ORIGINAL ARTICLE

Assessing coral reef fish biomass at Ko Khai Nok, the Andaman Sea

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Abstract. Estimates of coral reef fish biomass are reliable indicators of coral reef fish and ecosystem health, which are essential for evaluating reef status and setting management targets. Fish biomass is a primary driver of coral reef ecosystem services and has a high sensitivity to anthropogenic disturbances. This study aimed to estimate reef fish biomass at Koh Khai Nok, Phang Nga Province, the Andaman Sea using the underwater visual census (UVC). The target fish groups, i.e., Mullidae, Carangidae, Siganidae, Kyphosidae, Lutjanidae, Nemipteridae, Scaridae, and Serranidae were selected as representatives for estimating the coral reef fish biomass. Fish size and abundance were estimated. Length estimates from each species were converted to weights using species-specific length-weight relationships from FishBase (Froese and Pauly 2022). The density of coral reef fish between the study sites was significantly different ($p<0.01$). The estimated biomass of target fish ranged from ~893.64 - ~9508.06 kg/ha. The Lutjanidae exhibited the highest fish biomass. The fish length of most target families was approximately 20 cm. This study provides the baseline data of coral reef fish biomass at Ko Khai Nok and highlights the importance of assessing coral reef fish biomass in Thailand's coral reef monitoring program.

Keywords: Andaman Sea, Coral reef, Fish biomass, Management, Monitoring

1. Introduction

Fish represent the largest group of vertebrates. Almost half of them are marine fish, especially in tropical coral reefs, with an abundance of over 6,000 species. Based on data gathered over decades of studies, the total number of coral reef fish is believed to range between 2,400 to 8,000 species from 100 families (Pyle 2000; Ravi and Venkatesh 2008; Eschmeyer et al. 2010; Duffy et al. 2016; Brandl et al. 2018; Mathon et al. 2021). The environmental traits and the feeding requirements of each fish species are linked to their abundance and distribution (Glyn 1976). Fish and fisheries play a major role in most societies, contributing significantly to economic, social health, and well-being in many countries. It has been estimated that approximately 58.5 million people are engaged in fishery-related activities (FAO 2022). Despite the importance and value of the world's fish resources, severe overfishing and environmental deterioration are having a cumulatively negative impact on population losses and species extinctions, as well as the stability of ecosystem structure and function (Vitousek et al. 1997; FAO 2002; McCann 2000). Understanding the controls on marine fish biomass production is essential for both ecosystem sustainability and a component of fishery management (Cochrane 2002; Duffy et al. 2016).

Currently, studies on fish biomass in Thailand are limited. Many previous studies have focused on the diversity and abundance of coral reef fish communities in the Gulf of Thailand (Satapoomin 2000), including Chonburi Province (Manthachitra 2001; Songploy et al. 2006; Manthachitra and Munkongsomboon 2014; Phuengsomboon 2015; Meenapha 2017), Rayong Province (Manthachitra and Cheevaporn 2007), Chanthaburi Province (Songploy et al. 2013), Nakhon Si Thammarat, Songkhla, and Pattani Province (Chantrapornsyl 2013), as well as the Andaman sea (Satapoomin 2011, 2013), including Ranong Province (Vilasri et al. 2015), Phang Nga Province (Keawsang 2016), Phuket Province (Satapoomin 2002; Noonsang et al. 2016), and Krabi Province (Pengchumrus et al. 2016). However, the studies of coral reef fish biomass have not been clearly reported.

Ko Khai Nok is located in Phang Nga Province, approximately 14 kilometers from Cape Panwa in Phuket Province. Ko Khai Nok is a small island that once had beautiful coral reefs in the past. In 1999, Ko Khai Nok was surrounded by a wide area of shallow reefs in good condition, with 30%-60% cover of live corals. However, the continued expansion of tourism around Koh Khai Nok has resulted in ongoing damage to coral reefs caused by anchoring, stepping on coral, fish feeding, littering, wastewater pollution, and other tourism activities. The damage to coral reefs that was caused by weather-related events also occurred, including coral bleaching in 2010 and extreme weather in 2011(Department of Marine and Coastal Resource 2018, 2020). Therefore, the coral reefs at Ko Khai Nok are currently in moderate condition (DMCR 2021). This study aimed to estimate coral reef fish biomass at Koh Khai Nok, Phang Nga Province, the Andaman Sea.

