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To Cite:
Baiju PT, Benno Pereira FG, Sethu MR, Limna Mol VP, Prabhakaran MP, Jayaprakas V. New Distributional Records of 31 Marine Fish Species from Rocky Reefs of Kerala: Insights from Underwater Visual Census on the Southwest Coast of India. *Species* 2025; 26: e24s3127
doi: https://doi.org/10.54905/disssi.v26i77.e24s3127

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Peer-Review History
Received: 03 February 2025
Reviewed & Revised: 07/February/2025 to 12/May/2025
Accepted: 16 May 2025
Published: 21 May 2025

Peer-Review Model
External peer-review was done through double-blind method.

Species
pISSN 2319–5746; eISSN 2319–5754

DISCOVERY SCIENTIFIC SOCIETY

New Distributional Records of 31 Marine Fish Species from Rocky Reefs of Kerala: Insights from Underwater Visual Census on the Southwest Coast of India

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ABSTRACT

Ichthyofaunal diversity monitoring through in-situ approaches is crucial in critical habitats like rocky reefs, which serves critical ecological role including feeding, breeding, and nursery grounds for various marine organisms. However, these ecosystems face significant threats like habitat loss, pollution, climate change, and overfishing. This study evaluates the efficacy of underwater visual census (UVS) in documenting rocky reef associated fish diversity along the Kerala coast, southwest coast of India. Underwater surveys were conducted between December 2013 and February 2018 across varying reef habitats, including shallow waters of reefs (1m), intertidal reef (1-5 m), and adjacent sandy bottom of reefs (06 - 12 m). The study documented ichthyofaunal diversity and used extrapolation and modelling to predict species diversity at depths of 15–30 m. A total of 232 fish species were recorded, representing two classes, 16 orders, 62 families, and 114 genera. Notably, 31 species from 17 families and 24 genera had extended distribution ranges within the Indian Ocean and India. Among this, 13 species were identified as first report from Indian waters, and 18 were new regional distributional records from Kerala coast. This study underscores the significance of in-situ approaches such as UVS in biodiversity assessments of rocky reef ecosystems. The results were explicating the detailed and follow-up study of reef-associated biodiversity, particularly in species-rich and ecologically sensitive habitats, to enhance conservation and management strategies for marine ecosystems.

Keywords: ichthyofaunal diversity, underwater visual census, rocky reefs, marine biodiversity, Indian Ocean, Kerala coast.

1. INTRODUCTION

Approximately 40% of the global ichthyofaunal diversity is contributed by the shallow continental shelf waters of tropical and subtropical latitudes (Lowe-

McConnell, 1999; Nelson, 2006; Eschmeyer et al., 2010). Ichthyofaunal diversity accounts for more than half of the world's vertebrate diversity (54,711 species), with a total of 36,983 listed fish species spanning 8 classes, 93 orders, 601 families, and 5,192 genera. Among these, freshwater species contribute nearly half, while marine and brackish species constitute the remainder (Fricke & Eschmeyer, 2025). Indian waters are home to both freshwater and marine fish species, with a total estimated diversity of 3,231 species, of which more than 75% (2,443 species) are marine (Gopi and Mishra, 2015).

Among the various coastal ecosystems along the southwest coast of India, the coastal waters of Kerala hold an inimitable position on the marine biodiversity map. This uniqueness is primarily due to the presence of rocky reefs of the coast, primarily at the two distal ends of the state. Especially, the southern coast noticed with the presence of rocky reef habitats, which supports extensive mussel bed ecosystems, which play the crucial role in the ecology of the coast. These mussel bed ecosystems provide habitat and support a wide array of marine biota, including seaweeds, invertebrates and diverse fish species. "They primarily serve as feeding, breeding, and nursery grounds for various marine life (Baiju et al., 2016).

Among the 2,456 marine fish species recorded in India, 402 are found in the Gulf of Kutch, 603 in Lakshadweep, 762 in the Gulf of Mannar, and more than 1,200 in the Andaman and Nicobar Islands. However, the precise number of fish species associated with India's coral reefs remains uncertain. Various studies have been conducted on coral reef fish diversity, identifying species from groups such as damselfish (52 species), butterflyfish (32 species), sweetlips (16 species), angelfish (16 species), parrotfish (14 species), snappers (42 species), wrasses (53 species), groupers (43 species), and surgeonfish (18 species) (Venkatraman and Wafar, 2005). A total of 720 reef fish species belonging to 90 families have been reported in the Andaman and Nicobar Islands (Rao, 2004), 71 species in the Gulf of Mannar (Mathews et al., 2010), 121 species from Kavaratti Island in Lakshadweep (Anand and Pillai, 2002), and 56 species from the Mithapur reef in the Gulf of Kutch (Subburaman, 2014).

India is classified as one of the world's megadiverse countries, holding a significant position in global ichthyofaunal diversity (Gopi and Mishra, 2015). The country hosts 2,456 fish species, of which 930 are freshwater and 1,526 belong to marine ecosystems (Joshi et al., 2018). India has a coastline spanning 8,118 km, with Kerala contributing approximately 590 km (Joshi et al., 2015).

Kerala, part of the Western Ghats, is recognized as one of the world's 25 biodiversity hotspots. The state features diverse aquatic ecosystems, including a 590-km-long coastline, 44 rivers, 34 lakes, and 11 backwaters. The marine fish diversity of Kerala comprises 1,020 marine finfish species (Joshi et al., 2015). The state's continental shelf extends over an area of 40,000 km², with about 13,000 km² falling within the 50-m depth zone. In-spite this, a few studies was done on the rocky reef fish diversity of the Kerala coast (Sluka and Lazarus, 2010; Sluka, 2013; Sirajudheen & Bijukumar, 2013; Baiju et al., 2016; Baiju et al.,2019). A review of available literature suggests that this study is a pioneering effort in assessing reef ichthyofaunal diversity and fish assemblages along the Kerala coast. No previous studies on diversity assessments have been integrated with assemblage studies using the Underwater Visual Census (UVC) method specifically for the rocky reef ichthyofauna, a key biotic component of the intertidal ecosystems along the Kerala coast. A study focusing on the rocky reef-associated ichthyofaunal diversity of southern Kerala documented 228 fish species (Baiju et al., 2016). Additionally, a comprehensive checklist of fishes associated with rocky reefs reported 232 species belonging to 2 classes, 16 orders, 62 families, and 114 genera (Baiju et al., 2019).

Marine biologists and conservationists globally are seeking non-destructive yet accurate methods for fish diversity monitoring (McLaren et al., 2015). The study of reef fish diversity and assemblages presents significant challenges. Underwater visual census (UVC) is widely regarded as the most practical and extensively utilized method for reef fish diversity and assemblage studies (Nagelkerken et al., 2000). Visual census methods have proven effective in assessing reef fish populations and have been adopted by pioneering researchers since the mid-20th century (Brock, 1954, Brock,1982). Extensive ichthyofaunal diversity studies utilizing underwater visual censuses have been conducted in various parts of India, including Lakshadweep (Anand and Pillai, 2002; Anand and Pillai, 2005), the Andaman and Nicobar Islands (Madhu and Madhu, 2007; Rajaram and Nedumaran, 2009), and islands off the central western coast, such as Goa and Karnataka (Sluka and Lazarus, 2005; Sluka and Lazarus, 2006; Zacharia et al., 2008; Thomas et al., 2011). Rapid surveys have proven particularly useful in ichthyofaunal diversity studies, particularly in ecosystems like rocky reefs that require conservation-focused biodiversity assessments. Rapid marine biodiversity assessments have been conducted in Seychelles, in the Western Indian Ocean (Daly et al., 2018), and fish diversity in the Lakshadweep Archipelago has been studied using rapid survey techniques (Rajan et al., 2021).

A review of existing literature highlights that documentation and assemblage studies on ichthyofauna associated with unique ecosystems such as rocky reefs remain scarce. Additionally, the application of UVC methods for ecosystem-based diversity studies is rare along the southwestern coast of India, particularly in Kerala. The present study underscores the significance and potential of the

UVC method in ichthyofaunal diversity research, specifically in rocky reef ecosystems along the coastal waters of southern Kerala. Through systematic underwater surveys conducted at major rocky reef locations, this study successfully documents a new distributional range for 31 fish species from prominent rocky reef ecosystems along the selected locations of Kerala, southwest coast of India.

2. MATERIALS AND METHODS

Study Design and Survey Methods

Underwater visual survey (UVS) is the most common observational method for studying shallow reef fish (<20 m) and was adopted for this study using snorkeling (Brock 1954). The survey employed an underwater visual census method, complemented by video recording and the line transect method, to assess fish diversity and reef assemblages. Site selection was done based on the presence of prominent rocky reef formations. Start and end coordinates were marked parallel to the reefs at each site (Table 1).

Underwater visual surveys were conducted fortnightly from December 2013 to February 2018 at selected rocky reef sites along the Kerala coast (Fig. 1). Fish species were recorded at varying depths, ranging from shallow waters (~1 m), reef crests, reef slopes (up to 10 m), to sand flats (up to 12 m).

During each survey, observed fish species were identified in the field, recorded, and photographed for revalidation and further identification. A photographic library was created to serve as a reference for future studies. Underwater images were captured using a Canon D15 digital camera with an underwater casing. Fish species were identified from photographs taken during the fortnightly diving observations. No collection of specimens or damage to the rocky reefs occurred during the surveys.

Study Sites and Survey Coordinates

The study was conducted at three key locations along the Kerala coast: Kovalam, Vizhinjam, and Mulloor. The geographical coordinates for each site are provided in Table 1.

Table 1 Geographic coordinates of underwater visual survey sites

Location	Start Coordinates	End Coordinates
Kovalam	8°23′34.6″ N, 76°58′24.2″ E	8°23′34.4″ N, 76°58′21.6″ E
Vizhinjam	8°22′32″ N, 76°59′28″ E	8°22′36″ N, 76°59′32″ E
Mulloor	8°22′04″ N, 77°00′11″ E	8°22′02″ N, 77°00′12″ E

Species Identification and Taxonomy

Fish species taxonomy and systematics were determined using standard references (Nelson et al., 2016). Species identification and distribution ranges were verified using multiple databases, including FishBase (www.fishbase.org), the Global Biodiversity Information Facility (GBIF, www.gbif.org), the Ocean Biogeographic Information System (OBIS, www.iobis.org), and the Check List of Fishes of Kerala. Identification was confirmed using photographic guides, taxonomic references, and online databases such as the Catalog of Fishes and FishBase.

3. RESULTS

Rocky reef fish diversity composition

A total of 232 fish species were recorded during the underwater visual census (UVS) survey conducted from 2013 to 2016. The identifying characters of the newly recorded species was presented below, including extracts from their original descriptions, in-situ observations, and field photographs. The original species descriptions can be referenced through the citations corresponding to the respective authors, cited in full. For species confirmation, the identified taxa were cross-verified with FishBase (www.fishbase.org), and relevant links are provided for further reference (Tables 2 and 3).

