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Long-term changes in coral assemblages under natural and anthropogenic stress in Jakarta Bay (1920–2005)

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ABSTRACT

Coral reefs in Jakarta Bay have been subjected to scientific studies since the 1920s. Also from that time on biological collections were made. The reefs in the Jakarta Bay have been under long-term natural and anthropogenic stress. With the biological collections and historical documents the coral species richness in Jakarta Bay around 1920 was reconstructed. New data from this bay and the adjacent offshore Thousand Islands archipelago were obtained during a 2005 research expedition. A comparison of the coral assemblages between 1920 and 2005 reveals a clear decline in species numbers. The most prominent results include the near-shore disappearance of species belonging to the families Acroporidae, Milleporidae, and to a lesser extent Poritidae. The overall coral species composition of the reefs has changed considerably, which is partly reflected in a strong decline in coral species richness. About half the number of species recorded in 1920 was found again in 2005.

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1. Introduction

Species-rich coral reef ecosystems are under pressure worldwide from both natural and anthropogenic disturbance. Disturbances such as changes in seawater temperature and terrestrial run-off negatively influence coral reef ecosystems. The spatial complexity, biodiversity, and dynamic nature of these ecosystems are influenced by the intensity and variation in scale of both natural and anthropogenic disturbances (Wilkinson, 1996; Hoeksema, 2004; Fabricius, 2005; Wilson et al., 2006). Reefs are resilient to natural disturbances; but vulnerable to chronic stress, such as pollution and degradation of water quality (Wilkinson, 1993). Data on benthic marine ecosystems show directional changes in the structure of these ecosystems, which are related to the increasing occurrence, diversity, and scale of anthropogenic disturbances (Jackson et al., 2001; Hughes et al., 2003).

Throughout the tropics, centres of high reef coral diversity coincide with human population centres, and thus the greatest potential for species loss lies in these geographical areas (Chadwick-Furman, 1996; Bryant et al., 1998; Burke et al., 2002). Coastal resources such as coral reefs are susceptible to considerable pressure from large metropolises. Coral reefs in areas with low human population densities are doing relatively well compared with reefs close to urban centres (Rogers, 1990; Roberts, 1993; Edinger et al., 1998; Rees et al., 1999). Regional anthropogenic impacts

are the largest threats to coral diversity and may interact with global climate change to exacerbate rates of local species extinctions (Chadwick-Furman, 1996).

Several studies have been published on the effects of anthropogenic pollution and sediments on local ecosystems over longer time periods. Based on historical data, McCulloch et al. (2003) found a five- to 10-fold increase in the delivery of sediments onto the inner Great Barrier Reef following the beginning of European settlement in the coastal area. Jackson et al. (2001) used historical research to show changes in coastal ecosystems, including work on coral reefs in the Caribbean and the Great Barrier Reef in Australia, showing dramatic phase shifts in dominant species on the reefs due to intensified human disturbances. A study in the Netherlands Antilles shows that rare coral species became extinct in permanent quadrats, and that other species became less abundant over a 20-year period, likely as a result of urbanisation (Bak and Nieuwland, 1995), whereas a study in the Red Sea shows a lack of recovery for disturbed reefs close to sources of pollution (Wielgus et al., 2003).

Despite the aforementioned studies on local changes in coral reef diversity, only little work has been carried out on multi-year changes in Indo-Pacific coral reef assemblages. In view of the importance of Indonesia's position in relation to the Coral Triangle (Hoeksema, 2007), there is a need for more long-term studies on reef coral diversity in this region. Furthermore, data from historical expeditions can provide information about distribution ranges of species and changes herein (van der Meij and Visser, in press). A 17-year study at Ko Phuket (Thailand) demonstrated the destructive effects of dredging and anomalously low sea water levels on

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coral communities (Brown et al., 2002). Research on mushroom coral assemblages near Singapore (1860s–2006) showed a loss of species richness, probably caused by anthropogenic disturbance (Hoeksema and Koh, 2009). Similar research carried out on the molluscan fauna of Jakarta Bay revealed a strong decline in species diversity over a ~75-year time period (van der Meij et al., 2009).

This study aims at documenting changes in coral reef biodiversity since the first half of the 20th century in Jakarta Bay and the adjacent Thousand Islands archipelago (Kepulauan Seribu), Java, Indonesia. This area has received increasing amounts of sewage since the early 1900s, and has been subjected to siltation, coastal development and coral mining. Furthermore, the corals have suf-

fered from large-scale mortality resulting from natural stress, such as crown-of-thorns starfish (*Acanthaster planci* (Linnaeus, 1758)) outbreaks and bleaching resulting from ENSO (El Niño Southern Oscillation) events (Verstappen, 1988; Brown and Suharsono, 1990; Warwick et al., 1990; Hoeksema, 1991; Tomascik, 1997). Several reefs here have been extensively studied in the early 1900s, providing a baseline for the present study (e.g., Umbgrove, 1928a, b; Umbgrove and Verwey, 1929; Verwey, 1931; Delsman, 1937). Exploiting field data from an 85-year time span from a single area, combined with historical documents (notebooks, journals, and nautical maps) enables us to follow time trends in diversity on these coral reefs. The present study spans a period over which

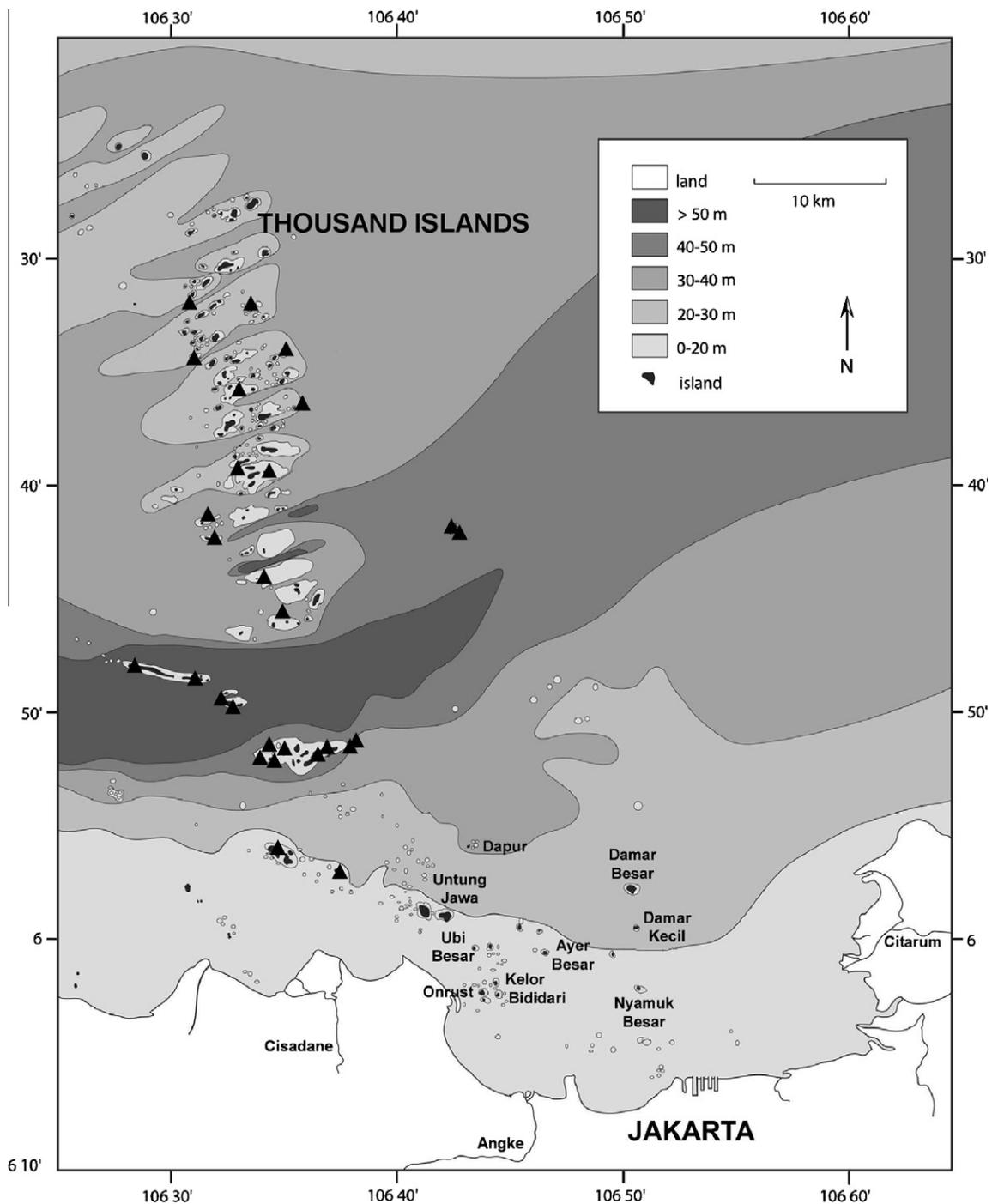


Fig. 1. Map of research area, with triangles indicating the 2005 sampling localities in the Thousand Islands archipelago.

possible anthropogenic changes are documented, and offers the opportunity to detect changes in Jakarta Bay's coral fauna.

