remove “,” “,” add “and”

    Response: We agree to modify the text suggested.

25. Line 41: Remove “and” “the” and add “The”

    Response: modify the text suggested.

26. Line 42: Remove”,” and “main” add “primary”

    Response: We agree to modify the text suggested.

27. Line 44: Replace “Effective” with “Therefore, effective”

    Response: We agree to modify the text suggested

28. Line 45: Remove “the”

    Response: Agree to remove the text suggested

29. Line 46-47: Remove “The” and replace “the important regions for coral reef fisheries in Indonesia” to “Indonesia’s crucial regions for coral reef fisheries”

    Response: Agree to modify the text suggested

30. Line 47: Remove “largest” add “most extensive” “is”

    Response: Agree to modify the text suggested

31. Line 8: Add “.” “The” “to” and remove “and” “for”

    Response: Agree to modify the text suggested

32. Line 52: Remove “the”

    Response: Agree to remove the text suggested

33. Line 53: Add “limited status and trend” replace “affects” to “affect”

    Response: Agree to modify the text suggested

34. Line 57-58: Replace “Biological investigated characteristics and stock conditions of the species were investigated by” with “The species' biological characteristics and stock conditions were investigated”

    Response: Agree to modify the text suggested

35. Line 62: Remove “the”

    Response: We agree to remove the text suggested

36. Line 66: Remove “a total of”

Response: We agree to remove the text suggested

37. Line 67: Remove “individual”

    Response: We agree to remove the text suggested

38. Line 68: Remove “,” and replace “the” to “and”

    Response: We agree to modify the text suggested

39. Line 69: Add “the” and remove “sex and”

    Response: We agree to modify the text suggested

40. Line 72: Add “The sex” and remove “Sex”

    Response: We agree to modify the text suggested

41. Line 77: Add “the”

    Response: We agree to add the text suggested

42. Line 80: Replace “Udupa” to “Udupe”

    Response: We agree to modify the text suggested

43. Line 87: Replace “Length” to “The length” and remove “of” “were”

    Response: We agree to modify the text suggested

44. Line 88: Remove “).” “The” “the species was” “cm” “SD =” and add “) with an” “cm”

    Response: We agree to modify the text suggested

45. Line 92: Replace “Sex” to “The sex”

    Response: We agree to modify the text suggested

46. Line 96: Replace “Growth” to “the growth”

    Response: We agree to modify the text suggested

47. Line 98: Replace “year” to “years” and “Length” to “The length”

    Response: We agree to modify the text suggested

48. Line 101: Add “an”

    Response: We agree to add the text suggested

49. Line 104: Remove “the” add “a”

    Response: We agree to modify the text suggested

50. Line 109: Add “study” and replace “study” to “finding”

    Response: We agree to modify the text suggested

51. Line 111: Remove “the”

    Response: We agree to remove the text suggested

52. Line 112: Add “of this emperor”

    Response: We agree to add the text suggested

53. Line 113: Remove “’s”

    Response: We agree to remove the text suggested

54. Line 115: Remove “in”

    Response: We agree to remove the text suggested

55. Line 121: Add “the” to “the sex” and remove “the” from “the L. atkinsoni”

    Response: We agree to modify the text suggested

56. Line 122: Add “the” to “the sex” and remove”found”

    Response: We agree to modify the text suggested

57. Line 126: Add “a” and remove “s” from “considerations”

    Response: We agree to modify the text suggested

58. Line 129: Add “the”

    Response: We agree to add the text suggested

59. Line 130: Replace “of” to “on” and remove “the”

Response: We agree to modify the text suggested

60. Line 132: Remove “the” and replace “the” to “an”

    Response: We agree to modify the text suggested

61. Line 133: Replace “s” from “values” and add “a”

    Response: We agree to modify the text suggested

62. Line 135: Add “s” in “temperature”

    Response: We agree to add the text suggested

63. Line 137: Add “The” to “Length”

    Response: We agree to add the text suggested

64. Line 138: Replace “at” to “in”

    Response: We agree to replace the text suggested

65. Line 142: Add “The”

    Response: We agree to add the text suggested

66. Line 143-144: Replace “be the cause of” to “cause”

    Response: We agree to replace the text suggested

67. Line 145: Replace “of” to “for”

    Response: We agree to replace the text suggested

68. Line 151: Remove “the” add “a”

    Response: We agree to modify the text suggested

69. Line 153: Remove “be used to”

    Response: We agree to remove the text suggested

70. Line 158: Add “low SPR”

    Response: We agree to add the text suggested

71. Line 159: Remove “,” add “and”

    Response: We agree to modify the text suggested

72. Line 162: Replace “stock” with “biomass” and remove “in”

    Response: We agree to modify the text suggested

73. Line 164: Add “the”

    Response: We agree to add the text suggested

74. Line 174: Remove “of”

    Response: We agree to remove the text suggested

Reviewer #2

General comments:
This paper is thought to be useful in understanding the ecological characteristics and the stock status of *Lethrinus atkinsoni*, which should be managed effectively in the area. However, I think this paper should be revised or more samples should be taken for this study, and the major things to be revised are as follows.
Another comment is recommended to be submitted as a short communication rather than an article. This is because the sampling period of this study is too short and the results presented in the paper include only a part of the ecology of the species.

Response: Thank you very much for your fruitful comments and suggestion in our manuscript. We have revised the manuscript text thoroughly based on your comments as well as comment from the Reviewer #1. Please see our responses (point by point) to your comments below.

Unfortunately, we disagree with your suggestion that our manuscript to be submitted as a short communication rather than an article. We thought that we have now a quite robust data (now added more period of samples, from 5 months to 10 months based on your comment). Also, the number of individuals sampled now increasing significantly from 952 to 4,887 individuals.

1. Line 34) pacific → Pacific: “P” should be uppercase

   Response: Thank you. Agreed. We have modified the text as suggested.

2. In “Introduction”: Previous studies on *Lethrinus atkinsoni* should be introduced/described, and the purpose and necessity of this study should be further strengthened.

Response: Agreed. We have now added texts explaining the previous studies of the species (*L. atkinsoni*) in the introduction. We have also added context the necessity of this study to be conducted (i.e., *L. atkinsoni* stock assessment in Indonesia, particularly in the studied site). Please see the added text in the 2nd paragraph of the Introduction section.

3. line 60) This study collected samples from January to May 2022, but I can't see how these samples are used in this study. And I wonder why the samples were collected for 5 months. Generally, samples are collected for at least for one year for ecological studies.

   Response: The samples include the fish length (total samples of 952 individuals) that were collected from January to May 2022. Of those 952 individuals, there were 152 samples that were collected in April and May 2022 to examine reproductive information (sex examination (male/female) and gonad maturity). As stated in the "Data analysis" section, both the fish' length and reproductive information were used to examine 1) size frequency distribution of the fish; 2) sex ratio; 3) the fish stock status using the Length-Based Spawning Potential Ratio (LBSPR) model; and 4) recruitment pattern. We modified the text in the methods to make it clearer, especially adding the formulae on how to calculate/estimate the results. Please see also our response to your comment No. 5 below related to "Data Analysis".

   We agree to add the data from 5 months to 10 months (almost 1 year). We have reanalyzed the data and made the necessary changes, including modifying the text and the figures. We initially have continued data for 10 months (from January to October 2022). However, at the time we submitted our manuscript in the journal, we have only data of fish' length for 5 months (Jan – May 2022), as the other data from June to October 2022 were not ready yet (not compiled and not cleaned).

4. line 64) Why did you use only the samples from April to May for examining sex ratio?

   Response: To examine individual reproductive biology (examining sex of the fish and examining gonad maturity) required high efforts and resources. We have limited resources (enumerators) and logistical constraints to conduct reproductive examination for longer term. Based on these constraints, we could only conduct this only for 2 months (April to May 2022).

5. The "Data Analysis" section does not specifically address how to calculate/estimate the results such as growth parameters, lengths at first maturity and at first capture, recruitment, etc. For example, to estimate gear selectivity (length at first capture), authors assumed the curve shape as the logistic function, but the shape differs depending on the gear characteristics. In addition, recruitment pattern analysis would be key results in this study, so it needs to describe the method and results in detail.

Response: We have modified the Data Analysis section to specifically address on how to calculate/estimate the results, including specifically address how to calculate the growth parameters, lengths at first maturity and at first capture, recruitment. We inserted the formulae of the data in the manuscript text.

6. line 96) 0.38 year → -0.38 years : it differs from Table 1.

   Response: The value of T0 supposed to be in negative format. However, as we added the data, the T0 changed from -0.38 year to -0.33 year. We have modified the value throughout the manuscript text.