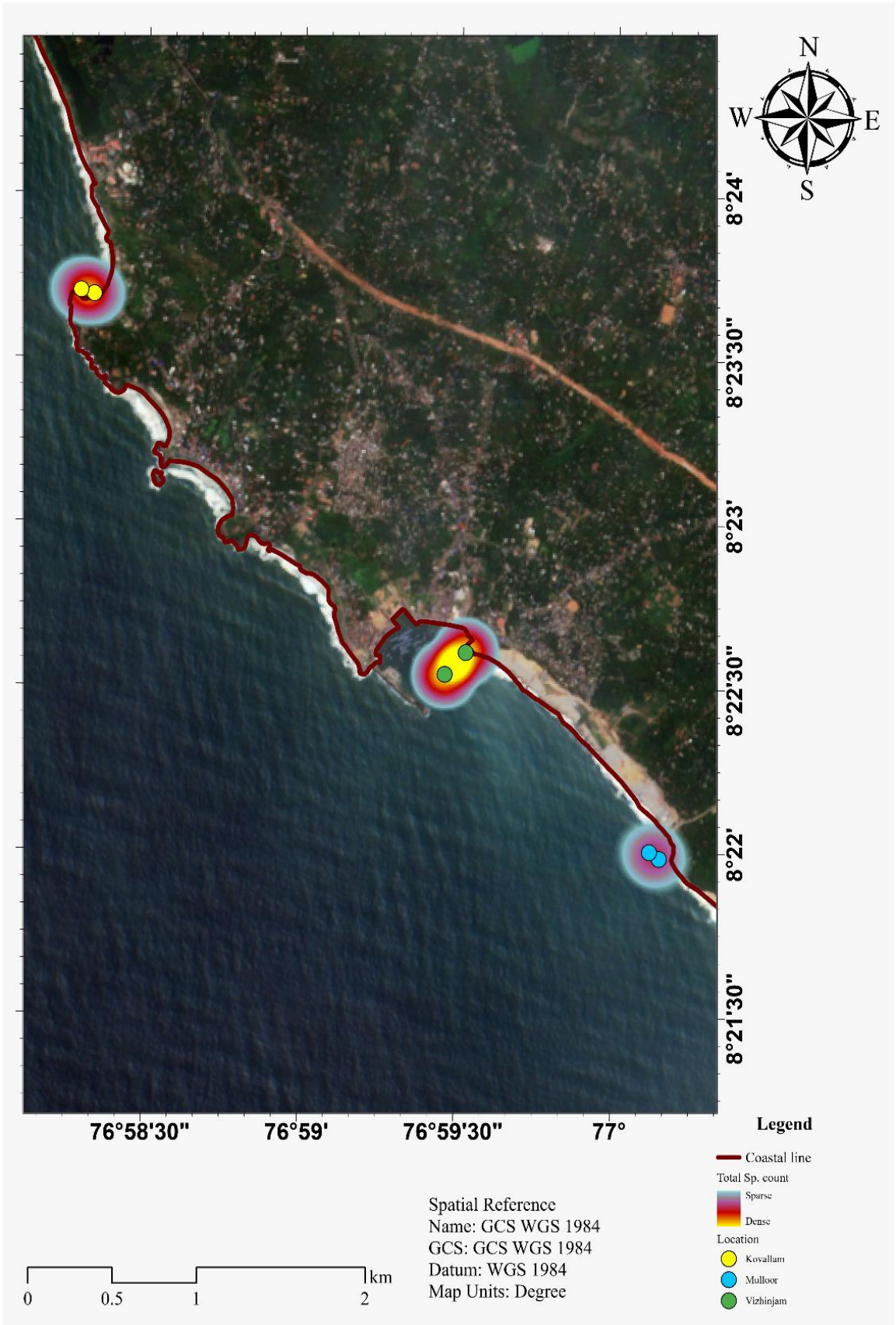

Fig. 1. Study sites and heat map of site-wise species distribution.

Table 2 List of rocky reefs associated with fishes regionally recorded from the coast of Kerala as new report with underwater visual survey methodology

Sl. No	Name of the species	Remarks	FishBase link	IUCN Status
Family: Muraenidae (Moray eels)				
1	Starry moray - *Echidna nebulosa* (Ahl, 1789) **(Fig. 2a)**	New from Kerala coast	https://www.fishbase.de/photos/thumbnailssummary.php?ID=5388	Least Concern (LC)
2	Giant moray - *Gymnothorax javanicus* (Bleeker, 1859) **(Fig. 2b)**	New from Kerala coast	https://www.fishbase.se/photos/thumbnailssummary.php?ID=6380	Least Concern (LC)
Family: Apogonidae (Cardinalfishes)				
3	Cook's cardinal fish - *Ostorhinchus cookii* (Macleay, 1881) **(Fig. 2c)**	New from Kerala coast	http://www.fishbase.us/photos/ThumbnailsSummary.php?ID=9240	Least Concern (LC)
4	Moluccan cardinal fish - *Ostorhinchus moluccensis* (Valenciennes, 1832) **(Fig. 2d)**	New from Kerala coast	http://www.fishbase.us/photos/ThumbnailsSummary.php?id=8589	Least Concern (LC)
Family: Gerreidae (Mojarras)				
5	Common silver-biddy - *Gerres oyena* (Forsskal, 1775) **(Fig. 2e)**	New from Kerala coast	http://www.fishbase.us/photos/ThumbnailsSummary.php?id=5996	Least Concern (LC)
Family: Nemipteridae				
6	Thumb print monocle bream - *Scolopsis bimaculata* Ruppell, 1828 **(Fig. 2f)**	New from Kerala coast	https://www.fishbase.se/photos/thumbnailssummary.php?ID=5886	Least Concern (LC)
Family: Chaetodontidae (Butterfly fishes)				
7	Melon butterflyfish - *Chaetodon trifasciatus* Park, 1797 **(Fig. 2g)**	New from Kerala coast	http://www.fishbase.us/photos/ThumbnailsSummary.php?id=5579	Least Concern (LC)
Family: Cirrhitidae (Hawk fishes)				
8	Yellow hawkfish - *Cirrhitichthys aureus* (Temminck and Schlegel 1842) **(Fig. 2h)**	New from Kerala coast	https://www.fishbase.de/photos/thumbnailssummary.php?ID=10473	Not Evaluated
9	*Cirrhitichthys bleekeri* Day, 1874 **(Fig. 3i)**	New from Kerala coast	https://www.fishbase.de/photos/thumbnailssummary.php?ID=58167	Not Evaluated
10	Stocky hawkfish - *Cirrhitus pinnulatus* (Forster, 1801) **(Fig. 3j)**	New from Kerala coast	https://www.fishbase.se/photos/thumbnailssummary.php?ID=5831	Least Concern (LC)
Family: Labridae (Wrasses)				
11	Nebulous wrasse - *Halichoeres*	New from	http://www.fishbase.us/photos/Thu	Least Concern (LC)

	nebulosus (Valenciennes, 1839) **(Fig. 3k)**	Kerala coast	mbnailsSummary.php?id=6663	
12	Jansen's wrasse - *Thalassoma jansenii* (Bleeker, 1856) **(Fig. 3l)**	New from Kerala coast	https://www.fishbase.se/photos/thumbnailssummary.php?ID=5644	Least Concern (LC)
Family: Acanthuridae (Surgeon fishes)				
13	Blues pine unicornfish - *Naso unicornis* (Forsskal, 1775) **(Fig. 3m)**	New from Kerala coast	http://www.fishbase.us/photos/ThumbnailsSummary.php?id=1265	Least Concern (LC)
14	*Zebrasoma desjardinii* (Bennett, 1836) **(Fig. 3n)**	New from Kerala coast	http://www.fishbase.us/photos/ThumbnailsSummary.php?ID=58791	Least Concern (LC)
Family : Sphyraenidae (Barracudas)				
15	Obtuse barracuda - *Sphyraena obtusata* Cuvier, 1829 **(Fig. 3o)**	New from Kerala coast	http://www.fishbase.us/photos/ThumbnailsSummary.php?ID=4493	Not Evaluated
16	*Sphyraena qenie* Klunzinger, 1870 **(Fig. 3p)**	New from Kerala coast	http://www.fishbase.us/photos/ThumbnailsSummary.php?ID=7939	Not Evaluated
Family: Paralichthyidae (large tooth flounders)				
17	Peacock sole - *Pardachirus pavoninus* (Lacepede, 1802) **(Fig. 4q)**	New from Kerala coast	http://www.fishbase.us/photos/ThumbnailsSummary.php?ID=8271	Least Concern (LC)
Family: Balistidae (Trigger fishes)				
18	Half-moon triggerfish - *Sufflamen chrysopterum* (Bloch and Schneider, 1801) **(Fig. 4r)**	New from Kerala coast	http://www.fishbase.us/photos/ThumbnailsSummary.php?ID=5842	Least Concern (LC)

The identified species were categorized into two groups: (i) marine fish species recorded for the first time regionally in the state of Kerala, and (ii) marine fish species representing new range extensions within the Indian Ocean. Underwater photographs of observed species are provided in two categories: (i) rocky reef-associated fishes regionally recorded from the Kerala coast (Figs. 2 to 4), and (ii) rocky reef-associated fishes newly recorded from Indian waters, documented using the underwater visual survey methodology (Figs. 5 and 6).

The 232 fish species reported in this study belong to two classes, 16 orders, 62 families, and 114 genera. Among the 62 families recorded, Pomacentridae was the most species-rich, with 20 species across 7 genera. This was followed by Labridae (18 species, 11 genera), Lutjanidae (15 species, 2 genera), Chaetodontidae (11 species, 2 genera), Apogonidae (10 species, 6 genera), Acanthuridae (11 species, 2 genera), Muraenidae (9 species, 3 genera), Serranidae (9 species, 3 genera), Scorpaenidae (8 species, 4 genera), Blenniidae (8 species, 4 genera), Haemulidae (6 species, 2 genera), Mullidae (6 species, 2 genera), Holocentridae (5 species, 2 genera), Carangidae (5 species, 3 genera), Gobiidae (5 species, 1 genus), and Balistidae (5 species, 4 genera).

Among the 232 recorded species, a total of 31 species were identified as new records from Indian and Kerala waters. Specifically, 13 species belonging to 10 families were recorded as new to Indian waters, while 18 species represent new regional records from Kerala waters.

The document provides a detailed taxonomic account of observed fish species from Vizhinjam and Kovalam, along with distribution records, taxonomic references and IUCN status.

