Bioecological parameters and exploitation of yellow boxfish *Ostracion cubicus* in Wallace Line, Makassar Strait, Indonesia

[1]Putri Y. Rahmani, [2]Andi I. Burhanuddin, [3,4]Joeharnani Tresnati, [2,4]Syafiuddin Syafiuddin, [2]Muhammad Hatta, [5]Tri H. Prihadi, [2,4]Ambo Tuwo

[1] Master Degree Program in Marine Science, Faculty of Marine Sciences and Fisheries, Hasanuddin University, Makassar, Indonesia; [2] Marine Science Department, Faculty of Marine Sciences and Fisheries, Hasanuddin University, Makassar 90245, Indonesia; [3] Fisheries Department, Faculty of Marine Sciences and Fisheries, Hasanuddin University, Makassar 90245, Indonesia; [4] Multitrophic Research Group, Faculty of Marine Sciences and Fisheries, Hasanuddin University, Makassar 90245, Indonesia; [5] National Research and Innovation Agency, Bogor, Indonesia. Corresponding author: A. Tuwo, ambotuwo62@gmail.com

Abstract. A thorough understanding of bioecological characteristics and levels of exploitation is necessary for both the conservation of marine biodiversity and sustainable fisheries management. The yellow boxfish, *Ostracion cubicus*, is the subject of this study because it is valuable economically and plays a crucial ecological role in coastal habitats. *O. cubicus* is a boxfish with a wide distribution in the world's coral reef ecosystems. This study aims to examine the bioecological parameters and exploitation of *O. cubicus*. *O. cubicus* samples were collected from fishermen's catches landed at the Paotere Fish Landing, Makassar city. Fishermen catch *O. cubicus* in the Liukang Kalmas waters, Makassar Strait. *O. cubicus* samples were taken every mid-month from August 2022 to October 2023. The parameters measured were morphometric-meristic parameters, and total weight. *O. cubicus* shows sexual dimorphism where female fish have larger eye width, mouth opening width, head length, tail stem length, feed weight, intestine weight, and fish weight to feed weight ratio than male fish. *O. cubicus* can reach a total length of 39.9 cm. *O. cubicus* has a relatively slow growth rate (0.180) with a smaller growth performance index (2.46) when compared to fish with flat bodies. The average length at first catch (Lc) was 24.0 cm. *O. cubicus* was completely subsumed to capture fisheries (L100) at a size of approximately 28.0 cm. The total, natural, and capture mortality rates were 3.30, 1.89, and 1.41, respectively. The exploitation rate and growth performance index were 0.43 and 2.46, respectively. O. *cubicus* became susceptible to fishing gear at a size of 26.5 cm. Although there is still potential to increase catches because there has been no apparent acceleration in fishing mortality, the exploitation rate is still below 0.5, and the catch per recruit is relatively low (0.02); increasing the exploitation rate must be done carefully because the growth rate is slow. The recommended catch size is above 24 cm.
Key Words: exploitation rate, growth, mortality, morphometrics-meristics, recruitment.

Introduction. Boxfish include 37 species categorized into two families: Aracanidae, which includes 13 species, and Ostracidae, which encompasses 24 species (Santini et al 2013). Morphologically, *Ostracion cubicus* lacks dorsal and anal spines. *O. cubicus* possesses eight to nine dorsal soft rays, nine anal soft rays, and ten caudal fin rays. Juveniles exhibit a vibrant yellow hue adorned with black spots; as they mature, the spots diminish in number, and the yellow transitions to a muted mustard shade; huge adults develop a bluish coloration with yellowish seams interspersed throughout the plates.

O. cubicus exhibits a broad distribution, inhabiting coral reef habitats in the Pacific Ocean, Indian Ocean, Southeast Atlantic Ocean, and Mediterranean Sea (Bariche 2011). Smith (1986) indicates that *O. cubicus* inhabits Indo-Pacific waters, specifically in the Persian Gulf, Red Sea, and East Africa, extending to the Hawaiian Islands and Tuamoto, from the Ryukyu Islands in the north to Lord Howe Island in the south.

The fishing sector of the Republic of Indonesia 713 plays a crucial economic and ecological function. The Fishing Area of the Republic of Indonesia 713 is a vibrant fishing zone, serving as a crucial center for economic development, especially for fishermen's families. The Fishing Area of the Republic of Indonesia 713 is situated on the Wallace Line, a prominent hotspot of global megadiversity. Fishing must not jeopardize the world's center of megadiversity, nor should its designation as such compel local fishermen to abandon their operations in order to preserve the sustainability of this megadiversity center. Consequently, it is imperative to uphold the equilibrium of economic, social, and ecological functions in the Fishing Area of the Republic of Indonesia 713 through sustainable management.