2. Methods

2.1. Research area

All research was carried out on reefs in Jakarta Bay and the adjacent Thousand Islands archipelago (Fig. 1). This reef complex extends from Jakarta's coastline to more than 80 km offshore in a NNW–SSE direction, perpendicular to the coast line, and 30 km from east to west (5°47'–5°24' S, 106°23'–106°37' E). The reef complex consists of over 108 small (<10 ha) and low-lying (<3 m asl) coral cays (Brown, 1986). The Thousand Islands are separated from the bay area by a channel with a depth of about 100 m connected to the Sunda Strait (Umbgrove, 1929). Jakarta's extended agglomeration houses over 23 million inhabitants in an area of about 2700-km² and it is the world's largest conurbation located in close vicinity to a coral reef complex. Jakarta Bay is less than 30 m deep, with a bottom composed of terrigenous mud, coral sand, rubble, and coralline algae (Ongkosongo, 1989).

The bay is bordered by two capes, Tanjung Pasir to the west and Tanjung Karawang to the east. Three major rivers discharge fresh water and silt into Jakarta's reef area: the Cisadane, most westward and just outside the bay, the Angke, most southward inside the bay, and the Citarum, with a large river delta in the easternmost cape (Verstappen, 1953; Moll and Suharsono, 1986). The river Citarum

carries large quantities of silt to the east side of the bay, confining the presence of coral reefs to its western part only (Umbgrove and Verwey, 1929). In addition, the bay receives highly polluted water from the rivers that drain metropolitan Jakarta. The present research area consists of a series of coral reefs ranging from those living in the polluted waters of Jakarta Bay to those in the clearer waters of the Java Sea (Brown, 1986).

2.2. Water quality

Secchi disk depth measurements near Onrust Island and Kelor Island did not show significant different results among 1929, 1985, and 1993 data, whereas for reefs further offshore a dramatic reduction in water transparency was noted (Tomascik et al., 1993). Little data is available on salinity and Cl content; in 1927 Kelor had salinity and Cl levels of respectively 29.4 and 17.8, Damar Kecil of 30.3 and 18.4, Nyamuk Besar of 31.2 and 18.9, and Bidadari of 31 and 18.8 (Umbgrove, 1928a). Historical data on the nutrient concentration (PO₄ and NO₃) shows that Jakarta Bay has become progressively more eutrophic in time, paralleled by a strong reduction of the maximal depth of coral reef communities with stronger effects for islands further away (Tomascik et al., 1993). The effluents of the rivers Cisadane, Ciliwung, and Citarum have contributed greatly to this degradation of the bays' water quality. Studies in the western part of the bay have revealed that the degradation of water quality was due to household waste, whereas the studies in the eastern part of the bay re-



Fig. 2. Satellite photo showing river plumes (obtained via <http://glof.umiacs.umd.edu> (Landsat), image taken in 2002).

vealed that water pollution was caused by hydrocarbons and heavy metals. For Pb, Cd, Hg, Cu, and Zn, the levels have reached or surpassed the permissible limits defined for standard water quality. Furthermore, the power plant at Tanjung Priok harbour produces vast amounts of cooling water, which results in thermal pollution (Sutamihardja, 1985).

2.3. Data collection

The scientific natural history collections in the Netherlands had much benefit from the availability of Jakarta's research facilities in the early 20th century: the Fisheries Station at Jakarta's fish market, which later became the Laboratory for the Investigation of the Sea, and some research facilities at Damar Besar Isl. Old collection labels indicate that maximum depths of 12 m were reached through dredging, helm diving, wading, and snorkelling. In the 1920s, mainly the exposed north-western sides of Jakarta Bay's reefs were sampled. The reefs Onrust, Damar Besar, and Ayer Besar

were more thoroughly sampled in the early 1900s than other reefs in the bay, especially the reefs Kelor, Ubi Besar, and Bidadari seem to be undersampled. In addition to the collected material, historical documents were studied for further information on the reef condition in Jakarta Bay around 1920 and before.

In 2005, 28 patch reefs throughout the Thousand Islands archipelago (including Jakarta Bay) were assessed. The reefs were sampled using the roving diver technique (Schmitt et al., 2002; Munro, 2005) in an environmental south-to-north, near-shore to off-shore gradient, with increasing distance from urbanization and river discharge (Figs 1 and 2). At the NW-side of each locality, one hour per observer was spent with the help of SCUBA equipment, reaching depths down to 30 m, which was deeper than in 1920. Per encountered species, specimens were collected, photographed and/or noted on a PVC underwater writing board. Collected specimens were deposited in the Zoological Museum of Bogor (PPB-LIPI, presently at Cibinong). Due to a lack of trained observers, the genera *Alveopora* and *Montipora* were undersampled in 2005. After the

Table 1

General condition of the islands in Jakarta Bay (and two reefs in Kepulauan Seribu), based on historical publications and notebooks from 1888 onwards. Present topographical names (Indonesian Navy, 2002: map 86) are used, with the addition of alternative/old Dutch names (Dutch Navy, 1899: maps 86/87) in between brackets.