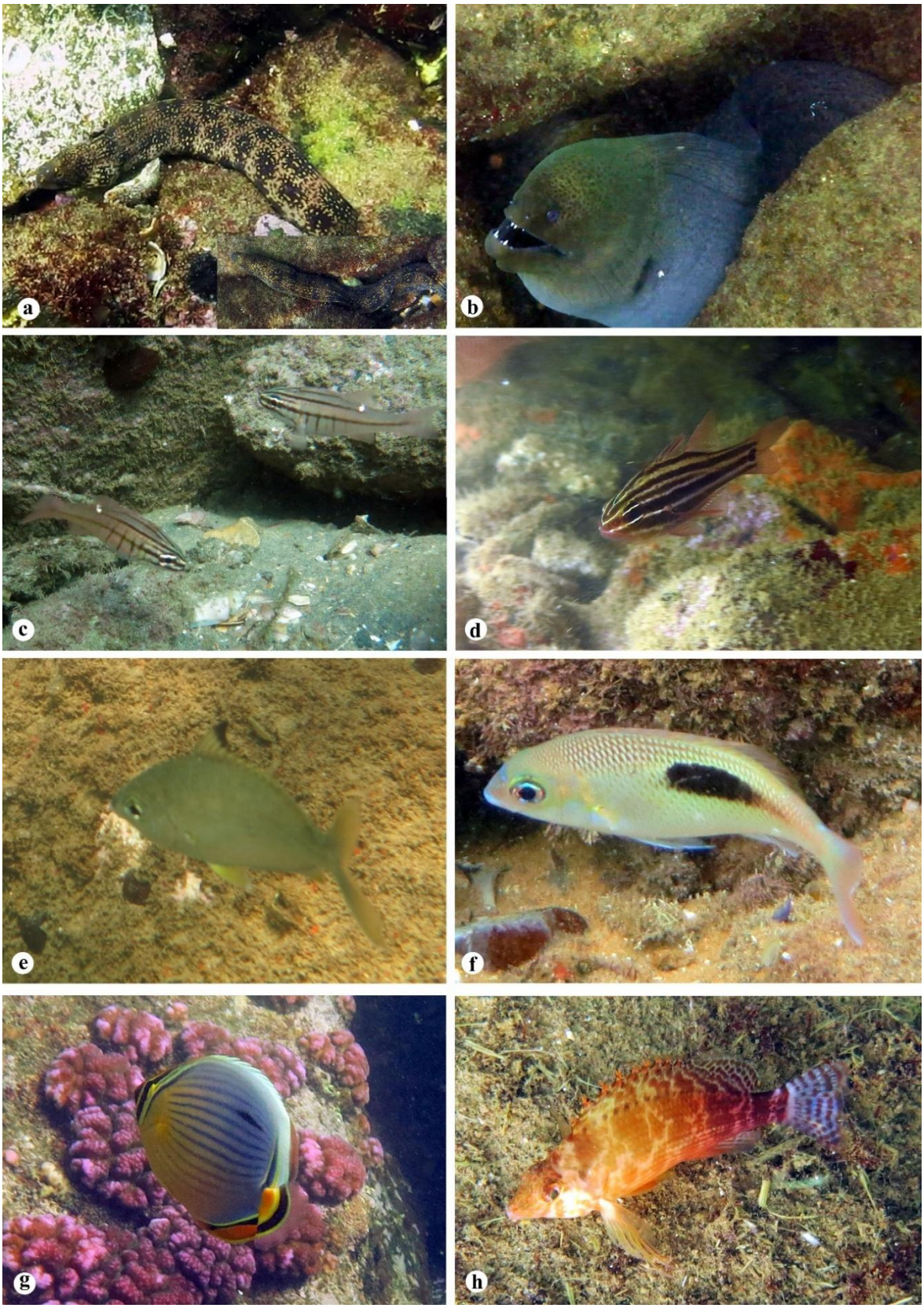

Fig. 2 Rocky reef associated fish species reported as regionally new record from the coast of Kerala. **a.** *Echidna nebulosa*. **b.** *Gymnothorax javanicus*. **c.** *Ostorhinchus cookii*. **d.** *Ostorhinchus moluccensis*. **e.** *Gerres oyena*. **f.** *Scolopsis bimaculata*. **g.** *Chaetodon trifasciatus*. **h.** *Cirrhitichthys aureus*.

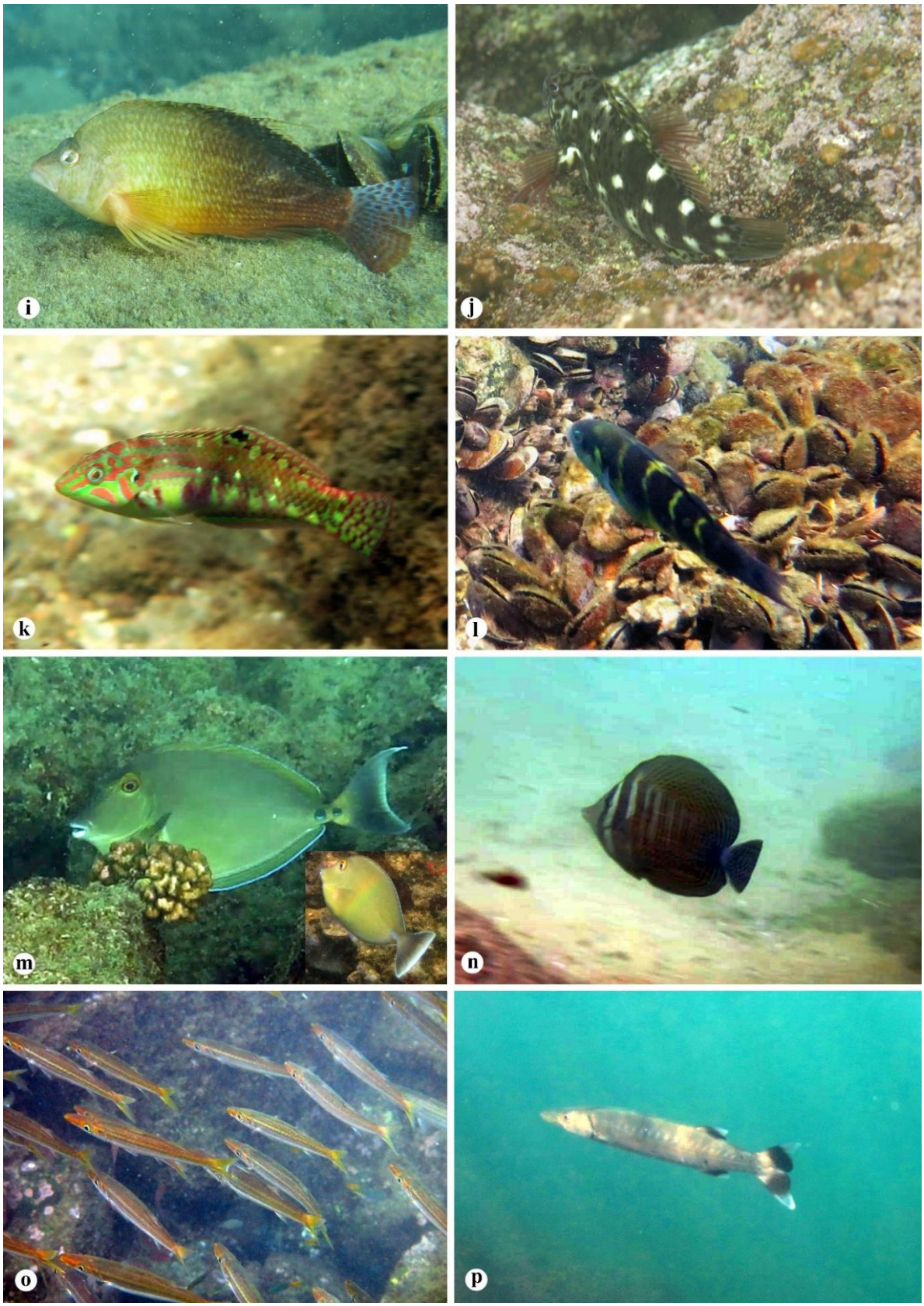

Fig. 3 Rocky reef associated fish species reported as regionally new record from the coast of Kerala. **i.** *Cirrhitichthys bleekeri*. **j.** *Cirrhitus pinnulatus*. **k.** *Halichoeres nebulosus*. **l.** *Thalassoma jansenii*. **m.** *Naso unicornis* (Right bottom: Juvenile). **n.** *Zebrasoma desjardinii*. **o.** *Sphyraena obtusata*. **p.** *Sphyraena qenie*.

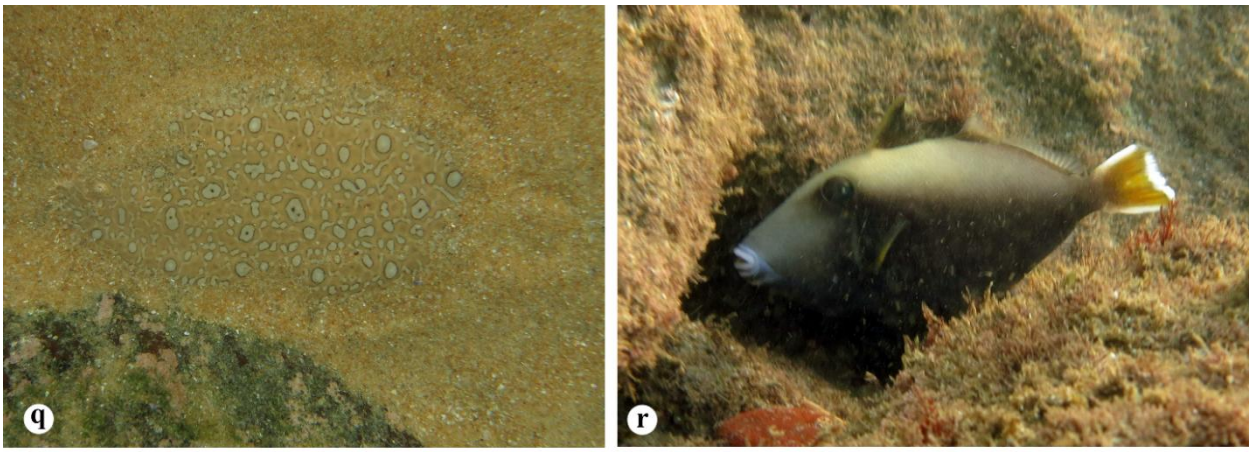

Fig. 4 Rocky reef associated fish species reported as regionally new record from the coast of Kerala. **q.** *Pardachirus pavoninus*. **r**. *Sufflamen chrysopterum*.

a. ***Echidna nebulosa*** **(Ahl, 1789) - Starry Moray**

Observation: The species was recorded from the rocky reefs of Vizhinjam (8°22′32″ N, 76°59′28″ E to 8°22′36″ N, 76°59′32″ E) at a depth of 1 m on April 27, 2017.

Diagnosis: Identified by its moderately stout body, short snout, and tubular broad nostrils. The species exhibits three rows of large black blotches adorned with yellowish spots. The dorsal fin originates just before the gill opening.

Distribution: Widely distributed across the Indo-West Pacific and Eastern Pacific, including the Red Sea, East Africa, the Persian Gulf, and Micronesia.

Remarks: The species first reported from India in 2002 (Kapoor, 2002). Previously listed from Kerala waters (Baiju et al., 2016; Baiju et al., 2019).

b. ***Gymnothorax javanicus*** **(Bleeker, 1859) - Giant Moray**

Observation: Recorded from Vizhinjam (8°22′32″ N, 76°59′28″ E to 8°22′36″ N, 76°59′32″ E) at a depth of 3 m on April 13, 2015.

Diagnosis: Largest moray eel species with a robust body, reaching up to 2 m in length and 70 kg in weight. It has a dorsal fin originating just before the gill opening and eyes positioned over the middle of the upper jaw. The body coloration features darker brown or black markings arranged in irregular rows.

Distribution: Indo-West Pacific, recorded throughout the Red Sea to East Africa.

Remarks: The species first reported in Indian waters by (Kapoor, 2002), and subsequently documented from the Kerala coast (Baiju et al., 2016; Baiju et al., 2019).

c. ***Ostorhinchus moluccensis*** **(Valenciennes, 1832) - Moluccan Cardinalfish**

Observation: Sighted in pairs at Kovalam (8°23′34.6″ N, 76°58′24.2″ E to 8°23′34.4″ N, 76°58′21.6″ E) at 2 m depth on March 8, 2015.

Diagnosis: Characterized by a fluorescent snout, light brown to tan posterior, and three prominent body stripes.

Distribution: Indo-Pacific, recorded from the East Indies and Northern Australia to Fiji.

Remarks: Occurs inshore, primarily in silty habitats. Previously listed by Baiju et al., (2016), Baiju et al., (2019).

d. ***Ostorhinchus cookii*** **(Macleay, 1881) - Cook's Cardinalfish**

Observation: Recorded at Vizhinjam (8°22′32″ N, 76°59′28″ E to 8°22′36″ N, 76°59′32″ E) at a depth of 2 m on April 27, 2017.

Diagnosis: Moderately elongated body with 5-6 dark and white lateral stripes, ending in a distinct black spot at the caudal fin base.