2. Materials and Methods

2.1. Study sites

This study was carried out at two study sites of Ko Khai Nok, located in Phang Nga Province, The field works were took place in July 2022. Two study sites at Ko Khai Nok were selected, i.e., Site 1 (west) and Site 2 (east). The average depth of the study sites was about 6 meters.

2.2 Coral reef fish surveys

The coral reef fish communities were assessed using the modified underwater visual census technique (English et al. 1997) along 3 replicas of 2 x 30 m belt transect, giving a total area of 60 m^2 per transect. The coral reef fish were in situ identified to species level, and dubious species were later rechecked with identification books (Allen et al. 2015; Lieske and Myers 2001). The abundance of coral reef fish was also estimated as individuals per 100 m^2.

2.2 Coral reef fish biomass estimates

Coral reef fish were instantaneously visually identified, counted, and estimated total lengths (TL), which were later converted into weights using species-specific length-weight relationships from Froese and Pauly (2022) to determine the biomass (McClanahan and Kaunda-Arara 1996, Kulbicki et al. 2005; McClanahan et al. 2019).

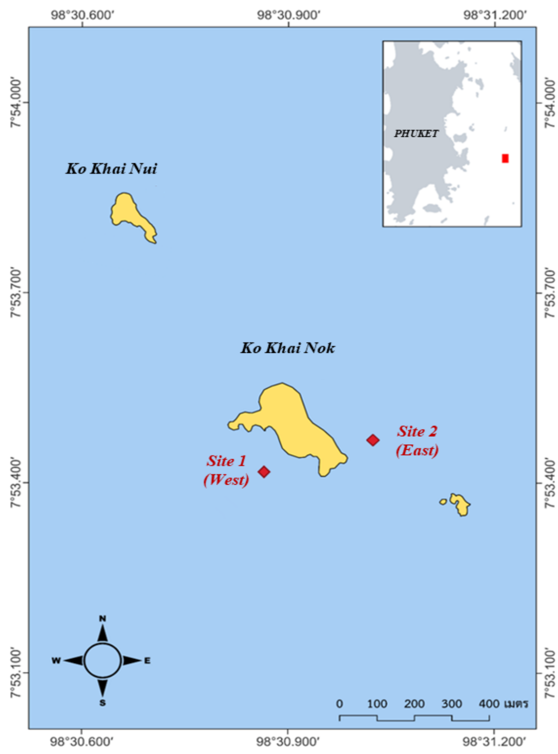

Figure 1. Map of the study sites

When no relationship was available for a species, an average for the genus was applied. The total lengths of individuals were estimated and classified into 5 cm size-class intervals, with a minimum size of 5 cm and a maximum size of 40 cm. Biomass estimation was therefore presented as a fish family based on target fish from eight families, including Mullidae, Carangidae, Siganidae, Kyphosidae, Lutjanidae, Nemipteridae, Scaridae, and Serranidae. Data were then summed to estimate the fish biomass at each study site.

2.3 Statistical analyses

The one-way analysis of variance (ANOVA) and t-test were used to determine the difference in the density and biomass of coral reef fish between the study sites.

3. Results

3.1 Coral reef fish community

The results revealed that the density of coral reef fish between the study sites was significantly different (p<0.01). The abundance of coral reef fish on Site 1 was higher than that of Site 2 in both species richness and density. At Site 1, 74 species representing 18 families were recorded with an average density of 4244.17±907.22 individuals/100 m^2. On the contrary, Site 2 showed a slightly lower abundance with 65 species representing 23 families with an average density of 2361.67±1653.22 individuals/100 m^2 (Table 1, Figure 2). The composition of the target fish found at each study site is shown in Figure 3. Most of target fish at both study sites was Lutjanidae.