Island/area	Remarks
Jakarta Bay, Teluk Jakarta (Bay of Batavia)	In comparison to the coasts of Singapore and Sumatra, the coast of NW Java around Jakarta is richer in species (Sluiter, 1888). Hardenberg (1939) expresses the need for marine reserves to protect reefs from dredging and other threats. Coral mining was common and carried out by means of explosives and crowbars, mainly targeting <i>Porites</i> and <i>Acropora</i> . About 12–15 dam ³ of coral was landed annually, with exceptions of up to 25 dam ³ . The municipality of Jakarta was the largest buyer (Hardenberg, 1939).
Ayer Besar (Hoorn)	The coral island has been elevated with coral rubble for development, like building a restaurant (Hardenberg, 1939). The reef was in good condition (Umbgrove, 1939).
Ayer Kecil (= Nusi) (Haarlem)	Young vegetation was planted on the cay. Large fields of <i>Acropora</i> were demolished in a storm (1934). Hardenberg (1939) proposed a marine reserve as the reef is 'not inferior to the reefs of Ambon'. Coral mining eventually caused this island to disappear (Stoddart, 1986; DeVantier et al., 1998).
Ayer Sedang (= Gosong Putih) (Monnikendam)	The cay was elevated with coral rubble (van Benthem-Jutting and Westenberg, unpublished; Hardenberg, 1939).
Bidadari (= Sakit) (Purmerend) Cipir (= Burung) (Kuiper)	A leper colony was located on the island (van Benthem-Jutting and Westenberg, unpubl.). Inhabited by staff of the meteorological observatory, which altered the flora (van Benthem-Jutting and Westenberg, unpublished; Hardenberg, 1939).
Damar Besar (Edam)	Sluiter (1888) considered this reef, together with Nyamuk Kecil, to be most species-rich. The W and N side of the reef consisted of live coral, whereas the E side consisted of dead coral (Boschma, unpublished, 1921–22; Boschma, 1936). The island was elevated with coral rubble (Hardenberg, 1939). A house and lighthouse were constructed, inhabited by the lighthouse keeper's family.
Damar Kecil (=Monyet) (Alkmaar) Kapal (Onrust)	This island was privately owned (Verstappen, 1988). The documented history of this island goes back far. Before Dutch settlement (17th C.) the Banten kings used it as a holiday resort. Since 1610 the Dutch East India Company (VOC) used the island as a trading post with fortification, a naval base and pilgrim (haj) quarantine. In 1875–76 the Dutch Navy performed well drills, but the water appeared undrinkable (Hooze, 1877; Sluiter, 1890). Settlements included a public aquarium. Hardenberg (1939) mentioned that humans altered the island's flora. Currently a small human population lives here (Attahiyat, 2000).
Karang Karang Timbul (Bonte Ezel = Van Dorth?)/ Karang Cikasi (Broenda Droogte) Kelor (Kerkhof)	These reefs (first buoys outside of Tanjung Priok harbour) remained 2–3.5 m below water (Sluiter, 1888). Kelor has a history of coral mining and extensive fishing, as a result of which the reef is almost completely destroyed (Verstappen, 1988).
Nyamuk Besar (= Nirwana) (Leiden)	From mangroves on the N side of the island, a (possibly man-made) dam of dead coral stretched out into the sea. On both sides of this dam a rich marine fauna could be found, most of which was unique for Jakarta Bay (Sluiter, 1888). <i>Montipora</i> corals were abundant (Umbgrove, 1928b, 1939). Tourism, introduced in the 1960s, was moved to Bidadari because of the rapid abrasion of the cay (Verstappen, 1988). Coral mining caused the island's disappearance (Stoddart, 1986; DeVantier et al., 1998).
Nyamuk Kecil (= Tala) (Enkhuizen)	Nyamuk Kecil, together with Damar Besar, was considered to be the richest reef in Jakarta Bay (Sluiter, 1888). The reef is largely dead because of water pollution and coral mining (Verstappen, 1988).
Putri (Vader Smit)	In 1824 Putri was a vegetated island (Verstappen, 1988). Sluiter (1888, 1890) mentioned that the reef partially emerged during low tide, which he considered to be the first stage towards becoming a true coral cay. The island degraded and became a shoal due to coral mining (Hardenberg, 1939).
Ubi Besar (Rotterdam)	Settlements of native fishermen altered the flora (van Benthem-Jutting and Westenberg, unpublished; Hardenberg, 1939). Coral mining eventually caused the island to disappear (Stoddart, 1986; DeVantier et al., 1998).
Ubi Kecil (Schiedam)	In 1753 Ubi Kecil was a wooded island (Verstappen, 1988), which lasted at least till 1904. The island became eroded by the sea, and in 1939 the island was a bare sand cay (Hardenberg, 1939). Coral mining caused the island's disappearance (Stoddart, 1986; DeVantier et al., 1998).
Jaga Utara (Noordwachter, northern part of Kepulauan Seribu)	According to Boschma (unpublished 1921–22), this island had a surf reef with large <i>Pocillopora</i> corals. The W and N side of the reef were covered by living coral, whereas the E side consisted of dead coral. Various <i>Fungia</i> species were observed in the 1920s. <i>Montipora</i> corals were very abundant.
Menyawa/Rakittiang (= Kelapa) (Boompjeseiland, Kepulauan Seribu)	Although, the water around this reef contained less silt than around reefs in Jakarta Bay, the reef fauna here was comparatively less rich (Wichmann, 1912; Zaneveld and Montagne, 1950).

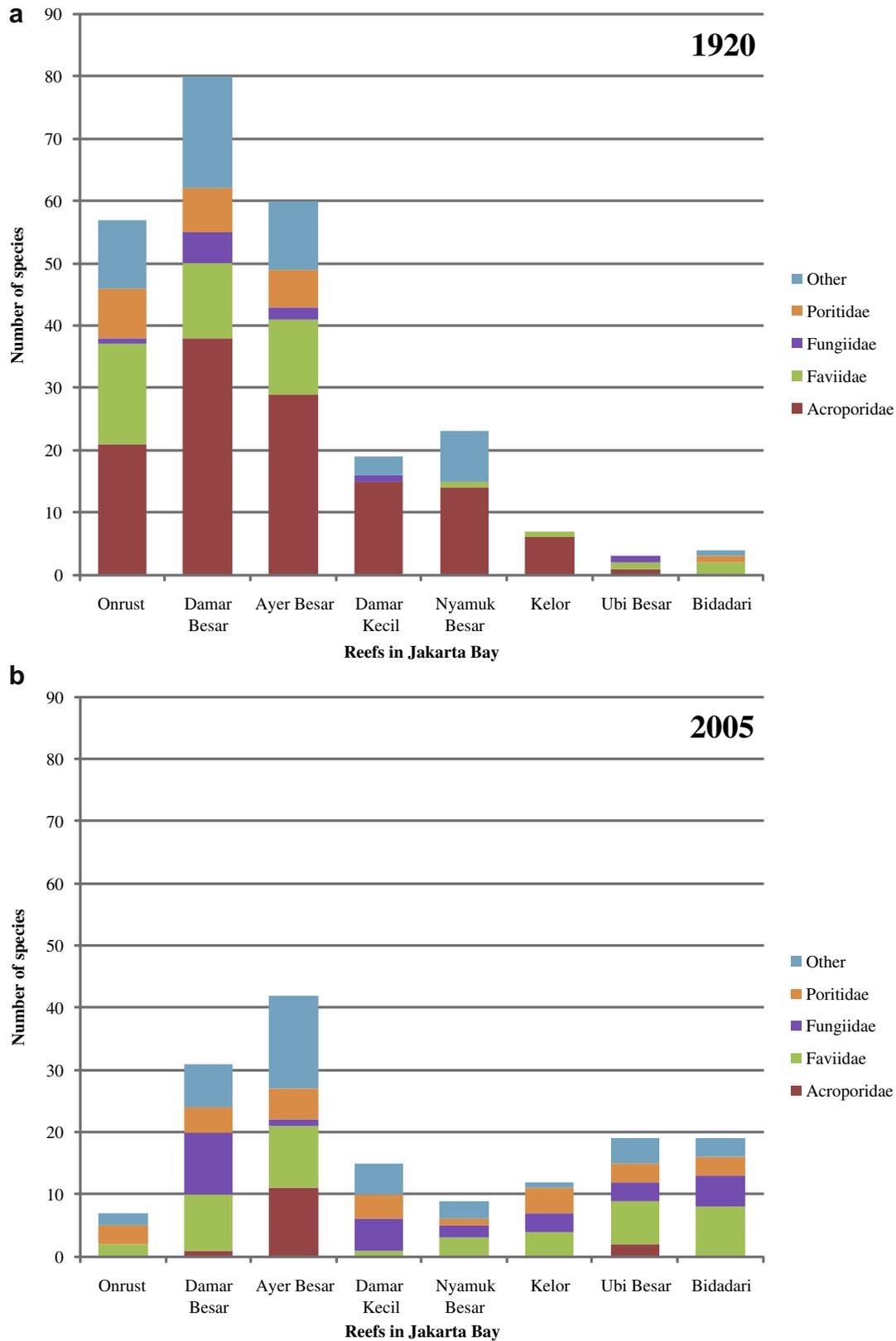


Fig. 3. (a and b) The number of coral species per reef in Jakarta Bay in 1920 and 2005, reefs are ranked from high to low impact in terms of species numbers.

2005 survey the historical coral collections of Naturalis were re-identified by the same researchers, to avoid observer bias.

Although additional data is available from surveys in 1985 and 1995 (Brown, 1986; Cleary et al., 2006, 2008), it was decided not to

refer to those data in the present study. Different recording methods and observers, also between 1985 and 1995, and the lack of collections resulting from the 1985 and 1995 surveys, almost certainly influenced the data to the extent that its unreliability out-

Table 2

List of coral species recorded from Jakarta Bay around 1920, based on literature and museum collections. All identifications have been updated to current knowledge (Wijsman-Best, 1972; Veron and Pichon, 1976; Veron et al., 1977; Veron and Pichon, 1980; Veron and Pichon, 1982; Veron and Wallace, 1984; Hoeksema, 1989; Wallace and Wolstenholme, 1998; Cairns et al., 1999; Wallace, 1999; Veron, 2000; Razak and Hoeksema, 2003). Species lists are compared with 2005 data from Jakarta Bay and Kepulauan Seribu. * = records from Wallace and Wolstenholme (1998); ? = doubtful due to the absence of voucher specimens; RMNH = material present in NCB Naturalis, including the majority of specimens described by Umbgrove (1939).

