The Philippines

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Abstract

The Philippines is situated within the Coral Triangle marine biodiversity hotspot and supports highly diverse coral reef communities. However, Philippine reefs are exposed to many natural and anthropogenic disturbances. Consequently, mesophotic coral ecosystems (MCEs) have drawn increasing interest because of their potential significance as refugia for many reef species. MCEs in the Philippines occur in a variety of settings, reflecting the wide diversity of reef habitats within the archipelago. MCEs remain poorly studied compared to shallow reefs, but preliminary investigations show that MCE sites support diverse ecological communities. Here, we describe the physical features, biodiversity, and current condition of three MCE sites in the Philippines that occur in different environmental settings: surge-exposed fringing reefs at Patnanungan, turbid fringing reefs at Abra de Ilog, and the oceanic atolls of Apo Reef. Patnanungan is dominated by rubble fields with high macroalgae cover, an indication of destructive fishing and overexploitation of herbivorous fishes and invertebrates. Abra de Ilog is exposed to turbid waters due to two nearby rivers, and as a result, hard corals are not found below 30 m. Apo Reef, an oceanic atoll located within a marine park, supported higher abundance and diversity of benthic and mobile megafauna at mesophotic depths than the other two sites. MCEs are probably common throughout the Philippines, and future research should investigate additional sites, include long-term monitoring of factors driving spatial and temporal patterns of biodiversity, and investigate the potential importance of Philippine MCEs as refugia.

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Keywords

Mesophotic coral ecosystems · Biodiversity · Macroinvertebrate · Megafauna · Reef fish

15.1 Introduction

The Philippines is situated within the Coral Triangle, the epicenter of global marine biodiversity (Carpenter and Springer 2005; Veron et al. 2009; DeVantier and Turak 2017). The Philippine islands support a diverse range of different reef habitats from turbid fringing reefs to oceanic atolls. At least 468 identified species of scleractinian corals (Veron and Fenner 2002; Licuanan and Capili 2003, 2005), 736 reef fishes (Allen 2002; Nañola et al. 2006), 648 mollusks (Wells 2002), 16 seagrasses (Fortes and Santos 2004), and 820 marine algae (Trono 1999) have been recorded from the Philippines. Shallow-water reefs (SWRs) in the country are exposed to both natural and anthropogenic disturbances such as destructive fishing and land-based runoff, and the increasing frequency of disturbances is leading to declining reef health in many areas (White et al. 2000; Wilkinson 2008; Burke et al. 2012).

A nationwide assessment of SWRs in the 1990s highlighted the degraded state of many Philippine reefs (Gomez et al. 1994), a finding supported by more recent assessments of reef fishes (Nañola et al. 2011; Go et al. 2015) and corals (Licuanan et al. 2017). Continuing or accelerating habitat loss is increasing the extinction risk of important coral reef taxa such as fish (Graham et al. 2011) and corals (Carpenter et al. 2008). However, most coral reef research in the Philippines has been conducted in relatively shallow waters less than 10 m deep. The spatial extent, biodiversity, and conservation status of mesophotic coral ecosystems (MCEs; 30–150 m deep; Hinderstein et al. 2010) is largely unknown.

Considering the high biodiversity of SWRs in the Philippines and its location in the Coral Triangle, it has strong potential for harboring significant biodiversity at

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mesophotic depths. Indeed, in other areas of the Indo-Pacific, MCEs exhibit high regional endemism compared to nearby SWRs (e.g., Kane et al. 2014) and because they are poorly documented, often support a high proportion of undescribed species. The recent discovery of at least two new species of coral reef fishes from Philippine MCEs (Anderson et al. 2016; Rocha et al. 2017) highlights their likely biodiversity value. Consequently, increased knowledge of MCEs is important for understanding biodiversity and conservation status of coral reefs in the Philippines.

Herein, we describe the physical features, biodiversity, and current condition of three MCE sites in the Philippines that occur in different environmental settings: surge-exposed fringing reefs at Patnanungan, turbid fringing reefs at Abra de Ilog, and the oceanic atolls of Apo Reef.

15.1.1 Research History

Coral reef research in the Philippines started four decades ago and included the discovery and identification of a number of coral species in the Philippines by Francisco Nemenzo and his associates (Nemenzo 1986). Since then, major efforts on coral reef research continued, spearheaded by two prominent coral reef scientists, Edgardo D. Gomez and Angel C. Alcala (1979). Pioneering studies were conducted and influenced the establishment of marine protected areas on coral reef fish communities (Alcala 1988). Also, one of the first countrywide coral reef assessments in the world was initiated (Gomez and Alcala 1979; Gomez et al. 1994). The status of coral reef ecosystems in the Philippines were monitored in the succeeding years (Yap and Gomez 1985; Gomez 1991; Gomez et al. 1994; Nañola et al. 2006, 2011; Go et al. 2015; Licuanan et al. 2017). However, all of these studies had focused on SWRs with a maximum depth of 10 m.

The earliest known study on MCEs in the Philippines was conducted by Ross and Hodgson (1981) to quantify coral diversity and percent cover in a depth range of 3–35 m in Apo Reef Natural Park, Philippines. While little is known about Philippine MCEs, significant efforts have been recently made to address this research gap. The Geophysical Coral Reef Mapping (GCM) project of the Marine Science Institute of the University of the Philippines, which includes geological, oceanographic, and biological components, is the first major MCE research project in the Philippines. Together with the MCE assessment efforts of other institutions in the Philippines (Abesamis et al. 2017; Nacorda et al. 2017), 15 MCE sites have been studied systematically to date (Fig. 15.1), spanning a broad range of environmental settings from coastal fringing reefs such as Abra de Ilog to Benham Rise, a deep, submerged bank located far offshore. Analysis of data collected by GCM is still ongoing, but detailed observations from three sites in different environmental contexts are presented below. A brief summary of information on all 15 MCE sites examined is shown in Table 15.1.

Data collected during the GCM includes geomorphological maps of the study sites and oceanographic data surveys of fish and benthic communities. Bathymetric maps of the sites were collected using a multibeam echosounder and side-scan sonar. The raw multibeam data were acquired and processed through HYPACK and HYSWEEP software to produce the final gridded bathymetric datasets. Oceanographic data on spatial flow, temperature and salinity profiles were also collected. The degree of water column stratification can be estimated using the temperature and salinity profiles indicating the magnitude of the vertical variations and the degree of mixing in the water column. Biodiversity surveys of fish and benthic communities were limited to the upper mesophotic zone (30–40 m depth) using SCUBA, while surveys greater than 40 m were conducted using remotely deployed videos (RDV; 30–40 m) and remotely operated vehicles (ROVs; 50–200 m). For benthic diversity surveys, 1 × 1 m photoquadrats were taken every 1 m along a 30 m transect (total surveyed reef area per transect = 30 m^2). To quantify benthic community composition, a uniformly spaced grid of 25 points was overlaid onto each photoquadrat, and the benthic category that fell under each point was categorized. Fish diversity surveys were conducted simultaneously with benthic surveys and involved a single diver noting counts and size of all fishes encountered within 5 m on either side of the 30 m belt transect (total surveyed reef area per transect = 300 m^2).

15.2 Environmental Setting

The Philippines experiences a tropical climate, with seasonal changes in temperature, humidity, and rainfall brought about by monsoonal variations. The Philippines is exposed to monsoonal climate and tides, responding to various physical oceanographic factors (e.g., water and wind circulation) from the South China Sea and the West Pacific that make the country prone to tropical cyclones (Gordon et al. 2011). The archipelagic nature of the Philippines results mainly from its active tectonic setting evolving from a complex assemblage of accreted island arcs, marginal basins, oceanic crusts, and continental terraces (Karig 1983; McCabe et al. 1987).

Coral reefs in the Philippines are exposed to surface water current systems driven by monsoon winds. There are two main seasons: the northeast monsoon from November to mid-April and southwest monsoon from July to mid-October.