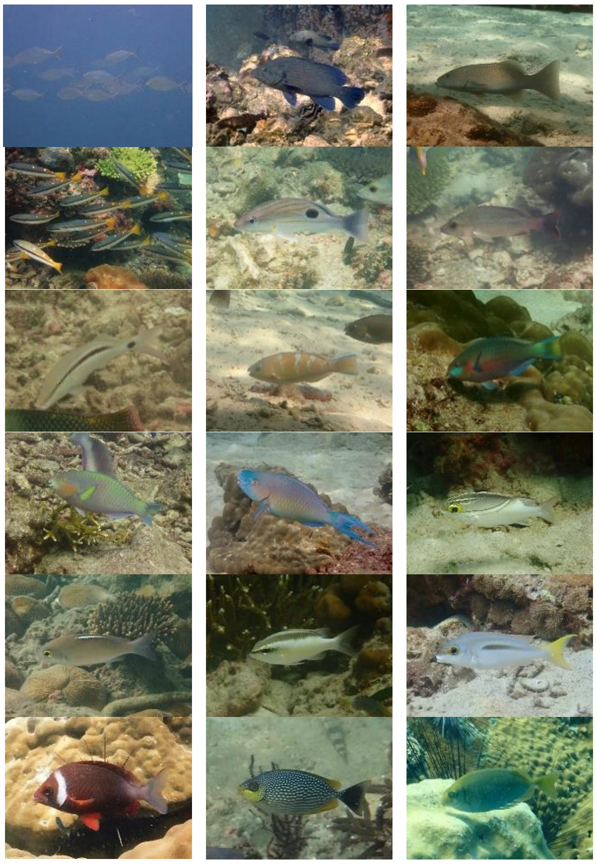

Figure 2. Some target species found at the study sites (left to right) *Alepes vari*; *Cephalopholis formosa*; *Plectropomus leopardus*; *Lutjanus biguttatus*; *L. indicus*; *L. lemniscatus*; *Parupeneus barberinus*; *Scarus ghobban*; *S. quoyi*; *S. rivulatus*; *S. rubroviolaceus*; *Scolopsis bilineata*; *S. ciliata*; *S. margaritifera*; *S. monogramma*; *S. vosmeri*; *Siganus javus*; *S. fussescens*

3.2 Biomass of target fish

A total of eight groups of targeted fish, i.e., Mullidae, Carangidae, Siganidae, Kyphosidae, Lutjanidae, Nemipteridae, Scaridae, and Serranidae were recorded at the study sites. The densities of the target fish were significantly different between the study sites ($p<0.01$). The estimated biomass of target fish at Site 1 (~9508.06 kg/ha) was higher than Site 2 (~893.64 kg/ha) (Figure 4). The Lutjanidae represented the highest biomass

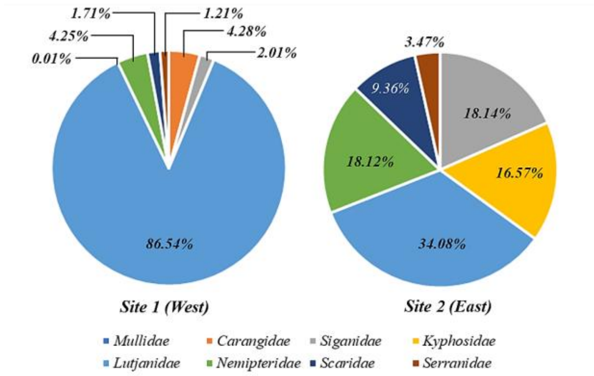

Figure 3. Composition of target fish found at each study site

in both study sites, where the fish biomass at Site 1 was higher (~8227.94 kg/ha) compared with Site 2 (~304.52 kg/ha). The fish biomasses of other target families between the study sites were not much different. The highly commercial food fish Carangidae and Serranidae) was also observed with relatively low biomass.

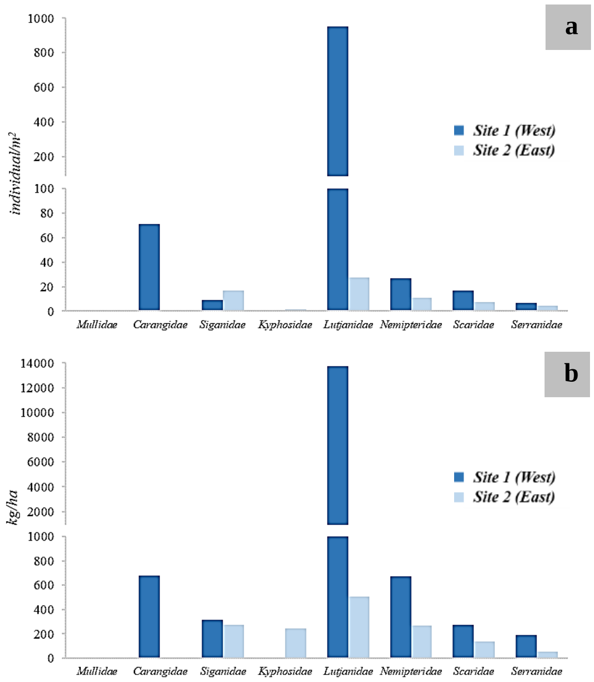

Figure 4. Fish density (a) and biomass (b) of each target fish family from the study sites.

