

# A Systematic Review of the Status, Knowledge, and Research Gaps of Dugong in Southeast Asia

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## Abstract

The dugong (*Dugong dugon*; Müller, 1776) is a vulnerable marine mammal species. This systematic review aims to provide information about the remaining populations, distributions, and habitat sites of the dugong in Southeast Asia. By combining this information with scientific research, critical knowledge gaps about dugongs in this region can be filled. This review showed that dugong populations have not only been reduced but also scattered in coastal waters. Little information is available about the remaining population numbers and distributions of dugongs. The largest estimated populations were reported around East Malaysia (688 to 1,376 dugongs); North Sulawesi, Indonesia (1,000 dugongs); and in the Andaman Sea, Thailand (200 to 250 dugongs). Published research has been very limited—approximately two articles per year. From 1993 until 2021, articles about the dugong were published in the context of ecology, conservation, biology, socioecology, biochemistry, and physiology. Visual and aerial surveying and anecdotal information about sightings and strandings of dugongs were the typical methods of research in Southeast Asia. The conservation strategy in this region is still focused on specific subject areas. The knowledge base for the species is lacking detailed quantitative data on remaining dugong populations, movements, habitats, and mating periods. Behavioral information lacks data for both spatial and temporal variations in foraging behavior, for example. Elucidation is needed in several different aspects of seagrass ecosystem dynamics. Improvements in captive dugong husbandry are also needed to ensure the sustainable conservation of the dugong in the region. National and international management decisions must be based on solid scientific data and multisector integration.

**Key Words:** sea cow, marine herbivorous mammal, distribution, gaps of knowledge

## Introduction

The dugong (*Dugong dugon*; Müller, 1776) is a large, herbivorous marine mammal. The life span of dugongs is about 70 years or more, and their rate of reproduction is very slow. Dugongs reach maturity at about 10 to 20 years old (Marsh et al., 1984; Cherdsookjai et al., 2020). The gestation period is about 13 to 15 months, and calves nurse for 14 to 18 months. The calving interval is spatially and temporally variable; estimates range from 2.4 to 7 years (Marsh et al., 1984, 2002; Marsh & Kwan, 2008). The dugong is one of four species in the Order Sirenia and is the sole member of the Family Dugongidae. The other three species in the order are manatees: the West Indian manatee (*Trichechus manatus*; Linnaeus, 1758), the African manatee (*Trichechus senegalensis*; Link, 1795), and the Amazonian manatee (*Trichechus inunguis*; Natterer, 1883), which belong to the Family Trichechidae (Preen, 1995; Marsh et al., 1996, 2011). The dugong's closest non-sirenian relative is the elephant. The dugong and the manatee are both commonly referred to as sea cows, but the dugong is really the seagrass specialist. Seagrass is the dugong's only source of food (Marsh et al., 2002), and a mature dugong can consume 30 to 40 kg in 1 day. A biological study found that the main contribution to the digesta (61.0 to 98.9%) in the stomach of a dugong came from pioneering seagrass species such as *Halodule* sp., *Halophila* sp., and *Cymodocea* sp. (Erfemeijer et al., 1993; Adulyanukosol et al., 1999).

Dugongs inhabit shallow to medium-deep coastal and island waters, supported by tropical and subtropical seagrass species. Longitudinally, their range extends from East Africa to New Caledonia, and latitudinally from Okinawa Island, Japan, to Australia (Marsh et al., 2002; Marsh, 2012; Marsh & Soltzick, 2019). The range comprises 41 countries (Marsh &

Sobtzick, 2019). According to an assessment by Marsh et al. (2011), the dugong is now extinct in the Maldives, Mauritius, and Taiwan. The largest population, with 10,000 individuals, was found off northern Australia and Papua New Guinea (Marsh & Sobtzick, 2019). The waters of Bahrain, Qatar, and the United Arab Emirates supported the second largest dugong population of about 6,000 individuals (Al-Abdulrazzak & Pauly, 2017; Marshall et al., 2018), and the third largest population, of 2,000 dugongs, was found in the Red Sea (Marsh et al., 2015). Southeast Asian waters supported about 1,000 dugongs (Hines, 2002; Marsh et al., 2002; Rajamani, 2009). Significant populations of about 898 and 300 individuals were reported off New Caledonia (Cleguer et al., 2017) and Mozambique (Marsh et al., 2015), respectively.

Southeast Asia is a global biodiversity hotspot, with high numbers of endemic species in its marine environments (Tittensor et al., 2010) and the highest diversity of seagrass species and habitat types (Fortes et al., 2018). The area of seagrass in this region is estimated at 3,655,829.14 ha (Stankovic et al., 2021), which can support large dugong populations. Nevertheless, in this region, based on population declines and habitat quality, the dugong is considered critically endangered on the global scale by the classification of the International Union for Conservation of Nature's *Red List of Threatened Species* (Marsh & Sobtzick, 2019). Seagrass ecosystems are among the most rapidly declining ecosystems worldwide, with almost 15% of seagrass species listed as threatened (Hughes et al., 2009). The estimated area of seagrass loss was 7% per year (Waycott et al., 2019). In Southeast Asia, the known seagrass area is shrinking at a rate of 2.82% (103,094.38 ha) per year (Stankovic et al., 2021).

Since the distribution range of the dugong is wide, its survival is dependent on a range of marine and coastal habitats which overlap with areas of human activity. An effective, sustainable conservation plan would help reduce the loss of dugongs and their seagrass habitats in this region. But before such a plan can be discussed, knowledge limitations about the status and distribution of the species in this region need to be addressed. Filling critical knowledge gaps about the dugong and its seagrass habitat in the region is the first and most important step to be considered. This systematic review aims to gather the available information about (1) dugong status and distribution in every Southeast Asian country, (2) the areas of scientific research focused on the dugong, (3) the knowledge gaps about the dugong in Southeast Asia, and (4) the way forward for dugong research.

## Methods

Information about the dugong in Southeast Asia was identified in June 2021 through literature searches of electronic databases, including the Web of Science, Science Direct, Google Scholar, and Scopus. Key words used for the searches were “dugong” or “marine megafauna,” “endangered” or “cryptic marine mammal,” and combinations of terms that included “Southeast Asia,” “seagrass,” and the name of each Southeast Asian country. After duplicates had been removed, the 601 articles identified in the literature search were screened to determine if they met the relevant criterion that required the examination of any information on the dugong in Southeast Asia. Materials used to determine the distributions and habitat sites of the dugong in Southeast Asia included published scientific literature (academic journals, review papers, conference proceedings, project reports, and internal research reports), annual or activity reports from government organizations and private sectors, electronic media (Web pages), and the authors' observations. The articles were reviewed and categorized according to their source, as well as evidence contributed regarding dugong distribution in Southeast Asia. Data about the articles were recorded and included information about the country, region coast, recorded year, number of dugongs, data description, and source of information. To ascertain the scientific studies on dugongs and knowledge gaps in Southeast Asia, only papers describing the results of original research on the dugong in Southeast Asia that had been published in academic journals, review papers, and other reports such as conference proceedings, project reports, and internal research reports submitted to government and nongovernment organizations (NGOs) were collected. Reference lists of articles were also utilized to find additional papers. During these literature searches, the first articles that appeared in many databases tended to be the most frequently cited and most recently published articles. A total of 76 articles met this criterion. The articles were reviewed and recorded in a database indexed according to the type of article, author, year of publication, the location where research was conducted, the discipline of study, methods used in the paper, response variable of the study, and highlighted results.

The data collated were not suitable for statistical analysis. Quantitative data (e.g., data on the abundance of dugongs) were tabulated, and data on the number of dugong-related research articles in each scientific field were charted in bar and pie charts. The data were analyzed descriptively and evaluated in the context of dugong status (distributions and habitat sites), as well as in the context of knowledge and research gaps in relation to dugong research.