Distribution: Widely distributed across the Indo-West Pacific, including the Red Sea, East Africa, and the Persian Gulf.

Remarks: Prefers shallow, protected waters near rocky or coral reefs. Previously listed by Baiju et al., (2016), Baiju et al., (2019); Saravanan and Rohit, 2017.

e. ***Gerres oyena*** **(Forsskål, 1775) - Common Silver-Biddy**
Observation: Recorded at Kovalam (8°23′34.6″ N, 76°58′24.2″ E to 8°23′34.4″ N, 76°58′21.6″ E) at a depth of 1.6 m on March 1, 2015.
Diagnosis: Brownish-green body with 6-8 pale vertical bands; distinctively colored fins, with dull yellow anal and pelvic fins.
Distribution: Indo-Pacific, from the Red Sea and Persian Gulf to the western Pacific.
Remarks: Previously recorded by Baiju et al., (2016), Baiju et al., (2019).

f. ***Scolopsis bimaculata*** **(Rüppell, 1828) - Thumbprint Monocle Bream**
Observation: Recorded at Kovalam (8°23′34.6″ N, 76°58′24.2″ E to 8°23′34.4″ N, 76°58′21.6″ E) at a depth of 1.6 m on February 28, 2015.
Diagnosis: Grey dorsal side with a silvery belly, a fluorescent line on the forehead, and a black "thumbprint" mark on the upper middle body.
Distribution: Indian Ocean, previously recorded in Tamil Nadu (Mogalekar et al., 2018). **Remarks:** The species was previously listed by Baiju et al., (2016), Baiju et al., (2019).

g. ***Chaetodon trifasciatus*** **(Park, 1797) - Melon Butterflyfish**
Observation: Recorded at Vizhinjam (8°22′32″ N, 76°59′28″ E to 8°22′36″ N, 76°59′32″ E) at a depth of 2 m on February 3, 2015.
Diagnosis: Small, oval, laterally compressed body with complex coloration including dark brown on the forehead, pale yellow ventrally, and bluish dorsally. Alternating yellow and black stripes on fins.
Distribution: Indian Ocean, from East Africa to the Andaman Sea.
Remarks: The species was previously listed by Baiju et al., (2016), Baiju et al., (2019).

h. ***Cirrhitichthys aureus*** **(Temminck & Schlegel, 1842) - Yellow Hawkfish**
Observation: Recorded at Vizhinjam (8°22′32″ N, 76°59′28″ E to 8°22′36″ N, 76°59′32″ E) at a depth of 2 m on February 23, 2014.
Diagnosis: Moderately elongated body with a pointed snout and five vertical yellowish-brown blotches. The anterior part is bright yellow, transitioning to dark brown posteriorly.
Distribution: Indo-West Pacific, from India to Japan and Taiwan.
Remarks: The species was previously recorded by Baiju et al., (2016), Baiju et al., (2019).

i. ***Cirrhitichthys bleekeri*** **Day, 1874**
Common Name: Hawkfish
Observation Site: Rocky reefs of Kovalam (8°23′34.6″ N, 76°58′24.2″ E; 8°23′34.4″ N, 76°58′21.6″ E) at a depth of 1.6 m on 23rd February 2015.
Diagnosis: Moderately elongated body with a pointed snout. A hinge is present above the eyes, leading to a curved forehead. Preopercular spines are evident. The anterior part of the body is pale yellow, transitioning to dark brown towards the posterior end. The dorsal spine terminates in tufts of cirri. The dorsal fin has an extended, unbranched ray, with the distal ends of the posterior dorsal fin being transparent. The caudal fin is characterized by brown spots.
Distribution: Mauritius, Sri Lanka, Reunion, and the east coast of India.
Remarks: Originally described by Day, (1874) from the east coast of India. Randall (1963) validated the species. Recent records include (Baiju et al., 2016; Baiju et al., 2019) and (Ramachandran et al., 2020) from the Kerala coast.

j. ***Cirrhitus pinnulatus*** **(Forster, 1801)**
Common Name: Stocky Hawkfish
Observation Site: Rocky reefs of Vizhinjam (8°22′32″ N, 76°59′28″ E; 8°22′36″ N, 76°59′32″ E) at a depth of 2 m on 1st December 2014.
Diagnosis: Moderately elongated and robust body with a short, blunt snout. A prominent cluster of cirri is visible on the hind edge of the anterior nostril. The body is green-olivaceous with black spots, and three rows of white blotches run along the lateral sides. Fin rays are distinctly brown.

Distribution: Indo-Pacific: Red Sea and East Africa to the Marquesas Islands, Mangareva, southern Japan, the Hawaiian Islands, and south to the Kermadec and Rapa Islands.
Remarks: The species was previously recorded by Baiju et al., (2016), Baiju et al., (2019).

k. ***Halichoeres nebulosus*** **(Valenciennes, 1839)**
Common Name: Nebulous Wrasse
Observation Site: Rocky reefs of Kovalam (8°23′34.6″ N, 76°58′24.2″ E; 8°23′34.4″ N, 76°58′21.6″ E) at a depth of 1.6 m on 1st March 2015.
Diagnosis: Morphologically adapted for cryptic coloration, mimicking rocky reef habitats. Identified by a black ocellus outlined by light green in the middle of the dorsal fin. Juveniles exhibit a green tint with yellow spots, pink markings below the eyes, and on the belly, indicating a developing specimen.
Distribution: Red Sea, coasts of India, Malay Archipelago, the Philippines, and Australia.
Remarks: The species was previously recorded by Baiju et al., (2016), Baiju et al., (2019) from the Kerala coast.

l. ***Thalassoma jansenii*** **(Bleeker, 1856)**
Common Name: Jansen's Wrasse
Observation Site: Rocky reefs of Kovalam (8°23′34.6″ N, 76°58′24.2″ E; 8°23′34.4″ N, 76°58′21.6″ E) at a depth of 1.6 m on 18th January 2016.
Diagnosis: Exhibits cryptic coloration. Juveniles have a green tint with yellow spots. Adults display dark green dorsal coloration with yellow vertical bands, and pale yellow ventrally.
Distribution: Indo-West Pacific: Maldives to Fiji, north to southern Japan, south to Lord Howe Island.
Remarks: The species was previously recorded by Baiju et al., (2016), Baiju et al., (2019) from the Kerala coast.

m. ***Naso unicornis*** **(Forsskal, 1775)**
Common Name: Blue Spine Unicornfish
Observation Site: Rocky reefs of Vizhinjam (8°22′32″ N, 76°59′28″ E; 8°22′36″ N, 76°59′32″ E) at a depth of 2 m on 6th June 2014.
Diagnosis: Greenish-grey body with a unique bony horn in front of the eyes. Two blue plates with knife-like spines on either side of the caudal peduncle. The dorsal and ventral fin margins are white in juveniles and bluish fluorescent in adults. The caudal fin transitions from emarginate with a white distal margin in young individuals to a truncated shape with filamentous lobes in adults.
Distribution: Tropical reef waters of the Indo-Pacific.
Remarks: The species was previously recorded by Baiju et al., (2016), Baiju et al., (2019) from the coast.

n. ***Zebrasoma desjardinii*** **(Bennett, 1836)**
Observation Site: Rocky reefs of Kovalam (8°23′34.6″ N, 76°58′24.2″ E; 8°23′34.4″ N, 76°58′21.6″ E) at a depth of 1.6 m on 11th February 2018.
Diagnosis: Large dorsal fin. White and dark stripes on the head, more pronounced in juveniles. The body exhibits linear vertical yellow lines ending in yellow spots on the belly. Dorsal and anal fins are adorned with yellow spots. The caudal peduncle contains a scalpel-like spine.
Distribution: Indian Ocean: East Africa, Red Sea to the Andaman Sea, western Sumatra, and rare occurrences at Christmas Island.
Remarks: The species was previously recorded by Zacharia et al., (2008) from Karnataka coast and Baiju et al., (2016), Baiju et al., (2019).

o. ***Sphyraena obtusata*** **Cuvier, 1829**
Common Name: Obtuse Barracuda
Observation Site: Rocky reefs of Vizhinjam (8°22′32″ N, 76°59′28″ E; 8°22′36″ N, 76°59′32″ E) at a depth of 1 m on 3rd February 2015.
Diagnosis: Elongated, sub-cylindrical body. Long, pointed snout. Color varies from pale brown to greyish yellow. A yellow line runs from the snout tip above the eye to the caudal fin base. Caudal fin is pale yellow.
Distribution: Red Sea, Indo-West Pacific: East Africa to Samoa, south to Lord Howe Islands.
Remarks: The species was previously recorded by Baiju et al., (2016), Baiju et al., (2019) from the coast.

p. ***Sphyraena qenie*** **Klunzinger, 1870**

Observation Site: The species was observed and photographed in the rocky reefs of Vizhinjam (8°22′32″ N, 76°59′28″ E to 8°22′36″ N, 76°59′32″ E) at a depth of 1 m on 18 January 2015.

Diagnosis: The species has a comparatively elongated body, which is sub-cylindrical or slightly laterally compressed. The head is long and pointed, with a nearly horizontal, large mouth. The elongated jaws have a considerably projecting lower jaw. The opercula are demarcated by black edges. The dorsal fins are widely spaced and separated, with the second dorsal fin originating just behind the anal fin and positioned closer to the caudal fin. The caudal fin is forked with a pair of small lobes at the posterior margin. The dorsal, anal, and caudal fins are darker at the base and transition to a transparent white at the distal ends. The body is marked with multiple dark bars crossing the lateral line, which originates just above the pectoral fin and extends to the caudal base.

Distribution: Indo-Pacific: Persian Gulf, Red Sea, and East Africa to the central Indian Ocean and French Polynesia. Eastern Pacific: Mexico and Panama.

Remarks: This species was previously listed in the two consecutive studies Baiju et al., (2016), Baiju et al., (2019).

q. ***Pardachirus pavoninus*** **(Lacepède, 1802)**

Common Name: Peacock Sole

Observation Site: The species was observed and photographed in the rocky reefs of Kovalam (8°23′34.6″ N, 76°58′24.2″ E to 8°23′34.4″ N, 76°58′21.6″ E) at a depth of 1.6 m on 13 January 2017.

Diagnosis: The species is highly camouflaged against the sandy bottom. The body is brownish yellow with dense spotting, with spots of various shapes and sizes. These spots are grey with black centers and black edges. The eyes are positioned on the dorsal side of the body.

Distribution: Indo-Pacific: Sri Lanka eastward to Samoa and Tonga, north to Japan, and south to Onslow and Australia.

Remarks: This species was previously recorded in the author's studies (Baiju et al., 2016; Baiju et al., 2019).

r. ***Sufflamen chrysopterum*** **(Bloch & Schneider, 1801)**

Common Name: Half-moon Triggerfish

Observation Site: The species was observed and photographed in the rocky reefs of Kovalam (8°23′34.6″ N, 76°58′24.2″ E to 8°23′34.4″ N, 76°58′21.6″ E) at a depth of 1.6 m on 29 October 2015.

Diagnosis: The juvenile specimen exhibited a yellowish dorsal region, a white ventral region, and black lateral coloration. Adult specimens display variable color patterns, with a mixed body coloration and a whitish tinge on the dorsal side. The jaws and lips have a whitish coloration. A distinct light-yellow bar runs through the pectoral base. The posterior ends of the dorsal and anal fins are transparent. The caudal fin is triangular, truncate, and yellowish, with a white margin.

Distribution: Widely distributed throughout the Indo-West Pacific region, from the Persian Gulf and East Africa to Samoa, north to southern Japan, and south to Lord Howe Island.