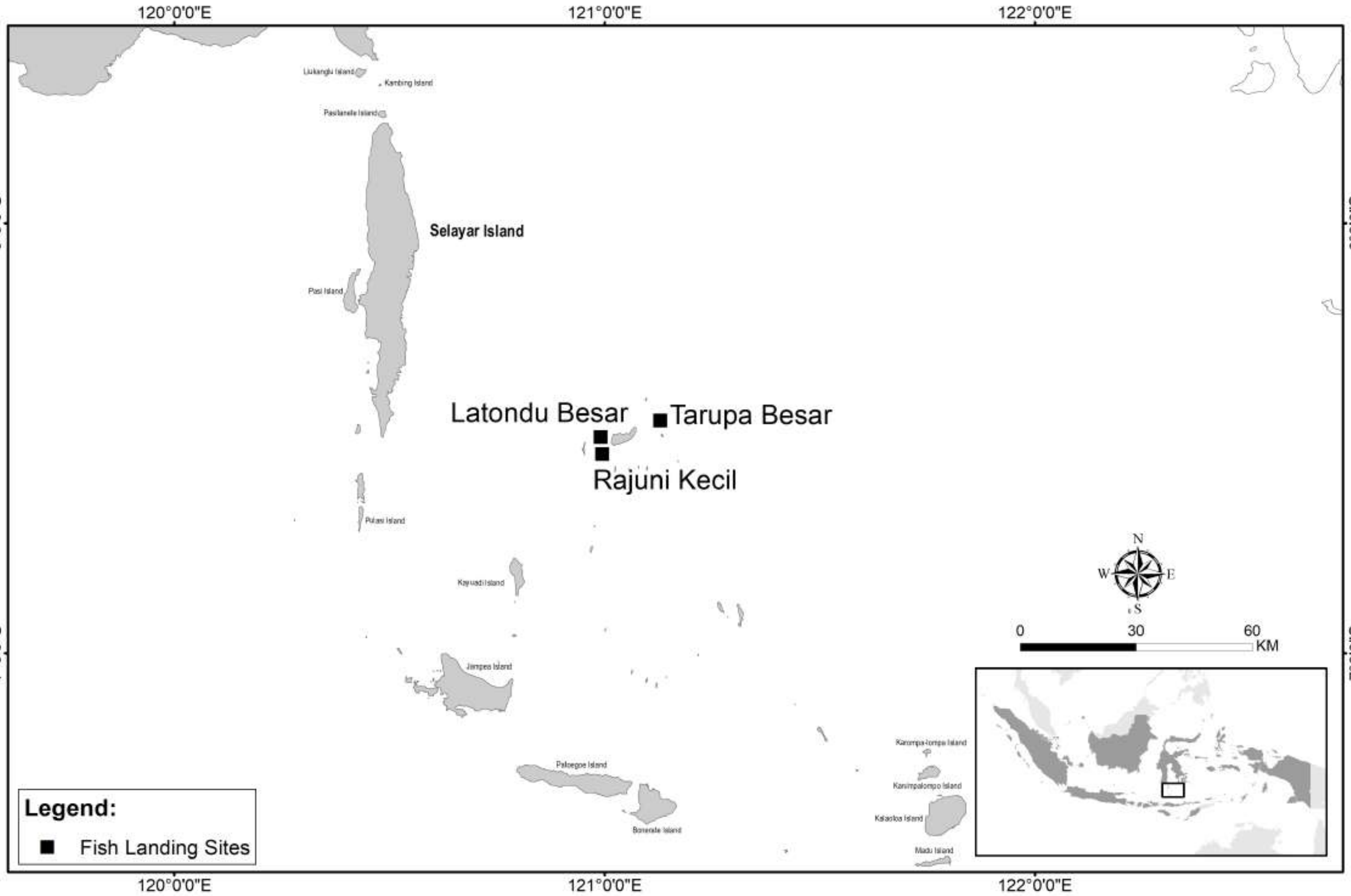
Table 1. Life history parameters and spawning potential ratio of *Lethrinus atkinsoni* in Southern Sulawesi, Indonesia

Parameter	**Unit**	**Value**
Asymptotic length (L∞)	cm	41.14
Growth coefficient (k)	Per year	0.45
The theoretical age at a length 0 cm (t0)	year	-0.33
Natural mortality (M)	Per year	0.60
Length at first maturity (Lm)	cm	23.40
Length at first capture (Lc)	cm	19.59
Spawning potential ratio (SPR)	%	12

Table 2. Growth parameters of *Lethrinus atkinsoni* in different locations

Location	**L∞ (cm)**	**k (/year)**	**References**
Yaeyama, Japan	30.9 (FL)	0.186	Fishbase (2022)
Great Barrier Reef and Eastern Torres Strait, Australia	32.5 (FL)	0.32	Fishbase (2022)
Northern coast, Fiji	42.8 (SL)	0.29	Fishbase (2022)
Okinawa, Japan	35.1 (SL)	0.26	Fishbase (2022)
Great Barrier Reef, Australia	32.2 (FL)	0.32	Currey et al., (2013)
Wakatobi, Indonesia	38.2 (FL)	0.44	Prihatiningsih et al., (2021)
East Seram, Indonesia	34.2 (TL)	0.42	Rumania et al., (2020)
Southern Sulawesi, Indonesia	*40.5 (TL)*	*0.40*	*This study*

File name: fas-2022-0136-FIG-Fig1.jpg
Description: Fig 1



File name: fas-2022-0136-FIG-Fig2.tif
Description: Fig 2

File name: fas-2022-0136-FIG-Fig3.tiff
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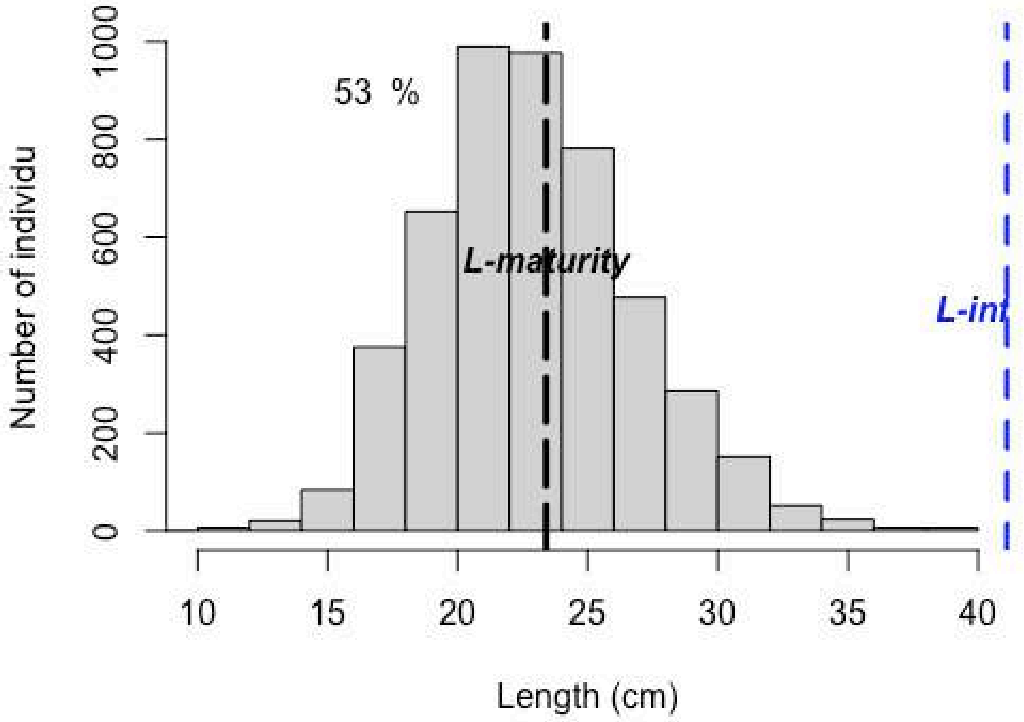