## Dugong Status: Distributions and Habitat Sites in Southeast Asia

In this review, we categorized the description of dugong information according to the type of anecdotal evidence: bycatch (accidentally caught in fishing gear), captive (for some purpose), carcass (estimated from the interview, survey, or feeding trail), feeding trail sighting, hunting, interview (questionnaire), mention (the information that we get just mentions only the name of the location; no detailed information or evidence is provided), sighting, specimen, stranded, survey (aerial survey, boat survey, or underwater camera recording), and other (e.g., dugong meat was sold in the local market). Furthermore, most data on the distribution and abundance of dugongs and their habitats are reported about the occurrence of dugong sightings, dugong bycatch in fishing gear, and dugong carcasses (Table S1; the supplementary tables for this article are available in the “Supplemental Material” section of the *Aquatic Mammals* website: [https://www.aquaticmammalsjournal.org/index.php?option=com\\_content&view=article&id=10&Itemid=147](https://www.aquaticmammalsjournal.org/index.php?option=com_content&view=article&id=10&Itemid=147)).

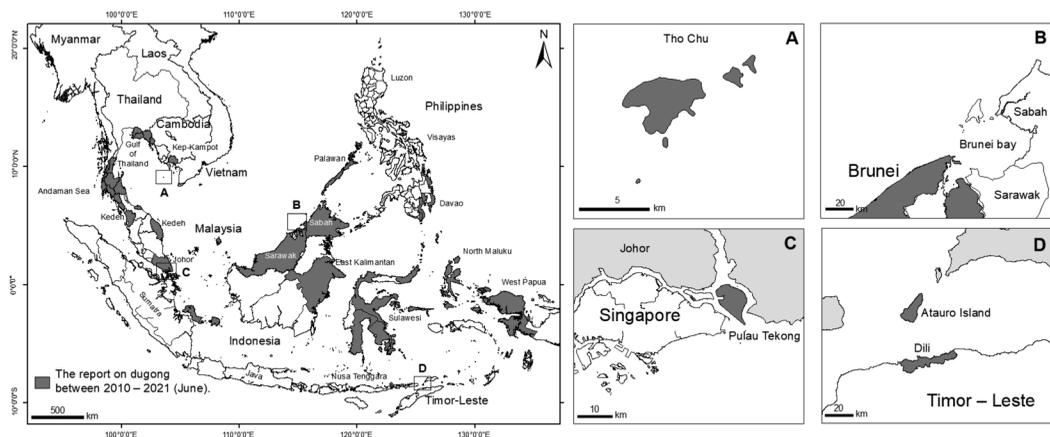
Dugongs in Southeast Asia are usually scattered throughout shallow island and coastal waters. According to this review, a recent study over an 11-year period (2010 to June 2021) reported dugong presence in Brunei Darussalam (Brunei Bay), Cambodia (Kampot and Kep), Indonesia (East Kalimantan, North Moluku, West Papua, Central Sulawesi, North Sulawesi, South Sulawesi, and Southeast Sulawesi), Malaysia (Bangka Island, Riau Archipelago, Sarawak, Johor, Kedah, and Terengganu), the Philippines (Davao and Palawan),

Thailand (Andaman Sea and Gulf of Thailand), Timor–Leste (Atauro Island and Dili), and Vietnam (Tho Chu) (Figure 1). Dugong sighting locations have declined; and in several areas, there have been no observational reports of dugongs in the wild. The dugong was reported only until the 1970s to the 2000s in Cambodia (Koh Kong and Koh Rong), Indonesia (South Bali, Java, South Kalimantan, Maluku, and East Nusa Tenggara), Malaysia (Bintan Island and Sabah), Myanmar (Yangon, Mon, Tanintharyi, and Rakhine coast), the Philippines (Luzon, Caraga, Soccsksargen, and Visayas), and Vietnam (Tonkin Gulf, Con Dao, and Phu Quoc) (Table S1).

Information about the size and distribution of remaining dugong populations is still limited in every country throughout this region, and most of the studies are over 10 years old. Based on our review, the largest estimated dugong population is located in East Malaysia (Sabah and Sarawak; 688 to 1,376 dugongs; Rajamani, 2009), followed by North Sulawesi, Indonesia (1,000 dugongs; Marsh et al., 2002), and the Andaman coast of Thailand (150 to 200 dugongs; Hines et al., 2005a; Department of Marine and Coastal Resources [DMCR], 2011, 2018). However, the recorded numbers of dugongs are generally believed to be lower than actual numbers due to a lack of accurate surveys. Provided herein is a summary of dugong populations, distributions, and habitats in an alphabetical list of Southeast Asian countries.

### Cambodia

Information on the distribution and number of dugongs in Cambodia is limited (Hines et al., 2015). Dugongs were apparently most abundant along the



**Figure 1.** Map of the overall regions assessed showing the latest data reported on dugong (*Dugong dugon*) distribution in Southeast Asia over the last 11 years, 2010 to June 2021, along with maps of (A) Vietnam, (B) Brunei Darussalam, (C) Malaysia, and (D) Timor–Leste

coast of Koh Kong Island (near Thailand) until approximately the 1970s but are now believed to be extinct in the area (Marsh et al., 2002). Local people reported sightings of a small population of dugongs off the coasts of Kampot and Kep Provinces, near the Vietnam border (Marsh et al., 2002; Perrin et al., 2005). Since 1998, dugongs are likely to have disappeared in Stoeng Hau, Kompong Som Bay, based on the increase in motorboat traffic (Marsh et al., 2002). In 2004, Hines et al. (2008) did not see any dugongs or feeding trails during aerial and boat surveys around Koh Kong Island, Koh Rong Island, Kampong Som Bay, Kampot, and Kep. Moreover, local fishers interviewed in villages in Kampot and Kep Provinces responded that they had not seen a live dugong for several years. One year later, in 2005, a stranded dugong was found along the coast of Kampot Province (Marsh, 2012). In 2018, bycatch of one dugong was reported in Kampot Province (Tubbs et al., 2019).

### *Indonesia*

The first record of a dugong in Indonesia was made in 1712 by Samuel Falours, a Dutch artist, who described how a juvenile dugong was kept in a bathtub on Ambon Island in the Maluku Archipelago (Pietsch, 1991). Marsh et al. (2002) believed that important dugong habitats were located around Flores and Lembata Islands in East Nusa Tenggara, the Lease and Aru Islands in the Maluku Archipelago, along the east coast of Biak Island and west coast of Cendrawasih Bay in Papua, and from Arakan Wawontulap to the Lembeh Strait between Lembeh and the mainland of North Sulawesi.

In Java, dugongs have been reported at Ujung Kulon National Park, Cilegon coast, Labuhan coast, south of Cilacap, Segara Anakan, southeast of Blambangan, and at Banten Bay (Hendrokusumo et al., 1979; De Iongh et al., 1997; Marsh et al., 2002).

In Maluku, dugongs were reported during 1972 to 1997 in Maluku Province (Allen et al., 1976). One juvenile dugong was captured at Ambon Island in 1972 (Marsh, 2012). De Iongh et al. (1995) estimated the minimum population of dugongs along the coast of Lease Islands by aerial survey in 1990 and 1992; the population was estimated to be between 22 and 37 animals. Moreover, this researcher also found dugong feeding trails in Nang Bay, east of Ambon Island. Four dugongs (one male and three females) were caught and tracked with buoyant, tethered, and conventional satellite radio transmitters in 1994 to observe the distance traveled between Ambon and the Lease Islands (De Iongh et al., 1998). In 1997, three dugongs were sighted around the Lesser Islands (Aru Island and Balikpapan Bay) (De Iongh et al., 1997). Dugongs have also been reported off

the north and south coasts of Seram Island and Halmahera in North Maluku (De Iongh et al., 1995, 1997; De Iongh, 1996; Marsh et al., 2002). Also, in North Maluku Province, a pregnant female was caught by local fishers at East Halmahera in 2011 (Nontji et al., 2012). In 2016, Mamayu Utami et al. (2018) reported that two dugong carcasses were found stranded at Morotai Island (Cio Dalam Beach and Sanggowo Village). Moreover, the researcher also reported that two dugongs had been captured as a tourist attraction at Kokoya Island. It is unclear how long the two dugongs had been kept in the cages; however, they were rescued and released in the waters of Kokoya Island by The Indonesian Ministry of Marine Affairs and Fisheries rangers in March 2016.