	1920	2005		Reference 1920
	Jakarta Bay	Jakarta Bay	Kep. Seribu	
Acroporidae^a				
<i>Acropora abrolhosensis</i> Veron, 1985	x		x	RMNH
<i>A. abrotanoides</i> (Lamarck, 1816)	x			Umbgrove and Verwey, 1929
<i>A. aculeus</i> (Dana, 1846)	x		x	RMNH
<i>A. acuminata</i> (Verrill, 1864)	x		*	RMNH
<i>A. anthocercis</i> (Brook, 1893)	x			RMNH
<i>A. aspera</i> (Dana, 1846)	x		*	Boschma, 1936
<i>A. austera</i> (Dana, 1846)		x	x	
<i>A. carduus</i> (Dana, 1846)	x			RMNH
<i>A. cerealis</i> (Dana, 1846)	x		x	RMNH
<i>A. cytherea</i> (Dana, 1846)	x		x	RMNH
<i>A. digitifera</i> (Dana, 1846)	x			Boschma, 1936
<i>A. divaricata</i> (Dana, 1846)	x		x	RMNH
<i>A. donei</i> Veron and Wallace, 1984	x		x	RMNH
<i>A. echinata</i> (Dana, 1846)	x		x	RMNH
<i>A. elseyi</i> (Brook, 1892)	x			RMNH
<i>A. florida</i> (Dana, 1846)	x	x	x	RMNH
<i>A. grandis</i> (Brook, 1892)	x			RMNH
<i>A. hoeksemai</i> Wallace, 1997	x			RMNH
<i>A. humilis</i> (Dana, 1846)	x		x	RMNH
<i>A. hyacinthus</i> (Dana, 1846)	x	x	x	Umbgrove and Verwey, 1929
<i>A. indonesia</i> Wallace, 1997	x	x	*	RMNH
<i>A. intermedia</i> (Brook, 1891)	x		x	RMNH
<i>A. latistella</i> (Brook, 1892)	x		x	RMNH
<i>A. longicyathus</i> (M. Edwards & Haime, 1860)	x		x	RMNH
<i>A. loripes</i> (Brook, 1892)	x		*	RMNH
<i>A. lutkeni</i> Crossland, 1952	x			RMNH
<i>A. microphthalma</i> (Verrill, 1869)	x		x	RMNH
<i>A. millepora</i> (Ehrenberg, 1834)	x	x	x	Boschma, 1936
<i>A. muricata</i> (Linnaeus, 1758)	x	x	x	Hardenberg, 1939
<i>A. nana</i> (Studer, 1878)	x		x	RMNH
<i>A. nasuta</i> (Dana, 1846)	x		x	RMNH
<i>A. pharaonis</i> (M. Edwards & Haime, 1860)	x			Umbgrove and Verwey, 1929
<i>A. prolifera</i> (Lamarck, 1816)	x			Boschma, 1936
<i>A. pulchra</i> (Brook, 1891)	x		x	RMNH
<i>A. robusta</i> (Dana, 1846)	x		*	RMNH
<i>A. samoensis</i> (Brook, 1891)	x	x	x	RMNH
<i>A. sarmentosa</i> (Brook, 1892)	x		x	Umbgrove, 1928b
<i>A. secale</i> (Studer, 1878)	x		x	RMNH
<i>A. solitaryensis</i> Veron and Wallace, 1984	x		x	RMNH
<i>A. spicifera</i> (Dana, 1846)	x		*	Boschma, 1936
<i>A. subulata</i> (Dana, 1846)	x	x	x	RMNH
<i>A. sukarnoi</i> Wallace, 1997	x			RMNH
<i>A. tenuis</i> (Dana, 1846)	x		x	RMNH
<i>A. tortuosa</i> (Dana, 1846)	x			RMNH
<i>A. valida</i> (Dana, 1846)	x	x	x	Boschma, 1936
<i>A. vaughani</i> Wells, 1954	x		*	RMNH
<i>A. yongei</i> Veron and Wallace, 1984	x		*	RMNH
<i>Astreopora myriophthalma</i> (Lamarck, 1816)	x		x	Umbgrove, 1939
<i>Isopora brueggemanni</i> (Brook, 1893)	x		*	RMNH

Table 2 (continued)

	1920	2005		Reference 1920
	Jakarta Bay	Jakarta Bay	Kep. Seribu	
<i>I. palifera</i> (Lamarck, 1816)	x		x	Boschma, 1936
<i>Montipora aequituberculata</i> Bernard, 1897	x			RMNH
<i>M. angulata</i> (Lamarck, 1816)	x			RMNH
<i>M. australiensis</i> Bernard, 1897	x			RMNH
<i>M. cactus</i> Bernard, 1897	x			RMNH
<i>M. calcarea</i> Bernard, 1897	x			Boschma, 1936
<i>M. confusa</i> Nemenzo, 1967	x			RMNH
<i>M. digitata</i> (Dana, 1846)	x	x	x	RMNH
<i>M. effusa</i> Dana, 1846	x			RMNH
<i>M. floweri</i> Wells, 1954	x			RMNH
<i>M. foliosa</i> (Pallas, 1766)	x			Umbgrove, 1939
<i>M. foveolata</i> (Dana, 1846)	x			RMNH
<i>M. gaimardi</i> Bernard, 1897		x		
<i>M. grisea</i> Bernard, 1897	x			RMNH
<i>M. hispida</i> (Dana, 1846)	x	x		RMNH
<i>M. hodgsoni</i> Veron, 2000	x			RMNH
<i>M. hoffmeisteri</i> Wells, 1954	x			RMNH
<i>M. informis</i> (Bernard, 1897)	x			RMNH
<i>M. nodosa</i> (Dana, 1846)	x			RMNH
<i>M. peltiformis</i> Bernard, 1897	x			RMNH
<i>M. porites</i> Veron, 2000	x			RMNH
<i>M. samarensis</i> Nemenzo, 1967	x		x	RMNH
<i>M. spumosa</i> (Lamarck, 1816)		x	x	
<i>M. stilosa</i> (Ehrenberg, 1834)	x			Hardenberg, 1939
<i>M. turgescens</i> Bernard, 1897	x			RMNH
<i>M. turtlensis</i> Veron and Wallace, 1984	x			RMNH
<i>M. undata</i> Bernard, 1897	x			RMNH
<i>M. verrucosa</i> (Lamarck, 1816)	x			RMNH
Agariciidae				
<i>Coeloseris mayeri</i> Vaughan, 1918	x	x	x	Umbgrove, 1939
<i>Pachyseris rugosa</i> (Dana, 1846)	x		x	Umbgrove, 1939
<i>P. speciosa</i> (Dana, 1846)	x		x	Umbgrove, 1939
<i>Pavona cactus</i> (Forskål, 1775)	x	x	x	Umbgrove, 1939
<i>P. clavus</i> (Dana, 1846)	x		x	Umbgrove, 1939
<i>P. decussata</i> (Dana, 1846)	x	x	x	Umbgrove, 1939
<i>P. divaricata</i> Lamarck, 1816	x			Umbgrove, 1939
<i>P. frondifera</i> Lamarck, 1816	x		x	Umbgrove, 1939
<i>P. varians</i> Verrill, 1864	x	x	x	Umbgrove, 1939
<i>P. venosa</i> (Ehrenberg, 1834)	x		x	Umbgrove, 1939
Dendrophylliidae				
<i>Turbinaria peltata</i> (Esper, 1794)	x	x		Umbgrove, 1939
<i>T. mesenterina</i> (Lamarck, 1816)	x		x	RMNH
<i>T. reniformis</i> Bernard, 1896	x		x	RMNH
Euphylliidae				
<i>Euphyllia glabrescens</i> (Chamisso & Eysenhardt, 1821)	x	x	x	Umbgrove and Verwey, 1929
Faviidae				
<i>Caulastrea furcata</i> Dana, 1846	x		x	RMNH
<i>C. tumida</i> Matthai, 1928	x		x	Umbgrove, 1939
<i>Cyphastrea chalcidicum</i> (Forskål, 1775)	x	x	x	Umbgrove, 1939
<i>C. microphthalma</i> (Lamarck, 1816)	x	x	x	Umbgrove, 1939
<i>C. serailia</i> (Forskål, 1775)	x	x	x	Umbgrove, 1939