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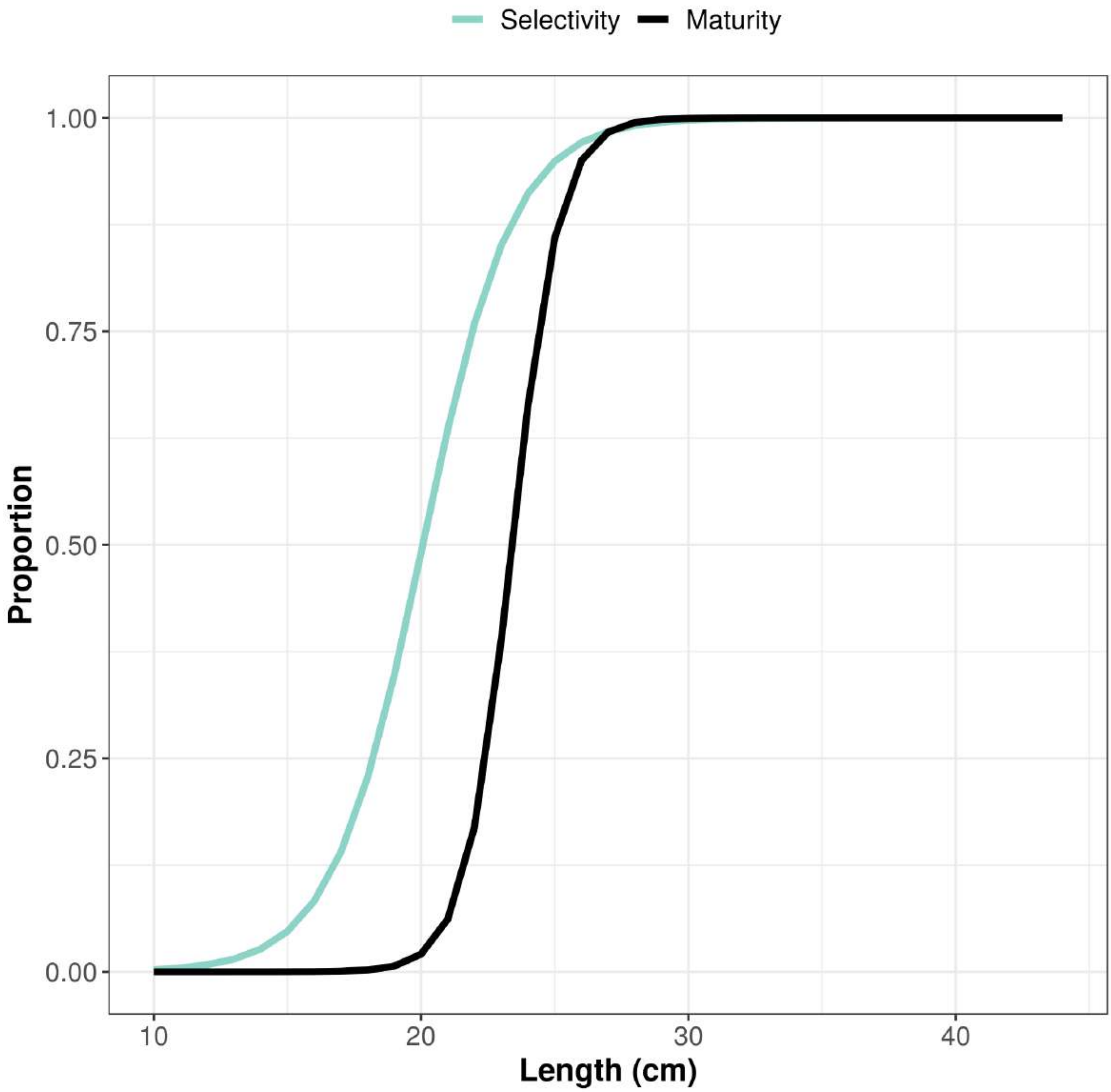

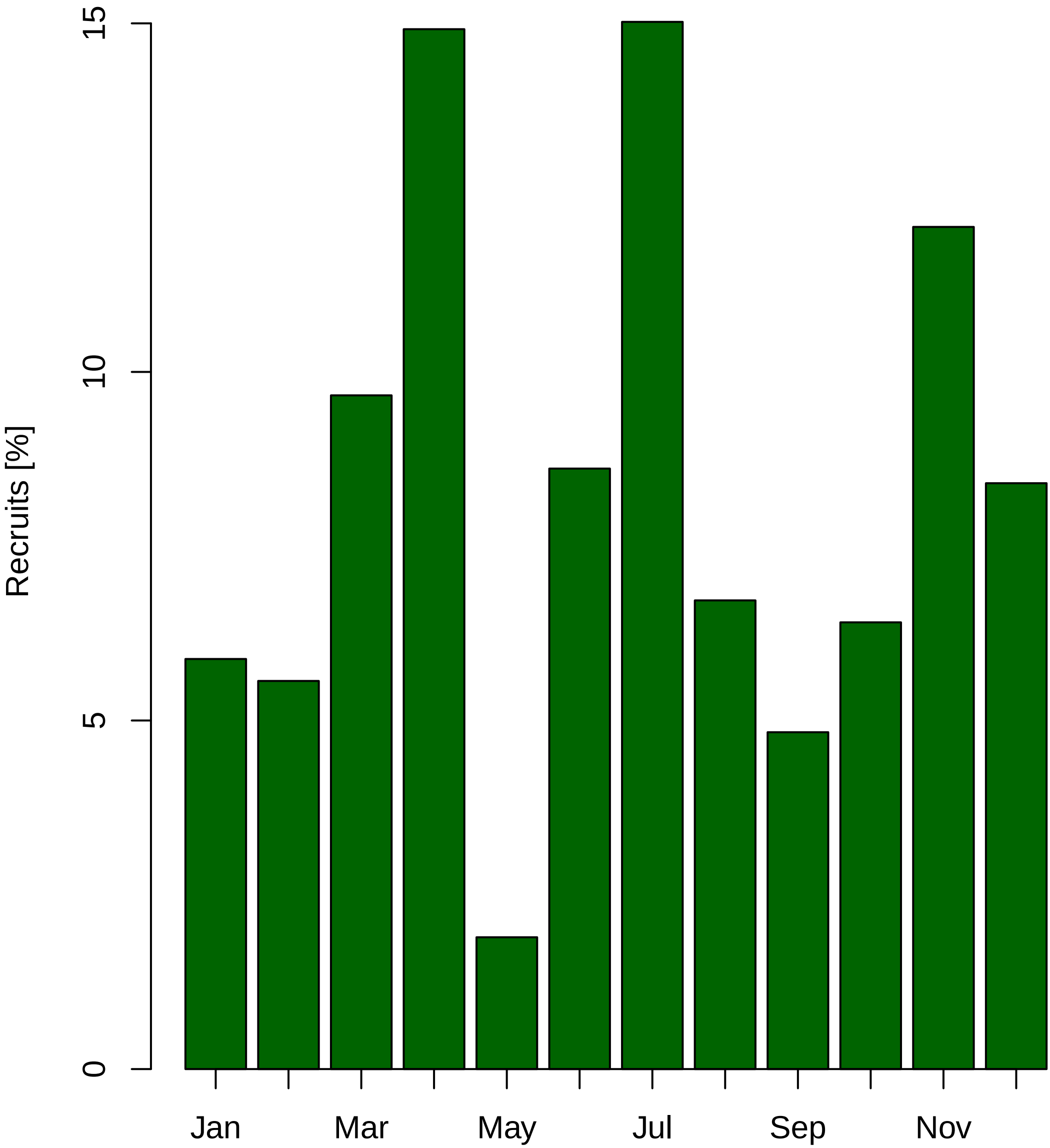

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View Submission	fas-2022-0136 (2nd)	Research Article (**Fast-track**) (Ecology and Fisheries Resource Management)	Length-based stock assessment of the Pacific Yellowtail Emperor in the Southern Sulawesi, Indonesia	**Completed (Accept)** (2023-02-10)	I Nyoman Suyasa (2023-02-09)

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CONFIRMATION OF ACCEPTANCE

Name of Journal: **Fisheries and Aquatic Sciences**

Title of the submitted manuscript: **Length-based stock assessment of the Pacific Yellowtail Emperor in the Southern Sulawesi, Indonesia**

Authors: I Nyoman Suyasa[1], Alifah Fitam Rakhma Sari[1], Siska Agustina[2], Rian Prasetia[2], Ratna Suharti[1], Toni Ruchimat[1,2], Budy Wiryawan[2,3,4], Irfan Yulianto[2,3]

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[3]Department of Fisheries Resource Utilization, IPB University, Indonesia

[4]Environmental and Conservation Sciences, College of SHEE, Murdoch University, Australia

Probable date of publication**: March 31, 2023**

This is to certify that above mentioned original research article has been accepted in the journal of Fisheries and Aquatic Sciences. This article is in the press and will be published in due date.

Thank you very much for your endeavour in our Journal.