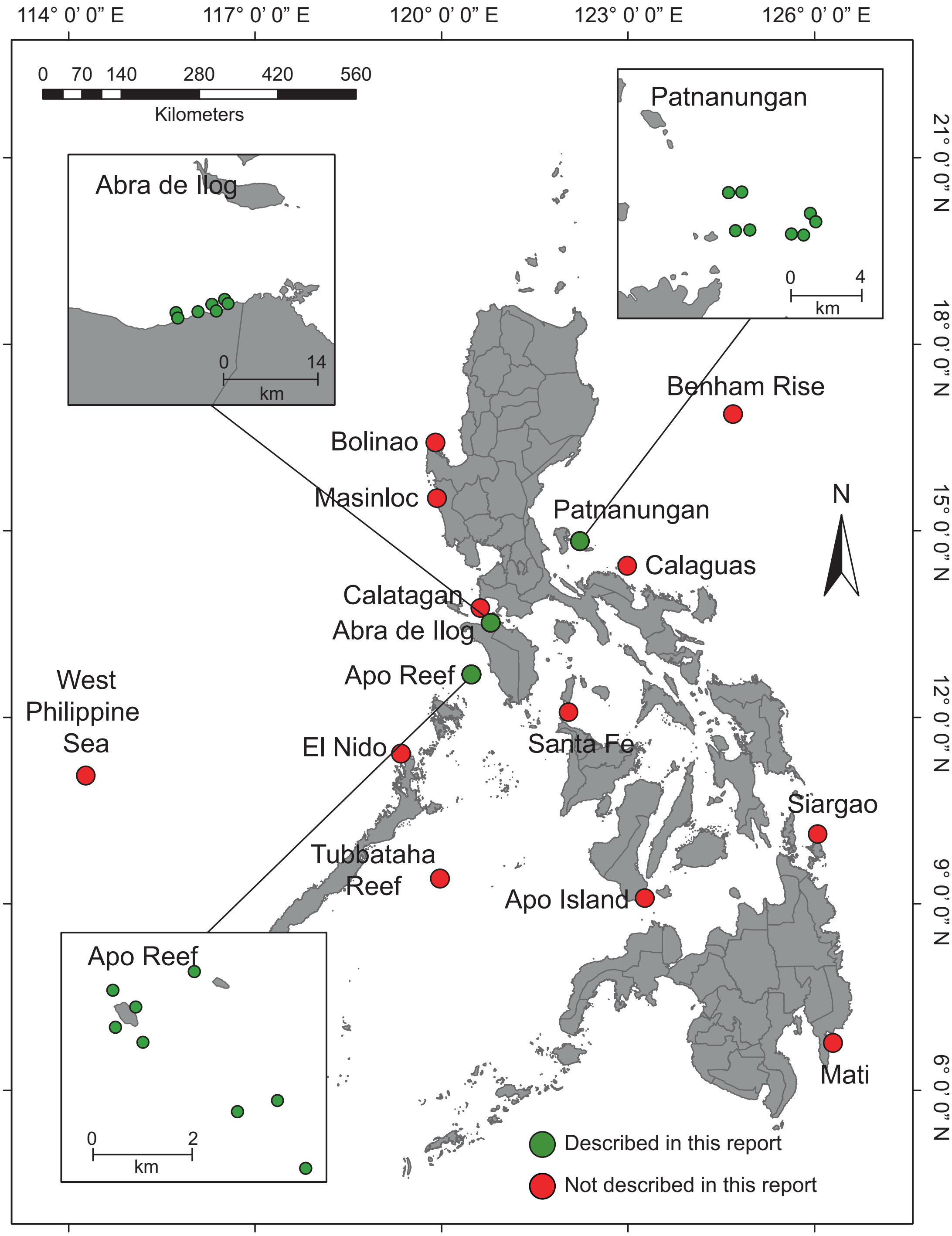

Fig. 15.1 Locations of MCEs in the Philippines surveyed as part of the GCM project of the Marine Science Institute of the University of the Philippines. Green circles show the location of sites described herein

During inter-monsoonal periods, which occur from March to June and in October, there is no predominant wind direction. Initial observations indicate upwelling around Abra de Ilog (Fig. 15.2) and Apo Reef (Fig. 15.3), which may enhance connectivity between MCEs and SWRs and contribute to the productivity and diversity in these areas, although this hypothesis remains to be tested.

15.3 Habitat Description

Most of the coral reefs in the Philippines consist of fringing reefs that vary in size from tens of meters to up to 5 km (Gomez et al. 1994). A few atoll reef systems have been studied and are protected as natural parks, such as the Tubbataha Natural Park

Table 15.1 Summary of information of the MCE sites

Site	Continuity with SWRs	Geological characteristics	Physical characteristics	Biological characteristics	Limits of coral dominance	Methods	Research conducted by
*Abra de Ilog	Yes	Fringing reefs; dominated by extensions of valleys and headlands; sediments were mostly fine and muddy	Upwelling area; water movement influenced by monsoons	Community structure of corals and fishes; presence/absence data on other benthic organisms	30 m	Diver-based surveys and ROV surveys	UP, Marine Science Institute
Apo Island	Yes	Fringing reefs	Unknown	Fish community structure	Unknown	BRUVS	Silliman University
*Apo Reef	SWRs in fringing reefs are continuous with MCEs	Fringing and atoll reefs; terraces and scarps present; carbonate sediments	General current direction from the south moving toward the lagoon area; thermally stratified water column	Community structure of corals and fishes; presence/absence data on other benthic organisms	60–70 m	Diver-based surveys and ROV surveys	UP, Marine Science Institute
Benham Rise	No	Atoll reefs	Data currently undergoing analyses	Fish community structure; presence/absence data on coral genera and other benthic organisms	Unknown	BRUVS and ROV surveys	UP, Los Baños; UP, Marine Science Institute; OCEANA
Bolinao	Yes	Fringing reefs	Data was not collected	Presence/absence of coral genera and fish species	40 m	RDV and diver-based surveys	UP, Marine Science Institute
Calaguas	Yes	Fringing reefs; gentle slope with three terraces in the mesophotic zone	Data currently undergoing analyses	Community structure of corals and fishes, and other benthic organisms	Unknown	Diver-based surveys and ROV surveys	UP, Marine Science Institute
Calatagan	Yes	Fringing reefs; distant features such as pinnacles and mounds present	Temperature profiles indicate a uniform water column; salinity profiles indicated a freshwater lens occurs at 2–4 m depth, near the surface	Presence/absence of coral genera and other benthic organisms	Unknown	Drop cameras and RDVs	UP, Marine Science Institute
El Nido	Yes	Fringing reefs	Data was not collected	Coral community structure; presence/absence of other benthic organisms	Unknown	Diver-based surveys and drop cameras	UP, Marine Science Institute
Masinloc	Yes	Fringing reefs	Data was not collected	Community structure of corals and fishes; presence/absence data on other benthic organisms	Unknown	RDV and diver-based surveys	UP, Marine Science Institute
Mati	Yes	Fringing reefs	Data was not collected	Coral community structure and presence/absence of other benthic organisms	Unknown	Diver-based surveys and drop cameras	UP, Marine Science Institute

(continued)

Table 15.1 (continued)

Site	Continuity with SWRs	Geological characteristics	Physical characteristics	Biological characteristics	Limits of coral dominance	Methods	Research conducted by
*Patnanungan	Yes	Fringing reefs; debris lobes, paleochannels, smooth seafloor, and terraces present; seafloor has carbonate and silicate materials	General current direction is toward the island; small variation in the temperature-salinity profile, indicative of mixing during the ebb tide	Community structure of corals and fishes; presence/absence data on other benthic organisms	Dominated by algae in SWRs and MCEs	Diver-based surveys and ROV surveys	UP-Marine Science Institute
Santa Fe	Yes	Fringing reefs	Data was not collected	Coral community structure; presence/absence of other benthic organisms	Unknown	RDV surveys	UP, Marine Science Institute
Siargao	Yes	Fringing reefs	Data was not collected	Coral community structure; presence/absence of other benthic organisms	Unknown	Diver-based surveys and drop cameras	UP, Marine Science Institute
Tubbataha Reefs	No	Atoll reefs	Data currently undergoing analyses	Presence/absence of coral genera and fish species	100 m	ROV surveys	UP, Marine Science Institute
West Philippine Sea	No	Atoll reefs	Data currently undergoing analyses	Community structure of corals and fishes, and other benthic organisms	Unknown	Diver-based and RDV surveys	UP, Marine Science Institute

Sites marked with * are described in more detail in the text
BRUVS baited remote underwater video system, *RDV* remotely deployed videos, *UP* University of the Philippines

(Dygico et al. 2013) and Apo Reef Natural Park (Quimpo et al. 2018a). A number of patch reefs are located in the western Philippines, particularly in the Spratly Islands, locally known as the Kalayaan Islands (Alino and Quibilan 2003).

