Estimating the catchable size of orange-spotted grouper (*Epinephelus coioides*) in Kwandang Bay, Gorontalo Utara District, Indonesia

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**Abstract.** The orange-spotted grouper (*Epinephelus coioides*) is a valuable food fish. To support the sustainable management of orange-spotted grouper fisheries, it is important to determine the optimum catchable size. The purpose of this study was to determine an optimal catchable size for the orange-spotted grouper stock in Kwandang Bay, North Gorontalo District, Indonesia. The catchable size was determined based on the size at first sexual maturity, fecundity, and reproductive potential. The study was conducted from December 2016 to November 2017. The size at first sexual maturity was estimated based on the examination of gonads from 141 specimens, while fecundity was estimated based on a sample of 40 female fish with ripe gonads. The mean total length (TL) at first maturity was 40 cm. Fecundity ranged from 30,526 to 1,395,846 eggs with a mean of 687,025 eggs. The reproductive potential was highest in the size range of 55-64 cm TL. The recommended size for orange-spotted grouper is above 64 cm, to enable females to attain their maximum level of egg production before capture and thus contribute to maintaining the stock.

1. Introduction

Groupers of the Family Serranidae, in particular the genera *Epinephelus* and *Plectropomus*, are high-value reef-associated food fishes [1–3], heavily exploited by small-scale fishermen in both the Atlantic and Indo-Pacific Oceans [4–6], including Indonesia [7–10]. Their fine flavour and delicate texture combined with excellent nutritional value, including high protein content [11], have made groupers a favourite food for many people in the Asia Pacific [12,13]. Kwandang Bay in North Gorontalo District, Gorontalo Province, is a prime grouper fishing area on the north coast of Sulawesi Island in Indonesia. The local name for groupers in this region is goropa [14].

Groupers are still mainly wild-caught, as aquaculture, developed for a small number of grouper species, cannot yet supply market demand [10,15,16]. There is a growing demand for groupers, and these fishes fetch a high price in the international marketplace [17], providing strong incentives for fishermen. This pressure has driven heavy and mostly uncontrolled exploitation [16,18], resulting in overfishing of many grouper stocks [10,12]. The impacts of overfishing can include a decline in local or regional grouper abundance and biodiversity, with extirpation of grouper stocks [14]. Several
grouper species are considered threatened with extinction, including *Mycteroperca marginata* [19], *Epinephelus striatus* [20], and *Epinephelus itajara* [21].

Kwandang Bay is one site where attempts are being made to implement responsible fisheries, under an Ecosystems Approach to Fisheries Management (EAFM) program at provincial and district level. The orange-spotted grouper (*Epinephelus coioides*) is one of the main grouper species targeted by fishermen in Kwandang Bay, and a focal species under the EAFM program. Knowledge regarding the reproductive patterns, in particular the mean size at first maturity, is vital for planning and implementing responsible fisheries management [22]. Fecundity is an important parameter in fisheries management [23], for assessing the reproductive potential of the population as well as for determining the optimal catchable size. Size at first maturity and fecundity should be determined by species and stock, to provide a sound scientific basis for management measures designed to maintain stocks at a productive level. The first aim of this research was to estimate the mean size at first maturity and fecundity of the orange-spotted grouper. The second aim was to use these data to formulate a recommendation on catchable size for this grouper species.

2. Methods

2.1. Sample collection and measurement

A total of 141 orange-spotted grouper (*Epinephelus coioides*) specimens were obtained mainly from fish landed at the Kwandang Fishing Port from December 2016 to November 2017, with some additional specimens collected from local grouper traders (middlemen) who had purchased fish from fishermen operating in Kwandang Bay. Of these, 40 specimens were used to study orange-spotted grouper fecundity. The total length (TL in cm) of each specimen was measured using a fish ruler (precision 1mm), and total body weight was measured using digital scales (precision 0.01 g).

2.2. Observation of samples in the laboratory

Each specimen was dissected and the gonads observed *in-situ*. The gonads were then carefully removed and weighed using high-precision analytical digital scales (precision 0.001 g). The gonad maturity stage of each specimen was determined based on the criteria and scale in [24].

In order to estimate the fecundity of mature female orange-spotted groupers, a gravimetric sampling method was used. Three sub-samples were taken from each gonad (ovary) and weighed using high-precision analytical digital scales (precision 0.001 g). Each of these sub-samples was soaked in Gilson solution for 24 hours to dissolve the connective tissues holding the eggs together so that the eggs could be separated and counted. The eggs in each subsample were counted using a magnifying glass.