Thanking you

February 15, 2023

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Length-based stock assessment of the pacific yellowtail emperor in the Southern Sulawesi, Indonesia

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Abstract

Pacific yellowtail emperor, *Lethrinus atkinsoni* Seale, 1910, is one of the most targeted reef fish species in Southern Sulawesi, Indonesia. Therefore, assessing its stock is important to understand the condition of the population, providing valuable inputs for sustainable fisheries management in the area. Here we assess the stock condition of *L. atkinsoni* in Southern Sulawesi, Indonesia, using the length-based spawning potential ratio model. A total of 4,887 individuals were collected from commercially small-scale fishers from January to October 2022. The total length, sex, and gonad maturity of the individuals were examined. We observed that the fish length ranged from 10.5 to 39.5 cm, with an average length of 23.3 cm. The sex ratio was equal (1:1.2) between male and female individuals. Length at first maturity and length at first capture were 23.4 and 19.6 cm, respectively. In addition, we observed a growth coefficient of 0.45/year, with an asymptotic length of 41.14 cm and natural mortality of 0.6/year. Based on these life history parameters, we observed the spawning potential ratio (SPR) value of 12%, indicating an unsustainable fishery level (SPR of < 30%). Further concerns related to the sustainability of the species and strategy to rebuild stock of the *L. atkinsoni* in Southern Sulawesi are of utmost importance.

Keywords: *Lethrinus atkinsoni*, Fisheries management, Length-based spawning potential ratio, Southern Sulawesi

Introduction

Indonesia is the second world's largest fisheries producer (FAO, 2020), with coral reef fisheries contributing to Indonesian fisheries productivity, estimated to reach a total of 800 thousand tons annually (MMAF, 2022). As a result, coral reef fishes are economically important commodities in Indonesia, demanded by domestic and international markets, such as Singapore and

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Hong Kong (Rizal et al., 2018). However, due to its high demand, populations of some reef fish species are threatened across the country (Campbell et al., 2013).

Reef fish of the family Lethrinidae (emperors) are abundant in tropical and subtropical regions where coral reefs, seagrass beds, and mangrove forest areas are their habitats (Young & Martin, 1982). Fishes within the family are one of the significant food resources in the Western Pacific and Indian Oceans due to their high catch amount (Carpenter & Allen, 1989). Among the lethrinids, the *Lethrinus atkinsoni,* known as pacific yellowtail emperors, is a highly targeted fish by local fishers in Indonesia (Mayunar, 1996), including in the Southern Sulawesi region (Agustina et al., 2021). There are numerous studies concerning the growth and biological parameters of the *L atkinsoni* (Currey et al., 2013; Ebisawa, 1999; Prihatiningsih et al., 2021; Rumania et al., 2020), while no studies yet about the status of its stock in Indonesia, particularly in the Southern Sulawesi region.

About 90%–95% of fishers in Indonesia are small-scale yet generating significant contributions for coastal communities (Sari et al., 2021). Small-scale fisheries often referred to as artisanal fisheries, is a traditional fishery that involves fishing households and uses relatively small fishing vessels and short fishing trips. The catch is mainly for local consumption. Most fishers in Southern Sulawesi are small-scale, contributing significantly to social and economic conditions in the area as the primary source of livelihood, providing food for the community. The fishers and the local community are dependent on fish resources. Accordingly, they are vulnerable to any change that disrupts their harvest (Wiyono, 2011). Therefore, effective management of small-scale fisheries in the area is crucial for the community.

Southern Sulawesi is one of Indonesia's crucial regions for coral reef fisheries, where the world's 3rd most extensive coral reef atoll is found (Malik et al., 2018). The coral reefs are home to more than 500 reef fish species, including the highly demanded reef fish emperors of the family Lethrinidae (Muhidin et al., 2019). However, the coral reefs there are being threatened due to destructive fishing activities by explosives and cyanide (Panuluh et al., 2020). Despite being one of the most important fishery commodities in Indonesia, the potential of lethrinid fish and its utilization status are still poorly understood (Restiangsih & Muchlis, 2019). In addition, the impact of fishing activities in Southern Sulawesi is not yet fully known due to limited data (Agustina et al., 2021). This limited status and trend certainly affect fishery management, hampering its resources to be sustainably managed (Rizal et al., 2018). In this context, identifying biological characteristics and assessing the stock condition of lethrinid fish is necessary to improve fisheries management in the area. This study aims to assess the stock status of *L. atkinsoni* in Southern Sulawesi, Indonesia. The species' biological characteristics and stock conditions were investigated using the length-based stock assessment approach.

Materials and Methods

Study site and sample collection

This study was conducted in Southern Sulawesi, Indonesia (Fig. 1), from January to October 2022. A total of 4,887 individuals of *L. atkinsoni* (Fig. 2) were collected from three landing sites; the Tarupa Besar, Rajuni Kecil, and Latondu Besar. The samples were commercially caught by small-scale handline and speargun fishers. The samples were measured to the nearest millimeter in total length.

From those total samples, in April and May 2022, 152 individuals of *L. atkinsoni* were examined for their sex and gonad maturity following West (1990). The sex of each sample was determined through macroscopic examination after dissection, whereby the shape and color of the testis and ovaries were used to assign the gonadal maturity of the fish.

Data analysis

The sex ratio of *L. atkinsoni* was estimated and tested for the significant differences in the proportion of males and females for a theoretical 1:1 relation using a Chi-square (χ^2) equation (Kenney & Keeping, 1951) following the formula:

$$X^2 = \sum \frac{(O-E)^2}{E}$$

Where O is the observed number of males and females; E is the expected number of males and females.

We assessed the fish stock using the length-based spawning potential ratio (LBSPR) model (Hordyk et al., 2015). The life-history parameters and length frequency distribution data were examined as its input. The life-history parameters consist of growth coefficient (k), asymptotic length ($L\infty$), natural mortality (M), length at first capture (Lc) and length at first maturity (Lm). Growth parameters (i.e., k and $L\infty$) were estimated by the von Bertalanffy growth model (Sparre & Venema, 1998) using the "TropFishR" package in Rstudio (Mildenberger et al., 2017), following the formula:

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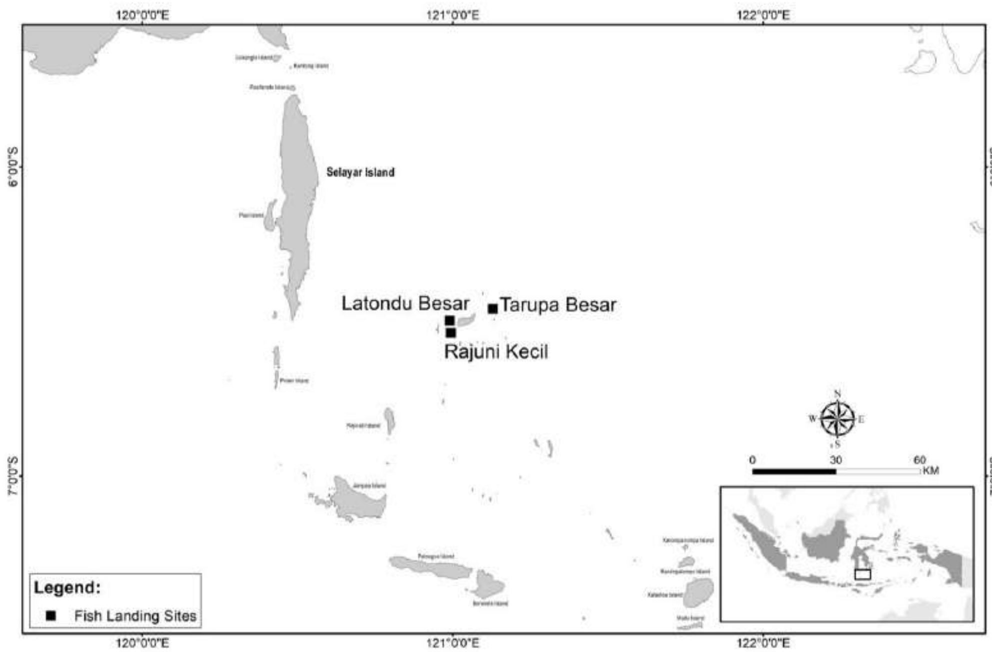

Fig. 1. Map of the study area where data of *Lethrinus atkinsoni* were collected from three landing sites in Southern Sulawesi, Indonesia.

Fig. 2. A sample of *Lethrinus atkinsoni* caught from small-scale fishers in Southern Sulawesi, Indonesia.

$$Lt = L\infty\ [1 - e^{-K(t - t0)}]$$

Where L∞ is the mean maximum length, k is a growth coefficient, and t_0 is the theoretical age at a size 0.