The high diversity of SWRs in the Philippines undoubtedly extends into mesophotic depths, resulting in strong regional differences in MCE communities. The 15 sites examined during the GCM aimed to capture some of the variation in MCE habitats and span a diverse range of reef environments from the deep slopes of fringing reefs to submerged banks. The geologic setting can strongly influence the characteristic geomorphology of each site. For example, some fringing reefs support continuous reef habitat extending into mesophotic depths, while others exhibit a wide span of sandy area that separates MCEs from SWRs. In Apo Reef Natural Park, an oceanic atoll, SWRs are separated from MCEs, which are concentrated on the edges of reef terraces separated by steep scarps. Multibeam bathymetric maps have revealed the existence of these terraces and scarps at multiple depth intervals between 40 and 150 m around all three sites, interpreted as the crests of reefs that were drowned by postglacial sea level rise. Such terraces and reef scarps are common antecedent structures that constitute an important substrate for MCEs.

Three sites surveyed during the GCM were submerged banks located offshore with no contiguous SWRs: in West Philippine Sea, some sites in Apo Reef, and Benham Rise. Benham Rise, recently renamed the Philippine Rise, is a 13 million-hectare undersea plateau (Nacorda et al. 2017) which rises from 3000 m to ~50 m at its shallowest point and is known to support very high coral cover. Most of the other sites represent the lower reef slopes of SWRs. Here, we present a detailed description of the three main study sites of GCM: Patnanungan, Abra de Ilog, and Apo Reef (Fig. 15.1). The three sites were selected because they differ greatly in geological setting, environmental conditions, disturbance history, and human population density (Fig. 15.4). These three sites, however, all had seafloors in the upper mesophotic zone (30–40 m) dominated by dead corals and abiotic features, including coral rubble, sand, and silt (Figs. 15.5 and 15.6).

Patnanungan reef is a fringing reef situated on an uplifted island on the Pacific side of the Philippines underlain by siliciclastic sedimentary rocks within the Bicol Shelf (Karig 1983; Lewis and Hayes 1983). The shallow fringing reef at Patnanungan is exposed to strong surge and current from the Pacific (Carpenter 1998). High-resolution multibeam bathymetry shows submerged paleochannels at the shallowest portion of the reef. Terraces also occur at depths of 20–30 m, 40 m, and 80–90 m and are separated by steep scarps where slumps and debris lobes were observed. The terraces in Patnanungan could be drowned coastal plains. Algal cover in these terraces are relatively high (59%) com-

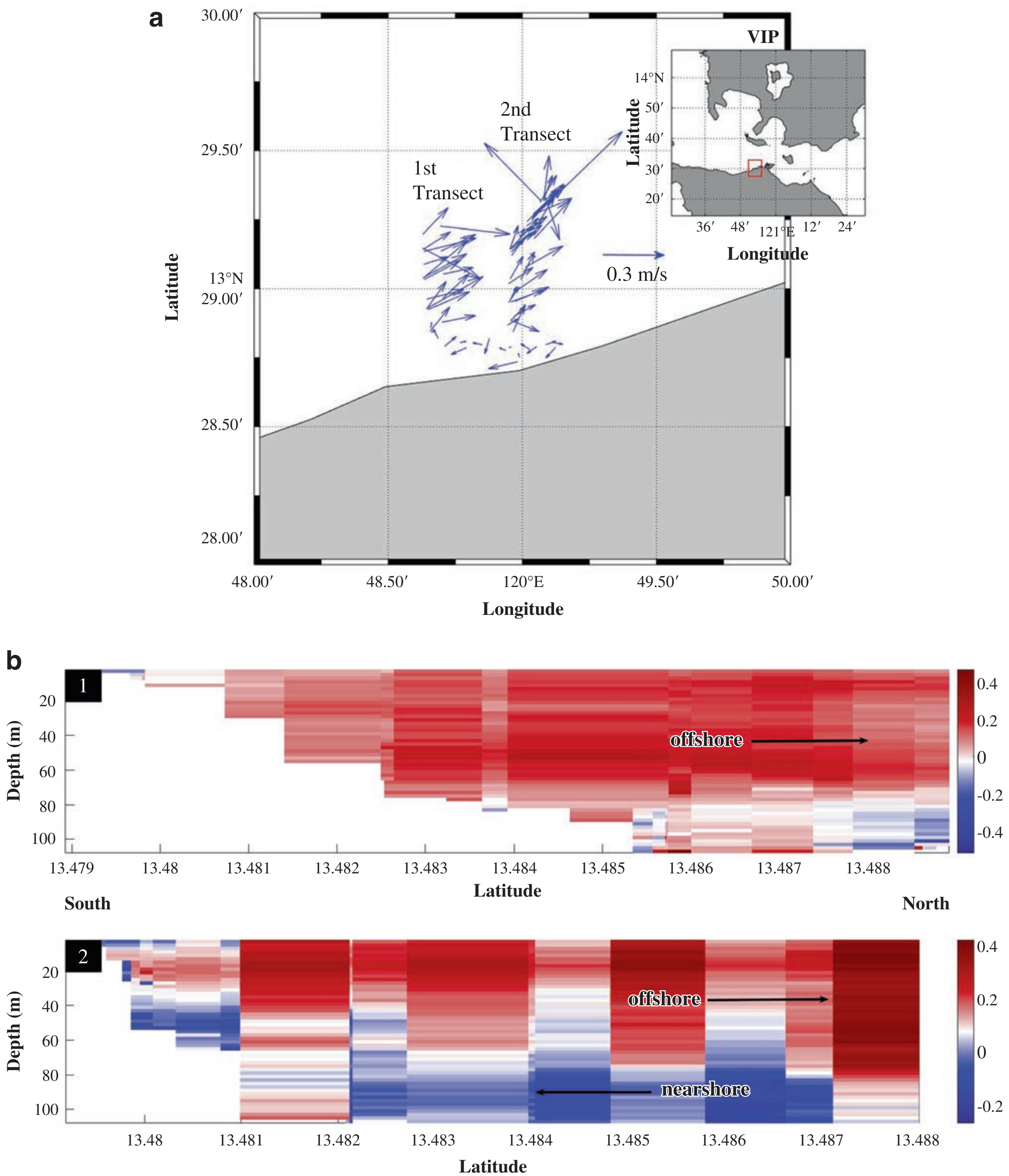

Fig. 15.2 Surface current velocities (**a**) and indicators of upwelling around Abra de Ilog based on depth-latitudinal flow (**b**). In (**b**), color contour represents meridional velocity of mean current for two transects (labeled 1 and 2); the red color indicates northward motion, while the blue color indicates southward motion. Looking at the meridional component of flow, that is, the north-south component of flow, the upper 70 m of the water column is predominantly moving to the north away from the coast, while the water column below is moving to the south or toward the coast. This combination of flow is indicative of upwelling along the coast