Economically, Ostracidea has a high value for consumption and ornamental fish (Sinansari & Priono 2019). Several species of Ostracidea serve as food fish in seafood restaurants, and they are known for their savory taste. In Makassar, seafood restaurants charge approximately US$10 per serving for *O. cubicus* large-sized. *O. cubicus*, one of the Ostracidae families, trades as an ornamental fish, fetching a price of approximately US$100. *O. meleagris*, another species of the Ostracidae family, trades as an ornamental fish in the United States (Walsh et al 2004).

Ecologically, *O. cubicus* lives in lagoons and semi-protected coral reefs. Acropora corals often harbor young fish (Lieske & Myers 1993). Young fish, still small, hide in narrow gaps in the coral (Kuiter & Tonozuka 2001). *O. cubicus* is a benthopelagic fish (Mundy 2005) whose primary food is algae, with supplementary foods from microorganisms, invertebrates, mollusks, sponges (Cornic 1987), sand-dwelling polychaetes, crustaceans, foraminifera, and fish (Myers 1999; Lougher 2006). *O. cubicus* is a solitary animal (Cornic 1987). Reproduction occurs in small groups of one male and two to four females (Moyer 1979). Being a reef fish, this fish plays a crucial ecological role, so it needs to be managed sustainably (Hu et al 2025).

A bibliometric analysis utilizing the "Scopus" database with the search term "*Ostracion cubicus*" produced 25 documents. The keyword mapping indicates that prior research on yellow boxfish has predominantly focused on taxonomy, diet, hydrodynamics, and related topics (Figure 1a). The mapping results reveal insufficient studies on bioecology and exploitation thus far. A separate bibliometric analysis utilizing the "Scopus" database and the search terms "boxfish or Aracanidae or Ostracidae" produced 111 documents. The findings indicate that prior research on boxfish has predominantly focused on hydrodynamics, morphology, biometry, physiology, and parasites (Figure 1b).

The findings of these two mapping studies reveal an absence of extensive research on bioecological and exploitation characteristics. This study seeks to examine the bioecological and exploitation aspects of *O. cubicus* in the Fishing Area Block 713 of the Republic of Indonesia. The Wallace Line, a focal point of global mega-diversity, traverses Block 713, rendering it both commercially and environmentally.

This study is relevant to the progression of marine research and the Indonesian marine industry as it investigates the bioecological and exploitation factors of *O. cubicus*, which are essential for efficient fisheries management (Hilborn & Walters 1992). This study improves the understanding of fish bioecology and exploitation in the Wallacea area, a hub of marine biodiversity (Roberts et al 2002). An examination of *O. cubicus* utilization will provide an overview of consumption rates and their impact on the population. The data can be employed to develop sustainable fisheries management strategies and prevent overfishing (Pauly et al 2002). The preservation of *O. cubicus* is crucial for Indonesia's marine biodiversity. This research supports appropriate conservation measures to protect this species and its habitat. The sustainable management of *O. cubicus* fisheries will ensure the long-term availability of this fish resource, strengthening the fisheries industry and the economics of coastal communities in the Wallacea region. The marine habitats in the Wallacea region represent a crucial element of Indonesia's biodiversity. This research improves the conservation of marine ecosystems and the sustainability of their functions.

This study aims to assess the bioecological parameters and exploitation levels of *O. cubicus* to support sustainable fisheries management in the Wallace Line, Makassar Strait, Indonesia. The objectives of this study are to analyze key biological parameters of *O. cubicus*, such as morphometric-meristic parameters, growth, mortality, exploitation, virtual population, recruitment, and yield per recruitment.