The first recorded sighting of a dugong in Papua, then called Irian Jaya, occurred in 1976 in what is now known as the province of West Papua (Allen et al., 1976). During an aerial survey in 1981, 14 dugongs were sighted along the coasts of Teluk Wondama, Roon Island, and Mioswaar Island, and two dugongs were found around the Auri reefs in Cendrawasih Bay (World Wildlife Fund [WWF], 1981). One year later, during an aerial survey above Cenderawasih Bay Marine National Park, 13 dugongs were sighted (De Iongh, 1996). A small dugong population was observed around northern West Papua in 1981 (Petocz, 1989). Dugongs also have been recorded in the Padaido Islands, the coasts of Sorong, the coasts of Wasur National Park, and Arakan Wawontulap (De Iongh et al., 1997; Marsh et al., 2002; United Nations Environment Programme/Convention on Migratory Species [UNEP/CMS], 2011). An aerial survey by the Wildlife Conservation Society in 2008 found 24 dugongs around the Raja Ampat Islands (De Iongh et al., 2009). A local fisher in Kiat Village, West Fakfak, had trapped one dugong there as a tourist attraction, allowing tourists to see, and even touch, the dugong freely (Mamayu Utami et al., 2018).

Dugongs have been found in Central, North, South, and Southeast Sulawesi (Marsh et al., 2002). In Central Sulawesi, a small group of five to 15 dugongs was sighted in 1975 (Allen et al., 1976). One individual was reported around the Togian Islands in 2001 (Marsh et al., 2002). In several different years (2001, 2002, and 2009), one dugong was sighted during site surveys at Palu Bay (Moore et al., 2017). Many years later (between 2011 and 2017), a small dugong population was sighted around Tomini Bay, Banggai Archipelago, off the west coast of Central Sulawesi (Makassar Straits and Sulawesi Sea) (Moore et al., 2017), near Togean Island, and Palu Bay (Moore, 2004; Moore et al., 2017). In 2015, one female dugong calf was found washed ashore in Donggala Regency, on the west coast of Central

Sulawesi, with an incompletely healed puncture wound. Local people rescued the animal and tied it by its tail. It was later released by a government officer (Moore et al., 2017). In the same year, another dugong calf washed up in Tomini Bay. Villagers attempted to return it to the sea, but for a long time it kept returning to shore (Moore et al., 2017). Three captive dugongs were reported in Toli-Toli Regency; one calf was kept in captivity for 9 years (from 2009) by a fisher after becoming entangled in a fishing net, and then was released by a government officer in 2015. A male dugong (168 cm in length) was tied to a stake by a rope around its tail by a fisher (duration unknown), and then tagged and released by a government officer in 2016 (Moore et al., 2017). Another dugong was captured at Lingayan Island and kept for research in a circular cage made of wood and net with an area of approximately 1,900 m<sup>2</sup> in seagrass beds (Nurdin et al., 2019; Satyaningtjias et al., 2020).

In 1994, the dugong population in North Sulawesi was estimated to be around 1,000 by a local NGO, "KELOLA," which has been studying dugongs in northern Sulawesi (Marsh et al., 2002). In this region, data were recorded about dugongs at Arakan reef (Salm & Clark, 1984). De Iongh (1997) reported one to four dugongs sighted during snorkeling at Bunaken Marine National Park in 1975, and McKenzie et al. (2006) found dugong feeding trails around the seagrass beds of the park in 2004. Local people of Bankga–Minahasa Utara Island found dugongs around the island twice per month in 2012 (Nontji et al., 2012). Dugongs were sighted in Banggi Archipelago and Taka Bonerate National Park in 2014 and 2017, respectively (Moore et al., 2017). In North Sulawesi, dugongs have also been caught for their meat. In 1997, nine dugongs were caught in Lembah Strait, and local people in Tumbak Village often caught them for their meat (Marsh et al., 2002). The Bajo communities at Gorontalo catch dugongs and use them for traditional ceremonies (Nontji et al., 2012).

In South Sulawesi, a team survey conducted by Jaya Ancol Oceanarium caught five dugongs near Ujung Pandang in 1975 (Allen et al., 1976; Hendrokusumo et al., 1979). An adult female dugong was incidentally caught by a local fisher around Barang Lompo Island in the Spermonde Archipelago in 1991, and another dugong was caught in 1993 (Erftemeijer et al., 1993; Moore et al., 2017). It was reported that the dugong sighted in the Spermonde Archipelago had not been seen since 1993, despite increased heavy boat traffic and marine and fisheries research expeditions in the area. Moore et al. (2017) believed that dugongs had been wiped out in this archipelago. In 2011, one dugong calf washed up on Slayer

Island. It was tied by its tail by a fisher and kept as a tourism attraction. Later, fears rooted in local superstition arose, and the animal was released. The latest report mentioned sightings in Tanakeke and Taka Bonerate Islands. A pregnant female was incidentally caught at Tanakeke Island in 2016, and six dugongs were sighted at Taka Bonerate Island in 2017 (Moore et al., 2017).

A few data are available on dugongs in Southeast Sulawesi. According to an interview with Cullen-Unsworth et al. (2018), the number of dugongs along the coast of Wakatobi National Park was down from approximately 38 in 2002–2009 to approximately 10 in 2010–2012.

Based on anecdotal evidence, the dugong was also present in South Kalimantan and West Kalimantan (Karimata Island) (Allen et al., 1976; Hendrokusumo et al., 1979; Marsh et al., 2002). In Central Kalimantan, dugongs have been sighted in Kumai Bay, West Kotawaringin Regency (Marsh et al., 2002). More dugong sightings have been reported in East Kalimantan than anywhere else in Kalimantan. According to anecdotal evidence and sighting reports, dugongs were found at Derawan Island in the Berau Archipelago between 2001 and 2006 (Kreb & Budiono, 2005; De Iongh et al., 2006) and in Balikpapan Bay in 2000 to 2007 (Marsh et al., 2002; Kreb & Budiono, 2005; De Iongh et al., 2006, 2007). Budiarsa et al. (2021) found dugong feeding trails around seagrass beds in Balikpapan Bay (Tanjung Batu, Pulau Kedumpit, Pulau Balang, Beranga, and Tempadung) where it is estimated that two to three dugongs currently graze. This may indicate a slight reduction in herd size compared to the population of three to five dugongs previously observed by De Iongh et al. (2007).

The Lesser Sunda Islands were home to dugongs at East Timor and East Nusa Tenggara in 1976 (Allen et al., 1976) and off the south coast of Bali during 1977–1978 as reported by the Jaya Ancol Oceanarium survey team (Hendrokusumo et al., 1979; Marsh et al., 2002; Nontji et al., 2012). Dugongs were also present at Sumbawa in West Nusa Tenggara, Selat Lintah Bay, and Padar Island in Komodo National Park (De Iongh et al., 1997; Marsh et al., 2002; Singleton & Sulaiman, 2002). Surfers and local people reported dugongs in Uluwatu and Padang Padang Beach, Bukit Peninsula (Marsh et al., 2002). In 1978, the Jaya Ancol Oceanarium team caught two dugongs in Kupang Bay, West Timor (Nontji et al., 2012). In 1997, during a diving trip, an individual dugong was sighted between Rote and Sumba Islands (De Iongh et al., 2009; UNEP/CMS, 2011), and another was sighted off Sumba Island (Nontji et al., 2012). In 2004, interviews conducted for a study by Mustika (2005) implied that dugongs

were incidentally caught by local fishers in the Savu Sea.