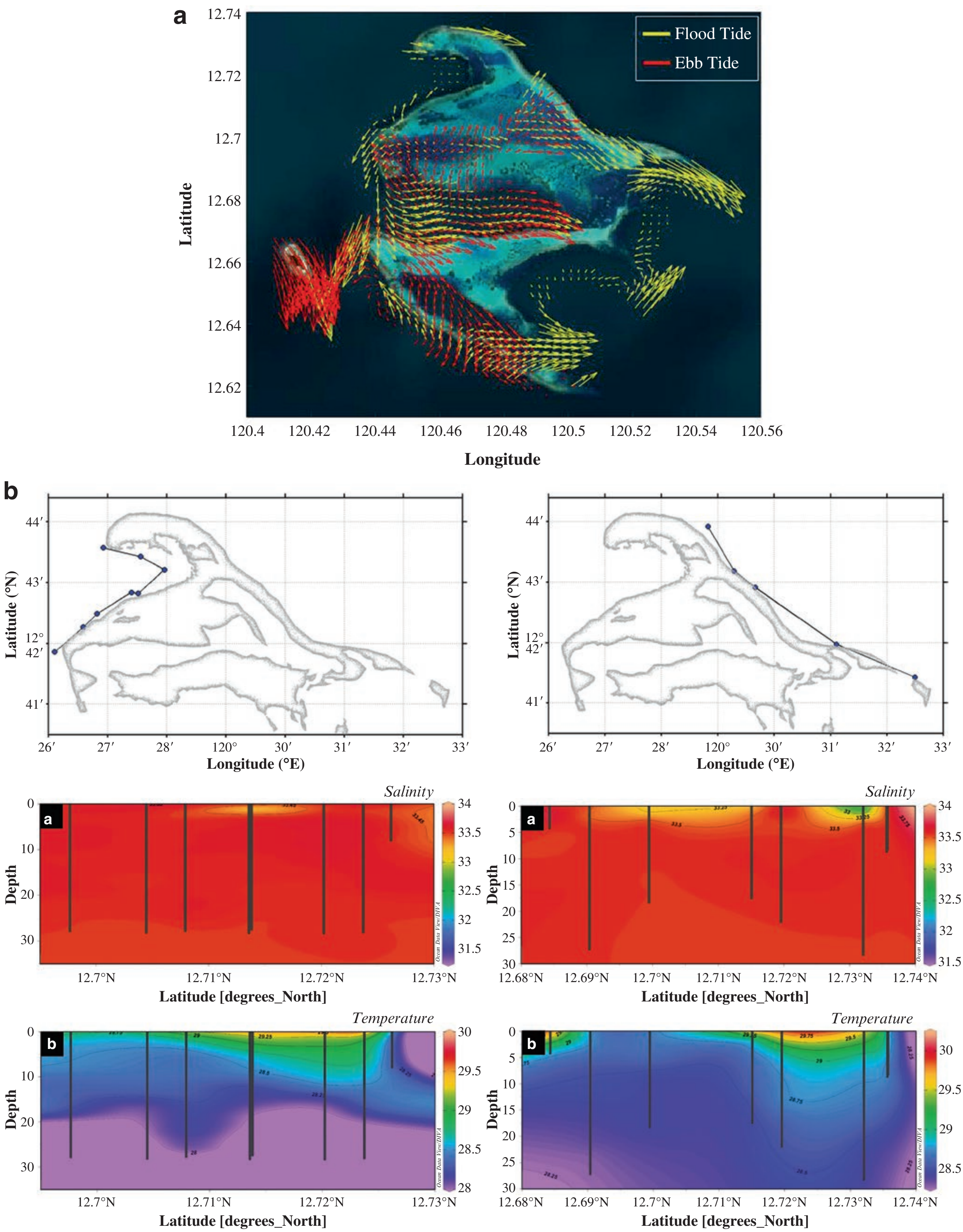

Fig. 15.3 Surface current velocities (**a**) and indicators of upwelling around Apo Reef based on salinity and temperature cross-sectional plots (**b**). In (**b**), maps represent sampling locations. Temperature plots show that the colder water temperatures dome toward the surface, indicating the presence of an upwelling

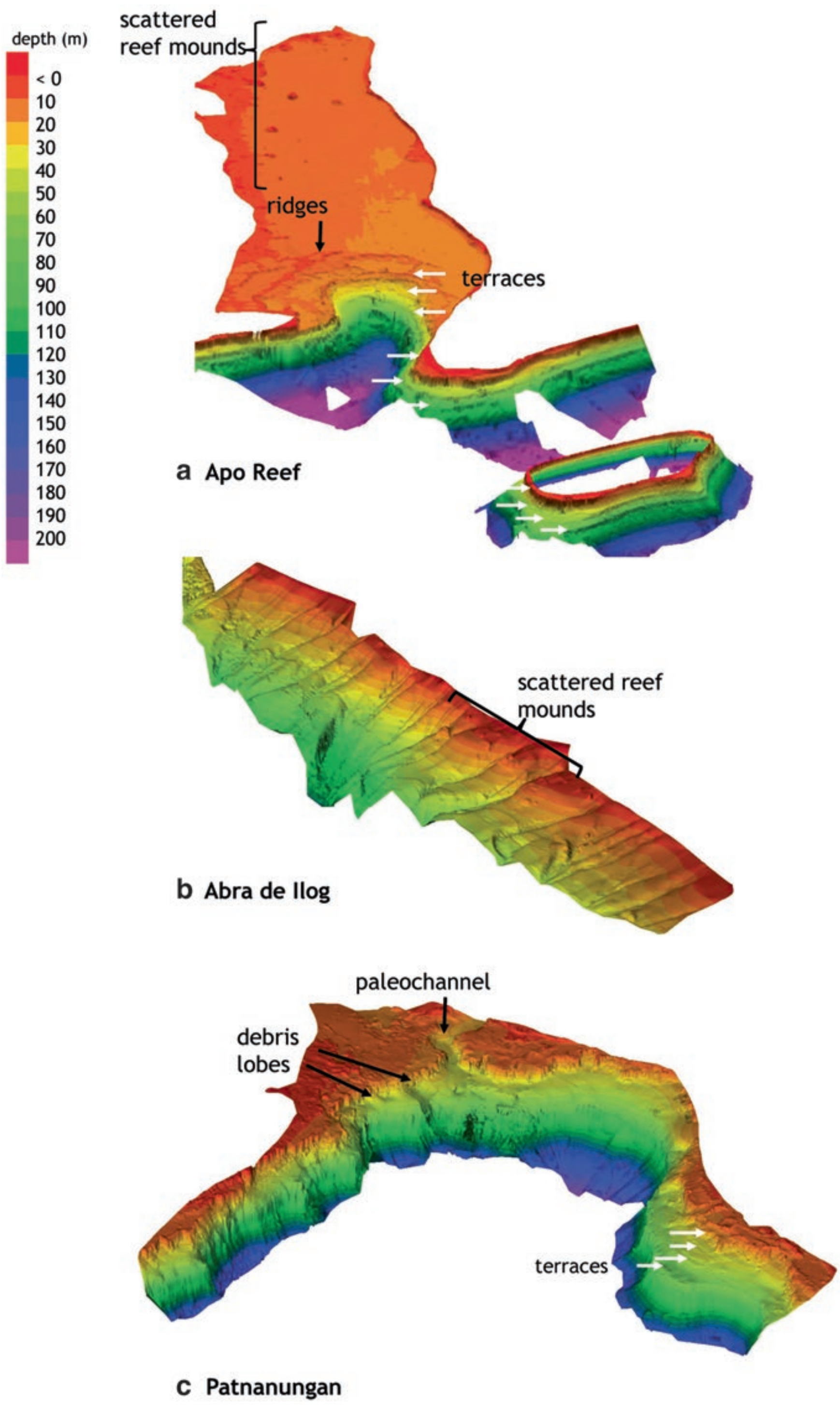

Fig. 15.4 Multibeam bathymetry maps of the study sites at Apo Reef (**a**), Abra de Ilog (**b**), and Patnanungan (**c**) showing the complexity of each reef's morphology. Geomorphic features such as terraces and scarps (white arrows), ridges, debris lobes, and paleochannels are indicated

prised mostly of turf algae, *Padina*, and *Halimeda*. Abundant sea fans, such as *Stylaster*, are found in steep scarps.

Abra de Ilog is located in the Verde Island Passage within the southern extent of the Macolod Corridor, a rift zone (Oles et al. 1991; Pubellier et al. 2000; Ohkura et al. 2001). The Verde Island Passage, the center of marine biodiversity in the Philippines (Carpenter and Springer 2005), is strongly influenced by terrestrial runoff. SWRs in Abra de Ilog are not extensive and do not have a reef flat. The MCEs in Abra de Ilog receive sediment from two nearby rivers that drain the northern flanks of Mindoro Island. Consequently, the occurrence of MCEs is patchy and appears to be dependent