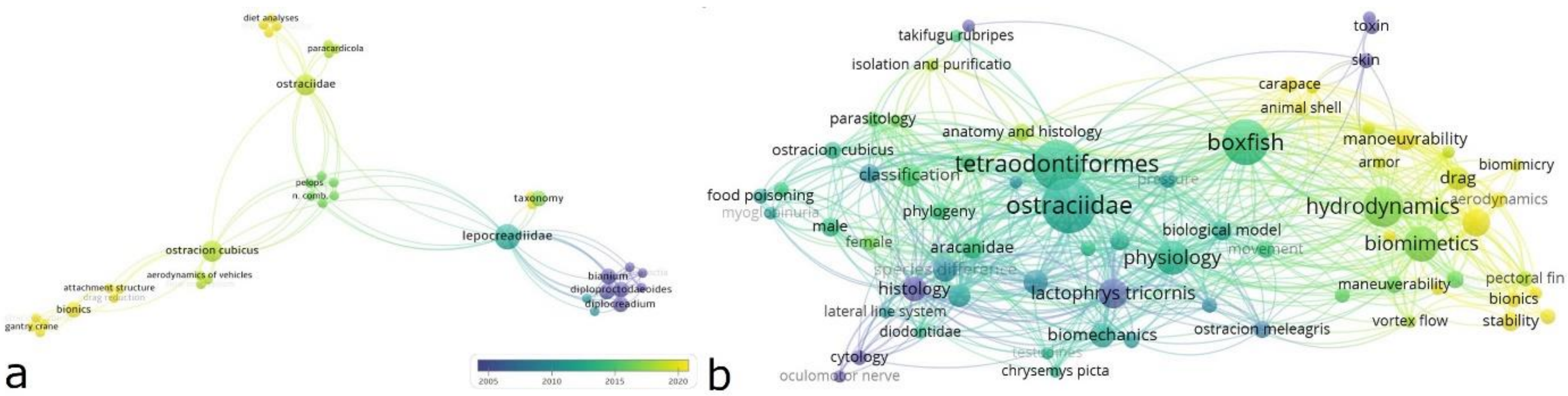

Figure 1. The mapping results for the keyword "*Ostracion cubicus*" (a), and the keyword "boxfish or Aracanidae or Ostracidae" (b).

Material and Method. *O. cubicus* specimens were obtained from fishermen's catches at the Paotere Fish Landing in Makassar City. Fishermen captured *O. cubicus* in the Liukang Kalmas Waters of the Makassar Strait, located inside Block 713 (Kantun et al 2012) (Figure 2). This study was conducted for one year, from August 2022 to October 2023.