(continued on next page)

Table 2 (continued)

	1920	2005		Reference 1920
	Jakarta Bay	Jakarta Bay	Kep. Seribu	
<i>Diploastrea heliopora</i> (Lamarck, 1816)	x	x	x	Umbgrove, 1939
<i>Echinopora gemmacea</i> (Lamarck, 1816)	x		x	Umbgrove, 1939
<i>E. hirsutissima</i> (M. Edwards & Haime, 1849)	x		x	RMNH
<i>E. horrida</i> Dana, 1846	x		x	Umbgrove, 1939
<i>E. lamellosa</i> (Esper, 1795)	x	x	x	Umbgrove, 1939
<i>Favia fava</i> (Forskål, 1775)	x	x	x	Boschma, 1936
<i>F. matthaii</i> Vaughan, 1918		x	x	
<i>F. maxima</i> Veron, Pichon & Wijsman-Best, 1977		x		
<i>F. pallida</i> (Dana, 1846)	x	x	x	Umbgrove, 1939
<i>F. rotumana</i> (Gardiner, 1899)		x	x	
<i>F. speciosa</i> (Dana, 1846)	x	x	x	Umbgrove, 1939
<i>F. stelligera</i> (Dana, 1846)	x		x	Umbgrove, 1939
<i>Favites abdita</i> (Ellis & Solander, 1786)	x	x	x	Umbgrove, 1939
<i>F. acuticollis</i> (Ortmann, 1889)	x			RMNH
<i>F. chinensis</i> (Verrill, 1866)	x	x	x	RMNH
<i>F. complanata</i> (Ehrenberg, 1834)		x	x	
<i>F. favosa</i> (Ellis & Solander, 1786) ^b	x			Umbgrove, 1939
<i>F. flexuosa</i> (Dana, 1846)	x		x	Umbgrove, 1939
<i>F. halicora</i> (Ehrenberg, 1834)		x	x	
<i>F. pentagona</i> (Esper, 1794)	x	x	x	Umbgrove, 1939
<i>Goniastrea aspera</i> (Verrill, 1865)	x	x	x	Umbgrove, 1939
<i>G. favulus</i> (Dana, 1846)	x	x	x	Geologisch Museum Artis
<i>G. pectinata</i> (Ehrenberg, 1834)	x		x	Umbgrove, 1939
<i>G. retiformis</i> (Lamarck, 1816)	x	x	x	Umbgrove, 1939
<i>Leptastrea pruinosa</i> Crossland, 1952		x	x	
<i>L. purpurea</i> (Dana, 1846)	x	x	x	Umbgrove, 1939
<i>L. transversa</i> Klunzinger, 1879		x	x	
<i>Leptoria phrygia</i> (Ellis & Solander, 1786)	x		x	Umbgrove, 1939
<i>Montastrea curta</i> (Dana, 1846)		x	x	
<i>M. valenciennesii</i> (M. Edwards & Haime, 1848)	x			Umbgrove, 1939
<i>Oulastrea crispata</i> (Lamarck, 1816)	x	x	x	Umbgrove, 1939
<i>Platygyra daedalea</i> (Ellis & Solander, 1786)	x	x	x	RMNH
<i>P. lamellina</i> (Ehrenberg, 1834)	x	x	x	Umbgrove, 1939
<i>P. pini</i> Chevalier, 1971		x	x	
<i>P. sinensis</i> (M. Edwards & Haime, 1849)	x		x	RMNH
<i>P. verweyi</i> Wijsman-Best, 1976	x	x	x	RMNH
<i>P. yaeyamaensis</i> Eguchi & Shirai, 1977		x		
<i>Plesiastrea versipora</i> (Lamarck, 1816)		x	?	
Fungiidae				
<i>Ctenactis albitentaculata</i> Hoeksema, 1989		x	x	
<i>C. echinata</i> (Pallas, 1766)	x	x	x	Umbgrove, 1939
<i>Fungia concinna</i> Verrill, 1864	x	x	x	Umbgrove, 1939

Table 2 (continued)

	1920	2005		Reference 1920
	Jakarta Bay	Jakarta Bay	Kep. Seribu	
<i>F. costulata</i> Ortmann, 1889		x	x	
<i>F. fungites</i> (Linnaeus, 1758)	x	x	x	Umbgrove, 1939
<i>F. horrida</i> Dana, 1846		x	x	
<i>F. moluccensis</i> Van der Horst, 1919		x	x	
<i>F. paumotensis</i> Stutchbury, 1833	x	x	x	Boschma 1921, 1922
<i>F. repanda</i> Dana, 1846	x	x	x	Umbgrove, 1939
<i>F. scruposa</i> Klunzinger, 1879	x	x	x	Umbgrove, 1939
<i>F. scutaria</i> Lamarck, 1801	x		x	Umbgrove, 1939
<i>Heliofungia actiniformis</i> (Quoy & Gaimard, 1833)	x	x	x	Umbgrove, 1939
<i>Herpolitha limax</i> (Esper, 1797)	x	x	x	Umbgrove, 1939
<i>Lithophyllon undulatum</i> Rehberg, 1892		x	x	
<i>Podabacia crustacea</i> (Pallas, 1766)	x		x	Boschma 1921, 1922
<i>Polyphyllia talpina</i> (Lamarck, 1801)	x	x	x	Umbgrove, 1939
<i>Sandalolitha robusta</i> (Quoy, 1801)	x	x	x	Umbgrove, 1939
Helioporidae				
<i>Heliopora coerulea</i> (Pallas, 1766)	x	x	x	Umbgrove, 1939
Merulinidae				
<i>Hydnophora exesa</i> (Pallas, 1766)	x	x	x	Umbgrove, 1939
<i>H. grandis</i> Gardiner, 1906	x			Umbgrove, 1939
<i>H. microconos</i> (Lamarck, 1816)	x	x	x	Umbgrove, 1939
<i>H. rigida</i> (Dana, 1846)	x		x	Umbgrove, 1939
<i>H. pilosa</i> Veron, 1985		x	x	
<i>Merulina ampliata</i> (Ellis & Solander, 1786)	x		x	Umbgrove, 1939
<i>Scapophyllia cylindrica</i> (M. Edwards & Haime, 1848)	x			Umbgrove, 1939
Milleporidae				
<i>Millepora dichotoma</i> Forskål, 1775	x		x	Umbgrove and Verwey, 1929
<i>M. platyphylla</i> Hemprich & Ehrenberg, 1834	x			Boschma, 1936
<i>M. intricata</i> M. Edwards, 1857	x		x	RMNH
<i>M. latifolia</i> Boschma, 1948	x		x	RMNH
<i>M. murrayi</i> Quelch, 1884	x			RMNH
<i>M. tenera</i> Boschma, 1949	x			RMNH
Mussidae				
<i>Lobophyllia corymbosa</i> (Forskål, 1775)	x	x	x	Umbgrove, 1939
<i>L. costata</i> (Dana, 1846)	x			Umbgrove, 1939
<i>L. hemprichii</i> (Ehrenberg, 1834)	x		x	RMNH
<i>Symphyllia agaricia</i> M. Edwards & Haime, 1849		x	x	
<i>S. radians</i> M. Edwards & Haime, 1849	x	x	x	Umbgrove, 1939
<i>S. recta</i> (Dana, 1846)	x	x	x	Umbgrove, 1939
Oculinidae				
<i>Galaxea astreata</i> (Lamarck, 1816)	x			Umbgrove, 1939
<i>G. fascicularis</i> (Linnaeus, 1767)	x	x	x	Umbgrove, 1939
<i>Simplastrea vesicularis</i> Umbgrove, 1939	x			Umbgrove, 1939

Table 2 (continued)

