

Marine Benthic Algal Composition After 45 Years in an Urbanized Bay in Cebu, Philippines

Dan Anthony U. Bataan^{1,4}, Paul John L. Geraldino²,
Judith R. Silapan¹, and Lawrence M. Liao³

¹Environmental Science Program, Sciences Cluster,
University of the Philippines Cebu, Cebu City 6000 Philippines

²Department of Biology, University of San Carlos, Cebu City 6000 Philippines

³Aquatic Botany Laboratory, Graduate School of Integrated Sciences for Life,
Hiroshima University, 1-4-4 Kagamiyama, Hiroshima 739-8528 Japan

⁴Graduate School of Kuroshio Science, Kochi University,
Okochi Campus, Nankoku, Kochi 783-8505 Japan

Coastal ecosystems have been seriously impacted by anthropogenic activities, which are compounded by recent climatic and environmental changes. To provide some evidence of these changes, a study of marine benthic algal composition was conducted by comparing historical (1969–1970) and contemporary (2013–2014) collections in Silot Bay in Cebu, Philippines. A quantitative survey revealed a total of 30 species of benthic algae (11 red, nine brown, and 10 green) in the historical collections, whereas only 15 species (four each of red and brown plus seven species of green algae) were accounted in the latter years. This decline in the marine benthic algal composition may be attributed to sedimentation, which is indirectly caused by urbanization and human population increase. Altered environmental conditions inside the Bay may also explain the decline and qualitative changes of algal species composition therein. Continued monitoring of the benthic macroalgal composition and environmental parameters may help document anthropogenic impacts on marine ecosystems. Historical herbarium samples represent a valuable yet underappreciated resource for tracking environmental changes through time.

Keywords: anthropogenic impact, ecological change, herbarium, seaweeds, urbanization

INTRODUCTION

Scientists have been alarmed over unprecedented climatic fluctuations and adverse ecological changes brought about by a combination of natural and anthropogenic factors. More than ever before, the threats of widespread environmental changes are impacting many marine ecosystems worldwide (Koch *et al.* 2013). A steady stream of evidence has appeared in the form of erratic weather patterns and diminishing glacial activity increasing

heat content and aquatic pollution. In addition, the most destructive seems to be human impacts leading to significant physical erosion of the coastal zones (Jonah *et al.* 2015). An association between the increasing number of marine invasive species and climate change has also been established (Tsiamis and Verlaque 2011), the former being often treated as a form of biological pollution.

There is a need to continuously document and assess the impacts of natural and man-made events on the environment (Oliveira and Qi 2003; Johnson and Roberts

*Corresponding author: danbataan@gmail.com

2009). A better understanding of such phenomena may help towards more effective environmental management and mitigation. One of the ways by which environmental change could be documented at a local level is by monitoring species changes in terrestrial and aquatic habitats (Johnson and Roberts 2009). Ideally, biological information obtained from a longer time span (> 10 yr) can provide a good environmental profile of the recent past and can likewise be useful as a predictor of changes expected in the near future. One approach gaining popularity among climate change scientists involves analyzing previous data sets spanning many decades and comparing them to recent observations. These may include biodiversity information and physico-chemical parameters obtained through a time series (de Paula *et al.* 2020).

Silot Bay is an enclosed shallow water embayment that is mostly of sandy substratum surrounded by patches of mangroves and fishponds. It is located in the town of Liloan, Cebu island, Philippines. In the 1950s, the University of San Carlos (USC) established its first marine station near the mouth of the Bay, where it empties into the Camotes Sea. As such, an extensive sampling of the marine and estuarine flora and fauna (Juario *et al.* 1970; Miller 1972; Zarsuelo 1975) was made around Silot Bay from that time until about the 1990s. Zarsuelo (1975) conducted the most extensive taxonomic survey of the marine benthic flora of Silot Bay together with their associated ecological factors. Her study represents an important contribution toward characterizing the ecological structure of the marine communities within Silot Bay as they existed in the 1960s and 1970s. This presents a unique opportunity for comparison to be made between these baseline data on algal species composition and diversity, together with historical herbarium samples, and data collected more recently in 2013–2014 (Liao and Bataan 2016). The extent of qualitative and quantitative changes in macroalgal species composition may present some evidence of anthropogenic impacts on the biota of the Bay. Information from this study may also help in identifying bio-indicator species from among the macroalgal species found in the Bay.

MATERIALS AND METHODS

Study Site

The study was conducted at Silot Bay (Figure 1) in the municipality of Liloan (10°23'29"N, 123°59'36"E) located 18 km north of Cebu City, Philippines. It is a 100-ha embayment with a narrow channel on its northeastern side that serves as its only connection to the outer Camotes Sea. Seawater fluxes in and out of the Bay during tidal changes provide the only mechanism for its water

exchanges with the open sea (Miller 1972). The narrow channel is now spanned by a concrete bridge. There is one small island situated at the center of the Bay with a zip line recreational infrastructure installed on it. Most of the irregular contours of its coastline are covered by fishponds and patches of mangroves. A sand bar, located near the center island adjacent to the mouth of the Bay, is moderately exposed during low tides. Water visibility of the Bay is low during the rainy season. The inner part of the Bay is shallower and heavily silted than the part close to the inlet with strong currents during periods of spring tides and tidal changes.