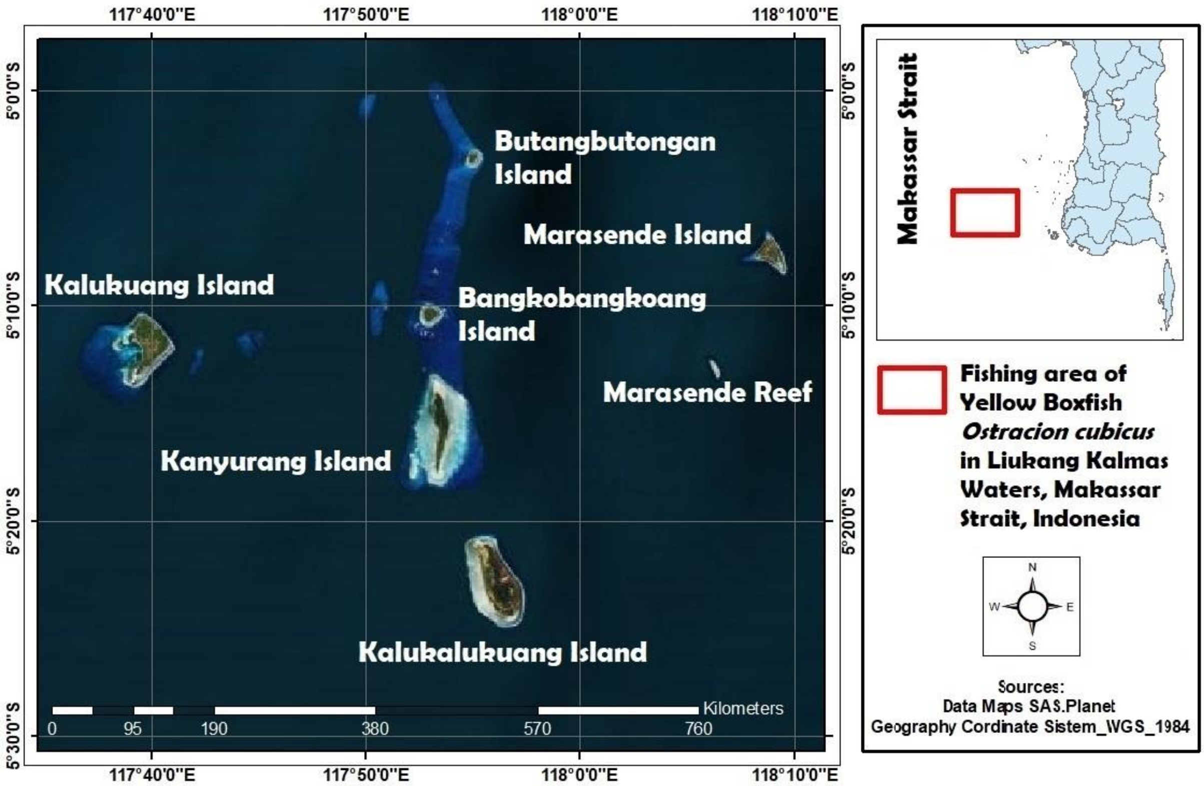

Figure 2. Fishing zones of yellow boxfish *Ostracion cubicus* collected in the Liukang Kalmas waters, Makassar Strait.

The overall total length of *O. cubicus* was assessed with a ruler calibrated to an accuracy of 1.0 mm. Samples of *O. cubicus* were collected bi-monthly. The population parameters of *O. cubicus* were examined by categorizing the total length into 24 classes, each with a 1 cm interval.

Data analysis. The bioecological parameters examined included morphometric characteristics, meristic traits, and dietary preferences. Morphometric parameters were assessed with digital calipers with a precision of 0.1 mm using 40 females and 40 males. The measured parameters comprise: (1) total length (TL), (2) standard length (ST), (3) length of the segment anterior to the dorsal fin (LFDF), (4) eye width (EW), (5) length of the dorsal fin base (LBDF), (6) length of the pectoral fin base (LBPF), (7) length of the anal fin base (LBAF), (8) length of the caudal fin base (LBCF), (9) body height (BH), (10) mouth opening width (WMO), (11) distance between the mouth and the eyes (LBME), (12) gill slit length (LGS), (13) head length (LH), and (14) caudal peduncle length (LCP).

Meristic characteristics were determined with a stereo microscope. The computed parameters comprised (1) pectoral fins (PF), (2) dorsal fin (DF), (3) anal fin (AF), and (4) caudal fin (CF) (Randall et al 1998). The examined dietary habit factors included meal type, feed weight, and intestinal weight. The t-test was employed to compare morphometric, meristic, and dietary factors between male and female populations. Principal component analysis (PCA) was employed to examine morphometric features and dietary habits between male and female fish populations. PCA offers a more thorough insight into morphometric variances and dietary preferences across male and female fish populations (Brosse et al 2001; Mojekwu & Anumudu 2015).

Exploitation data analysis. The projected exploitation parameters include age group, asymptotic length ($L\infty$), growth rate coefficient (K), theoretical age at which length equals zero (t_0), growth performance index (Ø'), total mortality (Z), natural mortality (M), catch mortality rates (F), exploitation rate (E), catch selectivity curve (CS), catch length (CL), and relative yield per recruitment (Y'/R). The age categories of *O. cubicus* fsh were delineated with the Bhattacharya approach. Response Surface Analysis was employed in ELEFAN I within the FISAT II software to derive the estimated values of the asymptotic length ($L\infty$) and growth rate coefficient (K) for *O. cubicus*. The theoretical age (t_0) at which the length of *O. cubicus* fish is zero was calculated using the empirical formula of Pauly (1983): $\log(-to) = -0.3922 - 0.2752 (\log L\infty) - 1.038 (\log K)$, where t_0 represents the theoretical age of *O. cubicus* in years when length is zero. The growth performance index (GPI) or phi-prime (Ø') was determined by the equation: $Ø' = \text{Log}(K) + 2\,\text{Log}(L\infty)$ (Pauly & Munro 1984).

The total mortality rate of *O. cubicus* was calculated using the Beverton and Holt formula (Sparre & Venema 1998):

$$Z = K[(L\infty-L)/(L-L')]$$

where: Z is the total mortality rate of *O. cubicus* (year), L is the average length of *O. cubicus* captured (cm), and L' is the smallest length of *O. cubicus* captured (cm).

The natural mortality rate of *O. cubicus* was estimated by Pauly (1983):

$$\log(M) = -0.0066 - 0.279 \log L\infty + 0.6543 \log K + 0.4634 \log T$$

where: M is the natural mortality rate of *O. cubicus* ($year^{-1}$), T is the average surface water temperature of the Southern Makassar Strait (27.89°C) (Susilo & Siwi 2021).

The capture mortality rate of *O. cubicus* was estimated using the equation (Sparre & Venema 1998):

$$Z = F + M \text{ or } F = Z - M$$

where: F is the capture mortality rate of (year-1).