M was calculated following the Pauly empirical equation (Pauly, 1980):

$$Log(-t_0) = -0.3922 - 0.2752\log(L\infty) - 1.038\log(K)$$

Lm was analyzed following the formula of Spearman-Karber (Udupe, 1986):

$$m = \left[Xk + \frac{X}{2}\right] - \left(X\sum pi\right)$$

With 95% confidence interval, it was calculated as:

$$Lm = anti\log\left(m \pm 1.96 \times \sqrt{X^2 \sum \frac{pi \times qi}{ni - 1}}\right)$$

Where: m = log of fish length at first mature gonad; Xk = log of mean length value at first mature gonad; X = log of median of last length at first mature gonad; X = log of increased length of the fish at the median; Pi = the proportion of mature gonad at the interval of ith with the number of fish at the interval of ith; ni = number of mature gonad at the interval of ith; qi = 1 – pi; M = antilog m of the length of first matured gonad.

The Lc was analyzed based on the logistic curve from the selection ogive function (Sparre & Venema, 1998). The recruitment pattern was estimated by backward projection using length frequency distribution data based on the von Bertalanffy growth curve (Mildenberger et al., 2017; Pauly, 1984).

Results

Size frequency distribution

The length range of *L. atkinsoni* was from 10.5 to 39.5 cm, with most individuals observed within the 22–24 cm size class (Fig. 3) with an average length of 23.25 (± 3.93 cm).

Sex ratio

From 152 samples of *L. atkinsoni* that were collected for gonad investigation, we found 83 female and 69 male individuals. The sex ratio (male:female) was 1:1.2, with the observed proportion was statistically not significantly different ($p > 0.05$).

Life history parameters and spawning potential ratio

We observed that the L∞ of *L. atkinsoni* was 41.14 cm (Table 1). The k of the species was 0.45/year, indicating a high growth rate (k > 0.3; Froese, 2005). The M of the species was 0.6/year, with theoretical age at length 0 cm (t0) was –0.33 years (Table 1). The Lm of the species was 23.40 cm, with the Lc was 19.59 cm (Table 1 and Fig. 4). Based on the LBSPR model, we observed that the spawning potential ratio (SPR) of the *L. atkinsoni* in Southern Sulawesi was 12%, indicating an unsustainable level of the stock condition (SPR < 30%) (Ault et al., 2008).

Recruitment pattern

We observed that *L. atkinsoni* in Southern Sulawesi was a partial spawner, with a range of monthly recruitment of 2%–15 % (Fig.

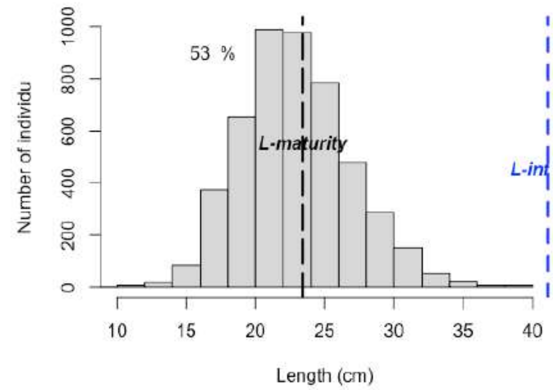

Fig. 3. Length frequency distribution of *Lethrinus atkinsoni* that were collected from three landing sites in Southern Sulawesi, Indonesia.

Table 1. Life history parameters and SPR of *Lethrinus atkinsoni* in Southern Sulawesi, Indonesia

Parameter	Unit	Value
Asymptotic length	cm	41.14
Growth coefficient	Per year	0.45
The theoretical age at a length 0 cm	year	–0.33
Natural mortality	Per year	0.60
Length at first maturity	cm	23.40
Length at first capture	cm	19.59
SPR	%	12

SPR, spawning potential ratio.

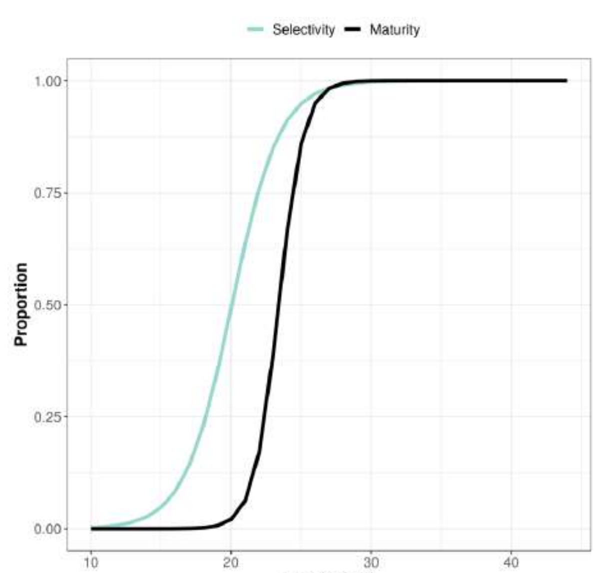

Fig. 4. Maturity and selectivity curve of *Lethrinus atkinsoni* in Southern Sulawesi, Indonesia.

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5). The peaks of recruitment were observed in April (15%), July (15%) and November (12%). The recruitment patern occurring in these months is likely influenced by the annual upwelling event in the respective area (Utama et al., 2017). According to Klein et al. (2018), the recruitment pattern revealed a strong relationship with the upwelling.

Discussion

This study is the first finding of the length-based stock assessment of *L. atkinsoni,* the pacific yellowtail emperor, in Southern Sulawesi, Indonesia. We provide scientific information regarding the biological characteristics of the species, providing valuable input for fisheries management in the region. Based on the biological characteristics, we found that the population of this emperor was harvested at an unsustainable level.

The length range of the *L. atkinsoni* in Southern Sulawesi was from 10.5 to 39.5 cm. In other sites within Indonesia, the ranges of the conspecific were from 15.1 to 32.5 cm and from 12.0 to 37.7 cm in East Seram (Rumania et al., 2020) and Wakatobi (Prihatiningsih et al., 2021), respectively. In the Great Barrier Reef, Australia, the maximum length reported was 48 cm (Currey et al., 2013). While the range was similar among sites within Indonesia, the length of the fish was relatively smaller compared to the conspecific in Australia (Currey et al., 2013). This discrepancy might be due to ecological and environmental conditions between Indonesia and Australia, such as water quality, genetics, catch rate, and food abundance (Nikolskii, 1963), which can affect the biological condition of the fish.

In the present study, we found that the sex ratio of *L. atkinsoni* in Southern Sulawesi was equal between male and female individuals. Similarly, the sex ratio of the conspecific in the Wakatobi was equal (sex ratio male:female = 0.55:1.00; Prihatiningsih et al., 2021). Variations in the sex ratio can be affected by several factors, including behavior patterns, mortality, and growth rates between male and female individuals, spawning behavior, sexual maturity, length distribution due to its depth ranges, and length (or age) of the individuals (Effendie, 1997; Nikolskii, 1963). However, a note should be taken into consideration that *L. atkinsoni* is protogynous hermaphroditism species, with the length of sexual transition was reported between 23.0 and 23.9 cm FL off Yaeyama and between 30.0 and 30.9 cm FL off Okinawa (Ebisawa, 1999). In protogynous species, the exact effect of fishing pressure on stock dynamics is complex (Alonzo & Mangel, 2004). In the case of the present study, no data on sexual transition length was reported on the species from the area. Accordingly, further measures of fishery management for the species might be challenging.

We observed that the k of *L. atkinsoni* was 0.46/year, with an $L\infty$ of 41.14 cm. Based on Froese (2005), the k value of a higher growth rate is above 0.3/year. In areas close to the equator (i.e., tropical region), *L. atkinsoni* tends to have higher k values than the conspecific in higher latitudes (Table 2). Higher annual seawater temperatures in the tropic might affect the higher growth rate of *L. atkinsoni* (Gislason et al., 2010).