Remarks: This species was previously recorded and listed in studies by Baiju et al., (2016), Baiju et al., (2019).

Table 3 List of rocky reefs associated with fishes regionally recorded from the coast of Kerala as new report with underwater visual survey methodology

Sl. No	Name of the species	Remarks	FishBase link	IUCN Status
Family: Scorpaenidae (Scorpionfishes or rockfishes)				
1	Zebra turkey fish - *Dendrochirus zebra* (Cuvier, 1829) **(Fig. 5a)**	New from Indian waters	https://www.fishbase.se/photos/thumbnailssummary.php?ID=5828	Least Concern (LC)
2	Northern scorpion fish - *Parascorpaena picta* (Cuvier, 1829) **(Fig. 5b)**	New from Indian waters	https://www.fishbase.se/photos/thumbnailssummary.php?ID=8296	Least Concern (LC)

Family: Serranidae (Sea basses: groupers and fairy basslets)				
3	Pink maomao - *Caprodon longimanus* (Gunther, 1859) **(Fig. 5c)**	New from Indian waters	https://www.fishbase.se/photos/thumbnailssummary.php?ID=15086	Least Concern (LC)
Family: Apogonidae (Cardinalfishes)				
4	*Apogonichthyoides cathetogramma* (Tanaka, 1917) **(Fig. 5d)**	New from Indian waters	http://www.fishbase.us/photos/ThumbnailsSummary.php?ID=59776#	Least Concern (LC)
Family: Gerreidae (Mojarras)				
5	Small-eyed whip fin mojarra - *Gerres microphthalmus* Iwatsuki, Kimura and Yoshino, 2002 **(Fig. 5e)**	New from Indian waters	https://fishbase.mnhn.fr/photos/thumbnailssummary.php?ID=59752	Not Evaluated
Family: Mullidae (Goatfishes)				
6	Short-fin goatfish - *Upeneus oligospilus* Lachner, 1954 **(Fig. 5f)**	New from Indian waters	https://www.fishbase.se/photos/thumbnailssummary.php?ID=65413	Least Concern (LC)
Family: Chaetodontidae (Butterfly fishes)				
7	Blue blotch butterfly fish - *Chaetodon plebeius* Cuvier, 1831 **(Fig. 5g)**	New from Indian waters	http://www.fishbase.us/photos/ThumbnailsSummary.php?ID=6613	Least Concern (LC)
Family: Pomacentridae (Damselfishes)				
8	Lagoon damselfish **-** *Hemiglyphidodon plagiometopon* (Bleeker, 1852) **(Fig. 5h)**	New from Indian waters	http://www.fishbase.us/photos/ThumbnailsSummary.php?id=5487	Least Concern (LC)
9	Ocellated damsel - *Neoglyphidodon bonang* (Bleeker, 1852) **(Fig. 6i)**	New from Indian waters	http://www.fishbase.us/photos/ThumbnailsSummary.php?id=10229	Least Concern (LC)
Family: Labridae (Wrasses)				
10	*Halichoeres binotopsis* (Bleeker, 1849) **(Fig. 6j)**	New from Indian waters	http://www.fishbase.us/photos/ThumbnailsSummary.php?ID=12789	Least Concern (LC)
11	Yellowtail tubelip - *Diproctacanthus xanthurus* (Bleeker, 1856) **(Fig. 6k)**	New from Indian waters	http://fishbase.us/photos/ThumbnailsSummary.php?ID=5108	Least Concern (LC)
12	*Halichoeres leucurus* (Walbaum, 1792) **(Fig. 6l)**	New from Indian waters	http://www.fishbase.us/photos/ThumbnailsSummary.php?ID=56811	Least Concern (LC)
Family: Monacanthidae (Filefishes)				
13	Sandwich isle file - *Cantherhines sandwichiensis* (Quoy and Gaimard, 1824) **(Fig. 6m)**	New from Indian waters	https://www.fishbase.se/photos/thumbnailssummary.php?ID=7835	Least Concern (LC)

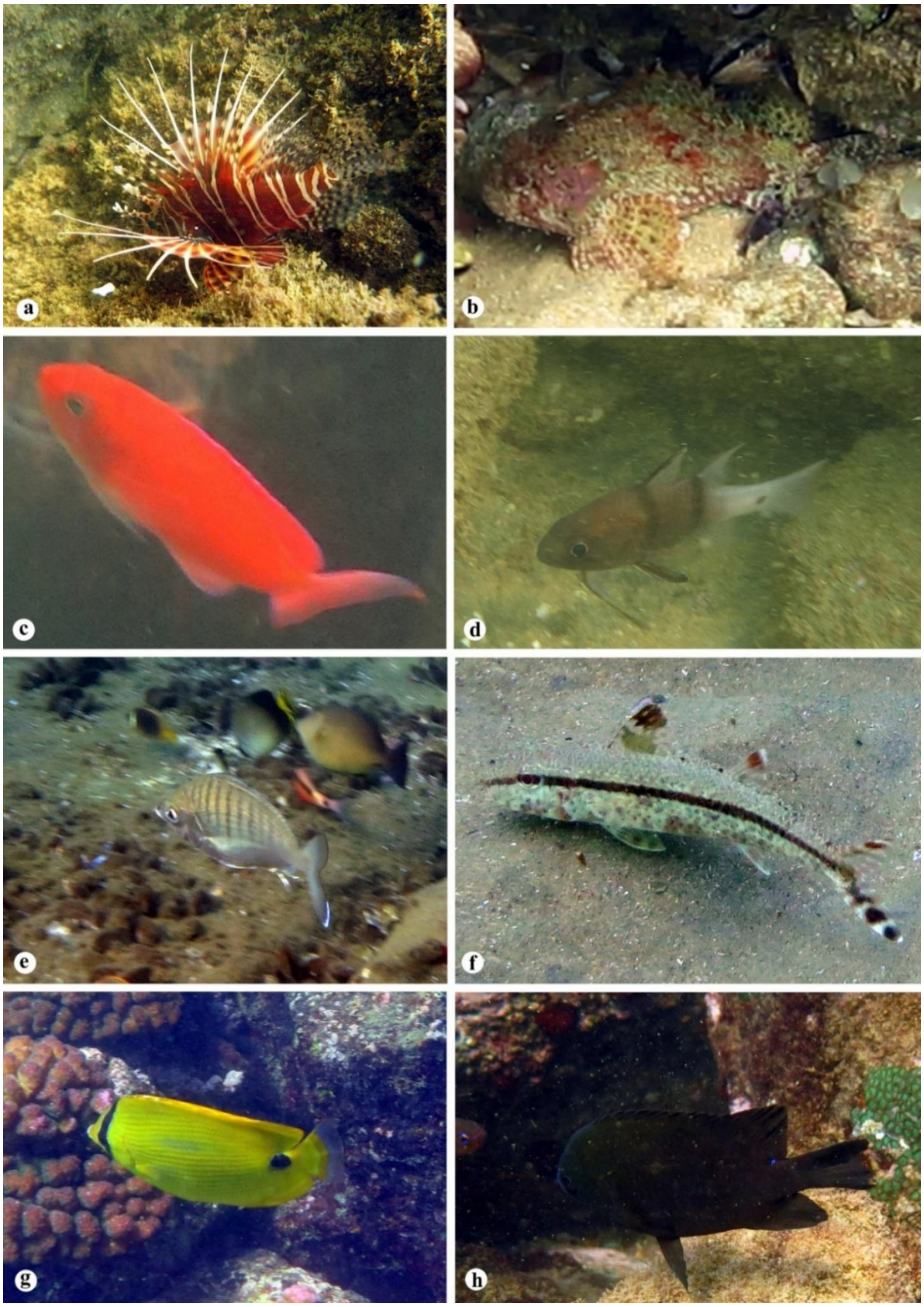

Fig. 5 a. *Dendrochirus zebra.* **b.** *Parascorpaena picta.* **c.** *Caprodon longimanus.* **d.** *Apogonichthyoides cathetogramma.* **e.** *Gerres microphthalmos.* **f.** *Upeneus oligospilus.* **g.** *Chaetodon plebeius.* **h.** *Hemiglyphidodon plagiometopon.*

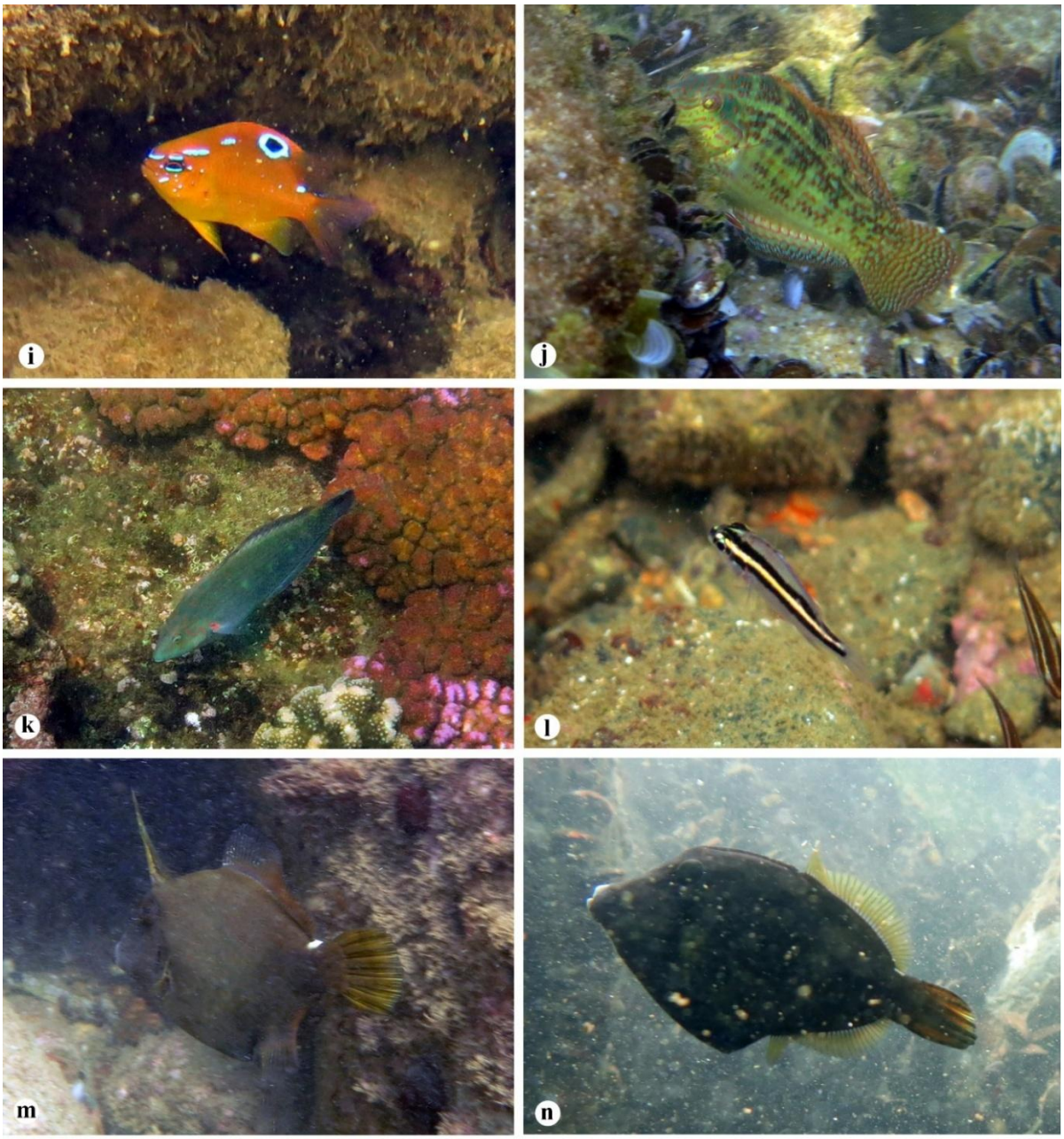

Fig. 6 i. *Neoglyphidodon bonang*. **j.** *Halichoeres binotopsis*. **k.** *Halichoeres leucurus*. **l.** *Diproctacanthus xanthurus*. **m.** *Cantherhines sandwichiensis*. **n.** *Cantherhines sandwichiensis* (colour morph).

a. *Dendrochirus zebra* (Cuvier, 1829)

Common Name: Zebra Turkeyfish

Observation: The species was observed and photographed in the rocky reefs of Kovalam (8°23′34.6″ N, 76°58′24.2″ E to 8°23′34.4″ N, 76°58′21.6″ E) at a depth of 2 m on 19 April 2015.