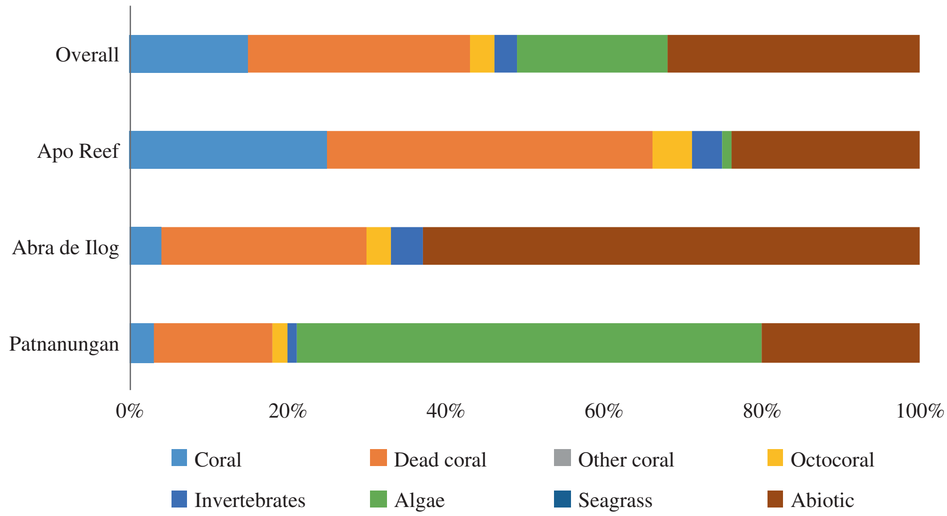

Fig. 15.5 Benthic community composition (% cover) in three MCE sites

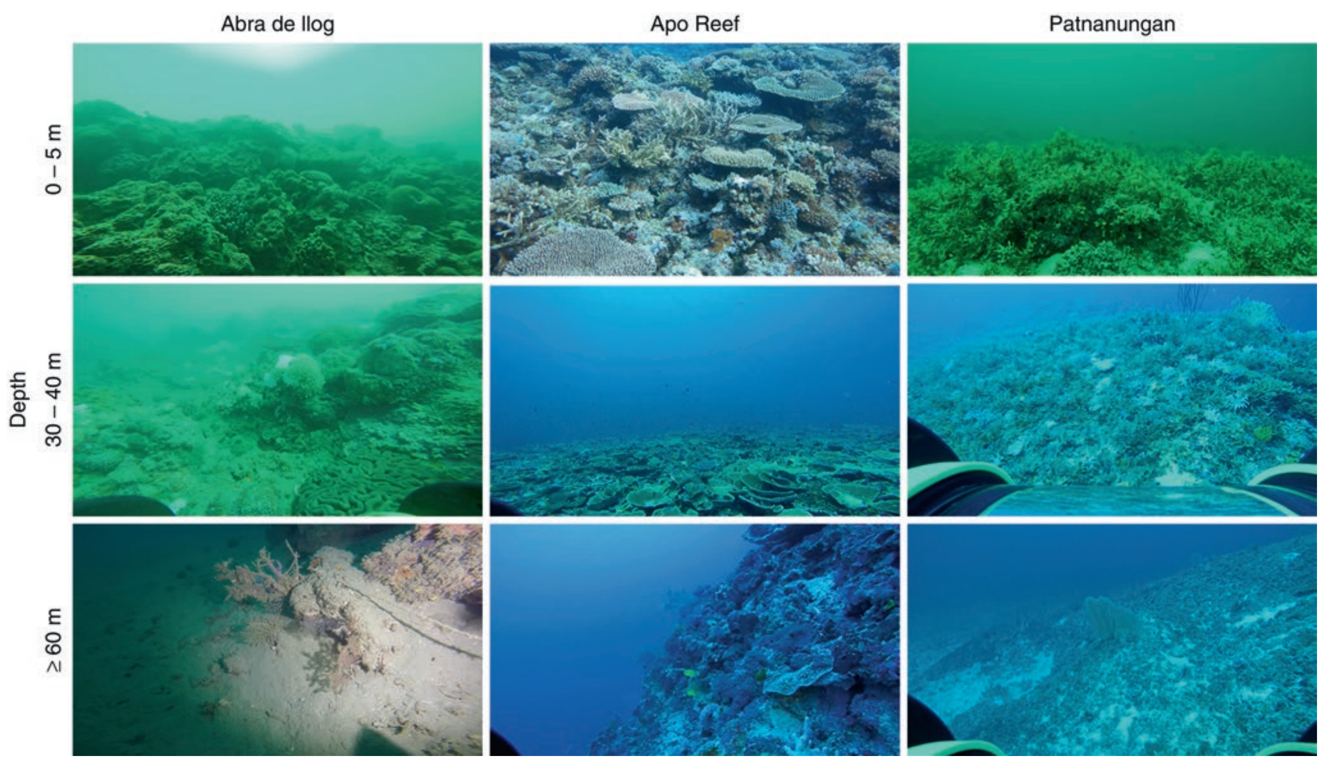

Fig. 15.6 Sample snapshots at each surveyed MCE site across depths, illustrating changes in benthic community composition. (Photo credits: Ronald Dionnie D. Olavides)

on rock outcroppings above the muddy siliciclastic sand. Due to this, dead corals and abiotic features dominate the benthos. Sea fans, sea whips, soft corals, calcareous algae, and sponges are observed, along with some encrusting and foliose forms of *Montipora* and *Porites*, in patch reefs at 40 m depth.

Apo Reef is located 15 km west of the island of Mindoro in the Mindoro Strait and is situated near a descending oceanic plate toward the Manila Trench. Apo Reef is composed of two adjacent atolls and a smaller emergent limestone island surrounded by fringing reefs. The two atolls both contain a smaller limestone island and are separated by a channel which deepens and opens to the west. Multiple terraces and ridges were generally observed between 40–50 m, 70–80 m, and ~150 m which separate several reef communities from each other. These terraces occur on the atoll walls, the broad shallow platforms on the west side of the channel, and the east side of Apo Reef. Due to its offshore location, Apo Reef receives little terrestrial sediment. Encrusting and foliose forms of corals and gorgonians dominate the reef walls and rocky transitions of these terraces. Beyond 60 m depth, few hydroids, sponges, and sea fans are conspicuous. Apo Reef is located in a national park and is a nominated UNESCO World Heritage site. It is one of the largest "no-take" marine protected areas in the country, and permanent human settlements are not permitted on the island (Weeks et al. 2010; Tabaranza et al. 2014).

15.4 Biodiversity

15.4.1 Macroalgae

The biodiversity of algae in MCEs in the Philippines has not been explicitly surveyed. In our assessment of benthic habitats, few species of algae could be identified, but further work may uncover diversity of algae. Algae assemblage was different across sites, with Apo Reef having the most diversity, followed by Patnanungan and Abra de Ilog. In Apo Reef, at least seven algae species were identified: *Caulerpa racemosa*, *Claudea* sp., *Halimeda macroloba*, *Halimeda opuntia*, *Halymenia durvillei*, *Halymenia maculata*, and *Portieria hornemannii*. Four species were observed in Patnanungan at a depth range of 30–40 m, characterized by thick beds of *Sargassum* along with other brown algal species such as *Padina japonica*, *P. australis*, and *P. minor*. In Abra de Ilog, the algal assemblage was mostly filamentous brown algae that grew in coral debris. These algae were not identified taxonomically because of the lack of morphologically distinct features.

Table 15.2 Coral genera recorded in three upper mesophotic (30–40 m) sites in the Philippines

Family/genera	Apo Reef	Abra de Ilog	Patnanungan
Acroporidae			
Acropora	x	x	x
Anacropora	x		
Astreopora	x		
Isopora			x
Montipora	x	x	
Agariciidae			
Gardineroseris	x		
Leptoseris	x	x	x
Pachyseris	x	x	x
Pavona	x		
Pectinia	x		
Dendrophylliidae			
Duncanopsammia			x
Tubastrea	x		
Turbinaria	x		
Diploastreidae			
Diploastrea	x		
Euphylliidae			
Catalaphyllia			x
Euphyllia	x		
Galaxea	x		
Physogyra			
Plerogyra	x	x	x
Faviidae			
Cyphastrea			
Favia	x		x
Goniastrea	x		
Montastrea	x		x
Moseleya			x
Fungiidae			
Ctenactis	x		
Fungia	x	x	x
Heliofungia	x		
Lithophyllon			
Podabacia			
Helioporidae			
Heliopora[a]	x		
Lobophylliidae			
Lobophyllia	x		
Merulinidae			
Echinopora	x		
Favites	x		x
Merulina	x		x
Oulophyllia	x		
Platygyra	x		
Mussidae			
Scolymia			
Symphyllia	x		
Pectiniidae			
Echinophyllia	x		x
Mycedium	x		
Oxypora	x	x	
Pocilloporidae			
Pocillopora	x		
Seriatopora	x		x
Stylophora			
Poritidae			
Alveopora	x		
Goniopora			
Porites	x	x	x
Siderastreidae			
Psammocora			
Stylasteridae			
Stylaster[a]			x
Trachyphylliidae			
Trachyphyllia	x		x
Tubiporidae			
Tubipora[a]	x		x
Total # of families (18)	16	6	13
Total # of genera (51)	38	8	19

[a]Non-scleractinian coral

15.4.2 Anthozoans

At least 46 coral genera from 16 families were identified from the three upper mesophotic sites (30–40 m depth) from diver-based surveys: 38 genera in Apo Reef, 8 in Abra de Ilog, and 19 in Patnanungan (Table 15.2). *Porites* was the most abundant genus at all sites, which comprised about 42% of all coral colonies recorded in surveyed photoquadrats, followed by *Acropora* (10%) and *Seriatopora* (9%). Similarly, coral density (individuals per m^2) was highest at Apo Reef, followed by Abra de Ilog and Patnanungan. Other common corals at mesophotic depths were *Mycedium*, *Leptoseris*, and the azooxanthellate *Tubastraea micranthus*. *Seriatopora hystrix* and *Porites rus* were both relatively common on both shallow and mesophotic reefs.