Six sampling stations were set up throughout the Bay as close as possible to the stations set by Zarsuelo (1975). Detailed descriptions of the location, substratum characteristics, and other physical parameters of these six stations are given in Table 1. These six stations form a ring around the center island, as indicated in Figure 1.

Table 1. Description of the six sampling stations in Silot Bay, Cebu, Philippines, where algal samples were collected in the present study.

Station	Coordinates	Description	Type of substratum
I	N 10°23'33.6" E 123°59'48.1"	Northeastern side in between the sand bar and middle island	Sand
II	N 10°23'36.7" E 123°59'42.2"	Northwestern side of the middle island	Sand
III	N 10°23'32.7" E 123°59'35.5"	Western side of the middle island	Sand
IV	N 10°23'23.8" E 123°59'37.2"	Southwest part of the middle island	Sand
V	N 10°23'22.4" E 123°59'43.9"	Southeast side of the bay	Sand
VI	N 10°23'28.2" E 123°59'48.6"	Eastern part of the Bay	Sand

Algal Collection

Collection of benthic algae from the six stations was done four times through gleaning or snorkeling at low tide, twice during the southwest monsoon (August and October 2013), and twice during the northeast monsoon (January and March 2014). Samples collected were photographed in the field and subsequently pressed. Samples were identified using reference books (Calumpang and Meñez 1997; Trono 1997, 2004) and online resources, and then compared with authenticated specimens deposited at the USC herbarium. The website www.algaebase.org (Guiry and Guiry 2021) was consulted as an authoritative reference for updating taxonomic information on species names following the current system of nomenclature.

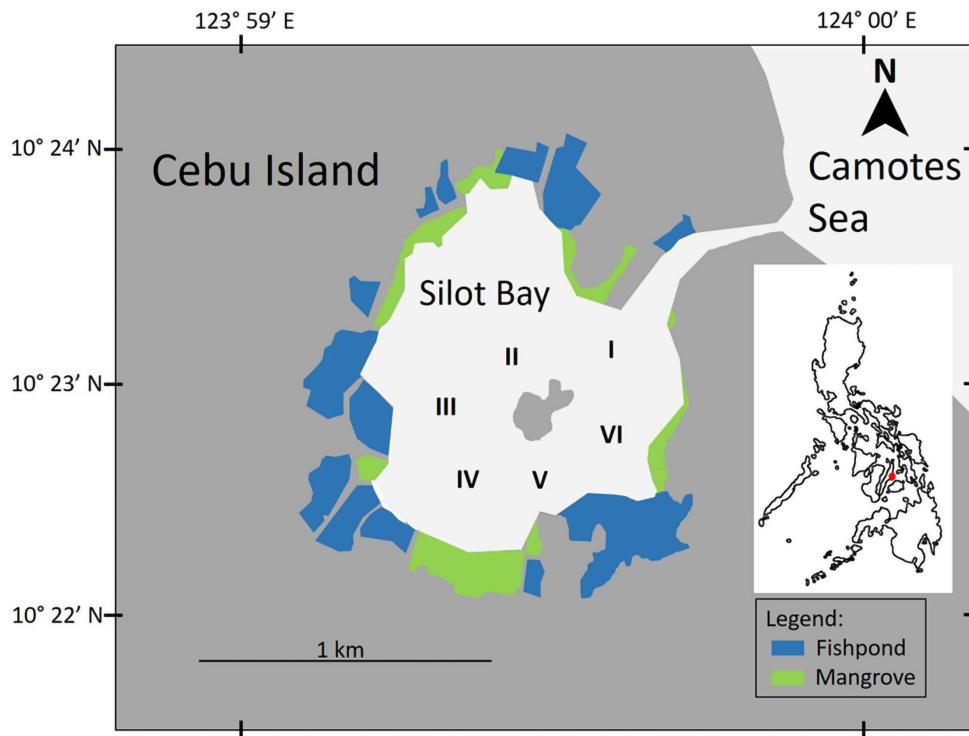


Figure 1. Map of Silot Bay showing the different sampling points indicated by I-VI. The entire bay is surrounded by fishponds (blue) and mangrove (green). Inset: Map of the Philippines showing the location of the bay (red dot).

On the other hand, algal collections studied by Zarsuelo (1975) were examined when available at the USC herbarium and/or determined using the illustrations in the original publication.

RESULTS

Comparison of Baseline and Recent Algal Data

Fifteen (15) species of benthic macroalgae were identified in the 2013–2014 collection (Table 2). The marine green algae dominated with seven species, followed by four species each for the red and brown algae. The green algae were represented by species of *Ulva*, *Caulerpa*, *Cladophora*, and *Halimeda*. Brown algae such as *Padina*, *Canistrocarpus*, and *Hydroclathrus* were encountered. *Hypnea*, *Amphiroa*, and *Jania* were the only red algae found. Brown algae – particularly *Padina australis* and *Padina minor* – and green algae such as *Halimeda macroloba* and *Halimeda opuntia* were consistently observed in all six stations.

Eleven (11) species of red algae, nine species of brown algae, and 10 species of green algae were recorded by Zarsuelo (1975) for a total of 30 species (Table

3), compared with four species of red, four species of brown and seven species of green algae in the current collections. Current collections therefore represent a 64% reduction in red, 56% in brown and 30% in green algae, or a reduction of 50% in total species number from the baseline collection.