The exploitation rate (E) of *O. cubicus* was estimated using the Beverton and Holt equation (Sparre & Venema 1998):

$$E = F/Z$$

The selectivity curve of *O. cubicus* was estimated using linear regression to obtain the first capture length (L_{50} or L_c) and capture length values at probabilities of 0.25 (L_{25}), 0.75 (L_{75}), and 1.00 (L_{100}). The selectivity curve of *O. cubicus* was obtained using FISAT II (Pauly 1983; Gayanilo et al 2005). FISAT II software was also used to estimate the recruitment pattern and relative yield per recruitment (Y'/R) of *O. cubicus* (Gayanilo et al 2005).

Results. A total of 368 *O. cubicus* specimens were collected during the investigation, with an average total length of 27.4±3.7 cm (ranging from 16.3 to 39.7 cm). *O. cubicus* is generally struck by a spear on the dorsal side of the head (Figure 3a). Female fish exhibit greater morphometric parameters, including eye width (EW), mouth opening width (WMO), head length (HL), and tail stem length (LTS), compared to male fish. *O. cubicus* lacks stiff fin rays Figure 3b). The meristic formula of fins for male *O. cubicus* is D.9-10; A.7-9; P.9-10; C.7-9, while for females it is D.8-9; A.8-9; P.9-10; C.7-9.

The PCA analysis results indicated that females are characterized by larger head length, caudal peduncle length, and mouth opening width (Figure 3c).

The asymptotic length ($L\infty$) was 39.9, while the growth coefficient (K) was 0.18. The mean length of the initial catch (Lc or L50) was 24.0 cm, whereas the length with a probability of 0.25 (L25) was 22.5 cm, and at a probability of 0.75 (L75) it was 25.5 cm. Fish were completely recruited to the catch fishery (L100) at an approximate size of 28.0

cm. The overall mortality rate was 3.30, with natural mortality at 1.89, capture mortality at 1.41, and an exploitation rate of 0.43. The GPI was 2.46.

The virtual population study indicated that natural mortality was the predominant factor contributing to stock depletion up to a size of 26.5 cm. Recruitment transpired biannually. The present exploitation shows a relative yield per recruitment (Y'/R) of 0.02, accompanied with an Ecurrent of 0.43.