Diagnosis: The body is moderately elongated and laterally compressed, with a broad head. The snout is blunt, and the eyes are large, with cirri present anteriorly. The body is dark brown with 12 white stripes. The post-pectoral stripes (4th and 5th) originate from the ventral side, bifurcate at the lateral line, and merge with the dorsal spine. The 6th to 9th stripes is separated. The dorsal spine has alternating dark and white bands. The dorsal, anal, and caudal fin (median fins) rays have dark spots, while the extended pectoral fin rays are white. The species is commonly found on rocky reef flats, in sheltered areas such as caves and creeks, and rarely forms small aggregations.

Distribution: This species is distributed across the Red Sea, East and South Africa, extending eastward to the Marshall Islands, Samoa, and Tonga, and northward to southern Japan and the Ogasawara Islands. It is also found southward to Shark Bay (Western Australia), Lord Howe, and Norfolk Islands. The native distribution of zebra turkey fish was reported from the Indo-Pacific region, span from the Red Sea to Indonesia and eastern Australia.
Remarks: The species is frequently found around the rocky reefs of Kerala. It was previously documented in studies by Baiju et al., (2016), Baiju et al., (2019).

b. ***Parascorpaena picta*** **(Cuvier, 1829)**
Common Name: Northern Scorpionfish
Observation Site: The species was observed and photographed in the rocky reefs of Mulloor (8°22′04″ N, 77°00′11″ E to 8°22′02″ N, 77°00′12″ E) at a depth of 1.5 m on 19 April 2015.
Diagnosis: The species has a deep, robust body with a short, blunt snout and a large, rounded head. It is characterized by a mottled red to brown or greenish-brown coloration. The iris has reddish bands, and the lips exhibit light and dark bars. Adult individuals have branched upper pectoral rays, a posterior lacrimal spine, and a fused first and second suborbital ridge forming a single ridge. Two blunt spines are present behind the orbit level on the suborbital ridge. The occipital pit is well-developed. The species is typically associated with rocky, pebbly substrates and often hides in reef crevices for camouflage.
Distribution: The species natively occurs in the Indo-West Pacific, particularly in Southeast Asia and Australian waters. Reports indicate its presence in Indian coastal waters and the Laccadive, although further confirmation of its distribution in Indian waters is needed.
Remarks: The species is commonly found camouflaged in rock crevices. It was previously documented in studies by Baiju et al., (2016), Baiju et al., (2019).

c. ***Caprodon longimanus*** **(Günther, 1859)**
Common Name: Pink Maomao
Observation Site: The species was observed and photographed in the rocky reefs of Vizhinjam (8°22′32″ N, 76°59′28″ E to 8°22′36″ N, 76°59′32″ E) at a depth of 1 m on 14 December 2013.
Diagnosis: The pink maomao is distinguished by its elongated pectoral fins, which extend beyond the head, a long-based dorsal fin, and a slightly forked caudal fin. The body is entirely pink, with males exhibiting color variations where the dorsal, caudal, anal, and pelvic fins appear yellowish.
Distribution: This species distributed throughout the eastern and western South Pacific (Anderson and Heemstra, 2012).
Remarks: The species was previously recorded in the studies by Baiju et al., (2016), Baiju et al., (2019).

d. ***Apogonichthyoides cathetogramma*** **(Tanaka, 1917)**
Observation Site: The species was observed and photographed in the rocky reefs of Kovalam (8°23′34.6″ N, 76°58′24.2″ E; 8°23′34.4″ N, 76°58′21.6″ E) at a depth of 2 m on 22nd March 2015.
Diagnosis: The body is moderately robust and laterally compressed. The snout is blunt, with large eyes featuring a yellow-margined iris. The species is characterized by a cocktail-like color pattern: the anterior region (snout) is comparatively darker, transitioning to light brown on the trunk, and ultimately white on the tail. Two vertical bands are present on the lateral sides, one at the beginning of the first dorsal fin and the other at the second dorsal fin, extending to the anterior margins of the dorsal fins.
Distribution: China, East China Sea, Gulf of Aqaba, Gulf of Eilat, Japan, Philippines, Sri Lanka, Taiwan, and the Ryukyu Islands.
Remarks: This species was previously recorded by Baiju et al., (2016), Baiju et al., (2019).

e. ***Gerres microphthalmus*** **Iwatsuki, Kimura & Yoshino, 2002**
Common Name: Small-eyed whip fin mojarra
Observation Site: The species was observed as a pair and photographed in the rocky reefs of Kovalam (8°23′34.6″ N, 76°58′24.2″ E; 8°23′34.4″ N, 76°58′21.6″ E) at a depth of 2.5 m on 23rd February 2015.
Diagnosis: The body is laterally compressed, oblong, and slender, with a gently convex antero-dorsal profile. The dorsal region exhibits a light brown-greenish hue, while the ventral side is silvery. The species features 9-10 faint black vertical bands dorsolaterally. The

dorsal fin is irregular, and the caudal fin is deeply forked with short, equal-length lobes. The distal end of the caudal fin is edged in black, with the lower caudal lobe featuring a fluorescent margin. The pectoral and anal fins are short and have fluorescent margins at their distal ends.

Distribution: Northwest Pacific, southern Japan.

Remarks: This species was previously recorded by Baiju et al., (2016), Baiju et al., (2019).

f. *Upeneus oligospilus* Lachner, 1954

Common Name: Short-fin goatfish

Observation Site: The species was observed and photographed in the rocky reefs of Kovalam (8°23′34.6″ N, 76°58′24.2″ E; 8°23′34.4″ N, 76°58′21.6″ E) at a depth of 1.6 m on 8th March 2015.

Diagnosis: A wide black horizontal stripe extends from the tip of the snout along the middle of the body, reaching the caudal base. The dorsal and ventral body shades are distinctly different, with the ventral side being darker and featuring brown blotches. The observed specimen's fins are characterized by a series of dark brown or black bars: three on the upper caudal-fin lobe and 3-4 on the lower lobe.

Distribution: Western Indian Ocean, Persian Gulf.

Remarks: This record from the Arabian Sea extends the known range of this species from the southwestern Atlantic to the western Indian Ocean. The species was previously listed in the author's studies (Baiju et al., 2016; Baiju et al., 2019).

g. *Chaetodon plebeius* Cuvier, 1831

Observation Site: The species was observed and photographed in the rocky reefs of Vizhinjam (8°22′32″ N, 76°59′28″ E; 8°22′36″ N, 76°59′32″ E) at a depth of 2 m on 3rd February 2015.

Diagnosis: The body is oval-shaped and laterally compressed. The species has a small, protractile mouth with a short snout, adapted for feeding on small zooplankton and coral polyps. A black vertical band with a fluorescent edge runs through the eyes and extends to the ventral side. The overall body color is yellow, with a faint fluorescent blotch on the sides. A white-edged black blotch is present on the caudal peduncle. The dorsal, anal, and pelvic fins are brilliant yellow. The caudal fin is yellow, with a deep, intense coloration at the center, fading to a transparent edge distally.

Distribution: Indo-West Pacific. This species is commonly found in tropical marine waters throughout the Indo-Australian Archipelago, extending north to Japan and east to Fiji.

Remarks: The species was previously recorded by Baiju et al., (2016), Baiju et al., (2019).

h. *Hemiglyphidodon plagiometopon* (Bleeker, 1852)

Common Name: Lagoon Damselfish

Observation Site: The species was observed and photographed from the rocky reefs of Kovalam (8°23′34.6″ N, 76°58′24.2″ E to 8°23′34.4″ N, 76°58′21.6″ E) at a depth of 1.6 m on March 1, 2015.

Diagnosis: One of the larger damselfish species, characterized by a dark brown body. The median fins and base of the pectoral fins are generally darker. A faint blue tint extends from the snout to the beginning of the dorsal fin. A distinct spot is present on the upper edge of the caudal peduncle.

Distribution: Indo-West Pacific, including the Eastern Indian Ocean and Western Pacific. Found in the Andaman Sea, Malaysia, Indonesia, Palau, Papua New Guinea, the Solomon Islands, the Philippines, northern Australia, and New Caledonia.

Remarks: The species has not yet been reported from Indian waters.

i. *Neoglyphidodon bonang* (Bleeker, 1852)

Common Name: Ocellated Damsel

Observation Site: The species was observed and photographed on the rocky reefs of Vizhinjam (8°22′32″ N to 76°59′28″ E and 8°22′36″ N to 76°59′32″ E) at a depth of 2 m on December 15, 2013.

Diagnosis: The body is predominantly orange, with yellow on the ventral side and bright orange on the upper body. Blue fluorescent spots are scattered along the anterior dorsal side. A comparatively large black spot, edged with a blue circle, is present at the junction of the dorsal fin and body.

Distribution: The species widely reported along the Indo-West Pacific, spans from Sri Lanka to the Indo-Australian Archipelago, including adjacent island ecosystems like Sumatra, Java, Sulawesi, and the Solomon Islands.
Remarks: Previously recorded in the two studies by Baiju et al., (2016), Baiju et al., (2019).

j. *Diproctacanthus xanthurus* (Bleeker, 1856)
Common Name: Yellowtail Tubelip
Observation Site: The species was observed and photographed on the rocky reefs of Vizhinjam (8°22′32″ N to 76°59′28″ E and 8°22′36″ N to 76°59′32″ E) at a depth of 2 m on May 14, 2015.
Diagnosis: The species can be identified by three broad, horizontally running lines with a centrally placed yellow shaded line that begins from the tip of the snout and passing through the eye and reaching to the base of the caudal peduncle. The central line is yellow, while the upper dorsal and ventral sides are greyish white.
Distribution: The species with extensive distribution pattern along the Western Central Pacific, along with regional reports from Philippines, Palau, Indonesia, New Guinea, and the Great Barrier Reef of Australia.
Remarks: Previously recorded in the studies by Baiju et al., (2016), Baiju et al., (2019).

k. *Halichoeres binotopsis* (Bleeker, 1849)
Common Name: Banded Rainbowfish / Saowisata Wrasse
Observation Site: The species was observed and photographed from the rocky reefs of Kovalam (8°23′34.6″ N, 76°58′24.2″ E to 8°23′34.4″ N, 76°58′21.6″ E) at a depth of 1.6 m on January 18, 2015.
Diagnosis: The body coloration is yellowish-green, with a darker green dorsal side and a yellowish-green ventral side. The snout and head region bear brown spots that form horizontal lines extending to the caudal peduncle. Distinguished by the prominent horizontal line pattern on the cheek (Kuiter and Tonozuka, 2001).
Distribution: Western Pacific, including Singapore, West New Guinea, Indonesia, and Papua New Guinea.
Remarks: Previously recorded by the author's studies (Baiju et al., 2016; Baiju et al., 2019).

l. *Halichoeres leucurus* (Walbaum, 1792)
Observation Site: The species was observed and photographed on the rocky reefs of Vizhinjam (8°22′32″ N to 76°59′28″ E and 8°22′36″ N to 76°59′32″ E) at a depth of 2 m on February 3, 2015.
Diagnosis: Recognized by its grey body and head bearing orange markings under natural light. Three to four light green blotches are present along the middle line of the body. The fins are margined with a light blue hue.
Distribution: Western Pacific, from the Philippines to New Guinea, north to the Yaeyama Islands, south to Flores, Indonesia, and Palau in Micronesia.
Remarks: The species was previously listed by Baiju et al., (2016), Baiju et al., (2019).

m. *Cantherhines sandwichiensis* (Quoy & Gaimard, 1824)
Common Name: Sandwich Isle Filefish
Observation Site: The species was observed and photographed from the rocky reefs of Kovalam (8°23′34.6″ N, 76°58′24.2″ E to 8°23′34.4″ N, 76°58′21.6″ E) at a depth of 1.6 m on March 22, 2015.
Diagnosis: A monocanthid species characterized by a prominent spine in the first dorsal fin. The body is laterally compressed and truncated, with a protruding snout and whitish lips. The body color changes to slightly yellowish with age. Fins are light yellow, and the upper part of the caudal peduncle bears a distinct white spot, which serves as a key identification mark.
Distribution: Eastern Central Pacific, primarily in the Hawaiian Islands.
Remarks: The species has not yet been reported from Indian waters.