A total of 39 unique algal taxa (Table 3) were recorded from the two sampling periods (1969–1970 baseline, 2013–2014 current). At least 24 species documented during the baseline collections had not been accounted for in the current collection. Nine species, including *Jania adhaerens*, *Hypnea nidulans*, *Hypnea spinella*, *Padina minor*, *Hydroclathrus clathratus*, *Caulerpa lentillifera*, *Halimeda macroloba*, *Cladophora socialis* and *Ulva intestinalis* have been added as new records for Silot Bay. Six species, including one red (*Amphiroa fragilissima*), two browns (*Canistrocarpus cervicornis*, *Padina australis*), and three green algae (*Caulerpa serrulata*, *Halimeda opuntia*, and *Ulva reticulata*) were recorded in both baseline and current collections (Table 3).

Current collection in southwest monsoon yielded a total of eight algal species and 15 species were collected in northeast monsoon (Table 3). Two red algae, *A. fragilissima* and *J. adhaerens*, were collected in both monsoons, whereas *H. nidulans* and *H. spinella* were only

Table 2. Algal species present in the six stations in Silot Bay, Cebu, Philippines observed in the present study.

	1	2	3	4	5	6
Rhodophyta						
<i>Amphiroa fragilissima</i> (Linnaeus) J.V.Lamouroux	+			+		
<i>Jania adhaerens</i> J.V.Lamouroux	+	+		+		
<i>Hypnea nidulans</i> Setchell		+			+	
<i>Hypnea spinella</i> (C.Agardh) Kützing	+	+		+		
Phaeophyceae						
<i>Canistrocarpus cervicornis</i> (Kützing) de Paula & De Clerck	+	+	+		+	+
<i>Padina australis</i> Hauck	+	+	+	+	+	+
<i>Padina minor</i> Yamada	+	+	+	+	+	+
<i>Hydroclathrus clathratus</i> (C.Agardh) M.A.Howe	+	+				+
Chlorophyta						
<i>Caulerpa lentillifera</i> J.Agardh	+					+
<i>Caulerpa serrulata</i> (Forsskål) J.Agardh	+					
<i>Halimeda macroloba</i> Decaisne	+	+	+	+	+	+
<i>Halimeda opuntia</i> (Linnaeus) J.V.Lamouroux	+	+	+	+	+	+
<i>Cladophora socialis</i> Kützing		+	+	+	+	
<i>Ulva intestinalis</i> Linnaeus		+				
<i>Ulva reticulata</i> Forsskål	+					

[+] Present

collected in the northeast monsoon. Brown algae such as *C. cervicornis*, *P. australis* and *P. minor* were collected in southwest and northeast monsoons, whereas *H. clathratus* was only collected in northeast monsoon. Three green algae *C. socialis*, *H. macroloba* and *H. opuntia* were collected in southwest and northeast monsoons, whereas two *Caulerpa* species (*C. lentillifera* and *C. serrulata*) and two *Ulva* species (*U. intestinalis* and *U. reticulata*) were only collected in northeast monsoon.

Algal composition from Zarsuelo (1975) showed that a total of 28 species were collected in each monsoon (Table 3). Red algae – particularly *A. fragilissima*, *Callophyllis adnata*, *Kallymenia sessilis*, *Kallymenia stipitata*, *Tricleocarpa cylindrica*, *Gelidiophycus divaricatus*, *Halymenia dilatata*, *Halymenia durvillei*, and *Laurencia okamurae* – were collected in southwest and northeast monsoons. *Gigartina* sp. was collected only in southwest monsoon, whereas *Zellera tawallina* was collected in northwest monsoon. Brown algae such as *Hormophysa cuneiformis*, *Dictyota bartayresiana*, *C. cervicornis*, *P. australis*, *Sargassum polyceratium*, *Sargassum granuliferum*, *Sargassum platycarpum*, *Sargassum miyabei*, and *Turbinaria ornata* were collected in southwest and northeast monsoons. Green algal species – namely, *Avrainvillea nigricans*, *Bryopsis corticulans*, *Bryopsis plumosa*, *Caulerpa racemosa*, *C. racemosa* var.

macrophysa, *C. serrulata*, *H. opuntia*, *Halimeda tuna*, and *U. reticulata* were collected in southwest and northeast monsoons.

DISCUSSION

Changes over time in the composition of marine flora and fauna have been used to provide indirect evidence for perceived environmental changes in many marine ecosystems (Titlyanov *et al.* 2011; de Paula *et al.* 2020). Silot Bay, an enclosed embayment with a single inlet/outlet to the open sea, is a tidal basin surrounded by a growing number of human settlements and built-up structures. Although no actual measurements were made, the bay has clearly been impacted by anthropogenic inputs in the past several decades.

Among the three major groups of marine macroalgae found in Silot Bay, a decreasing trend in species diversity was recorded in all, amounting to a 50% reduction in total species number. Oliveira and Qi (2003) observed a similarly drastic reduction in the diversity of seaweed species in Santos Bay, Brazil – which they attributed to increased pollution in the bay waters. In the present study, many species presumed to be more environmentally sensitive and fragile had disappeared. Among the marine

Table 3. Algal species composition in Silot Bay, Cebu City, Philippines from 1969–1970 and 2013–2014 collections with updated species names.