The dominant morphology of *Porites* varied with depth, with encrusting and foliose forms in the MCEs compared to massive and branching forms in the SWRs. Encrusting and foliose corals were the most abundant growth forms at mesophotic depths at all sites, a response to the reduced light irradiance in the mesophotic zone (Lesser et al. 2009).

Azooxanthellate corals were also observed in the study sites; however, these were not taxonomically classified; instead, they are described by their common names. All of the azooxanthellate corals (i.e., black corals, soft corals, sea fans, sea whips, and gorgonians) were not abundant in all the sites surveyed. They were particularly rare at a depth range of 30–40 m; however, beyond 40 m up until a depth of 165 m, they were frequently observed with the ROV, although the maximum depth range that they occupied was highly site specific. For example, their maximum depth range in Abra de Ilog was 47 m, 146 m for Apo Reef, and 165 m for Patnanungan (Fig. 15.7).

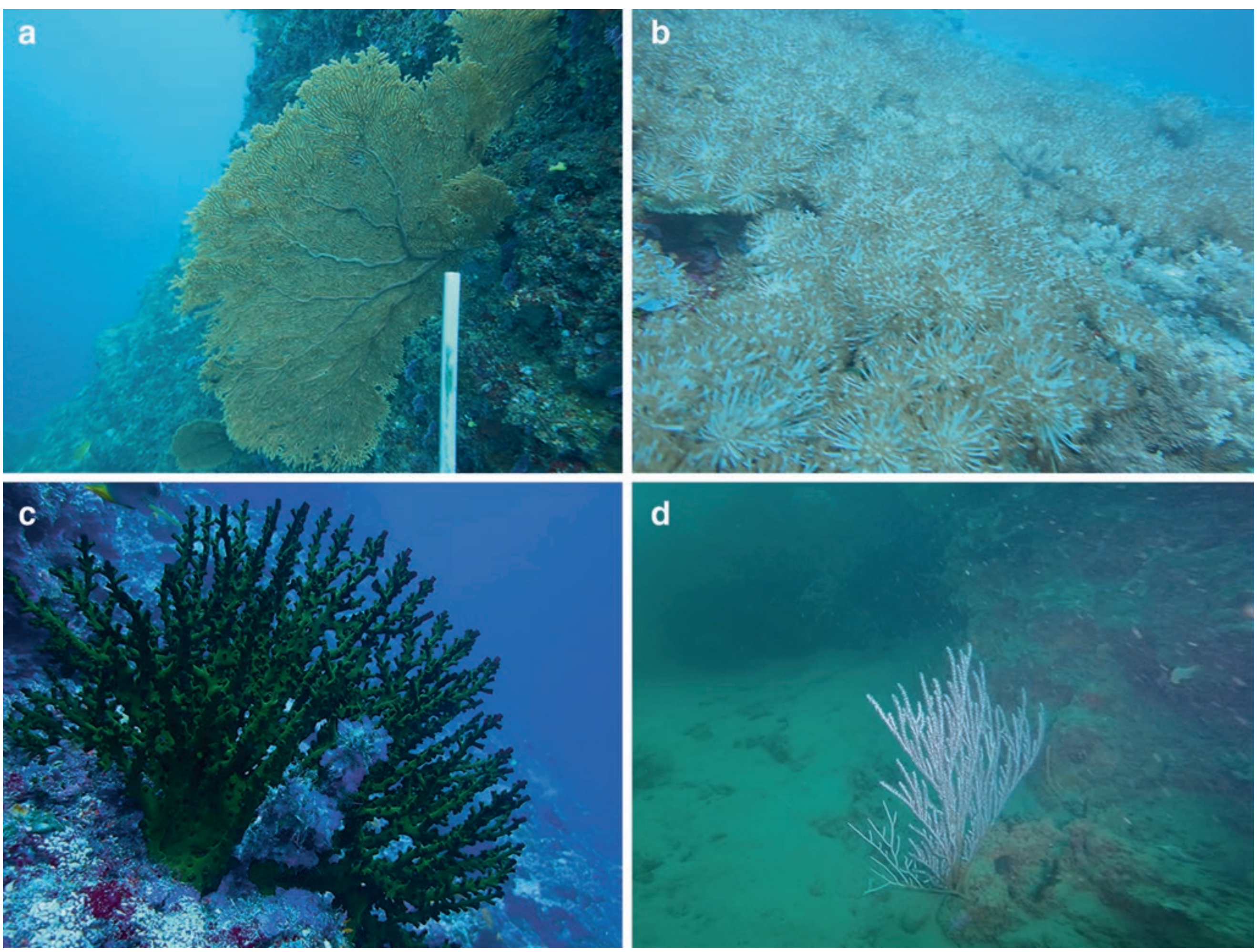

Fig. 15.7 Gorgonian coexisting with *Sargassum* algae at MCE in Patnanungan (**a**), soft coral beds (**b**) and *Tubastrea micranthus* at MCE in Apo Reef (**c**), and gorgonian at MCE in Abra de Ilog. (Photo credits: Edwin E. Dumalagan Jr.)

15.4.3 Sponges

Sponges were observed in MCEs in all the sites; however, these were not taxonomically identified as observations were done using ROV. In all three sites, Apo Reef had the most diverse morphology of mesophotic sponges. We observed four different morphologies: basket, vase, flat, and barrel sponges (presumably of the genus *Xestospongia*). In Patnanungan, only two sponge morphologies were observed: epiphytic with the macroalgae *Sargassum* and encrusting. In Abra de Ilog, only encrusting sponges were observed; however, they were covered with silt. The maximum distribution of sponges was highly site specific. For instance, the maximum distribution in Abra de Ilog was 47 m, while in Apo Reef, it was 60 m. In Patnanungan, sponges were only observed via SCUBA, which was confined to a depth range of 30–40 m.

15.4.4 Fishes

Based on diver-based visual censuses, fish species richness generally decreased with depth across all sites, with 140 species from 23 families observed in 30–40 m depth and 35 species in 17 families at 40–100 m (Table 15.3). The lower species richness at depths >40 m may be attributed to a number of factors including lower sampling effort at these depths where only RDVs and ROVs were used, vehicle avoidance, and time of sampling. Only two species were observed beyond 100 m—the pelagic thresher shark (*Alopias pelagicus*) and an unidentified cardinalfish (family Apogonidae). Although 16 species of apogonids are known to occupy depths of 100–290 m in the Indo-Pacific (Froese and Pauly 2017), the unidentified cardinalfish may be a new species. Unfortunately, the poor quality of the image obtained from the ROV precluded accurate species-level identification.

Species richness (Table 15.3) in the upper mesophotic zone (30–40 m) was highest at Apo Reef, followed by Abra de Ilog and Patnanungan (Quimpo et al. 2018b). Planktivorous fishes were the most abundant trophic group across all sites (Fig. 15.8). The dominant planktivores at Apo Reef were *Chromis margaritifer*, *Acanthurus thompsoni*, and *Dascyllus reticulatus* (see Fig. 15.9 for other species of planktivorous fishes). At Abra de Ilog, the most abundant planktivores were *Pomacentrus brachialis*, *Amblyglyphidodon aureus*, and *A. leucogaster*, while *Sufflamen chrysopterus*, *Pseudanthias pleurotaenia*, and *P. coelistes* were the most dominant in Patnanungan.

On the other hand, the trophic group with the highest fish biomass varied in the different sites. In Abra de Ilog, omnivores had the highest fish biomass, attributed primarily to two snapper species (*Lutjanus lutjanus* and *Lutjanus* sp.). In Apo Reef, the planktivores, benthic invertivores (*Paracaesio xanthura* and *Cheilinus undulatus*), and piscivores (*Sphyraena barracuda* and *Gymnosarda unicolor*) had the highest biomass. In Patnanungan, there was no discernible differences in biomass across the trophic groups, probably because fish biomass overall was low due to the degraded state of the site and high fishing pressure.

15.4.5 Other Biotic Components

Four species of macrobenthic mobile fauna were observed in Apo Reef, including three species of Holothuroidea (sea cucumbers *Holothuria atra*, *H. ananas*, and *H. rubralineata*) and one species of sea star (*Thromidia catalai*). Most of these individuals were observed at a depth range of 30–40 m, except for *H. atra* which was observed at 79 m.