Diversity and Distribution
The present study compared the recorded species diversity within various families to previously documented records from different regions of India. The analysis strongly validates the advantages of the Underwater Visual Census (UVC) method over other survey techniques employed in previous studies across the country. A total of 31 species from various families were newly documented in this

study, which had not been previously reported from Indian waters. These include species from Muraenidae (2 species), Scorpaenidae (2 species), Serranidae (1 species), Apogonidae (4 species), Gerreidae (2 species), Nemipteridae (1 species), Mullidae (1 species), Cirrhitidae (2 species), Chaetodontidae (2 species), Pomacentridae (2 species), Labridae (5 species), Acanthuridae (2 species), Sphyraenidae (2 species), Paralichthyidae (1 species), Monocanthidae (1 species), and Balistidae (1 species) (Table 4).

Species Distribution and Habitat Variability in the Rocky Reefs of Kerala

The UVC method was employed to map the species distribution at depths across 1–15 meters in the rocky reef ecosystems of the study area. The prediction model of species distribution pattern for 15–30 meters was extrapolated with the species distribution data recorded at the depth of 1–10 meters. Based on this, the study was able to predict the possibilities of 1–3 additional species per family likely due to depth-related habitat expansion. These results emphasizes the importance of UVC surveys and the need for advanced and extensive surveys to assess the diversity of deepwater rocky reef habitats along the Kerala coast. The species distribution prediction at 15–30 meters depth was achieved using the following methods:

Extrapolation Method

For genera recorded at 1–12 meters, species occurrence at 15–30 meters were extrapolated based on an observed increase in species richness with depth. An estimated 1–2 additional species per genus were projected at 15–30 meters compared to shallow water observations.

Predictive occurrence modelling of reef fish family distribution across depth gradients (15–30m) in Indian waters

Species distribution in various families at depths of 15–30m was modelled based on key habitat parameters, including substrate type, temperature, and salinity preferences. Families with a high probability of occurrence at deeper depths were prioritized for predictive analysis. A comparative assessment of reef fish family diversity in Indian waters was conducted, integrating newly documented distributional records with modelled species richness across the 15–30m depth gradient (Table 4, Fig. 7). The estimated minimum and maximum species richness for each family at 15–30 meters is as follows: *Labridae* (7–9 species), *Apogonidae* (6–8 species), *Cirrhitidae* (5–7 species), *Chaetodontidae*, *Pomacentridae*, and *Acanthuridae* (4–6 species), *Gerreidae*, *Muraenidae*, *Scorpaenidae*, and *Sphyraenidae* (3–5 species), *Balistidae, Mullidae, Nemipteridae, Paralichthyidae*, and *Serranidae* (2–4 species), and *Monocanthidae* (2–3 species). The present study was able to recorded the occurrence of rarely documented fish families from the Indian waters including *Gerreidae, Nemipteridae, Sphyraenidae, Paralichthyidae,* and *Monocanthidae*. These findings contributed to the strengthening the knowledge of reef fish diversity studies in Indian waters and underscore the need for further investigations into species distribution patterns across varying depth gradients.

Table 4 Family-wise species distribution from previous studies, the present study, and predicted occurrences within the 15–30m depth range.

Family	Genera recorded from Indian waters	Total species recorded from Indian waters	New distributional record of species in the present study (1-12m depth)	Min. Predicted No. of Species (15-30m)	Max. Predicted No. of Species (15-30m)
Muraenidae	3	9	2	3	5
Scorpaenidae	4	8	2	3	5
Serranidae	3	9	1	2	4
Apogonidae	2	10	3	6	8
Gerreidae	1	2	2	3	5
Nemipteridae	1	2	1	2	4
Mullidae	2	6	1	2	4
Cirrhitidae	2	3	3	5	7

Chaetodontidae	2	11	2	4	6
Pomacentridae	7	20	2	4	6
Labridae	11	17	5	7	9
Acanthuridae	2	10	2	4	6
Sphyraenidae	1	2	2	3	5
Paralichthyidae	1	3	1	2	4
Monocanthidae	1	1	1	2	3
Balistidae	4	5	1	2	4

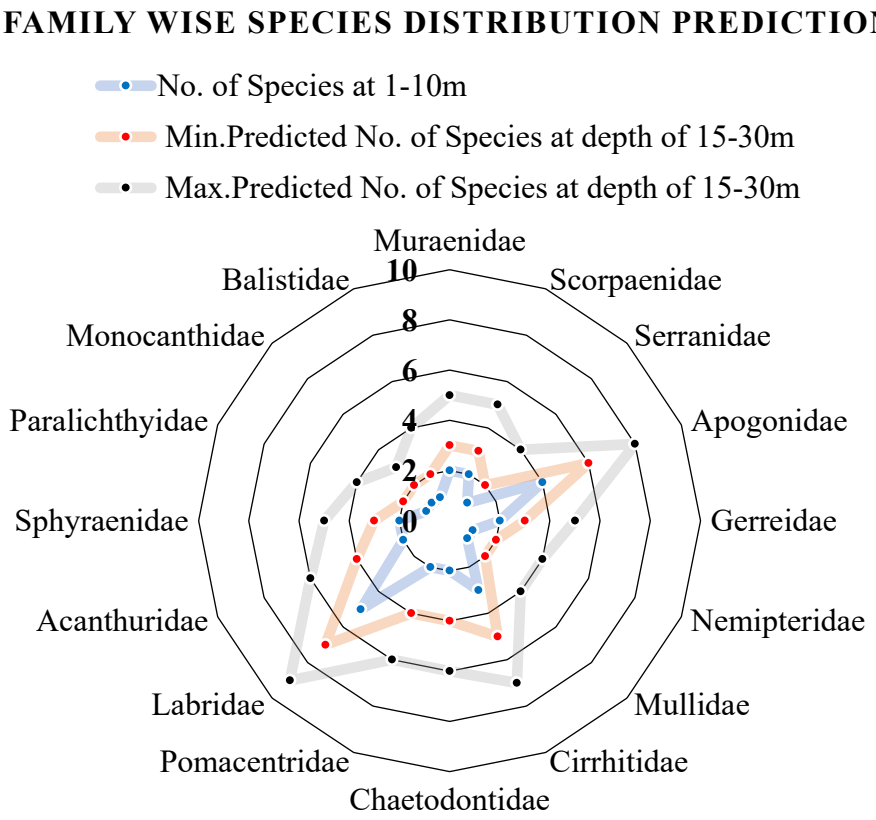

Fig. 7 Family-wise species distribution and predicted richness across depth gradients (15-30m) in Indian waters

Predictive occurrence modelling of reef fish genus-wise distribution across depth gradients (15–30m) in Indian waters

The comparative study of genus-wise species distributions in Indian waters was conducted using previous biodiversity assessments from various parts of the country and the present study results obtained through the Underwater Visual Census (UVC) method at a depth of 1 to 12 meters. Additionally, an attempt was made to predict the potential occurrence of new species within the depth range of 15 to 30 meters. Previous studies across India primarily relied on biodiversity assessments conducted at fish landing centers or through other extractive methods. These studies revealed that the most species-rich genera recorded from various regions of Indian waters included *Gymnothorax* (23 species), Chaetodon (22 species), *Halichoeres* (11 species), Gerres, *Scolopsis*, and *Sphyraena* (10 species each), *Ostorhinchus* (9 species), *Upeneus* (8 species), and Naso (7 species). Notably, the present study documented several genera for the first time in Indian waters, including *Dendrochirus*, *Caprodon*, *Apogonichthyoides*, *Hemiglyphidodon*, *Neoglyphidodon*, *Diproctacanthus*, and *Cantherhines*. Additionally, rarely observed genera such as *Parascorpaena*, *Cirrhitus*, and *Zebrasoma* were recorded. Based on this

comparative study, we attempted to predict the potential occurrence of new species within the 15 to 30-meter depth range (Table 5, Fig. 8). The findings highlight that the UVC method provides a more effective approach for exploring ichthyofaunal diversity, particularly in ecologically sensitive and underexplored ecosystems such as the rocky reefs along the Kerala coast. This method offers significant potential for discovering new species and expanding our understanding of marine biodiversity in these critical habitats.

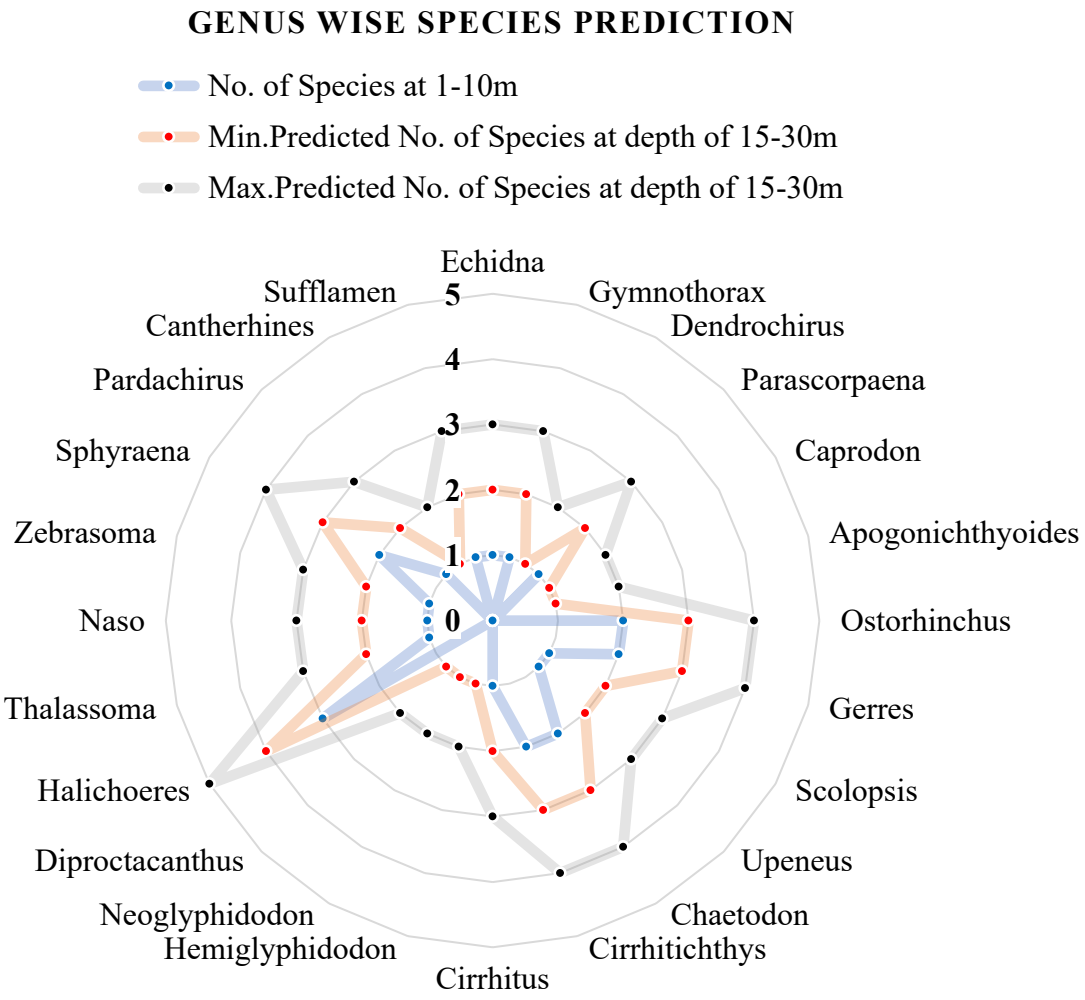

Fig. 8 Genus-wise species distribution and predicted richness across depth gradients (15-30m) in Indian waters