Order	Family	Species name	1969–1970 (Zarsuelo 1975)*		2013–2014 (present study)*		Remarks
			SW monsoon	NE monsoon	SW monsoon	NE monsoon	
Phylum Rhodophyta							
Ceramiales	Delesseriaceae	<i>Zellera tawallina</i> G.Martens	–	+	–	–	Misnamed as <i>Delesseria crassifolia</i> Ruprecht
	Rhodomelaceae	<i>Laurencia okamurae</i> Yamada	+	+	–	–	
Corallinales	Corallinaceae	<i>Amphiroa fragilissima</i> (Linnaeus) Lamouroux	+	+	+	+	
		<i>Jania adhaerens</i> Lamouroux	–	–	+	+	
Gelidiales	Gelidiaceae	<i>Gelidiophycus divaricatus</i> (G.Martens) G.H.Boo, J.K.Park & S.M.Boo	+	+	–	–	Previously identified as <i>Gelidium divaricatum</i> G. Martens
Gigartinales	Cystocloniaceae	<i>Hypnea nidulans</i> Setchell	–	–	–	+	
		<i>Hypnea spinella</i> (C.Agardh) Kützing	–	–	–	+	
	Gigartinaceae	<i>Gigartina</i> sp.	+	–	–	–	
	Kallymeniaceae	<i>Callophyllis adnata</i> Okamura	+	+	–	–	
		<i>Kallymenia sessilis</i> Okamura	+	+	–	–	
			<i>Kallymenia stipitata</i> Okamura	+	+	–	–
Halymeniales	Halymeniaceae	<i>Halymenia dilatata</i> Zanardini	+	+	–	–	
		<i>Halymenia durvillei</i> Bory de Saint-Vincent	+	+	–	–	
Nemaliales	Galaxauraceae	<i>Tricleocarpa cylindrica</i> (J.Ellis & Solander) Huisman & Borowitzka	+	+	–	–	Previously identified as <i>Galaxaura cylindrica</i> (J.Ellis & Solander) J.V. Lamouroux
Phylum Ochrophyta, Class Phaeophyceae							
Dictyotales	Dictyotaceae	<i>Canistrocarpus cervicornis</i> (Kützing) de Paula & De Clerck	+	+	+	+	Misidentified as <i>Dictyota dichotoma</i> (Hudson) Lamouroux
		<i>Dictyota bartayresiana</i> J.V.Lamouroux	+	+	–	–	Previously identified as <i>Dictyota bartayresii</i>
		<i>Padina australis</i> Hauck	+	+	+	+	
		<i>Padina minor</i> Yamada	–	–	+	+	
Ectocarpales	Scytosiphonaceae	<i>Hydroclathrus clathratus</i> (C. Agardh) M.A.Howe	–	–	–	+	
Fucales	Sargassaceae	<i>Hormophysa cuneiformis</i> (J.F.Gmelin) P.C.Silva	+	+	–	–	Previously identified as <i>Cystoseira articulata</i> J.Agardh
		<i>Sargassum granuliferum</i> C. Agardh	+	+	–	–	
		<i>Sargassum miyabei</i> Yendo	+	+	–	–	Previously identified as <i>Sargassum kjellmanianum</i> Yendo
		<i>Sargassum platycarpum</i> Montagne	+	+	–	–	
		<i>Sargassum polyceratium</i> Montagne	+	+	–	–	
		<i>Turbinaria ornata</i> (Turner) J.Agardh	+	+	–	–	

Table 3. Cont.

Order	Family	Species name	1969–1970 (Zarsuelo 1975)*		2013–2014 (present study)*		Remarks
			SW monsoon	NE monsoon	SW monsoon	NE monsoon	
Phylum Chlorophyta							
Bryopsidales	Bryopsidaceae	<i>Bryopsis corticulans</i> Setchell	+	+	–	–	
		<i>Bryopsis plumosa</i> (Hudson) C.Agardh	+	+	–	–	
Caulerpaceae		<i>Caulerpa lentillifera</i> J.Agardh	–	–	–	+	
		<i>Caulerpa racemosa</i> (Forsskål) J.Agardh	+	+	–	–	Previously identified as <i>Caulerpa racemosa</i> var. <i>clavifera</i> (Turner) Weber Bosse and <i>Caulerpa</i> <i>racemosa</i> var. <i>uvifera</i> (C.Agardh) J.Agardh
		<i>Caulerpa</i> <i>racemosa</i> var. <i>macrophysa</i> (Sonder ex Kützing) W.R.Taylor	+	+	–	–	
		<i>Caulerpa serrulata</i> (Forsskål) J.Agardh	+	+	–	+	
Dichotomosiphonaceae		<i>Avrainvillea</i> <i>nigricans</i> Decaisne	+	+	–	–	
Halimedaceae		<i>Halimeda</i> <i>macroloba</i> Decaisne	–	–	+	+	
		<i>Halimeda opuntia</i> (Linnaeus) Lamouroux	+	+	+	+	
		<i>Halimeda tuna</i> (J.Ellis & Solander) Lamouroux	+	+	–	–	
Cladophorales	Cladophoraceae	<i>Cladophora socialis</i> Kützing	–	–	+	+	
	Siphonocladaceae	<i>Boergesenia forbesii</i> (Harvey) Feldmann	+	+	–	–	
Ulvales	Ulveae	<i>Ulva intestinalis</i> Linnaeus	–	–	–	+	Previously identified as <i>Enteromorpha intestinalis</i> (Linn.) Nees
		<i>Ulva reticulata</i> Forsskål	+	+	–	+	