In Sumatra, a small group of 5 to 15 dugongs was sighted at Ujung Padang in 1975 (Allen et al., 1976; UNEP/CMS, 2011). Stories recounted by local people also suggest that dugongs could be found in the Riau Archipelago (Hendrokusumo et al., 1979) and near Siberut Island (De Iongh et al., 2009). Local people reported that two to three dugongs had been caught at Bangka and Belitung Islands in 1976, and dugong meat was sold in the market at Blinyu Bay, Bangka Island (Hendrokusumo et al., 1979; Syafutra et al., 2018). At Bangka Island, one dugong was caught for meat in 2006 (UNEP/CMS, 2011; Syafutra et al., 2018), and one to two dugongs were incidentally caught in gillnets in 2007 and 2017 (De Iongh et al., 2007; Syafutra et al., 2018). Moreover, between 2007 and 2010, four dugongs were incidentally caught in fishing traps at Bintan Island. Three of them were saved and released back to the sea (Nontji et al., 2012).

#### Malaysia

In East Malaysia (Sabah and Sarawak), dugongs have most often been seen in Sabah State, around the coasts of Pulau Tambisan, Sandakan, and Semporna in 1997, Kota Kinabalu and Pulau Banggi in 1999, and Tuaran and Kuala Penyu from 1996 to 2002 (Dolar et al., 1997; Marsh et al., 2002; Jaaman & La-Anyi, 2003). In 2000, one to two dugongs were sighted at Gaya and Tiga Islands in Kota Kinabalu (Jaaman & Lah-Anyi, 2003). During aerial surveys in 2000 and 2001, three dugongs were sighted along the coast of Kudat and one around Tiga Island (Jaaman et al., 2001; Jaaman & Lah-Anyi, 2003). From interviews conducted between 2001 and 2003, Rajamani & Marsh (2010) learned that a dugong had been sighted in Banggi and Mantanani Islands. The review also reported that four dugongs had been hunted in Banggi Island and that three to five dugongs had been incidentally caught in Banggi and Mantanani Islands. The key areas of dugong habitats in Sabah were East Nusa Tenggara, Indonesia Island, Brunei Bay, Sandakan Bay, Jambongan Island, Mantanani Island, and Banggi Island (Rajamani, 2009; Forth, 2021). According to Rajamani's (2009) review, the estimated dugong population in Sabah was approximately 688 to 1,376 and was likely to be declining.

In Sarawak State, dugongs were sighted along the coast of Teluk Serabang before the 1960s (Jaaman et al., 2000). Four dugong carcasses (one calf) were found at Labuan Island in 1996 and 2002, and one carcass was found in 2007 (Jaaman & Lah-Anyi, 2003; Rajamani, 2009). A group of 14 dugongs was sighted during aerial surveys in

Brunei Bay, Sarawak, in 2000 and 2001; in Sungai Padas (eight dugongs) in 2001; near the estuary of Batang Lawas (six dugongs) in 2001; and between Kampung Punang in 2007 (five dugongs) and Bukit Sari (one to two dugongs) in 2008 (Jaaman et al., 2001; Jaaman & Lah-Anyi, 2003; Bali et al., 2008). Also, an aerial survey sighted about 20 dugongs, including four mother-calf pairs, along the coasts of Sabah and Sarawak (Ponnampalam, 2011, as cited in UNEP/CMS, 2011).

In Peninsular Malaysia, dugongs have been reported at Pasir Puteh, Kelantan, and three dugongs were found in 1999 during a survey by the Malaysian Fisheries Department. One individual dugong was sighted at Pulau Kapas, Terengganu, in 2006, and a small number of dugongs was spotted around Langkawi Island, Kedah, between 2010 and 2011 (UNEP/CMS, 2011).

Dugongs have been found along the east coast of Johor where 18 individuals were sighted in 1999 during an aerial survey (Marsh et al., 2002). In the South of Johor, dugongs have been sighted off Sibu, Tinggi, Besar, Rawa, and Seribuat Islands (Marsh et al., 2002; Ponnampalam et al., 2014). In 1999, dugong feeding trails were observed in a meadow of *Halophila ovalis* at the mouth of the Pulai River in the Johor Strait (Kushairi, Mat Isa; Marsh, unpub. data cited in Marsh et al., 2002). Several boat and aerial surveys and interviews conducted in Johor between 2004 and 2009 confirmed the presence of one to four dugongs and dugong feeding trails around Jetty Kampung Tanjung Balang, the Sibu-Tinggi Group of Islands, Tanjung Kopok, the Johor Strait, the southeast coast of Johor (Desaru), Tanjung Adang-Merambong, and the Kelong area (Affendi et al., 2005; Ooi et al., 2008; UNEP/CMS, 2011). During a helicopter survey in 1999, the Malaysian Fisheries Department found at least 17 adult dugongs and one calf around Pulau Sibu Hujung and nearby Pulau Besar and Pulau Rawa.

More than 30 dugong carcasses were reportedly found in Peninsular Malaysia. In Johor, ten carcasses were stranded in Pulau Sibu Hujung, Sekakap, and Tanjung Sedili between 1994 and 1998, and 12 carcasses were stranded around the Johor Strait between 2005 and 2010. Ten carcasses were stranded at Pasir Puteh, Kelantan, in 1999; and between 2001 and 2005, one carcass was stranded at Kapas Island in Terengganu and one at Tuba Island in Kedah (UNEP/CMS, 2011).

#### Myanmar

Dugongs have been reported along the coast in Yangon (Thazin), Mon (Gyaing Le and Shwe Ya Gyaing), Rakhine, and Tanintharyi. In 1853, the first dugong sighting in Myanmar waters was reported by the Reverend S. Benjamin (Mason & Theobald,

1882). Since then, there had been no reports of dugongs until 1966 when a female dugong was captured alive by fishers on the Rakhine coast.

Dugong sightings have mostly occurred on the Rakhine coast. Man Aung Island was famous for dugongs, which could be observed from the shore. Regularly, they were found in groups numbering more than five with frequent sightings (at least one per week) throughout the year, especially during the rainy season (Tun et al., 2010). Along the Gwa coast, local fishers sighted dugongs during the fishing season (September to April) but not during the nonfishing season (May to August). In Hmawylene and Taung Kyun Islands, two to three dugongs were sighted in 2007. In Kan Thar Yar and Kyein Te Li, more than one dugong has been reported in shallow coastal waters (Ilangakoon & Tun, 2007; Tun & Ilangakoon, 2007).

Along the Tanintharyi coast, dugongs have been spotted at Nyawbyin and in the Myeik Archipelago near the Sular Islands, La Ngan Kyuun Su, Pale Island, Lampi Island, Wa Kyunn, Bo Lut Island, and Nyaung Wee Island (UNEP/CMS, 2011). Dugong trails were found for the first time in dense *Halophila ovalis* patches on the east coasts of Lampi and Nyaung Wee Islands (Tun, 2012).

Although bycatch of dugongs has been reported on Mon, the Myeik Archipelago, and the Rakhine coast, no research was conducted until 2005 when Tun & Ilangakoon (2007) started the first dugong interview survey in the Mon and Rakhine coastal areas. The dugong interview surveys revealed that one dugong was incidentally caught in fishing gear at Hmawylene in 2007. In Mon (Magyi Island and Shwe Ya Gyaing), four dugongs were incidentally caught in fishing gear between 2004 and 2007. Moreover, the interview indicated that at least one dugong was sighted along the coasts of Kyein Ta Li and Kan Tha Yar every month of the year (Ilangakoon & Tun, 2007; Tun & Ilangakoon, 2007). A few recorded data are available on stranded dead dugongs in Myanmar. In 2004, a carcass was found in Thazin, Yangon. In 2006, two dugongs were found in Hmawylene—one was dead and the other was alive when they found it but subsequently died (Tun & Ilangakoon, 2007).

### *Philippines*

The distribution of dugong in the Philippines is scattered (Nishiwaki & Marsh, 1985). Historically, it was thought that dugongs could be seen near every island of the Philippines (Marsh et al., 2002). According to this review, the presence of dugongs has been reported from Luzon, Mindanao, Palawan, and Visayas.

In Luzon, dugongs had been reported off the coasts of Aurora, Quezon, Polillo Island, and Cagayan

(Baltazar & Yaptinchay, 1998; van Lavieren, 1999; UNEP/CMS, 2011), while Marsh et al. (2002) thought they were likely extinct.