The Lm of *L. atkinsoni* in Southern Sulawesi was 23.40 cm at the age of approximately 1.5 years. The Lm in the present study was relatively lower compared to the conspecific in the Wakatobi (Lm for male = 30.7 cm; Lm for female = 27.18 cm; Prihatiningsih et al., 2021) but relatively higher in Japan (Ebisawa, 1999) with the Lm of 19 cm FL off Yaeyama and 21 cm FL off Okinawa. The Lm discrepancy was presumably due to the influence of environmental factors, including nutrient conditions, seawater temperature, irradiation, as well as species feeding habits and physiological conditions of fish, and the location of the fishing ground (Lagler et al., 1963; Udupe, 1986; Wootton, 1985). Latitudinal difference of more than 5° was thought to cause differences in age and length at first gonad maturity (Effendie, 1997). Moreover, high fishing pressure could affect the Lm, where rapid maturation was found as a strategy for fish populations to cope with high fishing pressure (Restiangsih & Amri, 2019). The rate of fishing pressure in Southern Sulawesi is relatively higher than in Wakatobi (Fatma et al., 2021). To maintain its population, *L. atkinsoni* in Southern Sulawesi was likely to follow a similar strategy where they tend to have rapid

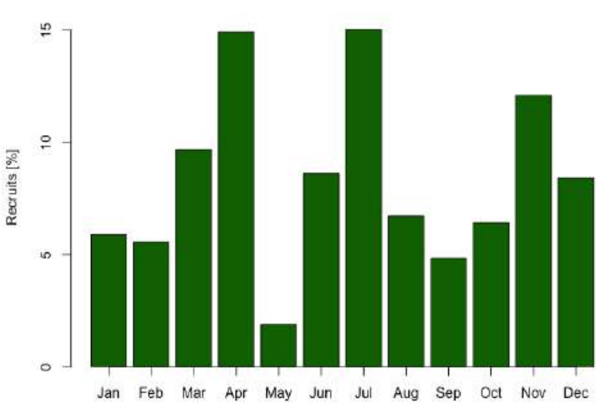

Fig. 5. Recruitment pattern of *Lethrinus atkinsoni* in Southern Sulawesi, Indonesia.

Table 2. Growth parameters of *Lethrinus atkinsoni* in different locations

Location	Asymptotic length (cm)	Growth coefficient (/year)	References
Yaeyama, Japan	30.9 (FL)	0.186	Froese & Pauly (2022)
Great Barrier Reef and Eastern Torres Strait, Australia	32.5 (FL)	0.32	Froese & Pauly (2022)
Northern coast, Fiji	42.8 (SL)	0.29	Froese & Pauly (2022)
Okinawa, Japan	35.1 (SL)	0.26	Froese & Pauly (2022)
Great Barrier Reef, Australia	32.2 (FL)	0.32	Currey et al. (2013)
Wakatobi, Indonesia	38.2 (FL)	0.44	Prihatiningsih et al. (2021)
East Seram, Indonesia	34.2 (TL)	0.42	Rumania et al. (2020)
Southern Sulawesi, Indonesia	40.5 (TL)	0.40	This study

FL, ???; SL, ???; TL, total length.

maturation to cope with high fishing pressure.

We observed that the average size of the Lc of *L. atkinsoni* in Southern Sulawesi was 19.59 cm at the age of approximately 1.1 years. The Lc was lower than the Lm, indicating that local fishers in Southern Sulawesi also caught a proportion of immature individuals (Fig. 4). Based on the size frequency distribution (Fig. 3), about 53% of immature individuals were caught by the local fishers. In addition, we found that the peak of recruitment of *L. atkinsoni* occurred in April, July, and November. This information can predict the spawning period of *L. atkinsoni* in Southern Sulawesi (Agustina et al., 2019), which can provide input to fisheries managers to apply temporary fishing closure.

Based on the LBSPR model, the SPR of *L. atkinsoni* in Southern Sulawesi was 12%, indicating that the population was harvested at an unsustainable level. The low SPR values (< 30%) can reduce the ability of spawning stock biomass to produce adult stock in the structure of the population (Ault et al., 2008). This low SPR reflects a reduction in the number of young fish, thereby triggering a decrease in spawning stock and limiting the number of eggs produced. The SPR, as the biological reference point, is used to define safe levels of fishery harvesting and as benchmarks against which the actual status of a fish stock can be measured (Collie & Gislason, 2001). Management actions to rebuild the biomass of the species are needed to increase SPR above the threshold (> 30%), which can be achieved by reducing fishing intensity, temporary fishing closure, and regulating the harvest size limit. Further management actions are needed to rebuild the stock of the species in the area to ensure a sustainable fishery.

Competing interests

No potential conflict of interest relevant to this article was reported.

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Availability of data and materials

Upon reasonable request, the datasets of this study can be available from the corresponding author.

Ethics approval and consent to participate

This article does not require IRB/IACUC approval because there are no human and animal participants.

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Length-based stock assessment of the pacific yellowtail emperor in the Southern Sulawesi, Indonesia

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Abstract
Pacific yellowtail emperor, *Lethrinus atkinsoni* Seale, 1910, is one of the most targeted reef fish species in Southern Sulawesi, Indonesia. Therefore, assessing its stock is important to understand the condition of the population, providing valuable inputs for sustainable fisheries management in the area. Here we assess the stock condition of *L. atkinsoni* in Southern Sulawesi, Indonesia, using the length-based spawning potential ratio model. A total of 4,887 individuals were collected from commercially small-scale fishers from January to October 2022. The total length, sex, and gonad maturity of the individuals were examined. We observed that the fish length ranged from 10.5 to 39.5 cm, with an average length of 23.3 cm. The sex ratio was equal (1:1.2) between male and female individuals. Length at first maturity and length at first capture were 23.4 and 19.6 cm, respectively. In addition, we observed a growth coefficient of 0.45/year, with an asymptotic length of 41.14 cm and natural mortality of 0.6/year. Based on these life history parameters, we observed the spawning potential ratio (SPR) value of 12%, indicating an unsustainable fishery level (SPR of < 30%). Further concerns related to the sustainability of the species and strategy to rebuild stock of the *L. atkinsoni* in Southern Sulawesi are of utmost importance.

Keywords: *Lethrinus atkinsoni*, Fisheries management, Length-based spawning potential ratio, Southern Sulawesi

Introduction

Indonesia is the second world's largest fisheries producer (FAO, 2020), with coral reef fisheries contributing to Indonesian fisheries productivity, estimated to reach a total of 800 thousand tons annually (MMAF, 2022). As a result, coral reef fishes are economically important commodities in Indonesia, demanded by domestic and international markets, such as Singapore and

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Hong Kong (Rizal et al., 2018). However, due to its high demand, populations of some reef fish species are threatened across the country (Campbell et al., 2013).

Reef fish of the family Lethrinidae (emperors) are abundant in tropical and subtropical regions where coral reefs, seagrass beds, and mangrove forest areas are their habitats (Young & Martin, 1982). Fishes within the family are one of the significant food resources in the Western Pacific and Indian Oceans due to their high catch amount (Carpenter & Allen, 1989). Among the lethrinids, the *Lethrinus atkinsoni,* known as pacific yellowtail emperors, is a highly targeted fish by local fishers in Indonesia (Mayunar, 1996), including in the Southern Sulawesi region (Agustina et al., 2021). There are numerous studies concerning the growth and biological parameters of the *L atkinsoni* (Currey et al., 2013; Ebisawa, 1999; Prihatiningsih et al., 2021; Rumania et al., 2020), while no studies yet about the status of its stock in Indonesia, particularly in the Southern Sulawesi region.

About 90%–95% of fishers in Indonesia are small-scale yet generating significant contributions for coastal communities (Sari et al., 2021). Small-scale fisheries often referred to as artisanal fisheries, is a traditional fishery that involves fishing households and uses relatively small fishing vessels and short fishing trips. The catch is mainly for local consumption. Most fishers in Southern Sulawesi are small-scale, contributing significantly to social and economic conditions in the area as the primary source of livelihood, providing food for the community. The fishers and the local community are dependent on fish resources. Accordingly, they are vulnerable to any change that disrupts their harvest (Wiyono, 2011). Therefore, effective management of small-scale fisheries in the area is crucial for the community.

Southern Sulawesi is one of Indonesia's crucial regions for coral reef fisheries, where the world's 3rd most extensive coral reef atoll is found (Malik et al., 2018). The coral reefs are home to more than 500 reef fish species, including the highly demanded reef fish emperors of the family Lethrinidae (Muhidin et al., 2019). However, the coral reefs there are being threatened due to destructive fishing activities by explosives and cyanide (Panuluh et al., 2020). Despite being one of the most important fishery commodities in Indonesia, the potential of lethrinid fish and its utilization status are still poorly understood (Restiangsih & Muchlis, 2019). In addition, the impact of fishing activities in Southern Sulawesi is not yet fully known due to limited data (Agustina et al., 2021). This limited status and trend certainly affect fishery management, hampering its resources to be sustainably managed (Rizal et al., 2018). In this context, identifying biological characteristics and assessing the stock condition of lethrinid fish is necessary to improve fisheries management in the area. This study aims to assess the stock status of *L. atkinsoni* in Southern Sulawesi, Indonesia. The species' biological characteristics and stock conditions were investigated using the length-based stock assessment approach.