Additionally, there was little difference in the length frequency of target fish between the study sites. According to the results, the fish length of most target families found at the study sites was approximately 20 cm. The size of target fish at Site 1 was smaller than that at Site 2 (Figure 5).

Table 1. List of coral reef fish species found at the study sites

Family/Species	Site 1 (West)	Site 1 (East)	Trophic	Habitat	Utilized
Muraenidae					
Gymnothorax javanicus (Bleeker, 1859)	×	×	CV	CT	ORN
Synodontidae					
Synodus variegatus (Lacepède, 1803)	×	-	PS	RA	EDI
Holocentridae					
Myripristis hexagona (Lacepède, 1802)	-	×	CV	CT	ORN
Sargocentron rubrum (Forsskål, 1775)	×	×	CV	CT	ORN
Mullidae					
Parupeneus barberinus (Lacepède, 1801)	×	×	CV	RA	EDI
Apogonidae					
Cheilodipterus macrodon (Lacepède, 1802)	×	×	CV	CT	ORN
Cheilodipterus quinquelineatus Cuvier, 1828	-	×	CV	CT	ORN
Ostorhinchus properuptus (Whitley, 1964)	×	×	CV	CT	ORN
Taeniamia fucata (Cantor, 1849)	×	×	CV	CT	ORN
Gobiidae					
Koumansetta hectori (Smith, 1957)	×	×	OM	CT	ORN
Carangidae					
Alepes vari (Cuvier, 1833)	×	×	PS	PL	EDI
Caranx melampygus (Cuvier, 1833)	×	×	PS	PL	EDI
Blenniidae					
Meiacanthus smithi Klausewitz, 1962	×	×	OM	CT	ORN
Pomacentridae					
Abudefduf vaigiensis (Quoy & Gaimard, 1825)	×	×	OM	RA	ORN
Amblyglyphidodon indicus Allen & Randall, 2002	×	×	OM	RA	ORN
Amphiprion akallopisos Bleeker, 1853	-	×	OM	RA	ORN
Amphiprion clarkia (Bennett, 1830)	-	×	OM	RA	ORN
Chromis cinerascens (Cuvier, 1830)	×	×	OM	RA	ORN
Chrysiptera rollandi (Whitley, 1961)	-	×	OM	RA	ORN
Dascyllus carneus Fischer, 1885	×	×	OM	RA	ORN
Dascyllus trimaculatus (Rüppell, 1829)	×	×	OM	RA	ORN
Dischistodus perspicillatus (Cuvier, 1830)	-	×	OM	RA	ORN
Hemiglyphidodon plagiometopon (Bleeker, 1852)	×	×	OM	RA	ORN
Neoglyphidodon nigroris (Cuvier, 1830)	-	×	OM	RA	ORN
Neopomacentrus bankieri (Richardson, 1846)	×	×	OM	RA	ORN
Neopomacentrus cyanomos (Bleeker, 1856)	×	×	OM	RA	ORN
Neopomacentrus filamentosus (Macleay, 1882)	×	×	OM	RA	ORN
Pomacentrus amboinensis Bleeker, 1868	×	×	OM	RA	ORN
Pomacentrus moluccensis Bleeker, 1853	×	×	OM	RA	ORN
Pomacentrus pavo (Bloch, 1787)	×	-	OM	RA	ORN
Pomacentrus similis Allen, 1991	×	×	OM	RA	ORN
Pomacentrus xanthosternus Allen, 1991	×	-	OM	RA	ORN
Stegastes lacrymatus (Quoy & Gaimard, 1825)	-	×	OM	RA	ORN
Plectroglyphidodon obreptus (Whitley, 1948)	×	×	OM	RA	ORN

Remark: CV=Carnivore; HB=Herbivore; OM=Omnivore; PK=Planktivore; PS=Piscivore; RA=Reef-associated; PL=Pelagic; CT=Cryptic; ORN=Ornamental; EDI=Edible

Table 1. List of coral reef fish species found at the study sites (continued)