Table 5 Genus-wise species distribution from previous studies, the present study, and predicted occurrences within the 15–30m depth range.

Genus	Genus wise species recorded from Indian waters	New distributional record of species in the present study (1-12m depth)	Min. Predicted No. of Species (15-30m)	Max. Predicted No. of Species (15-30m)
Echidna	4	1	2	3
Gymnothorax	23	1	2	3

Dendrochirus	0	1	1	2
Parascorpaena	1	1	2	3
Caprodon	0	1	1	2
Apogonichthyoides	0	1	1	2
Ostorhinchus	8	2	3	4
Gerres	10	2	3	4
Scolopsis	10	1	2	3
Upeneus	9	1	2	3
Chaetodon	22	2	3	4
Cirrhitichthys	2	2	3	4
Cirrhitus	1	1	2	3
Hemiglyphidodon	0	1	1	2
Neoglyphidodon	0	1	1	2
Diproctacanthus	0	1	1	2
Halichoeres	11	3	4	5
Thalassoma	6	1	2	3
Naso	7	1	2	3
Zebrasoma	1	1	2	3
Sphyraena	10	2	3	4
Pardachirus	2	1	2	3
Cantherhines	0	1	1	2
Sufflamen	2	1	2	3

4. DISCUSSION

Despite a history spanning over 200 years of ichthyofaunal diversity exploration in Indian waters, studies employing an ecosystem-based approach remain scarce. The rocky reef fish diversity along the coastal waters of Kerala has not been properly documented, despite its ecological significance. These unique coastal ecosystems demand more focused and detailed biodiversity assessment studies and conservation efforts (Baiju et al., 2016; Baiju et al., 2019). The present study, based on compiled data from underwater visual surveys conducted between December 2013 and February 2018, aims to address this gap.

Documentation and monitoring of fish diversity and assemblage studies in reef ecosystems across Indian waters can be taken as an ideal method to assessing ecosystem health and achieving conservation and management objectives. This study underscores the immense scope of underwater visual survey (UVS) methods in biodiversity exploration, particularly for rocky reef ecosystems that require conservation measures. The UVS method offers vast potential for marine biodiversity documentation.

A survey of coral reef-associated fishes along the southeastern coast of India, conducted from January 2012 to December 2013, recorded 162 species from 17 orders, 41 families, and 94 genera across three study sites (Jayaprabha et al., 2018). A comprehensive review of coral reef fish diversity in southern India reported a total of 2,810 species across 176 families (Chinmay et al., 2022). A rapid marine biodiversity assessment in Seychelles, West Indian Ocean, documented 514 marine fish species from 71 families at D'Arros Island and St. Joseph Atoll within a short time, with 16 new records (Daly et al., 2018). Similarly, a rapid survey in the Lakshadweep Archipelago identified 15 previously unreported fish species from these waters (Rajan et al., 2021).

In the present study, 31 species were identified as having a new distributional range in Indian and Kerala waters. Among them, 13 species belonging to 10 families were newly recorded from Indian waters, while 18 species from 11 families were newly documented in Kerala waters. These findings emphasize the importance of continued biodiversity assessments along the Indian coast.

Previous research has extensively focused on the diversity of edible (Nayar, 1958) and ornamental fishes (Sirajudheen and Bijukumar, 2012). However, studies on the diversity of rocky reef ichthyofauna are rare (Sirajudheen and Bijukumar, 2013; Sluka, 2013). A study conducted along the south Kerala coast between 2013 and 2015 recorded 228 fish species in 112 genera, 60 families, and 16 orders associated with rocky reefs. The most species-rich families were Pomacentridae (20 species), Labridae (17), Lutjanidae (15),

Chaetodontidae (11), Acanthuridae (10), Apogonidae (10), Serranidae (9), and Muraenidae (9). Additionally, a study utilizing underwater visual census surveys between December 2013 and February 2018 recorded 232 fish species belonging to 2 classes, 16 orders, 62 families, and 114 genera in the rocky reefs of south Kerala. This study highlighted the importance of underwater visual census methods in marine biodiversity documentation. These findings underscore the rich biodiversity associated with rocky reef habitats along the Indian coastline and highlight the need for further research in these areas.

The present study documented 232 fish species belonging to 2 classes, 16 orders, 62 families, and 114 genera through underwater visual census surveys conducted from December 2013 to February 2018. Among these, 31 species belong to 17 families and 24 genera were identified as new distributional record, with 13 species being unreported from Indian waters and 18 species regionally unreported from Kerala. These findings highlight the need for more detailed biodiversity documentation and assessment studies not only in the ichthyofauna but also in the other taxa along the coast. Furthermore, the Kerala coast has garnered increasing public attention due to recent large-scale developmental activities, including the construction of Vizhinjam International Port. These developments entail significant coastal modifications such as coastal mining and armouring, which can drastically impact local biodiversity. Therefore, continued monitoring and conservation efforts are imperative to mitigate potential ecological disturbances and safeguard the marine biodiversity of this region.

5. CONCLUSIONS

The ichthyofaunal biodiversity of Indian waters has been documented for over 200 years, yet ecosystem-based studies remain scarce. The present study tries to resolve this gap by utilizing data compiled through an underwater visual census (UVC) survey conducted across the coastal rocky reefs of South Kerala. By addressing the ecological significance and enduring threats to these unique reef ecosystems, which serve as critical habitats for marine biodiversity, this study highlights the importance of comprehensive biodiversity assessments and conservation efforts.

The present study findings accentuate the effectiveness of UVC as a robust and non-invasive method for documenting reef-associated fish diversity. The survey successfully recorded 232 fish species belonging to 2 classes, 16 orders, 62 families, and 114 genera. Notably, 31 species from 17 families and 24 genera were recorded as new occurrences, 13 species being previously unreported from Indian waters and 18 species regionally unreported from Kerala. These findings indicate a substantial extension in the known distribution range of several marine fish species in the Indian Ocean.

The study reaffirms that UVC-based biodiversity assessments play a crucial role in monitoring species richness, particularly in fragile ecosystems such as rocky reefs. Similar methodologies have been effectively applied in other reef systems, including Lakshadweep (Anand and Pillai, 2002; Anand and Pillai, 2005), the Andaman and Nicobar Islands (Madhu and Madhu, 2007; Rajaram and Nedumaran, 2009), and the offshore islands of Goa and Karnataka (Sluka and Lazarus, 2004; Sluka and Lazarus, 2005; Sluka and Lazarus, 2006; Sluka and Lazarus, 2009; Sluka and Lazarus, 2010; Zacharia et al., 2008; Thomas et al., 2011). Additionally, rapid UVC surveys have been recognized for their utility in ichthyofaunal assessments, particularly in ecologically sensitive and underexplored habitats like rocky reefs (Rajan et al., 2021).

Biodiversity assessments in Indian waters have traditionally relied on data from fish landing centers or other extractive sampling techniques, limiting the scope for detecting species inhabiting deeper or structurally complex habitats. This study integrates previous biodiversity records with new data obtained through the UVC method, conducted at depths ranging from 1 to 12 meters. Additionally, an attempt was made to predict the potential occurrence of new species in deeper waters (15–30 m), providing a more comprehensive understanding of ichthyofaunal diversity. In contrast, the present study, utilizing the UVC method, documented several genera for the first time in Indian waters, including *Dendrochirus, Caprodon, Apogonichthyoides, Hemiglyphidodon, Neoglyphidodon, Diproctacanthus,* and *Cantherhines*. Furthermore, rarely observed genera such as *Parascorpaena, Cirrhitus,* and *Zebrasoma* were recorded, indicating the effectiveness of the UVC method in detecting species that may be overlooked in conventional sampling approaches.

The comparative analysis suggests that the application of UVC in deeper waters (15–30 m) may lead to new species discoveries, particularly in ecologically sensitive and underexplored marine ecosystems such as rocky reefs. Given the increasing threats to marine biodiversity from anthropogenic and climatic stressors, adopting non-invasive survey techniques such as UVC holds significant promise for enhancing biodiversity assessments. This approach can contribute to a more accurate representation of species distributions in related with habitat complexity. And also improve our overall understanding of marine ecosystem dynamics which facilitate the helps to develop the conservation plan and objectives for the present and future prospects.

The present study highlights the need for continued biodiversity monitoring and assessment in the present context of emerging threats including habitat degradation, climate change, industrial pollution, and overfishing. By providing baseline data for species distribution and richness, this study contributes to the broader efforts in marine conservation and resource management. Moving forward, integrating UVC-based monitoring with advanced remote sensing and ecological modelling approaches could further enhance biodiversity assessment and conservation strategies for India's coastal ecosystems.

Acknowledgements
We express our sincere gratitude to the Kerala State Welfare Department for their financial support, which made this study possible.

Competing Interests
The authors declare no competing interests.

Funding
This study has not received any external funding from public, commercial, or non-profit funding agencies. The research on rocky reef-associated ichthyofaunal diversity along the south Kerala coast was conducted as part of a Ph.D. program.

Conflict of Interest
The authors declare that there are no conflicts of interests.

Authors' Contributions
Baiju P. T. conducted the diving surveys, photographed specimens, identified species, and contributed to manuscript preparation.
Sethu M. R. prepared the study site map and performed statistical analyses.
Limna Mol V. P., Prabhakaran M. P., Benno Pereira F. G., and Jayaprakas V. contributed to manuscript revision.

Informed consent
Not applicable.

Ethical approval & declaration
In this article, the animal regulations followed as per the ethical committee guidelines of Department of Marine Biosciences, Kerala University of Fisheries and Ocean Studies (KUFOS), Panangad, Kochi – 682506, Kerala, India.; the authors observed the ichthyofaunal diversity and assemblages of south Kerala coast was studied by UVC method. Observations and identification of species done by underwater videography and photographs. The Animal ethical guidelines are followed in the study for species observation & identification.

Data and materials availability
All data associated with this study are present in the paper.

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