	1920	2005		Reference 1920
	Jakarta Bay	Jakarta Bay	Kep. Seribu	
Pectiniidae				
<i>Echinophyllia aspera</i> (Ellis & Solander, 1786)	x	x	x	Umbgrove, 1939
<i>Mycedium elephantotus</i> (Pallas, 1766)	x	x	x	Umbgrove, 1939
<i>Oxypora lacera</i> (Verrill, 1864)	x			Umbgrove, 1939
<i>Pectinia lactuca</i> (Pallas, 1766)	x		x	Umbgrove, 1939
<i>P. paeonia</i> (Dana, 1846)	x		x	RMNH
Pocilloporidae				
<i>Pocillopora damicornis</i> (Linnaeus, 1758) ^c	x	x	x	Umbgrove, 1939
<i>P. eydouxi</i> M. Edwards & Haime, 1860	x	x	x	Umbgrove, 1939
<i>P. verrucosa</i> (Ellis & Solander, 1786)	x	?	x	Umbgrove, 1939
<i>Seriatopora hystrix</i> Dana, 1846	x	x	x	Umbgrove, 1939
<i>Stylophora pistillata</i> (Esper, 1797)	x	x	x	Umbgrove, 1939
<i>S. mordax</i> (Dana, 1846)	x		x	Umbgrove, 1939
Poritidae				
<i>Alveopora verrilliana</i> Dana, 1872	x			Boschma, 1936
<i>A. viridis</i> (Quoy & Gaimard, 1833)	x			Boschma, 1936
<i>Goniopora columna</i> Dana, 1846	x	x	x	Umbgrove, 1939
<i>G. djiboutiensis</i> Vaughan, 1907		x	x	
<i>G. eclipsensis</i> Veron and Pichon, 1982		?	x	
<i>G. fructifera</i> Saville-Kent 1891 ^d	x	?		RMNH
<i>G. lobata</i> M. Edwards & Haime, 1860		x	x	
<i>G. pendulus</i> Veron, 1985		?		
<i>G. planulata</i> (Ehrenberg, 1834)		x	x	
<i>G. stokesi</i> M. Edwards & Haime, 1851		x	x	
<i>G. stutchburyi</i> Wells, 1955		x	x	
<i>G. tenuidens</i> Quelch, 1886	x	x	x	Umbgrove, 1939
<i>Porites annae</i> Crossland, 1952	x	?		RMNH
<i>P. arantae</i> Nemenzo, 1955	x		x	RMNH
<i>P. attenuata</i> Nemenzo, 1955	x			RMNH
<i>P. australiensis</i> Vaughan, 1918	x	x	x	RMNH
<i>P. compressa</i> Dana, 1846	x			Umbgrove, 1939
<i>P. cylindrica</i> Dana, 1846	x	x	x	RMNH
<i>P. deformis</i> Nemenzo, 1955	x		x	RMNH
<i>P. lichen</i> Dana, 1846	x	x	x	RMNH
<i>P. lobata</i> Dana, 1846	x	x	x	Umbgrove, 1939
<i>P. lutea</i> M. Edwards & Haime, 1860	x	x	x	Umbgrove, 1939
<i>P. murrayensis</i> Vaughan, 1918		x		
<i>P. nigrescens</i> Dana, 1846 ^e	x	x	x	RMNH
<i>P. pukoenis</i> Vaughan, 1907 ^f	x			RMNH
<i>P. rus</i> (Forskål, 1775)	x		x	Umbgrove, 1939
<i>P. solida</i> (Forskål, 1775)	x	x	x	RMNH
<i>P. stephensoni</i> Crossland, 1952	x	x	x	Umbgrove, 1939
<i>P. vaughani</i> Crossland, 1952	x	?	x	RMNH
Siderastreaeidae				
<i>Psammocora contigua</i> (Esper, 1797)	x	x	x	Umbgrove, 1939
<i>P. digitata</i> M. Edwards & Haime, 1851	x		x	RMNH
<i>P. folium</i> Umbgrove, 1939	x			Umbgrove, 1939

Table 2 (continued)

	1920	2005		Reference 1920
	Jakarta Bay	Jakarta Bay	Kep. Seribu	
<i>P. haimeana</i> M. Edwards & Haime, 1851	x	x	x	Umbgrove, 1939
<i>P. profundacella</i> Gardiner, 1898		x	x	
<i>P. superficialis</i> Gardiner, 1898		x	x	
<i>Pseudosiderastrea tayami</i> Yabe & Sugiyama, 1935		x	x	
Tubiporidae				
<i>Tubipora musica</i> (Linnaeus, 1758)	x		x	Boschma 1921, 1922

^a Verwey informed Umbgrove that he intended to publish a monograph on the Acroporidae, including the description of 21 new species from Jakarta Bay. This unpublished manuscript was available to Wallace (1999).

^b *Favites favosa* is a possible synonym of *F. abdita*, *F. chinensis* and *F. flexuosa* (Veron et al., 1977; Scheer, 1990). Its identity is unclear, since Umbgrove (1939) did not indicate any types.

^c Boschma (1936) refers to *Pocillopora clavicornis* (Esper). This is a most likely a nomen nudum and perhaps an unintended mix-up of *P. clavaria* Ehrenberg, 1834, and *P. damicornis* (Linnaeus, 1758), since it was not mentioned by Esper (Scheer, 1990).

^d Recorded as *Goniopora arbuscula* spec. nov. by Umbgrove, 1939 (a junior synonym).

^e Hardenberg (1939) mentioned *Porites mucronata* Dana, 1846, which was originally published as a variety of *P. nigrescens*.

^f New record, formerly only known from Hawaii (Veron, 2000).

weighs the need for more. Especially recently revised coral taxa, such as the Fungiidae (Hoeksema, 1989) and *Acropora* (Wallace, 1999) show notable differences in observed species between years.

Data over an 85-year time period is compared and therefore differences in collection methods are unavoidable. Rigorous statistical analyses cannot be conducted, but the value of this historical dataset is compelling in a temporal sense. A total of 16 families of corals (including mostly zooxanthellate species of Scleractinia, as well as Helioporidae, Milleporidae, and Tubiporidae) are included in this study.

3. Results

3.1. Historical data

Information derived from historical data was used to reconstruct the environment of Jakarta Bay in the late 1800s and early 1900s. Already in 1927, anthropogenic influences were measured at Onrust Reef, and Zaneveld and Verstappen (1952) and Verstappen (1953) proposed to exclude it from further surveys. All derived information is summarized per reef (Table 1).

Sluiter (1888) discussed the possible formation of two shallow patch reefs close to Tanjung Priok harbour; Karang Prigem (St. Nicolaas Droogte) and Karang Cikasi (Broenda Droogte). Furthermore, he described the development of a new reef between Nyamuk Kecil and Nyamuk Besar, which was not indicated on any map (Dutch Navy, 1899). On several maps (see e.g., Umbgrove, 1939) islands and sandbanks are shown for which no or limited further information exists, such as Neptunus Droogte, Neerstuk, and Wapen van Purmerend.

3.2. Comparison 1920–2005

In the 1920s, the reefs Onrust, Damar Besar and Ayer Besar were studied most intensively, with only limited use of diving techniques, which were less advanced at that time. All three is-

Table 3

Coral species observed in the offshore Thousand Islands archipelago in 2005, but not encountered in Jakarta Bay in 1920 and 2005.

Acroporidae

Acropora clathrata (Brook, 1891)
A. horrida (Dana, 1846)
A. microclados (Ehrenberg, 1834)
A. selago (Studer, 1878)
A. spathulata (Brook, 1891)
A. striata (Verrill, 1866)
Montipora altasepta Nemenzo, 1967
M. hirsuta Nemenzo, 1967
M. mollis Bernard, 1897

Agariciidae

Gardineroseris planulata (Dana, 1846)
Leptoseris amitoriensis Veron, 1990
L. explanata Yabe & Sugiyama, 1941
L. foliosa Dinesen, 1980
L. hawaiiensis Vaughan, 1907
L. mycetoseroides Wells, 1954
L. papyracea (Dana, 1846)
L. scabra Vaughan, 1907
L. tubulifera Vaughan, 1907
Pavona explanulata (Lamarck, 1816)
P. maldivensis (Gardiner, 1905)
P. minuta Wells, 1954

Dendrophylliidae

Tabastrea coccinea Lesson, 1829
T. micranthus (Ehrenberg, 1834)

Euphylliidae

Euphyllia cristata Chevalier, 1971
Physogyra lichtensteini (M. Edwards & Haime, 1851)
Plerogyra sinuosa (Dana, 1846)