15.5 Ecology

Coral cover was low (3–4%) in Patnanungan and Abra de Ilog but was higher at Apo Reef (~25%). The coral cover in these MCEs is comparable to most of the SWRs in the Philippines, where coral cover is below 50% (Licuanan et al. 2017). Algal cover was relatively high (59%) at Patnanungan, which may be considered a mesophotic algae reef system (Lesser and Slattery 2011). The depth at which benthic composition transitions from being dominated by phototrophic taxa such as corals to filter feeders (e.g., sponges or azooxanthellate soft corals) varied at the different sites and appeared to be related to water clarity. The transition in Abra de Ilog, a site located between two rivers, occurred at a depth of ~30 m, whereas in Apo Reef, the transition occurred at 60 m (Fig. 15.6). There was no obvious transition observed in the MCEs at Patnanungan, with algae dominant on both SWRs and MCEs, perhaps because of the high water clarity. Dynamite fishing, which is still rampant in the area, and the low abundance of herbivorous fishes also likely contribute to the rubble fields and the proliferation of algae in Patnanungan.

Below 40 m depth, only qualitative descriptions based on ROV surveys were conducted because of the difficulty in standardizing the sampling area (e.g., the ROV must be kept at a minimum distance from the benthos to systematically sample a quadrat), and the resolution of ROV images was not sufficient to identify benthic organisms to species. Hence, common names were used to describe the benthic fauna observed. In Abra de Ilog, taxa observed beyond 40 m included sea fans, sea whips, soft corals, black corals, calcareous algae, and sponges. No sessile benthic fauna were observed from 47 to 61 m, where the substrate was composed of fine sand with burrows. In Apo Reef, hard corals were observed up to a depth of 60–70 m. Some conspicuous coral genera (e.g., encrusting and foliose *Montipora* and *Porites*) could be identified from the ROV images. Beyond

Table 15.3 Fish species recorded at 30–40 m and 40–100 m depths in three mesophotic sites in the Philippines

Families/species	Apo Reef		Abra de Ilog		Patnanungan	
	30–40	40–100	30–40	40–100	30–40	40–100
Acanthuridae						
Acanthurus auranticavus			x		x	
Acanthurus japonicus	x	x				
Acanthurus pyroferus	x				x	
Acanthurus sp.			x			
Acanthurus thompsoni	x	x				
Ctenochaetus binotatus	x		x		x	
Ctenochaetus striatus	x					
Naso hexacanthus	x	x				
Naso lituratus	x					
Naso minor						x
Naso vlamingii	x					
Unidentified						x
Zebrasoma scopas	x					
Zebrasoma veliferum	x					
Alopiidae						
Alopias pelagicus		x				
Apogonidae						
Unidentified						x
Balistidae						
Balistoides conspicillum					x	
Odonus niger	x	x				x
Sufflamen bursa	x				x	x
Sufflamen chrysopterus			x		x	
Unidentified						x
Xanthichthys auromarginatus	x					
Caesionidae						
Caesio cuning	x					
Caesio teres	x	x				
Pterocaesio pisang			x	x	x	
Pterocaesio tile	x	x		x		
Unidentified						x
Carangidae						
Caranx lugubris	x					
Caranx sexfasciatus	x			x		
Chaetodontidae						
Chaetodon auriga	x					
Chaetodon baronessa	x					
Chaetodon burgessi					x	
Chaetodon kleinii	x	x	x		x	x
Chaetodon lunulatus	x					
Chaetodon melannotus	x					
Chaetodon octofasciatus						
Chaetodon ornatissimus	x	x				
Chaetodon punctatofasciatus	x	x				
Chaetodon speculum	x					
Chaetodon unimaculatus	x					
Chaetodon xanthurus			x			
Coradion melanopus			x			
Forcipiger flavissimus			x			
Forcipiger longirostris	x	x				
Hemitaurichthys polylepis	x	x				
Heniochus acuminatus	x		x			x

(continued)

Table 15.3 (continued)

Families/species	Apo Reef		Abra de Ilog		Patnanungan	
	30–40	40–100	30–40	40–100	30–40	40–100
Heniochus chrysostomus	x					
Heniochus monoceros	x					
Heniochus varius	x					
Unidentified						x
Dasyatidae						
Taeniura lymma			x			
Haemulidae						
Plectorhinchus lineatus						x
Holocentridae						
Myripristis botche	x					
Myripristis murdjan	x					
Myripristis sp.			x			
Sargocentron caudimaculatum	x					
Sargocentron melanospilos			x			
Sargocentron sp.			x			
Labridae						
Bodianus mesothorax	x		x			
Cheilinus fasciatus	x					
Cheilinus undulatus	x					
Choerodon fasciatus						
Cirrhilabrus cyanopleura	x					
Coris aygula	x					
Epibulus insidiator	x					
Halichoeres chrysus	x					
Halichoeres hortulanus			x			
Hemigymnus fasciatus	x					
Labrichthys unilineatus			x			
Labroides dimidiatus	x				x	x
Labropsis manabei						
Oxycheilinus digramma	x					
Oxycheilinus unifasciatus	x					
Unidentified						x
Lethrinidae						
Gnathodentex aureolineatus	x					
Monotaxis grandoculis	x					
Lutjanidae						
Lutjanus bohar	x					
Lutjanus decussatus	x					
Lutjanus kasmira	x		x			
Lutjanus monostigma			x			
Lutjanus russellii	x					
Lutjanus sp.			x			
Macolor macularis	x	x				
Paracaesio xanthura	x					
Pinjalo lewisi	x					
Unidentified						x
Malacanthidae						
Hoplolatilus starcki	x					
Mullidae						
Parupeneus multifasciatus	x				x	x
Parupeneus trifasciatus	x					
Unidentified						x

(continued)

Table 15.3 (continued)

Families/species	Apo Reef		Abra de Ilog		Patnanungan	
	30–40	40–100	30–40	40–100	30–40	40–100
Nemipteridae						
Pentapodus bifasciatus					x	
Pentapodus caninus						
Pentapodus paradiseus					x	
Scolopsis bilineata	x		x			
Scolopsis ciliatus					x	
Scolopsis margaritifera					x	
Pinguipedidae						
Parapercis cylindrica			x			
Parapercis hexophtalma						
Plotosidae						
Plotosus lineatus						x
Pomacanthidae						
Apolemichthys trimaculatus	x					x
Centropyge bicolor	x		x			
Centropyge flavissimus			x			
Centropyge heraldi	x					
Centropyge vroliki			x			
Chaetodontoplus melanosome	x					
Genicanthus lamarck			x			
Pomacanthus imperator	x		x			
Pygoplites diacanthus	x		x			
Pomacentridae						
Acanthochromis polyacanthus	x					
Amblyglyphidodon aureus	x		x			
Amblyglyphidodon curacao				x		
Amblyglyphidodon leucogaster	x		x			
Amphiprion frenatus	x					
Amphiprion perideraion		x				
Chromis alpha	x					
Chromis amboinensis						x
Chromis stripes	x					
Chromis flavipectoralis	x		x			
Chromis margaritifer	x					x
Chromis ternatensis	x					
Chromis viridis			x			
Chromis xanthura	x					
Dascyllus reticulatus	x					
Dascyllus trimaculatus	x					
Neoglyphidodon melas	x					
Neoglyphidodon nigroris						
Neoglyphidodon thoracotaeniatus	x					
Neopomacentrus azysron	x					
Pomacentrus alexanderae	x					
Pomacentrus amboinensis	x					
Pomacentrus auriventris	x					
Pomacentrus brachialis	x		x			x
Pomacentrus coelestis					x	
Pomacentrus moluccensis	x					
Pomacentrus nigromanus	x					
Pomacentrus nigromarginatus	x		x			
Pomacentrus philippinus	x					
Pomacentrus stigma	x		x			
Pomacentrus vaiuli	x					x
Unidentified						x

(continued)

Table 15.3 (continued)

Families/species	Apo Reef		Abra de Ilog		Patnanungan	
	30–40	40–100	30–40	40–100	30–40	40–100
Priacanthidae						
Priacanthus blochii			x			
Scaridae						
Chlorurus bowersi						
Scarus chameleon	x					
Scarus forsteni	x					
Scarus niger	x					
Scarus sp.			x			
Scombridae						
Gymnosarda unicolor	x					
Serranidae						
Cephalopholis argus	x					
Cephalopholis urodeta	x					x
Epinephelus merra	x					
Gracila albomarginata	x					
Pseudanthias pleurotaenia	x	x	x	x	x	
Pseudanthias sp.	x					
Siganidae						
Siganus vulpinus	x					
Synodontidae						
Synodus variegatus					x	x
Tetraodontidae						
Arothron nigropunctatus	x					x
Zanclidae						
Zanclus cornutus	x	x	x		x	x
Total # of families (28)	20	9	16	4	11	13
Total # of species (148)	104	16	39	5	19	18