2.3. Mean size at first maturity

The mean size at first maturity of the Kwandang Bay orange-spotted grouper (*Epinephelus coioides*) population M with 95% confidence level limits was calculated using the Sperman Karber method [25] based on the following equations:

\[
m = x_k + \frac{X}{2} - \left( X \sum \pi_i \right)
\]

\[
M = \text{antilog}(m), \text{ with a 95% confidence limit of:}
\]

\[
M = \text{antilog} \left( m \pm 1.96 \sqrt{\frac{\pi_i (1-\pi_i)}{n_i-1}} \right)
\]

where \(x_k\) = last log size at which all fish are fully mature, \(X = \log\) size increment, \(m = \logarithm\) of the mean value of \(M\), \(\pi_i = \text{number of fully mature fish in size-class } i\), \(n_i = \text{total number of fish in size class } i\), \(\pi_i = \pi_i/n_i\) and \(q_i = 1-\pi_i\).
2.4. Fecundity and reproductive potential

The fecundity of ripe female orange-spotted grouper (*Epinephelus coioides*) was estimated using the standard gravimetric equation:

\[
F = \frac{W_g}{W_s} \cdot F_s
\]

where: \(F\) = fecundity (number of eggs), \(F_s\) = sum of the eggs in the three sampled portion(s) of the gonad, \(W_g\) = total gonad weight (g), \(W_s\) = sum of the weight of the three sampled portion(s) of the gonad (g).

Reproductive potential was estimated using the equation in [26] as follows:

\[
RP = \sum \left[ \text{number of individuals per size class} \times \text{mean fecundity for size class} \right]
\]

The relation between total length (TL, in cm), body weight (W, in g) and fecundity \(F\) (number of eggs) was obtained through multiple regression using the equation in [27] as follows:

\[
F = b_0 + b_1 \cdot TL + b_2 \cdot W
\]

where \(F\) = total fecundity, \(TL\) = total length (cm), \(W\) = body weight (g).

3. Results

3.1. Size at first maturity

The estimated mean size at first maturity for the Kwandang Bay orange-spotted grouper (*Epinephelus coioides*) population based on the Spearman-Karber formula was 40 cm TL (Figure 1).

![Figure 1](image-url)
3.2. Fecundity
The fecundity of the 40 orange-spotted groupers (*Epinephelus coioides*) from Kwandang Bay ranged from around 30,000 to around 1.4 million eggs with a mean value of 713,186 ± 275,335 (Table 1). Fecundity was highest in individuals between 65 and 84 cm TL. However, the one female over 85 cm TL had a lower fecundity, similar to that of females from 45 to 64 cm TL. Over half (57.5%) of the sample was in size class 55-64 cm TL. Despite the relatively low individual fecundity, this size class made the largest contribution to reproductive potential.

Table 1. Mean fecundity and total reproductive potential by size class based on total length (TL) of 40 female orange-spotted grouper (*Epinephelus coioides*) from Kwandang Bay

| Size class (TL in cm) | n  | Mean Fecundity | Reproductive Potential |
|----------------------|----|----------------|------------------------|
| 45-54                | 6  | 183,069        | 1,098,414              |
| 55-64                | 23 | 174,553        | 4,014,719              |
| 65-74                | 6  | 567,616        | 3,405,696              |
| 75-84                | 4  | 450,880        | 1,803,520              |
| 85-94                | 1  | 192,662        | 192,662                |

The multiple regression of fecundity (F) against total length (TL) and body weight (W) indicated that body weight had a significant effect on fecundity (P<0.05). The regression equation obtained was:

\[ F=868755.26 - 25288.08*TL + 299.31*W \]

3.3. Determining catchable size
There are several alternative ways of selecting a minimum catchable size, taking into account the reproductive potential of different size classes based on fecundity and the size-frequency distribution within a wild population (stock). In this study, orange-spotted groupers around the mean size at first maturity (40 cm TL) could potentially contribute significantly to overall reproductive potential (based on the number of eggs produced); however, they only comprised a small proportion of the population. The size class making the highest contribution to total egg production, and thus potentially to recruitment, was the 55–64 cm TL class, due to the relatively high number of individuals in this class. Based on this finding, a catchable size above 64 cm is recommended.

4. Discussion

4.1. Size at first maturity
Information on the mean size at first maturity of grouper stocks is extremely important for detecting and preventing over exploitation [28]. The mean size at first maturity is often used as a guideline in setting minimum allowable size limits for capture fisheries [29]. By allowing fish to reach or exceed this size before capture, there is a good chance that at least half of the fish caught will have already spawned and thus contributed to regenerating the stock. For a given species, the mean size at first maturity can vary between stocks. Reported values for several orange-spotted grouper (*Epinephelus coioides*) populations around the world (Table 2) illustrate this variability.