Family/Species	Site 1 (West)	Site 1 (East)	Trophic	Habitat	Utilized
Chaetodontidae					
Chaetodon andamanensis Kuiter & Debelius, 1999	×	×	CV	RA	ORN
Chaetodon auriga Forsskål, 1775	×	×	CV	RA	ORN
Chaetodon collare Bloch, 1787	×	×	CV	RA	ORN
Chaetodon lineolatus Cuvier, 1831	×	×	CV	RA	ORN
Chaetodon lunula (Lacepède, 1802)	×	-	CV	RA	ORN
Chaetodon octofasciatus Bloch, 1787	×	×	CV	RA	ORN
Chaetodon rafflesii Anonymous [Bennett], 1830	×	-	CV	RA	ORN
Chaetodon vagabundus Linnaeus, 1758	×	-	CV	RA	ORN
Chelmon rostratus Linnaeus, 1758	×	×	CV	RA	ORN
Heniochus pleurotaenia Ahl, 1923	×	-	CV	RA	ORN
Heniochus singularius Smith & Radcliffe, 1911	×	×	CV	RA	ORN
Siganidae					
Siganus fuscescens (Houttuyn, 1782)	×	×	HB	RA	EDI
Siganus javus (Linnaeus, 1766)	×	×	HB	RA	EDI
Siganus magnificus (Burgess, 1977)	×	-	HB	RA	ORN
Zanclidae					
Zanclus cornutus (Linnaeus, 1758)	×	×	PT	RA	ORN
Acanthuridae					
Acanthurus nigricauda Duncker & Mohr, 1929	×	-	HB	RA	EDI
Tetraodontidae					
Arothron nigropunctatus (Bloch & Schneider, 1801)	-	×	CV	RA	ORN
Balistidae					
Balistoides viridescens (Bloch & Schneider, 1801)	×	-	CV	RA	ORN
Kyphosidae					
Kyphosus vaigiensis (Quoy & Gaimard, 1825)	-	×	OM	RA	EDI
Pempheridae					
Pempheris adusta Bleeker, 1877	×	-	PT	CT	ORN
Pempheris vanicolensis Cuvier, 1831	-	×	PT	CT	ORN
Lutjanidae					
Lutjanus biguttatus (Valenciennes, 1830)	×	-	PS	RA	EDI
Lutjanus fulvus (Forster, 1801)	×	×	PS	RA	EDI
Lutjanus indicus Allen, White & Erdmann, 2013	×	-	PS	RA	EDI
Lutjanus lemniscatus (Valenciennes, 1828)	×	×	PS	RA	EDI
Nemipteridae					
Scolopsis bilineata (Bloch, 1793)	×	×	CV	RA	EDI
Scolopsis ciliate (Lacepède, 1802)	×	×	CV	RA	EDI
Scolopsis margaritifera (Cuvier, 1830)	×	×	CV	RA	EDI
Scolopsis monogramma (Cuvier, 1830)	×	-	CV	RA	EDI
Scolopsis vosmeri (Bloch, 1792)	×	×	CV	RA	EDI
Labridae					
Bodianus neilli (Day, 1867)	×	×	CV	RA	ORN
Cheilinus chlorourus (Bloch, 1791)	×	×	CV	RA	ORN
Cheilinus fasciatus (Bloch, 1791)	×	×	CV	RA	ORN

Remark: CV=Carnivore; HB=Herbivore; OM=Omnivore; PK=Planktivore; PS=Piscivore; RA=Reef-associated; PL=Pelagic; CT=Cryptic; ORN=Ornamental; EDI=Edible

Table 1. List of coral reef fish species found at the study sites (continued)