Materials and Methods

Study site and sample collection

This study was conducted in Southern Sulawesi, Indonesia (Fig. 1), from January to October 2022. A total of 4,887 individuals of *L. atkinsoni* (Fig. 2) were collected from three landing sites; the Tarupa Besar, Rajuni Kecil, and Latondu Besar. The samples were commercially caught by small-scale handline and speargun fishers. The samples were measured to the nearest millimeter in total length.

From those total samples, in April and May 2022, 152 individuals of *L. atkinsoni* were examined for their sex and gonad maturity following West (1990). The sex of each sample was determined through macroscopic examination after dissection, whereby the shape and color of the testis and ovaries were used to assign the gonadal maturity of the fish.

Data analysis

The sex ratio of *L. atkinsoni* was estimated and tested for the significant differences in the proportion of males and females for a theoretical 1:1 relation using a Chi-square (χ^2) equation (Kenney & Keeping, 1951) following the formula:

$$X^2 = \sum \frac{(O-E)^2}{E}$$

Where O is the observed number of males and females; E is the expected number of males and females.

We assessed the fish stock using the length-based spawning potential ratio (LBSPR) model (Hordyk et al., 2015). The life-history parameters and length frequency distribution data were examined as its input. The life-history parameters consist of growth coefficient (k), asymptotic length ($L\infty$), natural mortality (M), length at first capture (Lc) and length at first maturity (Lm). Growth parameters (i.e., k and $L\infty$) were estimated by the von Bertalanffy growth model (Sparre & Venema, 1998) using the "TropFishR" package in Rstudio (Mildenberger et al., 2017), following the formula:

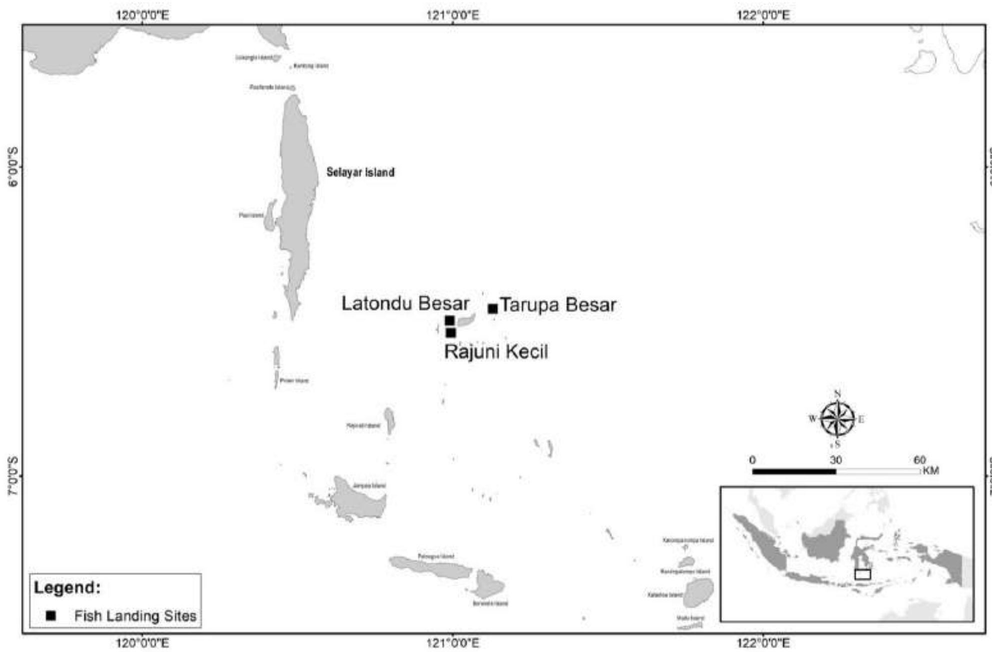

Fig. 1. Map of the study area where data of *Lethrinus atkinsoni* were collected from three landing sites in Southern Sulawesi, Indonesia.

Fig. 2. A sample of *Lethrinus atkinsoni* caught from small-scale fishers in Southern Sulawesi, Indonesia.

$$Lt = L\infty\,[1 - e^{-K(t-t0)}]$$

Where L∞ is the mean maximum length, k is a growth coefficient, and t_0 is the theoretical age at a size 0.

M was calculated following the Pauly empirical equation (Pauly, 1980):

$$Log(-t_0) = -0.3922 - 0.2752\log(L\infty) - 1.038\log(K)$$

Lm was analyzed following the formula of Spearman-Karber (Udupe, 1986):

$$m = \left[Xk + \frac{X}{2}\right] - \left(X\sum pi\right)$$

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With 95% confidence interval, it was calculated as:

$$Lm = anti\log\left(m \pm 1.96 \times \sqrt{X^2 \sum \frac{pi \times qi}{ni-1}}\right)$$

Where: m = log of fish length at first mature gonad; Xk = log of mean length value at first mature gonad; X = log of median of last length at first mature gonad; X = log of increased length of the fish at the median; Pi = the proportion of mature gonad at the interval of ith with the number of fish at the interval of ith; ni = number of mature gonad at the interval of ith; qi = 1 – pi; M = antilog m of the length of first matured gonad.

The Lc was analyzed based on the logistic curve from the selection ogive function (Sparre & Venema, 1998). The recruitment pattern was estimated by backward projection using length frequency distribution data based on the von Bertalanffy growth curve (Mildenberger et al., 2017; Pauly, 1984).

Results

Size frequency distribution

The length range of *L. atkinsoni* was from 10.5 to 39.5 cm, with most individuals observed within the 22–24 cm size class (Fig. 3) with an average length of 23.25 (± 3.93 cm).

Sex ratio

From 152 samples of *L. atkinsoni* that were collected for gonad investigation, we found 83 female and 69 male individuals. The sex ratio (male:female) was 1:1.2, with the observed proportion was statistically not significantly different ($p > 0.05$).

Life history parameters and spawning potential ratio

We observed that the L∞ of *L. atkinsoni* was 41.14 cm (Table 1). The k of the species was 0.45/year, indicating a high growth rate (k > 0.3; Froese, 2005). The M of the species was 0.6/year, with theoretical age at length 0 cm (t0) was –0.33 years (Table 1). The Lm of the species was 23.40 cm, with the Lc was 19.59 cm (Table 1 and Fig. 4). Based on the LBSPR model, we observed that the spawning potential ratio (SPR) of the *L. atkinsoni* in Southern Sulawesi was 12%, indicating an unsustainable level of the stock condition (SPR < 30%) (Ault et al., 2008).

Recruitment pattern

We observed that *L. atkinsoni* in Southern Sulawesi was a partial spawner, with a range of monthly recruitment of 2%–15 % (Fig.

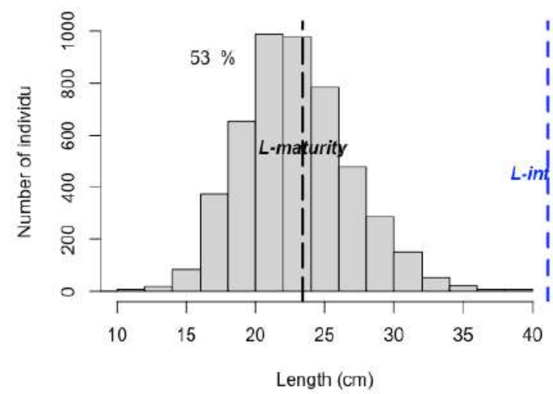

Fig. 3. Length frequency distribution of *Lethrinus atkinsoni* that were collected from three landing sites in Southern Sulawesi, Indonesia.

Table 1. Life history parameters and SPR of *Lethrinus atkinsoni* in Southern Sulawesi, Indonesia

Parameter	Unit	Value
Asymptotic length	cm	41.14
Growth coefficient	Per year	0.45
The theoretical age at a length 0 cm	year	–0.33
Natural mortality	Per year	0.60
Length at first maturity	cm	23.40
Length at first capture	cm	19.59
SPR	%	12

SPR, spawning potential ratio.