In Mindanao, the first dugong was recorded in 1933 when Robert L. Pendleton took a picture of a dugong in the market of Zamboanga City (University of Wisconsin–Milwaukee [UWM] Libraries, 2021). Many years later, Fortes (1990) reported dugong feeding trails in Zamboanga Province. Four dugongs were incidentally caught in gillnets in Mati (UNEP/CMS, 2011). According to the community recording dugong sightings in Cape San Agustin in 2006, most of the sightings occurred in Kabuaya, Luban, and Macambul (Dagondon et al., 2006). Sightings were also reported in eastern Mindanao (Siargao and Hinatuan), southern Mindanao (Pujada Bay, Mayo Bay, the Davao Gulf, Sarangani Bay, and the Moro Gulf), Tawi-Tawi, and the Sulu Archipelago (Baltazar & Yaptinchay, 1998; Marsh et al., 2002; Dagondon et al., 2006; UNEP/CMS, 2011; Aragonés et al., 2013; Mochizuki et al., 2013; Mizuno et al., 2017), but the species is probably no longer present in northeastern Mindanao (Marsh et al., 2002).

The dugong has been sighted all around Palawan, including the Cuyo and Calamianes Islands. Between 1989 and 1990, a local observer sighted at least five dugongs per survey day around Calauit Island; and between 1998 and 2000, 30 dugongs were incidentally caught in fish corrals (UNEP/CMS, 2011). In 2013, one dugong was entangled in ropes at Busuanga (Poonian & Lopez, 2016).

In Visayas, dugongs were only sighted along the western coast in Guimaras Strait and at Negros Occidental (Baltazar & Yaptinchay, 1998; UNEP/CMS, 2011) but were thought to have probably disappeared from the coastal areas of Visayas (Marsh et al., 2002).

A dugong stranding was first recorded in 2001 by the Philippines Marine Mammal Stranding Network (PMMSN). Seven individuals were stranded between 2001 and 2009 throughout the three main geographical divisions of the Philippines: Luzon, Visayas, and Mindanao (Aragonés et al., 2013). From 2005 to 2016, nine dugongs were stranded. They were found on the coasts of Central Luzon, Calabarzon, Immaropa, and Bicol in Luzon; on the coasts of the Western and Central Visayas regions; and on the shores of the Zamboanga Peninsula, Davao, and Soccsksargen in Mindanao (Aragonés et al., 2017). In recent years (2017–2018), 23 stranded dugong carcasses have been reported along the coasts of Palawan Province in Luzon and in Sarangani, Davao Oriental, and Zamboanga del Norte Provinces in Mindanao (Aragonés & Lagui, 2019).

### Thailand

Dugong research in Thailand has been conducted since the 1980s (Hines et al., 2005a). Several aerial surveys have been conducted along the Andaman Sea and the Gulf of Thailand by members of the Department of Marine and Coastal Resources (DMCR). The dugong population in Thai waters was estimated at around 30 animals in the Gulf of Thailand and 191 individuals in the Andaman Sea (DMCR, 2018).

In the Andaman Sea, dugongs are distributed along the coast of Krabi (at Sri Boya and Pu Islands), Phang-nga (at Phra Thong Island, Yao Island, and elsewhere in Phang-nga Bay), off Phuket Island (at Paklok and Chalong Bays), Ranong (Sai Dam), Satun (at Lidee and Sarai Islands), and Trang (at Chao Mai and Muk, Libong, and Sukorn Islands) (Adulyanukosol et al., 1997, 1999, 2004, 2008a, 2008b; Hines et al., 2005a; Nakanishi et al., 2006; DMCR, 2018). Most likely, the largest population of dugongs in Southeast and Eastern Asia is around Muk and Libong Islands in Trang Province along the Andaman coast (Adulyanukosol et al., 1997; Adulyanukosol, 2000, 2004; Hines et al., 2005a). The dugong population in Trang was estimated at about 154 individuals in 2017 (DMCR, 2018).

In the Gulf of Thailand, there are very few dugongs, and they are scattered in small numbers. The aerial surveys have been conducted only in some specific areas (e.g., Rayong, Chanthaburi, Trat, Surat Thani, and Nakhon Si Thammarat). The aerial survey between 2017 and 2019 reported sighting dugongs off the coast of Rayong (at Paknamprasae), Chonburi (at Sattahip Bay), Trat (at Mairood and Kood Island), Surat Thani (at Phumriang Bay and Samui Island), and Nakhon Si Thammarat (Tharai Island). Moreover, dugongs have also been found alive and dead in provinces such as Chonburi, Chumphon, and Pattani (Marsh, 2012).

The Phuket Marine Biological Center (PMBC) has kept a record of dugong carcasses washed up on the coasts of Thai waters. The information was obtained from the records of fishers and local communities, sightings of stranded dugongs, and specimens kept in museums, temples, or other institutions. From 1962 to February 2008, 282 stranded dugongs were recorded (Adulyanukosol et al., 2009), and 142 dugong strandings were recorded from 2009 to 2019 (DMCR, 2019a, 2019b).

From 1979 to 2019, at least 15 dugong calves have been caught, rescued from fishing gear, or washed ashore in Thai waters, but dugongs are sensitive animals and difficult to keep in captivity. Eleven of them were transferred to nursing enclosures at PMBC. The calves survived for periods

ranging from 7 to 153 days. Two of them were released back to the sea after 15 days in captivity — one at Ao Yon, Phuket, and the other at Chao Mai, Trang (Boonprakob et al., 1983; Adulyanukosol, 2002; Central Database System and Data Standard for Marine and Coastal Resources, 2019). One calf was caught around Adang-Rawi Island in Satun and kept at the Satun Coastal Fisheries Research and Development Center in 1982 but died after 79 days. The Department of Fisheries released one calf at Chao Mai, Trang, in 1993. Another calf was kept in a fish cage by a fisher at Klong Chao Mai, Trang, and released after approximately 20 days in 1995 (Adulyanukosol, 2002). The major problems for dugongs in captivity are food, the type of enclosure, injuries inflicted during capture and transportation, and susceptibility to diseases (Boonprakob et al., 1983; Adulyanukosol & Patiyasawee, 1994; Adulyanukosol, 1996, 2002). Moreover, the chances for young calves to survive after release seem to be low. These calves will find it difficult to fend for themselves in the wild and are unlikely to survive due to a lack of survival skills in their new, unfamiliar surroundings. An example of these difficulties occurred in April 2019 when a juvenile female dugong was famously stranded on Poda Island in Krabi. Authorities rescued the animal and released it back to the sea, but “Marium,” as she became known, returned to the shore. Authorities and veterinarians moved her to a dugong habitat near Libong Island in Trang and attempted to feed her in a natural area. Unfortunately, she died after 114 days from a blood infection and pus in her stomach (Central Database System and Data Standard for Marine and Coastal Resources, 2019).

### Vietnam

Lang Van Ken (1997) suggested that there may not be a local population of dugong in Vietnam waters but that they may migrate from another area when their food supply is low. Anecdotally, dugongs were historically more widely distributed along the coast of Vietnam in the provinces of Quang Ninh, Haiphong, Khanh Hoa, Binh Thuan, and Kien Giang (Ha Tien near the Cambodian border); at Ha Coi in the Tonkin Gulf, North Vietnam; and around Nha Trang (Van Gia, Khai Luong, Bahai, Cua Be, and Ninh Hai) (UNEP/CMS, 2011; Marsh, 2012). Unconfirmed dugong sightings have been reported in Quang Ninh Province (at Bai Tu Long National Park), in the Can Gio Biosphere Reserve, and in Bac Lieu Province (UNEP/CMS, 2011; Marsh, 2012). Other sightings have mainly been reported from the waters of Con Dao, Tho Chu, and Phu Quoc.