Family/Species	Site 1 (West)	Site 1 (East)	Trophic	Habitat	Utilized
Labridae					
Cirrhilabrus cyanopleura (Bleeker, 1851)	×	-	CV	RA	ORN
Coris batuensis (Bleeker, 1856)	×	×	CV	RA	ORN
Epibulus insidiator (Pallas, 1770)	-	×	CV	RA	ORN
Halichoeres chrysotaenia (Bleeker, 1853)	×	×	CV	RA	ORN
Halichoeres hortulanus (Lacepède, 1801)	×	×	CV	RA	ORN
Halichoeres marginatus Rüppell, 1835	×	×	CV	RA	ORN
Halichoeres timorensis (Bleeker, 1852)	×	-	CV	RA	ORN
Hemigymnus fasciatus (Bloch, 1792)	×	-	CV	RA	ORN
Hemigymnus melapterus (Bloch, 1791)	×	×	CV	RA	ORN
Labroides dimidiatus (Valenciennes, 1839)	×	-	CV	RA	ORN
Oxycheilinus digramma (Lacepède, 1801)	×	×	CV	RA	ORN
Thalassoma lunare (Linnaeus, 1758)	×	×	CV	RA	ORN
Scaridae					
Scarus ghobban Forsskål, 1775	x	x	HB	RA	EDI/ ORN
Scarus quoyi Forsskål, 1775	x	x	HB	RA	EDI/ ORN
Scarus rivulatus Valenciennes, 1840	x	x	HB	RA	EDI/ ORN
Scarus rubroviolaceus Bleeker, 1847	x	-	HB	RA	EDI/ ORN
Serranidae					
Cephalopholis formosa (Shaw, 1812)	x	x	PS	RA	EDI
Cephalopholis polyspila Randall & Satapoomin, 2000	x	x	PS	RA	EDI
Diploprion bifasciatum Cuvier, 1828	-	x	PS	RA	ORN
Plectropomus leopardus (Lacepède, 1802)	x	-	PS	RA	EDI

Remark: CV=Carnivore; HB=Herbivore; OM=Omnivore; PK=Planktivore; PS=Piscivore; RA=Reef-associated; PL=Pelagic; CT=Cryptic; ORN=Ornamental; EDI=Edible

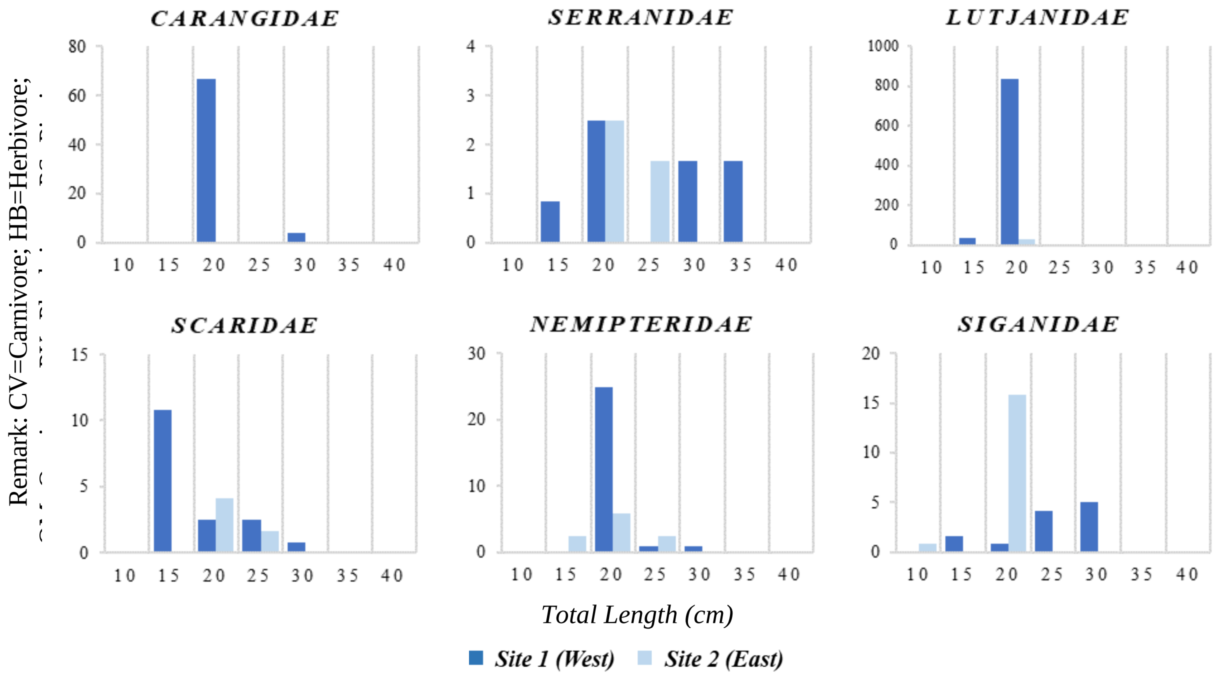

Figure 5. Size frequency of target fish families found at the study sites. The families Kyphosidae and Mullidae were not showed because of their small numbers.