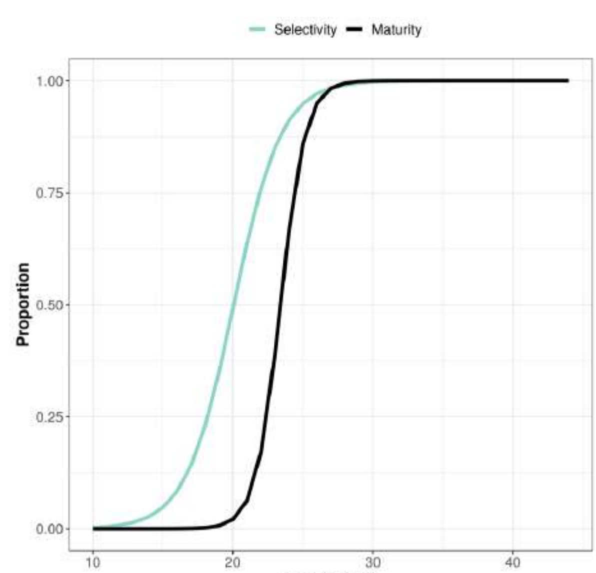

Fig. 4. Maturity and selectivity curve of *Lethrinus atkinsoni* in Southern Sulawesi, Indonesia.

5). The peaks of recruitment were observed in April (15%), July (15%) and November (12%). The recruitment patern occurring in these months is likely influenced by the annual upwelling event in the respective area (Utama et al., 2017). According to Klein et al. (2018), the recruitment pattern revealed a strong relationship with the upwelling.

Discussion

This study is the first finding of the length-based stock assessment of *L. atkinsoni,* the pacific yellowtail emperor, in Southern Sulawesi, Indonesia. We provide scientific information regarding the biological characteristics of the species, providing valuable input for fisheries management in the region. Based on the biological characteristics, we found that the population of this emperor was harvested at an unsustainable level.

The length range of the *L. atkinsoni* in Southern Sulawesi was from 10.5 to 39.5 cm. In other sites within Indonesia, the ranges of the conspecific were from 15.1 to 32.5 cm and from 12.0 to 37.7 cm in East Seram (Rumania et al., 2020) and Wakatobi (Prihatiningsih et al., 2021), respectively. In the Great Barrier Reef, Australia, the maximum length reported was 48 cm (Currey et al., 2013). While the range was similar among sites within Indonesia, the length of the fish was relatively smaller compared to the conspecific in Australia (Currey et al., 2013). This discrepancy might be due to ecological and environmental conditions between Indonesia and Australia, such as water quality, genetics, catch rate, and food abundance (Nikolskii, 1963), which can affect the biological condition of the fish.

In the present study, we found that the sex ratio of *L. atkinsoni* in Southern Sulawesi was equal between male and female individuals. Similarly, the sex ratio of the conspecific in the Wakatobi was equal (sex ratio male:female = 0.55:1.00; Prihatiningsih et al., 2021). Variations in the sex ratio can be affected by several factors, including behavior patterns, mortality, and growth rates between male and female individuals, spawning behavior, sexual maturity, length distribution due to its depth ranges, and length (or age) of the individuals (Effendie, 1997; Nikolskii, 1963). However, a note should be taken into consideration that *L. atkinsoni* is protogynous hermaphroditism species, with the length of sexual transition was reported between 23.0 and 23.9 cm fork length (FL) off Yaeyama and between 30.0 and 30.9 cm FL off Okinawa (Ebisawa, 1999). In protogynous species, the exact effect of fishing pressure on stock dynamics is complex (Alonzo & Mangel, 2004). In the case of the present study, no data on sexual transition length was reported on the species from the area. Accordingly, further measures of fishery management for the species might be challenging.

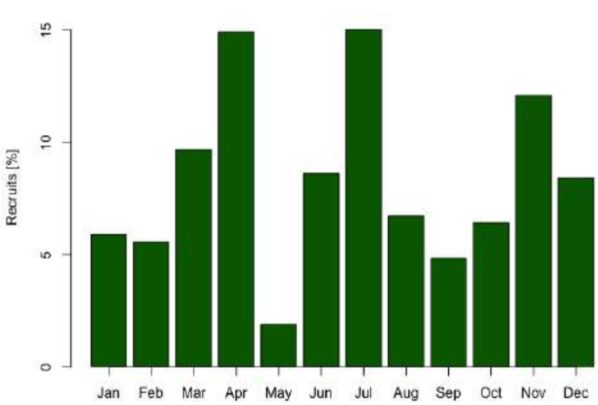

Fig. 5. Recruitment pattern of *Lethrinus atkinsoni* in Southern Sulawesi, Indonesia.

We observed that the k of *L. atkinsoni* was 0.46/year, with an $L\infty$ of 41.14 cm. Based on Froese (2005), the k value of a higher growth rate is above 0.3/year. In areas close to the equator (i.e., tropical region), *L. atkinsoni* tends to have higher k values than the conspecific in higher latitudes (Table 2). Higher annual seawater temperatures in the tropic might affect the higher growth rate of *L. atkinsoni* (Gislason et al., 2010).

The Lm of *L. atkinsoni* in Southern Sulawesi was 23.40 cm at the age of approximately 1.5 years. The Lm in the present study was relatively lower compared to the conspecific in the Wakatobi (Lm for male = 30.7 cm; Lm for female = 27.18 cm; Prihatiningsih et al., 2021) but relatively higher in Japan (Ebisawa, 1999) with the Lm of 19 cm FL off Yaeyama and 21 cm FL off Okinawa. The Lm discrepancy was presumably due to the influence of environmental factors, including nutrient conditions, seawater temperature, irradiation, as well as species feeding habits and physiological conditions of fish, and the location of the fishing ground (Lagler et al., 1963; Udupe, 1986; Wootton, 1985). Latitudinal difference of more than 5° was thought to cause differences in age and length at first gonad maturity (Effendie, 1997). Moreover, high fishing pressure could affect the Lm, where rapid maturation was found as a strategy for fish populations to cope with high fishing pressure (Restiangsih & Amri, 2019). The rate of fishing pressure in Southern Sulawesi is relatively higher than in Wakatobi (Fatma et al., 2021). To maintain its population, *L. atkinsoni* in Southern Sulawesi was likely to follow a similar strategy where they tend to have rapid

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Table 2. Growth parameters of *Lethrinus atkinsoni* in different locations

Location	Asymptotic length (cm)	Growth coefficient (/year)	References
Yaeyama, Japan	30.9 (FL)	0.186	Froese & Pauly (2022)
Great Barrier Reef and Eastern Torres Strait, Australia	32.5 (FL)	0.32	Froese & Pauly (2022)
Northern coast, Fiji	42.8 (SL)	0.29	Froese & Pauly (2022)
Okinawa, Japan	35.1 (SL)	0.26	Froese & Pauly (2022)
Great Barrier Reef, Australia	32.2 (FL)	0.32	Currey et al. (2013)
Wakatobi, Indonesia	38.2 (FL)	0.44	Prihatiningsih et al. (2021)
East Seram, Indonesia	34.2 (TL)	0.42	Rumania et al. (2020)
Southern Sulawesi, Indonesia	40.5 (TL)	0.40	This study

FL, fork length; SL, standard length; TL, total length.

maturation to cope with high fishing pressure.

We observed that the average size of the Lc of *L. atkinsoni* in Southern Sulawesi was 19.59 cm at the age of approximately 1.1 years. The Lc was lower than the Lm, indicating that local fishers in Southern Sulawesi also caught a proportion of immature individuals (Fig. 4). Based on the size frequency distribution (Fig. 3), about 53% of immature individuals were caught by the local fishers. In addition, we found that the peak of recruitment of *L. atkinsoni* occurred in April, July, and November. This information can predict the spawning period of *L. atkinsoni* in Southern Sulawesi (Agustina et al., 2019), which can provide input to fisheries managers to apply temporary fishing closure.

Based on the LBSPR model, the SPR of *L. atkinsoni* in Southern Sulawesi was 12%, indicating that the population was harvested at an unsustainable level. The low SPR values (< 30%) can reduce the ability of spawning stock biomass to produce adult stock in the structure of the population (Ault et al., 2008). This low SPR reflects a reduction in the number of young fish, thereby triggering a decrease in spawning stock and limiting the number of eggs produced. The SPR, as the biological reference point, is used to define safe levels of fishery harvesting and as benchmarks against which the actual status of a fish stock can be measured (Collie & Gislason, 2001). Management actions to rebuild the biomass of the species are needed to increase SPR above the threshold (> 30%), which can be achieved by reducing fishing intensity, temporary fishing closure, and regulating the harvest size limit. Further management actions are needed to rebuild the stock of the species in the area to ensure a sustainable fishery.

Competing interests

No potential conflict of interest relevant to this article was reported.

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Availability of data and materials

Upon reasonable request, the datasets of this study can be available from the corresponding author.

Ethics approval and consent to participate

This article does not require IRB/IACUC approval because there are no human and animal participants.

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