[+] present; [-] absent

red algae, foliose species such as *C. adnata*, *H. dilatata*, *K. sessilis*, *K. stipitata*, and *Z. tawallina* were never encountered in the current survey since their reported occurrence in the 1960s by Zarsuelo (1975). Foliose species with their larger blades and surface area are commonly found in more pristine subtidal waters and require optimum sunlight for photosynthesis in those depths (Gómez and Huovinen 2011). The increasing sediment load and siltation in Silot Bay throughout these years (unpublished data) may have caused a significant reduction of light penetration through the water column, thereby restricting photosynthetic activity and contributing to the eventual decimation of these deeper water forms. In addition, foliose species with a low surface area to volume ratio usually show growth rate decline concomitant with

environmental degradation. In a study on the impact of marine tourism on benthic communities in Rio Grande do Norte, Brazil, Azevedo *et al.* (2011) found similar foliose species only in areas without human interference, whereas only small turf algae were observed in areas characterized by heavy tourist presence.

On the other hand, some red algae, such as *A. fragilissima*, have been consistently collected in Silot Bay throughout both the periods surveyed. This is a calcified species with cylindrical branches, chemically defended, and shown to survive temperatures up to 32 °C (Yang *et al.* 2021), besides other environmental stressors. Also noteworthy was the presence of *H. nidulans* and *H. spinella* in the current collections but not in the earlier collections. Many

species of *Hypnea* are recognized as invasive, exhibiting various degrees of resistance to adverse environmental factors (Tsiamis and Verlaque 2011). *Hypnea nidulans* and *H. spinella* in Silot Bay are probably new introductions but may not be considered invasive owing to their low biomass. The introduction of these species might be attributed to the water current coming from Camotes Sea carrying tetraspores, which eventually germinated inside the Bay.

Among the brown marine algae, the species of *Sargassum* in Silot Bay was previously represented by no less than four species but were absent in current surveys, together with related species – *H. cuneiformis* and *T. ornata*. They have prominent holdfasts requiring hard substrata on which young sporelings and adults can attach. Their total disappearance from Silot Bay may therefore be attributed to the loss of rocky substrata, previously reported to be present in Silot Bay (Zarsuelo 1975). These hard substrata have likely been obliterated by heavy siltation, similar to that in Guanabara Bay, Brazil (de Paula *et al.* 2020). The mainly sandy substratum in Silot Bay has apparently favored those algal species with tiny rhizoids such that species of *Canistrocarpus* and *Padina* with small rhizoids were consistently recorded throughout the compared periods. In this current survey, *P. minor* and *H. clathratus* have been recorded as new additions to Silot Bay. Species of *Padina* are known as bioindicators of marine ecosystem health specifically indicative of heavy metal pollution (Dulymamode *et al.* 2001) and, therefore, showing hardiness uncommon in other species. *Hydroclathrus clathratus* was reported to have anti-fungal and anti-bacterial properties (Vimala and Poonghuzhali 2017).

Marked changes in the composition of marine green algae have also been observed in Silot Bay. Fleshy forms like *Boergesenia*, *Bryopsis*, and *Caulerpa* documented in the 1960s were nowhere to be found in the current survey. In a study of the marine green algae of Hainan Island, China, Titlyanov *et al.* (2011) found a similar dominance of the Caulerpaceae and Codiaceae in the 1930s, which have since been replaced by opportunistic green algal species such as members of the Ulvaceae (1.7-fold increase) and Cladophoraceae (1.6-fold increase). In Silot Bay, *C. racemosa* has been eliminated and replaced with species of the Ulvaceae. One species, *U. reticulata*, was consistently recorded inside Silot Bay throughout the compared periods. It is well-known that members of the Ulvaceae thrive under eutrophic conditions of high nutrients and have been widely recognized as a bioindicator of eutrophication associated with “green tide” or noxious algal bloom phenomena (Villaluz *et al.* 2016). In addition, sheetlike forms such as *Ulva* sp. were reported to be one of the pioneer species that dominated the cleared substrata (Littler and Littler 1980). *Caulerpa lentillifera* was recorded for the first time attached to a floater in Station I. This edible species was introduced

as part of an unsuccessful attempt to culture this seaweed inside the Bay. Two notable and often dominant species occurring in Silot Bay are *H. macroloba* and *H. opuntia*. The former possesses a large bulbous holdfast coated with sand and sediments that is suitable for muddy or silty bottoms; the latter has less prominent sand-coated rhizoidal basal parts. *Halimeda macroloba* and *H. opuntia* belong to a functional-form group that was reported to exhibit one of the lowest photosynthetic performances (Littler and Arnold 1982). Both species, however, have photosynthetic segments that are protected with a calcium carbonate layer, which might confer better resilience under environmental stress (Wei *et al.* 2020). In addition, *H. opuntia* has been shown to survive in stressful conditions through the development of segment plasticity (Pongparadon *et al.* 2020).