Faviidae

Caulastrea echinata (M. Edwards & Haime, 1849)
Echinopora mammiformis (Nemenzo, 1959)
E. pacificus Veron, 1990
Favia helianthoides Wells, 1954
F. maritima (Nemenzo, 1971)
F. rosaria Veron, 2000
F. rotundata (Veron, Pichon & Wijisman-Best, 1977)
F. veroni Moll & Best, 1984
Favites paraflexuosa Veron, 2000
Goniastrea edwardsi Chevalier, 1971
G. minuta Veron, 2000
G. palauensis (Yabe, Sugiyama & Eguchi, 1936)
Monastrea magnistellata Chevalier, 1971
Oulophyllia bennettiae (Veron, Pichon & Best, 1977)
O. crispa (Lamarck, 1816)

Fungiidae

Ctenactis crassa (Dana, 1846)
Fungia cyclolites Lamarck, 1816
F. fragilis (Alcock, 1893)
F. granulosa Klunzinger, 1879
F. sinensis (M. Edwards & Haime, 1851)
F. spec. nov.
F. tenuis Dana, 1846
F. vauhani Boschma, 1923
Halomitra pileus (Linnaeus, 1758)
Lithophyllon mokai Hoeksema, 1989
Sandolitha dentata Quelch, 1884

Mussidae

Acanthastrea echinata (Dana, 1846)
Lobophyllia hataii Yabe, Sugiyama & Eguchi, 1936
Symphyllia valenciennesi M. Edwards & Haime, 1849

Pectiniidae

Echinophyllia echinata (Saville-Kent, 1871)
E. patula (Hodgson & Ross, 1981)
Oxypora glabra Nemenzo, 1959
Pectinia alvicornis (Saville-Kent, 1871)

Poritidae

Alveopora cf. catalai Wells, 1968
Goniopora burgosi Nemenzo, 1955
G. cf. cellulosa Veron, 1990
G. minor Crossland, 1952
G. cf. norfolkensis Veron and Pichon, 1982
G. palmensis Veron and Pichon, 1982
G. polyformis Zou, 1980

G. somaliensis Vaughan, 1907
Porites cumulatus Nemenzo, 1955
P. cf. mayeri Vaughan, 1918
P. monticulosa Dana, 1846

Siderastreidae

Coscinaraea exaesa (Dana, 1846)
C. wellsii Veron and Pichon, 1980
Psammocora nierstraszi Van der Horst, 1921
P. obtusangula (Lamarck, 1816)

lands show a dramatic decline in species richness between 1920 and 2005 (Fig. 3a and b). Some genera surveyed in the 1920s were not thoroughly sampled in the 2005 campaign (*Alveopora*, *Montipora*), or have been synonymised since (*Tridacophyllia*). Based on our data, the total number of stony coral species in the Jakarta Bay sums up to 190 in 1920, whereas in 2005 105 species were recorded for Jakarta Bay and 160 for the more offshore Thousand Islands (Table 2), and 243 for the whole area, consisting of 236 zooxanthellate scleractinians, two azooxanthellate scleractinians, three milleporids and two octocorals (Tables 2 and 3). The total number of stony corals recorded over the period 1920–2005 is 296 for the whole area (Jakarta Bay and Thousand Islands), 286 of which are zooxanthellate scleractinians (Tables 2 and 3).

Umbgrove (1939) described *Simplastrea vesicularis* as a new coral species with Onrust Reef as type locality, but this species has not been found since in Jakarta Bay. In 1920, 57 coral species were encountered at Onrust Reef (Fig. 3a). Djohani (1994) recorded five species for Onrust (*Leptastrea pruinosa*, *Oulastrea crispata*, *Platygyra pini*, *Porites lutea*, and *Turbinaria peltata*), and in 2005 seven species were found (*Oulastrea crispata*, *Pavona decussata*, *Platygyra pini*, *Porites lichen*, *P. murrayensis*, *P. solida*, and *Psammocora digitata*). The reef flat has completely disappeared and only small colonies of the encountered species were found. According to Tomascik et al. (1993), Umbgrove (1939) recorded 96 species for Nyamuk Besar Island, 16 of which remained in 1993. However, Umbgrove did not record species per island, but for the entire Jakarta Bay.

Species with the most striking changes in richness belong to the coral families Acroporidae and Milleporidae. The species composition of the reefs in Jakarta Bay has changed considerably. In 1920, the Acroporidae were important contributors to Jakarta Bay's species numbers, but they became heavily reduced since then (Figs. 3 and 4). Some smaller families were also strongly affected. The Milleporidae (fire corals) appear to have disappeared from the bay, where they used to be common (Fig. 4, Table 2; Razak and Hoeksema, 2003). The increase in the encountered number of Fungiidae (Figs. 3 and 4) is an artefact of taxonomic resolution and observer bias, in that Hoeksema, who is a coral taxonomist specialized in fungiids, participated in the 2005 survey. Hoeksema also collected the data on the Siderastreidae.

3.3. Thousand Islands 2005

Some species that were not observed in Jakarta Bay in 2005 (but present in 1920), could still be found in the more offshore Thousand Islands archipelago. This is particularly true for species from strongly affected families such as Acroporidae and Milleporidae. The number of *Acropora* species (46) represented in Jakarta Bay in 1920 was even 10% more than the number (41) recorded in the Thousand Islands in 2005 (Tables 2 and 3). The Agariciidae, Faviidae, and Fungiidae appear to be much better represented on the offshore reefs of the Thousand Islands archipelago than they have ever been in Jakarta Bay (Tables 2 and 3).

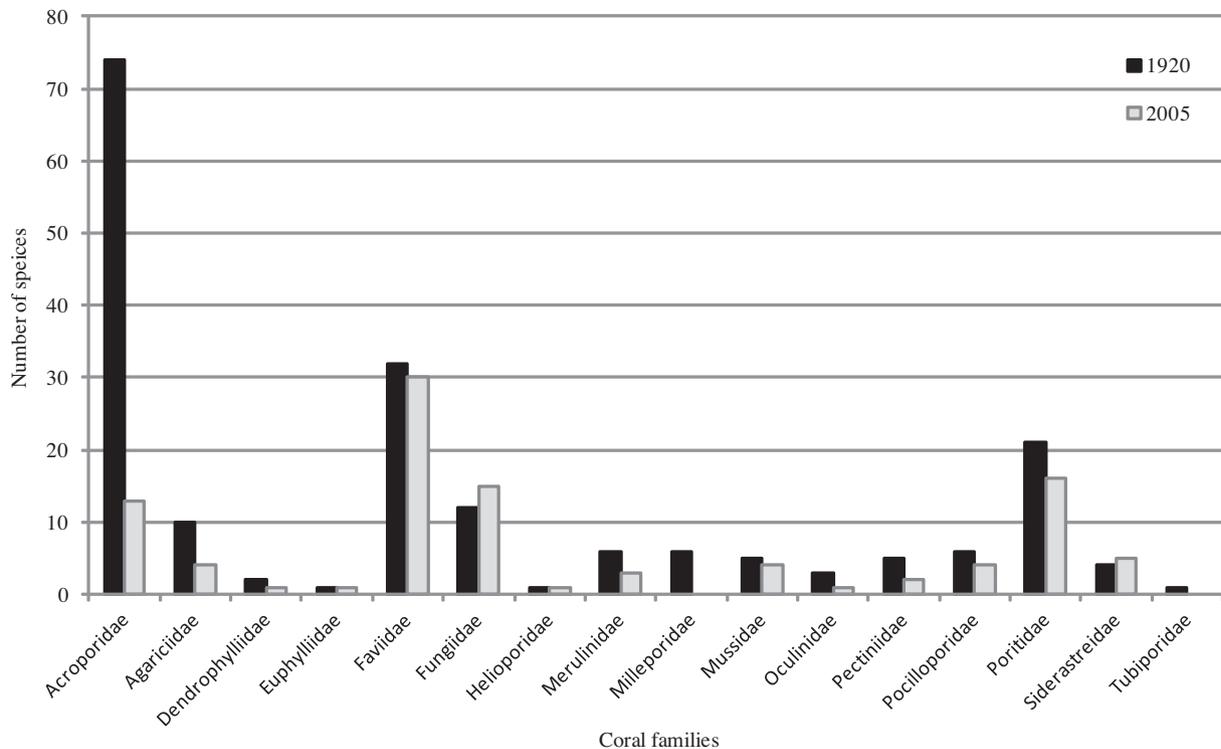


Fig. 4. Number of coral species, per family, found in Jakarta Bay in 1920 and 2005.