The first report of a dugong in Vietnam was in 1977 by Van Bree and Gallagher, who examined

seven specimens that were caught in the Con Dao Archipelago. Cox (2000) estimated that the population of dugongs in Tho Chu and Con Dao was ~42 individuals until the 1990s. In 1995, the Con Dao National Park staff interviewed local people in the Con Dao Archipelago and learned that dugongs were regularly seen in the area (Marsh et al., 2002). In 1997, a female dugong with a calf was sighted by a fisher in Con Dao. One year later, a dugong was sighted in Vo Sy Tuan, Con Dao (UNEP/CMS, 2011). In 2000, a small group of seven dugongs was sighted east of Ben Dam (Marsh et al., 2002). In 2007, two to three dugongs (with one calf) were sighted in Con Son, and one individual was reported around the coast in 2008 (UNEP/CMS, 2011).

An interview reported by Pham (2003) revealed that dugongs were a common sight in Con Dao and Phu Quoc between 1973 and 1993. Moreover, this interview estimated the number of dugongs in Con Dao and Phu Quoc at approximately 53 between 1997 and 1999, and approximately 73 between 2000 and 2003. Meanwhile, UNEP/CMS (2011) mentioned approximately five to six dugongs sighted in Con Dao between 2001 and 2009.

Hines et al. (2008) interviewed local people on Phu Quoc Island and found that dugongs were regularly sighted in the area in 2002. A more recent sighting of a dugong in Phu Quoc was reported by Phu Quoc MPA staff in 2010 at Ha Tien (UNEP/CMS, 2011). Moreover, in the period 1970 to 2009, the number of dugongs caught in Phu Quoc was more than 500, with approximately 12 to 13 caught each year (UNEP/CMS, 2011).

Dugongs were also sighted in Tho Chu. According to the review by Pham (2003), numerous feeding trails of dugongs were observed in Tho Chu in 2003, and the estimated number of dugongs in Tho Chu was approximately 68 between 1997 and 1999, and approximately 71 between 2000 and 2003.

Information about dugong strandings was recorded at Con Dao and Phu Quoc. From 1993 to 2001, at least 14 dugong carcasses were found in Con Dao (Cox, 2002; UNEP/CMS, 2011), and more than 30 were found in Phu Quoc between 1997 and 2003 (Pham, 2003; UNEP/CMS, 2011).

#### *Brunei Darussalam, Singapore, and Timor–Leste*

In Brunei Darussalam, the dugong population distributed in Brunei Bay is most likely the same population as found in Sabah and Sarawak, Malaysia (Marsh et al., 2002). In Singapore, dugong sightings have been reported in the northeastern and southern regions of mainland Singapore (Ho, 1988). The National Library Board Singapore (2009) provided dugong information on the

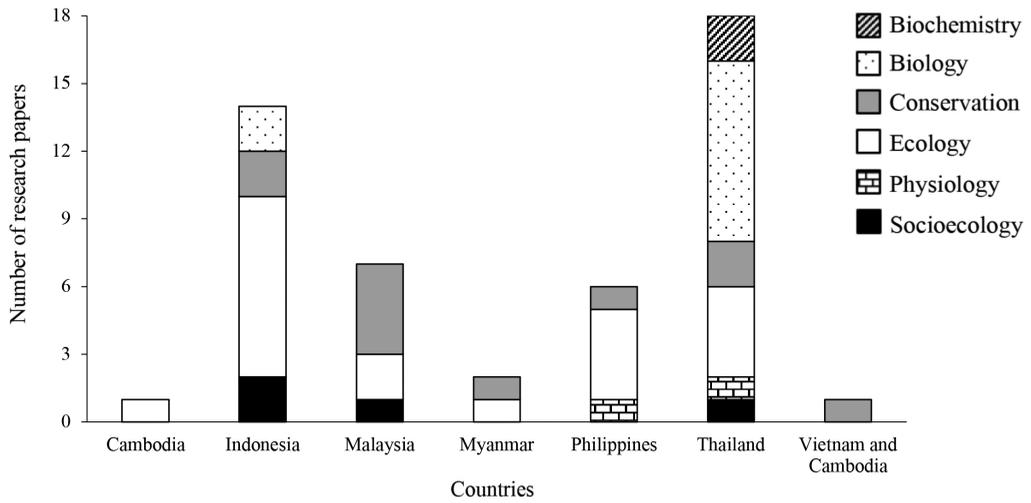
Singapore Government Agency website. In the 10-year study period (1996 to 2006), four dugong carcasses were found in the northeast region. A dugong carcass was found on Changi Beach in 1996 with many cuts on its body. Two years later, a female calf was found near Pulau Ubin swimming around a dead mother that had tangled in a fishing net in September 1998. The calf was taken to the Underwater World Singapore as the orphaned calf was too young to survive on its own in the wild. The calf was named “Gracie.” She became a star attraction at the oceanarium and died in January 2014 from complications arising from an acute digestive disorder 16 years after being rescued. In 1999, a dugong carcass was found near Pulau Ubin. Subsequently, a female dugong was found dead on the southern shore of Pulau Tekong in 2006. In Timor–Leste, the report in the *Dugong and Seagrass Hub* titled “Timor–Leste” (2021) mentioned a dugong sighting during a survey off the northern coast around Dili and Atauro Island in 2008, and a mother–calf pair was sighted in 2017.

#### **Dugong Scientific Research Knowledge in Southeast Asia**

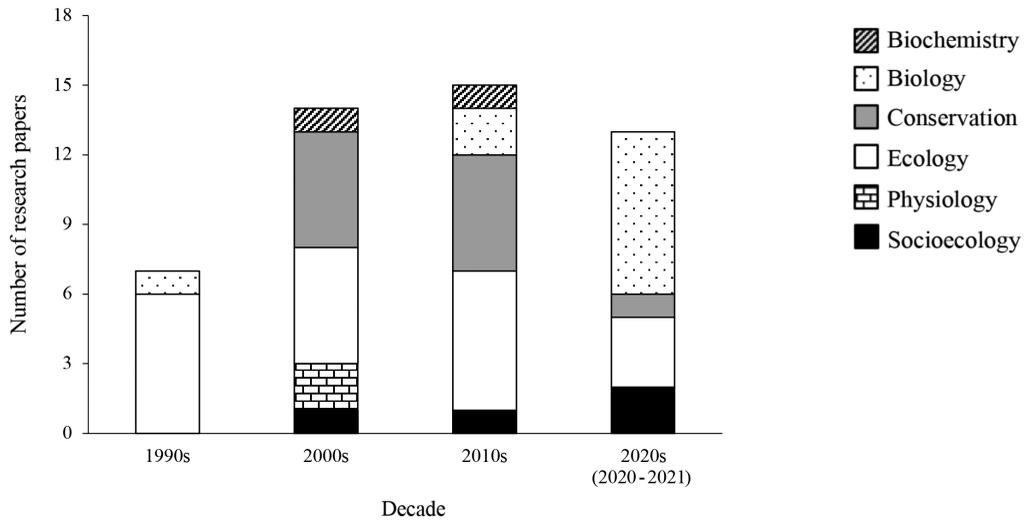
While conducting research for this review, we found 76 reported studies about dugong in Southeast Asian countries. The works were published in seven countries: Cambodia, Indonesia, Malaysia, Myanmar, the Philippines, Thailand, and Vietnam. There were 49 academic journal publications, 17 proceedings materials, and 10 reports. Focusing on academic journals (Table S2), research publications about dugong in this region were very limited in every country (max. = 18 articles; min. = 1 article), and only one transnational study was conducted (Cambodia and Vietnam) (Figure 2).

The number of published journal articles doubled from the 1990s to the 2000s, increasing from seven to 15. The number increased again in the 2010s when 15 more articles were published. In 2020 and 2021, 13 articles have been published. Over these 30 years, approximately two articles per year have been put into print (Figure 3).