Information on oceanographic conditions within Silot Bay is limited. Nonetheless, the impact of changes in oceanographic conditions over the years on algal flora within the bay may be inferred from observations made in other studies around the world. The perimeter of Silot Bay has experienced rapid urbanization and an increasing human population in the last few decades. An immediate implication of this is an increase in sewage discharge. Sewage discharges contribute to increasing water turbidity and bottom sludge that inhibit photosynthesis and algal spore settlement, respectively (de Paula *et al.* 2020). In addition, the construction of marinas (Rivero *et al.* 2013) and aquaculture fishponds (Muendo *et al.* 2014) could have contributed to increased sedimentation. These artificial structures may have altered the hydrodynamics of the bay, thus contributing to further sediment loading (Bishop *et al.* 2017), as revealed from key informants’ interviews (unpublished data) about the installation of fences in many sections of Silot Bay. Moreover, Silot Bay might act as a catchment basin that receives water runoff carrying sediments from land that contributed to the sandy substratum observed in all stations. Sedimentation can strangle marine organisms by preventing effective filter-feeding and photosynthesis, inhibiting spore and larval settling, and affecting the natural succession patterns (Eriksson and Johansson 2005). To illustrate, Schiel *et al.* (2006) found a 34–71% reduction in the attachment of algal zygotes over a layer of fine sediment that was experimentally introduced. No attachment of zygotes was seen when more sediments were added. Eriksson and Johansson (2005) found that ephemeral green algae such as the Ulvaceae are highly resistant to sedimentation, whereas perennial brown algae like the Sargassaceae and Fucaceae are not (Gorgula and Connell 2004). In a study of fucoids in the Baltic Sea, Vogt and Schramm (1991) recorded a 95% reduction in fucoid biomass, which they attributed to reduced light levels, increased epiphytism due to eutrophication, and decreased substrate availability. In addition, fucoid communities have been increasingly

encountered in shallower depths (from the original 11.5 m deep to 8.5 m within a 40-yr span), owing to the decreased transparency of the water column brought about by eutrophication, making deeper habitats inhospitable for new recruits (Kautsky *et al.* 1986). Sedimentation, with its associated effect on reducing the light levels and the availability of hard surfaces for spore settlement, is therefore clearly one of the most significant stressors to have caused the complete absence of tropical fucoids represented by species of the Sargassaceae in Silot Bay. On the other hand, however, sedimentation seems to favor algae with filamentous or cylindrical construction that makes them less likely to retain sediments, compared to crust-forming coralline algae like maerl or rhodoliths, which are sensitive to even thin layers of sediments (Gorgula and Connell 2004; Peña and Barbara 2008). This could explain the abundance of articulate coralline algae such as *Amphiroa* spp. and calcareous green algae such as *Halimeda* spp. in Silot Bay.

Increased temperature has been used as an indicator of climate change more often than other global-scale stressors such as sea-level rise, ocean acidification, rising ultraviolet radiation, and increased frequency and intensity of storms (Harley and Connell 2009). In Silot Bay, Zarsuelo (1975) recorded seawater temperature for only 4 mo (September–December) in 1969. These data alone could not provide a good picture of the temperature profile of the whole year. Nonetheless, long-term (1965–2020) air temperature data are available for Mactan International Airport (<https://weatherspark.com>), which is less than 10 km from Silot Bay. Air temperature profiles over these years do show a slight increase in mean temperature of about 0.5 °C between 1969 and 2013–2014. A peak of 34 °C was recorded only once in June 1969 with more 33.5 °C peaks in May–June and August–November 1969, in contrast to several peaks of 35 °C recorded in June and August in 2014. This increase in temperature is likely to be reflected in seawater temperature as well. However, the increased temperature should not be singled out to explain the changing ecological structure observed. The rising temperature should be considered alongside other stressors, including large-scale oceanographic processes, rather than local habitat changes alone (Smith *et al.* 2006). It has been argued that local weather descriptors can be better predictors of changes than large-scale processes, but both must be considered together (Helmuth *et al.* 2006). The synergistic effects of elevated seawater temperature, eutrophication, and sedimentation have begun to affect marine vegetation in many regions. Information on community characteristics of marine algae and their dynamic changes through time may be useful in providing evidence for perceived environmental change (Azevedo *et al.* 2011), as well as a useful tool for predicting future trends.

The present study provided an opportunity to show the value of using historical records and specimens such as those deposited in museums and herbaria to document biodiversity changes in a locality over time (Shaffer *et al.* 1998; Liao and Bataan 2016). This is similar to the specimen-based studies conducted by Bates *et al.* (2009) and Tomizuka *et al.* (2012). Examples of this type of study are few. Indeed, herbarium specimens are finding new uses for reconstructing past ecological and phytogeographical scenarios (Miller-Rushing *et al.* 2004; Liao and Bataan 2016). In the present study, historical records gleaned from the literature and herbarium collections have been supplemented with samples from virtually the same stations as those sampled earlier in Silot Bay, an approach similar to that employed by Oliveira and Qi (2003), de Paula *et al.* (2020), and others. This approach should prove to be valuable in evaluating biodiversity change. More localities with existing records of algal flora should be revisited in order to provide additional evidence on the impact of anthropogenic and other environmental stresses on natural flora around the Philippines.

CONCLUSION

Continuous monitoring of the composition of benthic macroalgal communities and environmental conditions could aid in documenting anthropogenic impacts on marine ecosystems. Certain species with their characteristic growth habits may be useful as ecological indicators. Herbarium samples, mainly collected to support purely taxonomic studies, can be viewed in a new light. Historical collections in natural history museums are an important yet underutilized resource for studying environmental changes throughout time. This valuable use of herbarium resources provides added impetus to the work of taxonomists and the relevance of natural history museums during this time of dwindling interest and support for taxonomists and their institutions. The maintenance and use of well-curated samples for environmental studies also bode well for work in developing countries like the Philippines, where sophisticated tools for environmental monitoring may be inaccessible. The ecological value of systematic works on Philippine algal flora should not be underestimated and should be given more support and attention.