The sizes at first maturity shown in Table 2 show that the Kwandang Bay stock has mean size at first maturity comparable to that reported from the Northern Arabian Gulf, which is both the most recent and the lowest reported value for any orange-spotted grouper wild population to date [30], although there are reports that cultured *E. coioides* can mature at smaller sizes [31]. There are several factors that can affect the size at maturation, including environmental conditions and fishing pressure [32–34]. In particular, heavy fishing pressure (overexploitation) can result in early maturing fish making an increasing contribution to successive generations [35-36], thus avoiding extinction when
most larger (more fecund) individuals have been captured [37]. The unusually early maturation for this species observed in this study could therefore be indicative of overfishing in Kwandang Bay.

| No | Region                          | Mean size at first maturity (TL in cm) | Source |
|----|---------------------------------|--------------------------------------|--------|
| 1  | Kwandang Bay, Indonesia         | 40                                   | This study |
| 2  | Southern Arabian Gulf           | 43.5                                 | [34]   |
| 3  | Arabian Gulf                    | 48                                   | [38]   |
| 4  | Northern Oman                   | 58                                   | [39]   |
| 5  | Northern Arabian Gulf           | 39                                   | [30]   |
| 6  | Eastern India                   | 53                                   | [28]   |

4.2. Fecundity

Many studies have found that, in general, the fecundity of female fish tends to increase with size, leading to the frequent stress placed on the importance of avoiding capture of these big old fat fecund female fish (BOFFFFs) [24,40]. This makes intuitive sense, as a larger body should enable larger gonads with more eggs. Although there was only one female in the largest size class, the relatively low fecundity of this female, and the slight decrease observed in fish of 75-84 cm TL compared to those in the 65-74 cm TL class indicate that in the orange-spotted grouper reproductive potential may peak around 65-74 cm TL and then decline. This may be related to the finding in a previous study that in the protogynous hermaphroditic orange-spotted grouper, individuals above 79 cm TL may undergo sex change, transitioning from functional females to functional males [9].

With respect to other studies on the orange-spotted grouper and some other grouper species in the genus Epinephelus (Table 3), the fecundity range found in this study is well within the overall range reported previously. The highest fecundity for a related grouper species was reported for E. marginatus from the western Mediterranean Sea [41], and the lowest was for E. areolatus from Kuala Dungun, Trengganu in Malaysia [32]. With respect to other populations of the same species, the observed fecundity of female Epinephelus coioides from Kwandang Bay was lower that that reported from the Arabian Gulf [38] but higher than that reported from India [28].

| No | Species                        | Location            | Fecundity                     | Source |
|----|---------------------------------|---------------------|--------------------------------|--------|
| 1  | *Epinephelus coioides*          | Kwandang Bay, Indonesia | 30,526 - 1,395,846            | This study |
| 2  | *Epinephelus coioides*          | Arabian Gulf        | 957,270 - 3,287,515           | [38]   |
| 3  | *Epinephelus coioides*          | India               | 43,618 - 463,940              | [28]   |
| 4  | *Epinephelus diacanthus*        | India               | 13,100 - 145,700              | [42]   |
| 5  | *Epinephelus marginatus*        | Mediterranean Sea    | 65,424 - 7,984,835            | [41]   |
| 6  | *Epinephelus guttatus*          | US Virgin Islands   | 240,000 - 2,400,000           | [43]   |
| 7  | *Epinephelus areolatus*         | Trengganu Malaysia  | 785 - 84,258                  | [32]   |

The data in Table 3 show that fecundity can vary both within and between species in the genus *Epinephelus*. Differences in fecundity between closely related species can reflect different reproductive strategies, but also different body sizes and adaptation to environmental conditions. Factors which can affect fecundity include nutritional status, fishing pressure, and fishing selectivity [37]. Other factors which can result in variations in fecundity include age, health (e.g. parasites),
population density, temperature, food availability, species specific traits and intra-species variability in genetic traits, and stress [41,42].

4.3. Determining catchable size
The FAO guidelines for responsible fisheries strongly advise the setting of a minimum catchable size above the mean size at first maturity, in order to maintain stock abundance by allowing a large enough proportion of the population to become reproductively active before capture. This is one reason why the selectivity of fishing gear is one important aspect of responsible fisheries management. Fishing gear should be designed and used in such a manner as to avoid the capture of individuals below this catchable size. In grouper hand line fisheries, hook size is one way of selecting for target fish size.

The recommended lower catchable size limit for orange-spotted grouper (Epinephelus coioides) in Kwandang Bay was 64 cm TL. Orange-spotted grouper fishing gear should therefore be selective for fish above this size. However, it might be difficult to avoid the accidental capture of smaller orange-spotted grouper with fishing gear targeting other carnivorous species, especially other groupers, if these can be caught at smaller sizes. Therefore, further research is needed to determine the reproductive characteristics and catchable size of other grouper species in Kwandang Bay.

5. Conclusion
The mean size (total length) at which orange-spotted grouper (Epinephelus coioides) reach first maturity was estimated as 40 cm TL. Observed fecundity ranged from around 30 thousand to 1.4 million eggs. Individual fecundity was highest in the 65-74 cm TL size class, but total reproductive potential was greatest in the 55-64 cm TL class, due to the size structure of the population. In order to increase the reproductive potential and maintain stock abundance, a minimum catchable size of 64 cm TL is recommended.

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