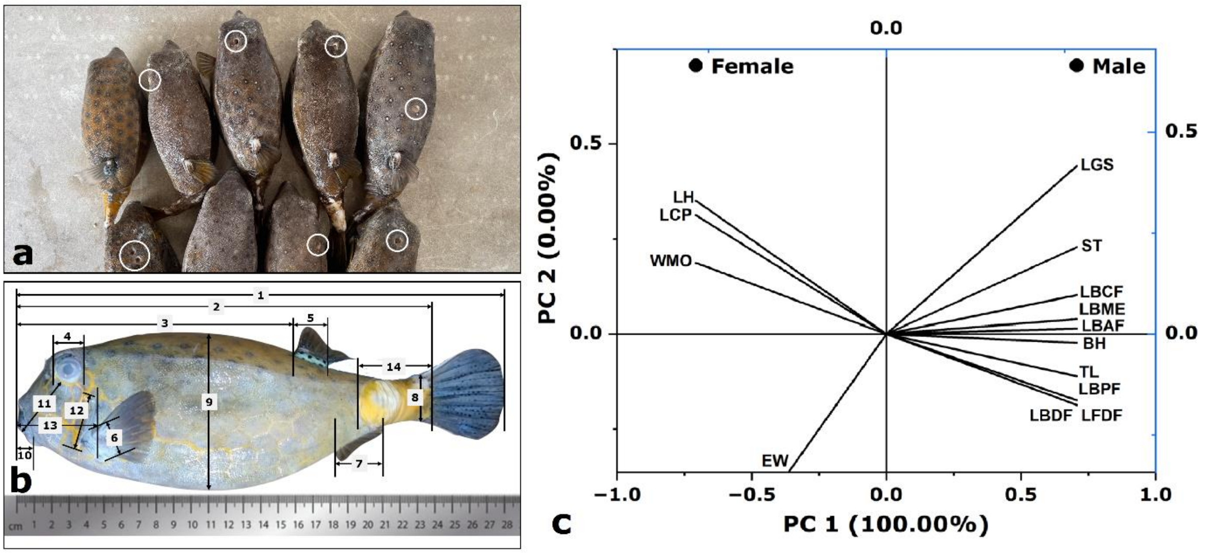

Figure 3. Yellow boxfish *Ostracion cubicus* specimens captured in Liukang Kalmas waters, Makassar Strait, and the location of the measured morphometric parameters (a), and the results of Principal Component Analysis (PCA) analysis using 14 morphometric parameters (b) 1: Total Length (TL), 2: Standard Length (SL), 3: Front Dorsal Fin Length (LFDF), 4: Eye Width (EW), 5: Dorsal Fin Base Length (LBDF), 6: Pectoral Fin Base Length (LBPF), 7: Anal Fin Base Length (LBAF), 8: Caudal Fin Base Length (LBCF), 9: Body Height (BH), 10: Mouth Opening Width (WMO), 11: Distance Between the Mouth and The Eyes (LBME), 12: Gill Slit Length (LGS), 13: Head Length (LH), and (14) Caudal Peduncle Length (LCP).

Discussion. PCA results showed sexual dimorphism in *O. cubicus*, where female fish have larger eye width, mouth opening width, head length, and tail peduncle length than males. Females' larger head and mouth sizes might be associated with their reproductive strategies. Females may need larger mouths to swallow more food to support gonad development and egg production (Wootton 1990; Wainwright & Richard 1995). Larger eyes in females may improve visual ability in finding mates, choosing suitable egg-laying sites, or detecting predators, especially when guarding eggs or larvae (Guthrie 1986; Jobling 2002). Different body sizes or body parts between males and females may be the result of sexual selection. In some fish species, males have striking morphological characteristics to attract females or compete with other males (Zahavi 1975; Andersson 1994). Morphological differences between male and female *O. cubicus* may reflect differences in resource utilization or ecological niche. For example, females with larger body sizes may utilize different prey or occupy different habitats than males (Schoener 1974; Pianka 1978).

Fish stock analysis and species identification frequently use meristic characters due to their relative stability. Until now, there has been no study of meristic characters in *O. cubicus*. The meristic characters currently available are in Triodontidae only, namely 8-9 dorsal fin soft rays, nine anal fin soft rays, and 10 caudal fin soft rays (Matsuura 2015). The meristic characteristics of *O. cubicus* fall within this range. Although relatively stable, meristic parameters can show variation between individuals in a population. Genetic differences, environmental factors, and sex can influence this variation, as some fish species exhibit meristic differences between males and females. In population studies, meristic parameter analysis can offer crucial insights into meristic variation, meristic changes, and the impact of overfishing, which can alter the meristic composition of the population by, for instance, decreasing the proportion of large individuals that typically possess more fin rays (Mayr 1944; Randall et al 1998).

PCA results demonstrated sexual dimorphism in *O. cubicus*, highlighting unique characteristics between males and females. Male fish demonstrated a higher overall weight. The increased overall weight of males indicates a higher investment in somatic growth and potential participation in intraspecific competition for mates or territory defense (Clutton-Brock 1988; Andersson 1994).

Asymptotic length (L∞) is the theoretical maximum length that an individual fish can reach if it lives indefinitely. L∞ is one of the important parameters in the von Bertalanffy growth model, which is commonly used to describe fish growth. *O. cubicus*, with its maximum length of 39.9 cm, qualifies as a large boxfish. This large size makes *O. cubicus* the most sought-after boxfish by seafood restaurants.

A K value of 0.18 indicates that *O. cubicus* has a relatively slow growth rate. This means that this fish takes a relatively long time to reach its asymptotic length (Von Bertalanffy 1938; Sparre & Venema 1998; King 2008). Slow-growing *O. cubicus* need to be managed carefully because they are more susceptible to overfishing (Hilborn & Walters 1992; Quinn & Deriso 1999).

The GPI is a metric that consolidates various critical growth characteristics to offer a holistic assessment of fish growth performance. Fish with a high GPI value have superior growth performance. GPI is necessary in understanding reproductive strategies, resilience of fish to environmental stressors and fishing, and sustainable resource management and ecosystem conservation. Multiple factors affect GPI, including genetic influences, water quality indicators such as temperature and food availability, population density, the quality and quantity of food resources, and fish health (Pauly 1980). *O. cubicus* and other boxfish have not yet provided any GPI, L, or K values. In comparison to other reef species, the GPI of *O. cubicus* (2.46) is within the GPI range of red snapper *Lutjanus kasmira*, which is 2.25-2.86 (2.55±0.19) (Morales-Nin & Ralston 1990). Manooch (1987) deems the GPI range of 2.25-2.86 for *L. kasmira* to indicate rapid growth, notwithstanding the absence of a reference range for elevated or diminished GPI.