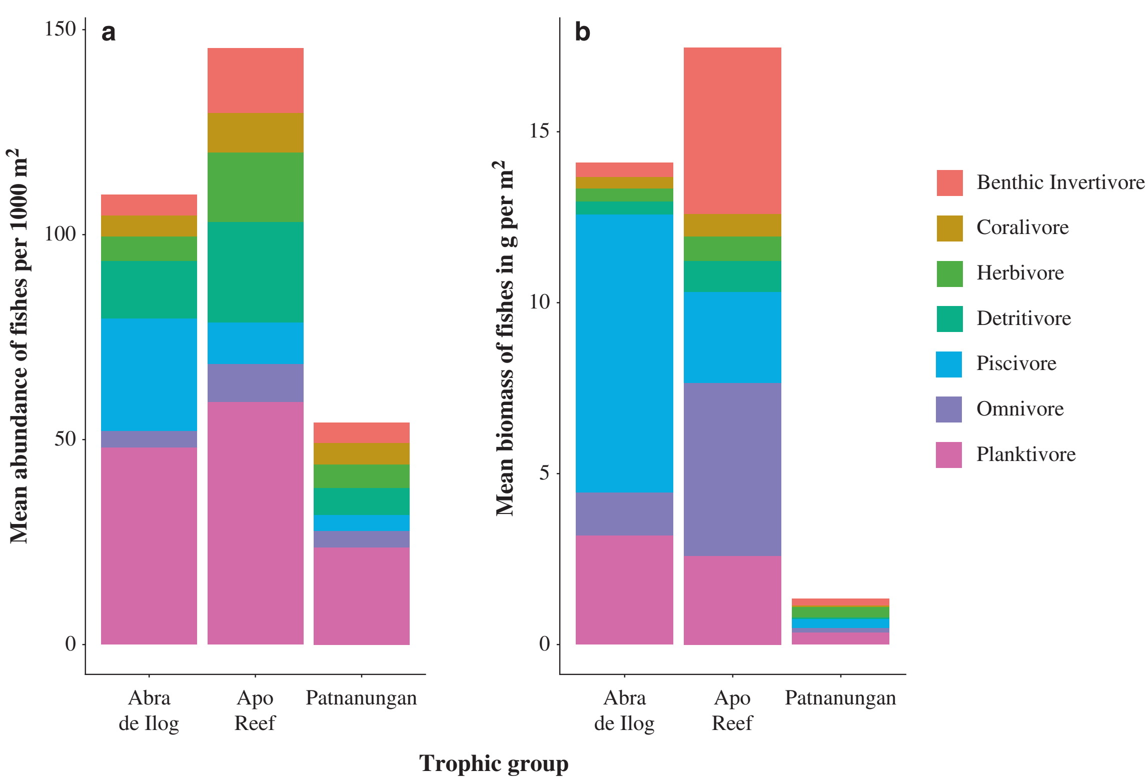

Fig. 15.8 Mean abundance (**a**) and mean biomass (**b**) of reef fish trophic groups in the three upper mesophotic sites (30–40 m depth) obtained using diver-based surveys

Fig. 15.9 ROV images of the planktivorous reef fishes observed in Apo Reef at a depth range of 30–50 m. (**a**) Pyramid butterflyfish (*Hemitaurichthys polylepis*), (**b**) false fusilier (*Paracaesio xanthurus*), (**c**) blue-dash fusilier (*Pterocaesio tile*), (**d**) yellow-tail fusilier (*Caesio teres*), and (**e**) sleek unicornfish (*Naso hexacanthus*). (Photo credits: Ronald Dionnie D. Olavides)

60 m, the benthic fauna were mostly dominated by hydroids, sponges (basket, vase, flat, and barrel of *Xestospongia* spp.), soft corals, gorgonians, sea whips, black corals, sea fans, anemones, and crinoids. In Patnanungan, macroalgae genera *Halimeda*, *Sargassum*, and *Gracilaria* were observed at a depth of 50 m. Beyond 50 m, sea fans, soft corals, sea whips, and crinoids were observed to a depth of 65 m. At depths between 65 and 165 m in Apo Reef and Patnanungan, crinoids and whip corals were observed, respectively.

Megafauna (organisms with >50 cm body length) were observed only in Apo Reef, a potential indicator of reduced fishing pressure and anthropogenic disturbance relative to other sites, and a more intact food web capable of supporting larger-bodied organisms. The abundance of megafauna was higher in SWRs than in MCEs (Quimpo et al. 2018a). Megafauna observed in upper mesophotic depths (30–40 m) included hawksbill sea turtle (*Eretmochelys imbricata*), humphead wrasse (*Cheilinus undulatus*), and whitetip reef shark (*Triaenodon obesus*), while the pelagic thresher shark (*Alopias pelagicus*) was observed at 113 m. Many marine megafauna are known to have large foraging areas that may include different depths (Papastiamatou et al. 2015), and MCEs may represent important habitats for these species.

15.6 Threats and Conservation Issues

Similar to many of the SWRs in the Philippines (Nañola et al. 2011), some MCEs are under threat from human and natural disturbances. For instance, the high cover of macroalgae and low number of herbivores in Patnanungan are indicative of overfishing. Although MCEs are perceived as less likely to be impacted by disturbances than SWRs, MCEs are not safe from overfishing. Spear fishing by hookah diving and dragnet fishing can potentially exploit fish populations and damage habitat complexity on deeper reefs (Lindfield et al. 2014, 2016). Moreover, MCEs such as Abra de Ilog, which are naturally exposed to turbid waters due to proximity to a river may be vulnerable to sedimentation or reductions in light irradiance if river runoff is eutrophic or highly sedimented from inland agriculture activities and coastal development (Kahng et al. 2010). MCEs can also be affected by thermal stress and associated coral bleaching and mortality as was observed in Apo Reef. In 2016, qualitative observations indicated that mesophotic corals bleached, with most of the affected colonies exhibiting a branching morphology. However, the severity of the coral bleaching was lower in mesophotic depths compared to the SWRs of Apo Reef. Philippine reefs are also subjected to typhoons that can cause physical destruction (Abesamis et al. 2017). The Philippines has experienced a number of very severe typhoons in recent years, a trend which is expected to increase due to climate change.

MCEs need to be protected for them to function as potential refugia. However, the protection of MCEs should focus on mitigating the local stressors within the area by designing appropriate management strategies. For example, dynamite fishing should be banned in Patnanungan, whereas the runoff from agriculture (e.g., pesticides and fertilizers) could be minimized in Abra de Ilog. In protecting MCEs, the communities may be allowed to recover from natural disturbances, as exemplified by the Apo Reef National Park where juvenile corals are now observed in high abundance. The higher abundance of large and commercially important fish species at Apo Reef (Quimpo et al. 2018a, b) compared to the other two sites also suggests that marine protected areas can be effective for protecting large-bodied and commercially important species from overexploitation. While marine protected areas cannot guard against climate-related disturbances such as coral bleaching, evidence from Apo Reef suggests that they can protect fish biomass and trophic structure, which in turn may assist recovery from disturbances.

15.7 Conclusions

Preliminary results confirm that MCEs in the Philippines support diverse ecological communities, but there is a need to further assess other MCEs in different geographic regions and environmental settings. Assessing representative MCEs in different biogeographic regions will allow the identification of ecological, geological, and oceanographic factors that influence the biodiversity in MCEs at different spatial scales. For example, understanding connectivity among MCEs and between SWRs and adjacent MCEs is essential for understanding the vulnerability of MCEs to disturbances and for testing the "deep reef refuge" hypothesis (Bongaerts et al. 2010). Identifying similarities in composition of coral reef communities between SWRs and MCEs represents an initial step toward the goal of identifying depth refuge. Establishing a long-term monitoring program would allow us to test whether reef communities that seem to be more connected based on oceanographic and genetic evidence can indeed recover faster from disturbances than more isolated reefs. Further studies should also focus on quantifying MCE biodiversity and taxonomic classification of many marine taxa (e.g., sponges, soft corals), particularly since mesophotic biodiversity in the Coral Triangle is poorly known. Moreover, institutional linkages with other academic institutions, non-governmental organizations, and government agencies are warranted for the advancement of MCE research in the Coral Triangle.

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