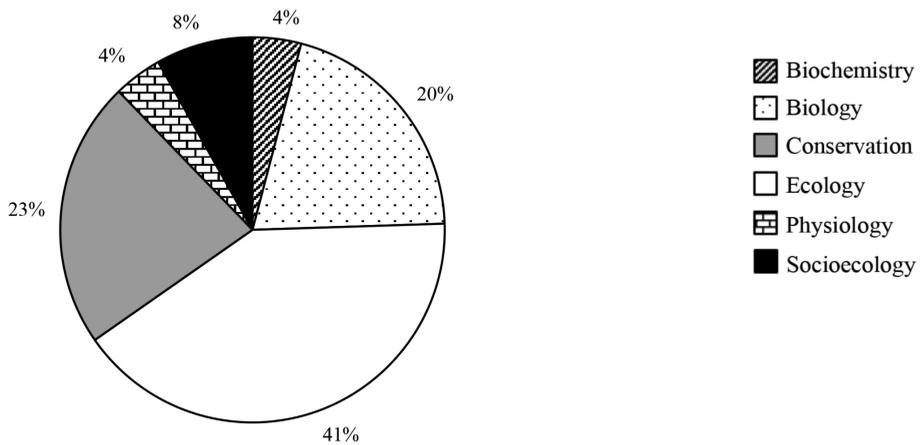
Contributions to the greater understanding of dugongs in Southeast Asia have come from many areas of study. From 1993 to June 2021, work was conducted in the fields of biochemistry, biology, ecology, conservation, physiology, and socioecology. Despite the variety, there are still notable gaps in knowledge. Most of the articles published were ecological, conservation, and biological studies (42, 22, and 20%, respectively). The fields of biochemistry, physiology, and socioecology together contribute less than 20% of the articles published (Figure 4).



**Figure 2.** Chart showing the number of research papers in each field of the study published in Southeast Asian countries from 1993 to June 2021



**Figure 3.** Chart showing the number of research papers in each field of the study published in the 1990s, 2000s, 2010s, and 2020s (2020 to June 2021)



**Figure 4.** Pie chart illustrating the percentage contribution by each research discipline to the total number of articles about dugong research published in Southeast Asia from 1993 to June 2021

### Ecology

Ecological research is the mainstay of research on the dugong in Southeast Asia. Visual and aerial surveys of dugong abundance and reported sightings and strandings have been a popular method of observing dugong populations and distributions (Aragones, 1994; Hines et al., 2005a; Aragones et al., 2010; Syafutra et al., 2018; Tubbs et al., 2019). Mizuno et al. (2017) developed a new method of mapping seagrass and feeding trails. Using breathing snorkels, continuous optical images were acquired for seagrass mapping and quantification of dugong trail distribution. This method produces clear, high-resolution images ( $2.96 \pm 0.17$  mm/pixel) but requires the skill, time, and effort of divers.

A few researchers have developed protocols to monitor dugong vocalizations. Tanaka et al. (2017) adapted underwater sound monitoring systems (AUS-OMS; AquaSound Inc., Kobe, Japan) to determine dugong vocal patterns in vocal areas (specific areas where dugongs show elevated levels of vocal behavior) and feeding areas. The results showed that the vocalization rate and power spectrum density were higher in vocal areas than in feeding areas. Tanaka et al. (2021) then automated the classification of dugong calls and tonal noise by combining signal contour features and Mel-frequency cepstral coefficient (MFCC) features. The classification of tonal vocalizations and tonal noise/seasonal compatibility of the classifiers needs to be tested, but this method could

facilitate long-term and wide-range passive monitoring of habitat use by the dugong. Yamato et al. (2020) developed a new method of automatically detecting dugong feeding sounds from acoustic data. This method reduced the time and effort of manual detection and, thus, extended the temporal and spatial scales of passive acoustic monitoring of dugong feeding behavior.

Infantes et al. (2020) used drones to observe the reproductive behavior of dugongs at Libong Island, Thailand. Detailed classification and quantitative data are large gaps in our knowledge of the remaining dugong population in Southeast Asia. Hines et al. (2005a) estimated population percentages by broadly grouping body size: 12 to 25% of sighted dugongs were calves and 75 to 88% were adults. Moreover, 45.6% of total sightings ( $n = 124$ ) reported groups of six or more animals. The first report of wild dugong mating behaviors in tropical Asian regions was conducted in Muk and Libong Islands, Trang Province, Thailand. The mating pattern was categorized into five stages: (1) following, (2) approaching and stimulating, (3) pairing, (4) mounting, and (5) separating (Adulyanukosol et al., 2007).

The movements and home ranges of dugongs have been studied only once in this region. De Iongh et al. (1998) studied the movements and home ranges of dugongs around the Lease Islands in East Indonesia by using GPS tracking on four dugongs (three adult females and one immature male). The home ranges covered 1.6 to 127.9 km<sup>2</sup> (mean = 4.1

to 43.4 km<sup>2</sup>), and the animals visited the same seagrass areas during tracking, which implied that they might exhibit cultivation grazing behavior.

Studies of the feeding behavior of dugongs in Indonesia found that the feeding trails of dugongs in the Lease Islands, Maluku, and Balikpapan Bay were located in *Halodule uninervis* beds (De Jongh et al., 1995, 1997; Budiarsa et al., 2021), whereas studies in Trang, Thailand, found feeding tracks of dugongs in *Halophila ovalis* beds (Nakaoka & Aioi, 1999; Nakaoka, 2005). Dugong trail distributions were influenced by the available pioneer seagrass biomass, wind speed, distance between the grazing area and coastal community (Budiarsa et al., 2021), and carbohydrate content in seagrass rhizomes and roots (De Jongh et al., 1997). The grazing rotation mechanism is not yet well understood, and the maximization of carbohydrates does not fully explain the behavior.

Only one study has considered the interaction between dugongs and other marine organisms. Nakaoka et al. (2002) demonstrated that the density of epifauna and shallow infauna was higher in *H. ovalis* beds than in dugong trails, while the density of deep infauna was lower in *H. ovalis* beds than in dugong trails. There has been some research on the interaction between dugongs and humans.

Incidental bycatch (Jaaman et al., 2009), pollution, and the human impact on habitat degradation and fragmentation were factors that were considered for capacity building and preliminary assessment of species status (Tun & Ilangakoon, 2006, 2007). Dugong threat factors have only been investigated in Malaysia and Myanmar. Dugong bycatch, particularly in gillnets, was a major risk for dugong stranding in Malaysia (Jaaman et al., 2009; Briscoe et al., 2014). In contrast to Malaysia, the dugong population along the Rakhine coast of Myanmar is less threatened by anthropogenic pressures, bycatch, habitat degradation, and fragmentation (Ilangakoon & Tun, 2007). Nonetheless, several studies have used predictive models to project the potential contributing variables that determine dugong distribution. Hadipour et al. (2021) managed and developed a GIS-based model to determine suitable locations of marine transportation for reducing wildlife habitat disturbance in the Malacca Strait. Briscoe et al. (2014) predicted habitat and bycatch risk for dugongs in Sabah, Malaysia, by using data from dugong sightings and strandings, hunting, fishery effort, fishery activity mapping, and environmental factors such as seagrass distribution, nutrient concentration, salinity, turbidity, and water currents. Idris et al. (2020) interviewed 56 local inhabitants in Bintan Island, Indonesia, and found that the majority (78 to 100%) had seen dugongs in the wild fairly frequently.

### Biology

The first biological research publication about the dugong in an academic journal analyzed the digesta in the stomach of one dugong in Indonesia. Around 98.9% of the digesta consisted of seagrass material; the main contribution was from pioneering species (i.e., *Halodule* sp., *Halophila* sp., and *Cymodocea* sp.; Erfteimeijer et al., 1993).

Dugong skeleton samples for morphological and morphometric studies by Nganvongpanit et al. (2017a) were obtained from the Animal Anatomy Museum, PMBC, Phuket, Thailand. The study found that dugong sex could be determined by the large tusks, skull, coracoid process, and caudal border tubercle of the scapula. The multivariate linear regression showed 100, 98.5, 96.15, and 91.30% accuracy, respectively. Nganvongpanit et al. (2017c) observed osteophyte formation and subchondral bone degradation of dugongs and other mammals. The study found that dugongs and dolphins showed signs of osteoarthritis and that gender did not influence the incidence of the disease. Nganvongpanit et al. (2020) found that the sex and body size of dugongs could be accurately identified and estimated from morphometric data obtained from pelvic bones. The pelvic bone was larger in a mature male than in a mature female and had the highest degree of correlation with body length, followed by body weight and age.