O. cubicus, characterized by its box-shaped body, exhibits a lower GPI in comparison to flat-bodied fish, such as *Psettodes erumei*, found in the Spermonde Islands (3.85) (Tresnati et al 2024), the Oman Sea, the Persian Gulf (3.10) (Gilanshahi et al 2012), and the coastal waters of Brunei Darussalam (2.99) (Silvestre & Garces 2004).

To date, the size of *O. cubicus* has not been documented; however, with a length range of 16.3-39.7 cm (average 27.4±3.7 cm), *O. cubicus* is categorized as a relatively larger boxfish species compared to others, such as the longhorn cowfish, *Lactoria cornuta*, which has a length range of 6.5-15.5 cm (average 10.3±2.1 cm in males) and 8.3-25.5 cm (average 12.1±2.7 cm) (Tresnati et al 2020).

Catch length measurements (Lc, L25, L75, L100) are critical factors in the analysis and management of fish populations (Gulland 1983; Hilborn & Walters 1992; Quinn & Deriso 1999; Sparre & Venema 1998). The values (Lc, L25, L75, L100) characterize the gear selectivity curve. The L25, L50, and L75 statistics are utilized to assess gear selectivity, determine fish sizes vulnerable to capture, and formulate sustainable fisheries management methods.

Mortality and exploitation rates in fish are crucial for comprehending fish population dynamics and executing sustainable fisheries management techniques. Sustainable management of fish resources for the benefit of current and future generations can be achieved by evaluating mortality rates in exploited fish populations. Natural factors, including predation by native predators, disease and parasites, competition, natural disasters, and senescence, contribute to the mortality of individuals in a fish population at a natural mortality rate (Beverton & Holt 1957; Jennings et al 2001). Pauly (1980) defines the mortality rate in a fish population as the death rate of individuals captured directly. Total mortality includes natural mortality and fishing mortality (Quinn & Deriso 1999). Mortality rates serve as indications of stock vitality. Elevated mortality rates, particularly due to fishing, may signify that a fish stock is experiencing undue stress and is at risk of overexploitation. The fishing mortality rate of

O. cubicus (1.41) is lower than the natural mortality rate (1.89), suggesting that fishing has a lesser impact on fish mortality compared to natural factors. The minimal impact of fishing on stock depletion is attributed to the selective nature of spear fishing equipment. Spears are solely effective for capturing huge *O. cubicus* specimens. Small *O. cubicus* are not only challenging to observe but also difficult to spear because of their diminutive size.

The exploitation rate serves as an indicator of the sustainability of fisheries resource consumption. An exploitation rate beyond 0.5 signifies that fish stocks are undergoing overexploitation, sometimes referred to as overfishing. This may result in population reduction and jeopardize the sustainability of fishery resources. The exploitation rate of *O. cubicus*, at 0.43, indicates that overfishing has not yet transpired, although it has beyond the sustainable threshold. The safe threshold for a typical population is roughly 0.40, representing 80% of the maximum exploitation rate. The safe threshold is 0.25 due to the slow development rate of *O. cubicus*. We advise limiting the catch to a maximum of 50% of the peak exploitation rate, or a maximum of 0.25, for populations characterized by moderate growth rates. In comparison to other reef fish inside the Wallace Line and Makassar Strait, the exploitation rate of *O. cubicus* is rather low. The dusky parrotfish, *Scarus niger*, in the Spermonde Islands in the Makassar Strait, exhibits an exploitation rate of 0.79 due to unregulated fishing practices (Fatihah et al 2021). The exploitation rate of parrotfish *Scarus ghobban* at the Wallace Line, Spermonde Islands, Makassar Strait is 6.84 (Mutiara et al 2021). The yellowfin parrotfish, *Scarus flavipectoralis*, in the Spermonde Islands of the Makassar Strait, exhibits an exploitation rate of 0.78 as a result of unregulated fishing activities (Ramla et al 2021). The exploitation rate of parrotfish *Chlorurus bleekeri* is 0.63 in the Wallace Line, Makassar Strait, attributed to heavy fishing (Mansyur et al 2021). Virtual population analysis, a crucial instrument in fisheries management, can quantify the fish population in a stock at a particular historical moment, evaluate fishing mortality, estimate the influx of new fish into the population, and determine the sustainability of fish stock exploitation (Sparre & Venema 1998). The measurement of 26.5 cm suggests that *O. cubicus* is increasingly susceptible to fishing gear; nonetheless, there has been no noticeable increase in fishing mortality. The exploitation rate, remaining under 0.5, corroborates this assertion.