ACKNOWLEDGMENTS

The authors thank Dr. Mary Joyce L. Flores and Dr. Brisneve Edullantes (University of the Philippines Cebu) for reading the first draft of this paper. This work represents a part of the master's thesis prepared by the first author and submitted to the University of the Philippines Cebu.

DAUB acknowledges Papa Kit's Marina and Fishing Lagoon for the permission to gain access to their property to conduct the survey. LML acknowledges the travel support granted by the Graduate School of Integrated Sciences for Life, Hiroshima University to enable field research in the Philippines. The authors greatly appreciate the valuable comments and suggestions of the anonymous reviewers, which improved the presentation and discussions in our manuscript, although we assume any remaining errors or interpretations as our own.

STATEMENT ON CONFLICT OF INTEREST

The authors express no conflict of interest in any form.

REFERENCES

- AZEVEDO CAA, CARNEIRO MAA, OLIVEIRA SR, MARINHO-SORIANO E. 2011. Macroalgae as an indicator of the environmental health of the Pirangi reefs, Rio Grande do Norte, Brazil. *Revista Brasileira de Farmacognosia* 21: 323–328.
- BATES CR, SAUNDERS GW, CHOPIN T. 2009. Historical *versus* contemporary measures of seaweed biodiversity in the Bay of Fundy. *Botany* 87: 1066–1076.
- BISHOP MJ, MAYER-PINTO M, AIROLDI L, FIRTH LB, MORRIS RL, LOKE LHL, HAWKINS SJ, NAYLOR LA, COLEMAN RA, CHEE SY, DAFFORN KA. 2017. Effects of ocean sprawl on ecological connectivity: impacts and solutions. *Journal of Experimental Marine Biology and Ecology* 492: 7–30.
- CALUMPONG HP, MEÑEZ EG. 1997. Field Guide to the Common Mangroves, Seagrasses, and Algae of the Philippines. Makati City, Philippines: Bookmark Inc. 197p.
- DE PAULA JC, PEREIRA-LOPES-FILHO EA, DE CARVALHO WF, DE SOUZA CORAÇÃO AC, YONESHIGUE-VALENTIN Y. 2020. Long term changes in macroalgae assemblages reveal a gradual biodiversity loss over the last 200 years in the hypereutrophic Guanabara Bay. *Marine Environmental Research* 162: 106153.
- DULYMAMODE R, SUKHOO N, BHUGUN I. 2001. Evaluation of *Padina boergesenii* (Phaeophyceae) as a bioindicator of heavy metals: some preliminary results from Mauritius. *South African Journal of Botany* 67: 460–464.
- ERIKSSON BK, JOHANSSON G. 2005. Effects of sedimentation on macroalgae: species-specific responses are related to reproductive traits. *Oecologia* 143: 438–448.
- GÓMEZ I, HUOVINEN P. 2011. Morpho-functional patterns and zonation of South Chilean seaweeds: the importance of photosynthetic and bio-optical traits. *Marine Ecology Progress Series* 422: 77–91.
- GORGULA SK, CONNELL SD. 2004. Expansive covers of turf-forming algae on human-dominated coast: the relative effects of increasing nutrient and sediment loads. *Marine Biology* 145: 613–619.
- GUIRY MD, GUIRY GM. 2021. AlgaeBase. World-wide electronic publication, National University of Ireland, Galway.
- HARLEY CDG, CONNELL SD. 2009. Shifts in abiotic variables and consequences for diversity. In: *Marine Hard Bottom Communities: Patterns, Dynamics, Diversity, and Change*. Wahl M ed. Berlin: Springer-Verlag. p. 257–268.
- HELMUTH B, BROITMAN BR, BLANCHETTE CA, GILMAN S, HALPIN P, HARLEY CDG, O'DONNELL MJ, HOFMANN GE, MENGE B, STRICKLAND D. 2006. Mosaic patterns of thermal stress in the rocky intertidal zone: implications for climate change. *Ecological Monographs* 76: 461–479.
- JOHNSON EL, ROBERTS DA. 2009. Contaminants reduce the richness and evenness of marine communities: a review and meta-analysis. *Environmental Pollution* 157: 1745–1752.
- JONAH FE, ADJEI-BOATENG D, AGBO NW, MENSAH EA, EDZIYIE RE. 2015. Assessment of sand and stone mining along the coastline of Cape Coast, Ghana. *Annals of GIS* 21: 223–231.
- JUARIO JV, GRANERT WG, ENCABO GB. 1970. Silot Bay – a marine biological station. *Philippine Scientist* 7: 7–12.
- KAUTSKYN, KAUTSKY H, KAUTSKY U, WAERN M. 1986. Decreased depth penetration of *Fucus vesiculosus* (L.) since the 1940's indicates eutrophication of the Baltic Sea. *Marine Ecology Progress Series* 28: 1–8.
- KOCH M, BOWES G, ROSS C, ZHANG XH. 2013. Climate change and ocean acidification effects on seagrasses and marine macroalgae. *Global Change Biology* 19: 103–132.
- LIAO LM, BATAAN DAU. 2016. Reclaiming the past in understanding the present: documenting environmental change in coastal ecosystems using seaweed herbarium specimens. In: *Proceedings of the International*