4. Discussion

This study provides the baseline data of coral reef fish biomass at Ko Khai Nok, Phang Nga Province, the Andaman Sea and highlights the importance of assessing fish biomass in the coral reef monitoring programs. There are several methods for estimating the biomass of coral reef fish. However, the underwater visual census and underwater video techniques have been frequently used because they are rapid and cost-effective methods (Murphy and Jenkins 2010; Mallet and Pelletier 2014). The advantage of underwater video techniques is that the data can be kept permanently and allowed to be studied repeatedly whereas the underwater visual census technique facilitates precise estimation of fish length (Harvey et al. 2002; Bennett et al. 2016; Wilson et al. 2009). Assessing coral reef fish biomass should be conducted by several divers because each fish group, such as damselfish, fisheries target fish, and ornamental fish should be examined separately by each diver to obtain more detailed information. The underwater stereo-video measurement has been developed and widely used. This method can count and measure fish for different purposes, such as aquaculture, fisheries, and conservation management, to determine population density, spatial or temporal changes, as well as age or weight distributions (Tillett et al. 2000; Spampinato et al. 2008; Shortis et al. 2013).

Ko Khai Nok is a tourism hot spot in the Andaman Sea, therefore, appropriate protection measures should be implemented. Tourism can affect coral reefs through various activities, such as direct contact with the reef animals, boating, fish feeding, diving, indirect impacts from coastal development and recreational fishing (Rouphael and Inglis 2001; Hawkins et al. 1999; Uyarra and Côté 2007; Yeemin et al. 2011; Siriwong et al. 2018). However, tourism may help to reduce overfishing through providing financial or social incentives for managing marine and coastal resources (Spalding et al. 2017). The aspects of ecosystem services and ecological resilience are very important for effective management of coral reefs (Albuquerque et al. 2014; Wen et al. 2019). The COVID-19 pandemic led to a lockdown in most countries for a few years, resulting in a rapid decline in travel and tourism industry. The marine tourism activities in the Andaman Sea were affected from early 2020. Previous studies showed that fish abundance increased in the absence of tourists as a result of changes in their behaviour because of the COVID-19 pandemic (Edward et al. 2021; Lecchini et al. 2021; Feeney et al. 2022). The number of tourists at Ko Khai Nok may return to usual levels in the future. Therefore, best practices for eco-tourism are needed for sustainable tourism development.

The most abundant target fish found at Ko Khai Nok was Lutjanidae (snapper) which are important targets for fisheries in several regions of the world, such as Australia (Evans and Russ 2004), South Pacific (Jennings and Poluin 1997), America (Ruttenberg 2001; Marko et al. 2004), and Brazil (Frédou et al. 2006). Snappers are important fisheries with high prizes in domestic and international seafood markets around the world. They also play an important role in livelihood and food security for small-scale fishers and local community economy (Sadovy de Mitcheson et al. 2013; Béné et al. 2016; Frisch et al. 2016; Thilsted et al. 2016). There are many fishing gears for harvesting groupers and snappers, such as hand-line, trolling, long-line, spear-fishing, gill net, and trap. Some illegal methods, particularly cyanide and blast fishing are also documented (Halim 2002; Frisch et al. 2016; Forero et al. 2017; Suebpala et al. 2017, 2021). Herbivorous fish are also an important component of target fish at Ko Khai Nok. They play a key role in controlling the benthic community (Bellwood et al. 2004; Hughes et al. 2010). Overfishing of herbivorous reef fish led to increasing of benthic macroalgae and consequently coral reefs degradation (Burkepile and Hay 2006). Some studies showed that grazing by herbivorous fish in coral reef ecosystems can prevent coral-macroalgal phase shifts and enhance coral reef resilience to climate change (Cheal et al. 2013; Mumby 2014; Nash et al. 2016). The species richness and abundance of herbivorous reef fish are positively correlated with water clarity. Therefore, managing water quality is very important to maintain the services of herbivorous fish in coral reefs (Cheal et al. 2013). Herbivorous reef fish assemblages can enhance coral recovery after the disturbances (Nash et al. 2016).

An ecological model study revealed that reductions in parrotfish grazing could have negative impacts on coral reef ecosystem. Ecosystem-based fisheries management has been proposed as a tool for restricting parrotfish harvest (Mumby 2014). This study highlights the importance of assessing coral reef fish biomass in Thailand's coral reef monitoring program.

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