Cherdsukjai et al. (2020) determined relationships between the ages of dugongs by using tusk dentin growth layer group (GLG) counts, telomere length, and body weight and length. They found that GLG counts were negatively correlated with telomere length and that the rate of telomere attrition was approximately 0.036 relative telomere length/year. Body weight and length were both positively correlated with GLG counts, with growth rates of approximately 8.8 kg/y for weight and approximately 3.58 cm/y for length. Nganvongpanit et al. (2017b) analyzed the elemental composition of dugong tusks to identify the sex and habitat of dugongs. The results showed that the elemental composition of tusks did not significantly differ between male and female dugongs but did differentiate dugongs from Andaman Sea habitats and dugongs from Gulf of Thailand habitats with overall high accuracy (88.1%).

In a parasitology study, Satyaningtijas et al. (2020) suggested that blood parasites could be a threat to dugong populations. A molecular technique was used to determine the genetic diversity of the dugong. From skin samples, Poommouang et al. (2021) used inter-simple sequence repeat (ISSR) markers and mtDNA D-loop typing to determine the genetic diversity of 118 dugongs from Thai waters. The

results showed the existence of two genetically different populations of dugongs—one in the Andaman Sea and one in the Gulf of Thailand. The genetic diversity of the Andaman Sea population was greater. Moreover, the dugong population in Thai waters was unique and separated from other groups around 1.2 mya.

### *Conservation*

Conservation studies have helped to develop the efficiency of locally based dugong surveys, as well as community perspectives and recommendations for supporting conservation strategies in Cambodia, Malaysia, Myanmar, Thailand, and Vietnam (Hines, 2002; Hines et al., 2005a, 2008; Ilangakoon & Tun, 2007). However, the overall conservation strategy in the region is still focused on specific areas of each country. Only one study was conducted at an international level—between Cambodia and Vietnam (Tubbs et al., 2019). Moreover, most conservation studies considered community-based conservation and education as a potential factor for successful conservation. Local knowledge, involvement, and consultation provided information about the abundance, distribution, and historical background of the dugong. This information helped local surveying and monitoring, and it supported associated resource management decisions (Hines, 2002; Hines et al., 2005b, 2008; Ilangakoon & Tun, 2007; Rajamani & Marsh, 2010; Hashim et al., 2017; Cullen-Unsworth et al., 2018).

Some researchers have recommended the prioritization of dugong and habitat management. Ponnampalam et al. (2014) recommended aligning conservation and research priorities for dugong and dugong habitat management. Effective marine spatial planning is essential to minimize overlap between dugong habitat and mariculture operations. According to Poonian & Lopez (2016), effective marine spatial management is essential to minimize the overlapping area between dugong habitat and mariculture activities because small-scale mariculture poses a potential threat to the dugong.

In 2013, a dugong drowned while entangled in the ropes of a seaweed farm in Busuanga, Palawan, in the Philippines. Also, at several locations, it is still the custom of some communities to hunt dugong, and this is one of the biggest direct threats to the conservation of the species (Poonian & Lopez, 2016). Owners of sustainable tourism businesses are a very important target group that must be invited to participate actively in the process of local conservation (Sondita et al., 2020).

### *Physiology, Biochemistry, and Socioecology*

Throughout the last 30 years, there has been a large gap in the knowledge base concerning the biochemistry, physiology, and socioecology of the dugong in the region. At this time, these fields of study have contributed a combined total of only eight published articles. A physiological study determined the annual changes of urinary progesterone and estradiol-17 $\beta$  of a captive dugong in the Philippines. The result showed that the ovulatory cycle of the dugong is about 50 days (Wakai et al., 2002).

A biochemical study by Kumar et al. (2003) found that the level of dioxins/furans and polychlorinated biphenyls (PCBs) (i.e., a persistent organic pollutant [POP], which is a carcinogenic, immunotoxic, and endocrine disruptor, causing toxicity to the reproductive organs) in dugong muscle tissue was greater in 2001 than in 1999. Another biochemical study by Harino et al. (2007) found that concentrations of organotin, butyltin (BT), and phenyltin (PT) (causative agents of neurotoxicity, hepatotoxicity, renal toxicity, and dermal toxicity) in the livers of dugongs decreased between 1998 and 2002, suggesting a decrease in organotin concentrations in the surrounding environment.

A socioecological study by Rajamani et al. (2006) interviewed villagers of Banggi Island and Kudat Town, Sabah, Malaysia, to obtain information about dugong hunting and the indigenous use and trade of dugongs. A study by Moore et al. (2017) collected, compiled, and evaluated data and information (mostly unpublished) on the distribution, exploitation, and community perceptions of the dugong around Sulawesi, including the islands of Togean, Banggai, Spermonde, Taka Bonerate, Selayar, and Tanakeke. The findings indicated that dugongs were rare and endangered in Sulawesi. Many fishing communities consider dugong meat superior to beef and see it as a welcome change from fish, while certain body parts fetch a high price as do dugong tears. In Thailand, Petcharat & Lee (2020) estimated the average willingness to pay for the most preferred dugong conservation strategies. The choices included a marker buoy system, habitat restoration, and slowing down population decline. The estimated acceptable cost was 4,382 Thai Baht (122 USD) annually per household. Significantly, developing a marker buoy system to identify dugong habitats was the strategy most valued by the general public; however, the respondents were not willing to pay to educate local fishers about dugong conservation. Moreover, the results of this study implied a consensus that the government should support the remaining dugong population by creating dugong sanctuaries.

### The Knowledge Gaps About Dugong in Southeast Asia

Although several scientific studies have been carried out on dugongs in the region, there are still noticeable gaps in our knowledge. The largest knowledge gap we must address is the detailed quantitative data of the remaining dugong population in the region. Population classification and habitat determination, dugong movements and home ranges, mating periods, and numbers of offspring have been inadequately studied. Knowledge of dugong behavior is lacking in both spatial and temporal variation data in fields such as foraging behavior, foraging patterns, feeding behavior, and patterns of dugong cultivation grazing. The dynamics of the seagrass ecosystem are very important and need elucidating in several different areas (e.g., rhizome demography, patch dynamic, and landscape pattern). The study and improvement of captive dugong husbandry are needed to increase the survival rate of rescued animals. New and more efficient technologies and methods should be encouraged to increase the reach of dugong and seagrass surveying and monitoring. To ensure the sustainable conservation of this species in the regional, national, cross-border, and international realms, management decisions should be based on solid scientific data and local community knowledge. Successful human–dugong interaction demands the effective integration of social considerations. Fishing activity should be mapped so that the potential threats posed by fishing efforts can be understood and the significant risks of bycatch reduced.

### Conclusion

To ensure the sustainable conservation of dugong in the region, regional, national, transboundary, and international management decisions should be based on solid scientific data and community knowledge. We found the scientific research of dugongs in this region to be lacking in several regards. To fill the current knowledge gaps, the following considerations need to be taken into account:

- The acquisition of detailed quantitative data of the remaining dugong population (i.e., population size, distribution, and trends)
- The determination of habitat boundaries (i.e., seagrass distribution and trends, main feeding areas of dugongs, and the optimum habitat condition for dugong populations)
- New and efficient technologies and methods of dugong and seagrass surveying and monitoring

- Spatial and temporal variations in dugong behaviors (i.e., foraging behaviors and patterns, feeding behaviors, and patterns of dugong cultivation grazing)
- Human–dugong interactions and more effective integration of social considerations
- Threats to the dugong
- Transboundary and community-based conservation strategies
- Study of and improvements in captive dugong husbandry

Furthermore, the information of dugong distributions and habitat sites in this review may contribute to future species assessments at the regional and global levels as one of the main IUCN criteria for the species assessments. The species assessments are based on geographic range, population size, and population decline/increase in addition to extinction probability analyses. A systematic review is a reproducible method to identify, select, and critically appraise all relevant research to answer a focused research question. The methodology used in this review may help or may be adapted to be useful in future literature reviews on the status, knowledge, and research gaps of other species of aquatic mammals, especially all species of Sirenia.

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