Recruitment is the process through which new fish individuals integrate into an exploitable population. The biannual recruitment of *O. cubicus* suggests the species may experience two peak spawning episodes annually. Reef fish in the Spermonde Islands, Makassar Strait, including the rivulated parrotfish *Scarus rivulatus* (Tuwo et al 2021) and the blue-barred parrotfish *S. ghobban* (Tresnati et al 2021), have two distinct peak spawning phases. The availability of fish resources, including plentiful food during specific seasons, may affect peak recruitment. Seasonality can influence fish recruitment, for instance, by alterations in water temperature, precipitation, and current dynamics (Pauly 1980; Blaber 2000; Houde 2008).

Relative yield per recruitment (Y'/R) quantifies catch per recruit adjusted to the greatest yield achievable from a recruit. Y'/R values vary from 0 to 1, with 1 signifying that the catch per recruit has attained its maximum level. A Y'/R ratio of 0.02 at an exploitation rate of 0.43 for *O. cubicus* signifies a rather low catch per recruit. Although the exploitation rate (E) is moderate at 0.43, the low Y'/R value indicates that *O. cubicus* has not been optimally exploited. Yield potential can yet be improved for *O. cubicus* by judiciously augmenting the exploitation rate. From a biological standpoint, it is essential to evaluate biological aspects such as growth, reproduction, and recruitment of *O. cubicus* prior to augmenting the exploitation rate. From a sustainability perspective, the augmentation of the exploitation rate must be conducted sustainably to guarantee the health and productivity of *O. cubicus* stock (Beverton & Holt 1957; Gulland 1983).

Conclusions. Morphometric and meristic characteristics demonstrate sexual dimorphism. *O. cubicus* can attain a theoretical maximum length of 39.9 cm, categorizing it as a sizable boxfish. *Ostracion cubicus* exhibits a somewhat moderate development rate, necessitating an extended duration to attain its maximum length. *O. cubicus* possesses a lower GPI compared to fish exhibiting a flattened body morphology. At a length of 26.5

cm, *O. cubicus* exhibits increased susceptibility to fishing apparatus. The exploitation rate remains under 0.5. Recruitment transpires biannually. The Y'/R ratio of 0.02 at an exploitation rate of 0.43 signifies a comparatively low catch per recruit. Although the exploitation rate is mild, heightened exploitation necessitates prudence owing to the comparatively sluggish development rate of the *O. cubicus* population.

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Conflict of interest. The author declares that there is no conflict of interest.

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Authors:
Putri Yuni Rahmani, Master of Marine Science Study Program, Faculty of Marine Sciences and Fisheries, Hasanuddin University, Perintis Kemerdekaan Street, Km. 10, Makassar 90245, South Sulawesi, Indonesia, e-mail: putriyunirahmani06@gmail.com
Andi Iqbal Burhanuddin, Marine Science Department, Faculty of Marine Sciences and Fisheries, Hasanuddin University, Perintis Kemerdekaan Street, Km. 10, Makassar 90245, South Sulawesi, Indonesia, e-mail: iqbalburhanuddin@yahoo.com
Joeharnani Tresnati, Fisheries Department, Faculty of Marine Sciences and Fisheries, Hasanuddin University, Perintis Kemerdekaan Street, Km. 10 Makassar 90245, South Sulawesi, Indonesia, e-mail: jtresnati@yahoo.com
Syafiuddin Syafiuddin, Marine Science Department, Faculty of Marine Sciences and Fisheries, Hasanuddin University, Perintis Kemerdekaan Street, Km. 10 Makassar 90245, South Sulawesi, Indonesia, e-mail: afi_makassar@yahoo.com
Muhammad Hatta, Marine Science Department, Faculty of Marine Sciences and Fisheries, Hasanuddin University, Perintis Kemerdekaan Street, Km. 10, Makassar 90245, South Sulawesi, Indonesia, e-mail: KIMOSKU@yahoo.co.id
Tri Heru Prihadi, National Research and Innovation Agency, Raya Jakarta-Bogor Street, Km. 46, Bogor 16911, Wast Java, Indonesia, e-mail: trih016@brin.go.id
Ambo Tuwo, Marine Science Department, Faculty of Marine Sciences and Fisheries, Hasanuddin University, Perintis Kemerdekaan Street, Km. 10, Makassar 90245, South Sulawesi, Indonesia, e-mail: ambotuwo62@gmail.com

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