4. Discussion

There is no doubt that the demise of the Jakarta Bay coral reef fauna has been the price of development, since in the past it had some of the most diverse coral reefs in the Java Sea (Sluiter, 1888; Umbgrove, 1939; Tomascik et al., 1997). Nevertheless, already in the 1920s the reefs were reported to be influenced by human impact (Zaneveld and Verstappen, 1952; Verstappen, 1953) and their degradation still continues. Jakarta's conurbation as a major source for pollution in the coastal zone and on nearby islands is clearly demonstrated by studies on beach litter, which indicate that most garbage on reefs consists of domestic and industrial refuse from Jakarta (Willoughby, 1986). The proximity of Jakarta also has secondary effects on pollution, since tourists from Jakarta and increased ship traffic to and from its harbour also cause pollution on the reefs (Uneputtu and Evans, 1997; Willoughby et al., 1997).

This multi-decade study shows the increased human impact from Jakarta's coast and hinterland on the reefs in Jakarta Bay and the adjacent archipelago. With the use of historical scientific collections baselines can be found for human-induced impact on the degradation of coral reefs close to major human settlements. While different collectors and collecting methods have influenced the data presented in this article, the observed decline in species numbers is indisputable. The present study shows the result of prolonged stress on the species composition of reefs in Jakarta Bay, in this case reflected by the loss of species belonging to Acroporidae, Milleporidae, and to a lesser extent Poritidae. The strong decline of Acroporidae and Milleporidae is most likely related to their higher susceptibility to stress, as Marshall and Baird (2000) observed at the Great Barrier Reef. Research in the Red Sea also shows a reduction in abundance of the hydrocoral *Millepora* (Wielgus et al., 2003). According to Edinger and Risk (2000) *Acropora*, tabular non-*Acropora*, *Heliopora*, and *Millepora* are disturbance-adapted ruderals, whereas (sub-)massive corals are more stress-tolerant. This agrees with the present data to a certain extent,

but sampling methods and observer bias are also likely important factors in the observed differences.

The present results complement recent work on the molluscan fauna in Jakarta Bay (van der Meij et al., 2009). The decline in coral species richness of Jakarta Bay as compared to the higher species richness of the Kepulauan Seribu resembles the changes reported for the molluscan fauna. Damar Besar and Nyamuk Besar Isl. are strongly affected reefs, and show a similar decline in mollusc species richness. At these reefs no conid, cypreaid or nassariid snails, nor venerid bivalves, were observed in 2005. The coral fauna in Jakarta Bay in 2005 consisted of about 55% ($n = 190$) of the number of species recorded in 1920. For molluscs the difference is larger, only about 33% ($n = 171$) of the number of species recorded in 1937/38 was still present in 2005. The depauperation of the reef coral fauna likely influenced the presence of reef-dwelling molluscs. The combined results suggest that other coral reef species, depending on corals for food, substrate and shelter, may also have become affected.

The major human-induced stressors on coral reefs have been identified for decades, including sewage, siltation, industrial discharge, urban development, and destructive fishing methods (Risk, 1999). A high load of suspended particulate matter may cause sediment accumulation on coral tissues and thereby stress and reduced growth and eventual smothering and death (Brown and Howard, 1985; Rogers, 1990). At regional scales, it is often difficult to assess causal relationships between increasing terrigenous runoff and reef degradation. Pollution effects and other disturbances are typically confounded, since historical data are often missing and reef communities change naturally along gradients from oceanic conditions to coastal conditions (Fabricius, 2005). Differentiation between natural and human impacts on coral reefs is hardly possible, since very few reef ecosystems are free of anthropogenic influence (Wilkinson, 1993). Hughes and Connell (1999) argue that human impact should be viewed in the context of the natural dynamics of coral reefs. Based on case studies in Jamaica and Australia, they show that recovery of reefs affected by natural factors

(e.g., hurricanes, extremely low tides, predator outbreaks, ENSO-events) is rapid compared to reefs affected by predominantly anthropogenic impact. Coral assemblages suffering from chronic (usually anthropogenic) impact recovered in only 27% of cases, compared to 69% for acute impacts (Connell, 1997). Apart from local anthropogenic stress, the coral reefs in the Jakarta Bay and Thousand Islands archipelago have also endured large-scale mortality resulting from natural stress (Brown and Suharsono, 1990; Hoeksema, 1991; Tomascik et al., 1997). The mass coral mortality in 1983 resulting from bleaching may not be relevant to the present results, since *Acropora* species in the Thousand Islands already showed signs of recovery within five years (Brown and Suharsono, 1990). Whether the coral fauna in Jakarta Bay became permanently affected by bleaching or has recovered afterwards, remains uncertain.

When considering the importance of coral reefs for the livelihood of millions of people in developing countries (e.g., fishing, tourism, and coastal protection) the need for coral reef conservation in the vicinity of large cities is obvious. Sunier (1923) considered the coral reefs in Jakarta Bay an extremely rich field for scientific studies. Nowadays this still holds, but for other reasons. The vast anthropogenic impacts on Jakarta Bay make it a perfect location to study human impact on coastal ecosystems. Current social and economic developments in densely populated regions include accelerated urbanization of coastal margins, increasing the pressure on these species-rich ecosystems (Bryant et al., 1998; Burke et al., 2002). Regarding the predicted population growth in Southeast Asia and upcoming large cities in the vicinity of coral reefs, this issue remains of high importance.

Considering the temporal changes in biodiversity, it remains to be seen how species richness data of various areas can be compared in a biogeographical context (e.g., Edinger et al., 2000; Karlsson et al., 2004). When species compositions of particular areas are compared, species records over longer periods are more comprehensive than only the most recent data. For the reefs off Jakarta, the record of 286 species of zooxanthellate scleractinians over the period 1920–2005 is higher than the 243 listed for 2005 only (Tables 2 and 3). This total of 286 species relates to numbers obtained from other reef systems in the proximity of large cities, such as the revised number of 255 scleractinians for Singaporean reefs, which also includes old and new records (Huang et al., 2009). A total of 262 recorded zooxanthellate scleractinians has been listed for the reefs off Makassar. This might be lower than expected because of an underrepresentation of the Acroporidae here (Best et al., 1989). When reef systems of Singapore, Jakarta, and Makassar are compared, the first appears to be entirely under siltation stress while the latter is situated in the Makassar Strait, where interoceanic currents pass and distinct onshore-offshore environmental gradients can be discerned (Hoeksema and Moka, 1989; Hoeksema, 2007). Regarding sponges, species richness data of reef systems near large cities follow a raising trend related to decreasing disturbance: 82 species at Singapore (de Voogd and Cleary, 2009), 118 at Jakarta (de Voogd and Cleary, 2008), and 151 at Makassar (de Voogd et al., 2006). However, this trend might be a biogeographic effect, reflecting a decreasing distance to the Coral Triangle (Hoeksema, 2007). Therefore it is important that in the present study a distinction is made between Jakarta Bay and the more offshore Thousand Islands, showing a clear species richness zonation between the two areas. Like in a similar case, involving molluscs (van der Meij et al., 2009), species loss in Jakarta Bay can therefore be attributed to the proximity of Jakarta and siltation from nearby river outlets.

When areas are compared for species richness, the available survey time and area may be limiting factors in obtaining reliable data for species-rich taxa. The use of species richness estimators may show whether monitoring time and habitat heterogeneity

are sufficient. Alternatively, reliable data can be obtained in relatively short periods when smaller model taxa are compared, such as the mushroom coral family Fungiidae, with 15 species recorded in 2006 and 19 in 1860s–2006 at Singapore (Hoeksema and Koh, 2009), 28 at Jakarta in the present study, and 37 at Makassar (Hoeksema, 1989, 2007). The availability of historical collections and long-term data may be complimentary to recent surveys, as demonstrated by the present study and other recent ones (Hoeksema and Koh, 2009; Huang et al., 2009; van der Meij et al., 2009). These studies show that variation in time range and sampling effort can be underestimated factors in comparing species richness patterns at local, regional, and global scale. However, it should also be noted that in small areas, natural disturbances may play a more visible role in the dynamics of coral assemblages than in larger ones (Karlsson and Cornell, 2002).

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