- Symposium on Interactions of Human, Culture, and Nature Explored with University Museum Collections; 11–12 Oct 2016; Hanoi, Vietnam. Nakayama N ed. VNU University of Science. p. 73–76.
- LITTLER MM, ARNOLD KE. 1982. Primary productivity of marine macroalgal functional-form groups from southwestern North America. *Journal of Phycology* 18: 307–311.
- LITTLER MM, LITTLER DS. 1980. The evolution of thallus form and survival strategies in benthic marine macroalgae: field and laboratory tests of a functional form model. *The American Naturalist* 116: 25–44.
- MILLER J. 1972. A review of ecological researches done at Silot Bay, Liloan Cebu. *Philippine Scientist* 9: 7–31.
- MILLER-RUSHING AJ, PRIMACK D, PRIMACK RB, IMBRES C, DEL TREDICI P. 2004. Herbarium specimens as a novel tool for climate change research. *Arnoldia* 63: 26–32.
- MUENDO PN, VERDEGEM MC, STORVOGEL JJ, MILSTEIN A, GAMAL EN, DUC PM, VERRETH JAJ. 2014. Sediment accumulation in fish ponds; its potential for agricultural use. *IJFAS* 1: 228–24.
- OLIVEIRA E, QI Y. 2003. Decadal changes in a polluted bay as seen from its seaweed flora: the case of Santos Bay in Brazil. *Ambio* 36: 403–405.
- PEÑA V, BARBARA I. 2008. Maerl community in the north-western Iberian Peninsula: a review of floristic studies and long-term changes. *Aquatic Conservation: Marine and Freshwater Ecosystems* 18: 339–366.
- PONGPARADON S, NOOEK S, PRATHEP A. 2020. Phenotypic plasticity and morphological adaptation of *Halimeda opuntia* (Bryopsidales, Chlorophyta) to light intensity. *Phycological Research* 68: 115–125.
- RIVERO NK, DAFFORN KA, COLEMAN MA, JOHNSTON EL. 2013. Environmental and ecological changes associated with a marina. *Biofouling* 29: 803–815.
- SCHIEL DR, WOOD SA, DUNMORE RA, TAYLOR DI. 2006. Sediment on marine intertidal reefs: effects on early post-settlement stages of habitat-forming seaweeds. *Journal of Experimental Marine Biology and Ecology* 331: 158–172.
- SHAFFER HB, FISHER RN, DAVIDSON C. 1998. The role of natural history collections in documenting species declines. *Trends in Ecology and Evolution* 13: 27–30.
- SMITH JR, FONG P, AMBROSE RF. 2006. Long-term change in mussel (*Mytilus californianus* Conrad) populations along the wave-exposed coast of southern California. *Marine Biology* 149: 537–545.
- TITLYANOVA EA, TITLYANOVA TV, XIAB, BARTSCH I. 2011. Checklist of marine benthic green algae (Chlorophyta) on Hainan, a subtropical island off the coast of China: comparisons between the 1930s and 1990–2009 reveal environmental changes. *Botanica Marina* 54: 523–535.
- TOMIZUKA T, IWATSUKI K, MIYATA M. 2012. Estimation of environmental changes on shallow seawater by the use of voucher specimens of seaweeds preserved in universities and museums. *Journal of Japanese Botany* 87: 31–40 (in Japanese with English abstract).
- TRONO GC. 1997. *Field Guide & Atlas of the Seaweed Resources of the Philippines*. Makati City, Philippines: Bookmark Inc. 306p.
- TRONO GC. 2004. *Field Guide & Atlas of the Seaweed Resources of the Philippines, Volume 2*. Bureau of Agricultural Research, Quezon City, Philippines. 261p.
- TSIAMIS K, VERLAQUE M. 2011. A new contribution to the alien red macroalgal flora of Greece (Eastern Mediterranean) with emphasis on *Hypnea* species. *Cryptogamie, Algologie*, 32: 393–410.
- VILLALUZ EA, LARGO DB, LIAO LM. 2016. Green tide-causing species in northern Mindanao, Philippines: taxonomic profiling and morphological descriptions. *Tropical Natural History* 16: 97–106.
- VIMALA T, POONGHUZHALI TV. 2017. *In vitro* antimicrobial activity of solvent extracts of marine brown alga, *Hydroclathrus clathratus* (C. Agardh) M. Howe from Gulf of Mannar. *Journal of Applied Pharmaceutical Science* 7: 157–162.
- VOGT H, SCHRAMM W. 1991. Conspicuous decline of *Fucus* in Kiel Bay (western Baltic): what are the causes? *Marine Ecology Progress Series* 69: 189–194.
- WEI Z, MO J, HUANG R, HU Q, LONG C, DING D, YANG F, LONG L. 2020. Physiological performance of three calcifying green macroalgae *Halimeda* species in response to altered seawater temperatures. *Acta Oceanologica Sinica* 39: 89–100.
- YANG F, WEI Z, LONG L. 2021. Transcriptomic and physiological responses of the tropical reef calcified macroalga *Amphiroa fragilissima* to elevated temperature. *Journal of Phycology* 57: 1254–1265.
- ZARSUELO JC. 1975. The benthic algae of Silot Bay (Liloan, Cebu) and some physico-chemical factors affecting their distribution and abundance. *National Research Council of the Philippines Technical Bulletin* 57: 18–49.