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**Research Article**

# Trends in Seagrass Research and Conservation in Malaysian Waters

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**ABSTRACT**

The seagrass ecosystems found in the marine and coastal areas, with substantial economic and ecological services and span all over the globe excluding the Antarctic region. The Coral Triangle and Southeast Asia are recognized as a worldwide hotspot of seagrass species and habitats, encompassing 10-21 species of seagrass in every nation, although the study, understanding, and quantity of publications on seagrass ecosystems are rather limited in the region, including Malaysia. Malaysia contains 18 seagrass species from three families, which occupy 16.8 $km^2$ of coastal area, where the study and discovery of seagrass species and meadows began in 1904 with the report of Beccari. All of the published papers reviewed reported on Malaysian seagrass-related research, which was divided into nine topic groups: biology and distribution, carbon sequestration, fauna, remote sensing, impact and pollution genetic study, restoration, microbiological investigation, and others. The extensive study of the seagrass ecosystem began in 1993, and we have identified 183 published papers from Scopus, 141 publications from Web of Science, and 42 from Google Scholar. However, the average trend of the number of publications from 1993 to 1999 was 0.71 ± 0.36, while from 2000 to 2022 was 7.70 ± 1.16 followed by the average trend of the yearly number of publications was 6.78 ± 1.08. The highest number of publications was found on faunal categories (43.17%), followed by biology and distribution (21.85%). The number of articles that were published on Malaysian seagrass meadows each year has been discovered to be rising, which indicates that the trends in seagrass study and publishing were progressively garnering the attention of researchers, academics, and the government. However, to better understand the sustainable ecology and ecosystem services provided by seagrass habitats, an emphasis on certain research niches, such as the genetic study of flora and fauna in seagrass meadows, microbial ecology, and restoration as well as conservation of seagrass species might be helpful.

*Keywords: Carbon sequestration, Conservation, Fauna, Malaysia, Restoration, Seagrass distribution*

## Introduction

Seagrasses are generally marine flowering plants that form ecologically and economically important habitats in coastal zones around the globe [1]. They are marine angiosperms inhabit and support different forms of life from different ecosystems while they co-exist with other ecosystems, including, estuaries, mangroves, coral reefs, and coastal wetlands [2–5]. The services that are provided by seagrass meadows are very wide, from recreation to carbon sequestration, where the economic valuation is considerably high compared to the other ecosystems [6-8]. Seagrass can be found everywhere, from tropical warm climate [9] to a temperate regions of the planet [10]. Short et al. [11] identified six seagrass bioregions with the the tropical Sundaland and the north coast of Australia being considered seagrass hotspot with

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more than 13 species present in each geographic country. These ecoregions are also known as the Coral Triangle consortium [12], where in addition to the availability of seagrass, more than 600 species of coral coexist [13]. As a hotspot of corals, seagrasses, and mangroves, countries like Malaysia lie in the coral triangle consortium and are situated in tropical climates [12, 14].

Among the 72 species of seagrass [11], according to the latest report, Malaysia comprises 16 species of seagrass [15]; but the number of seagrass species and area is still not completely reported from Malaysia and different reports have contradictory numbers of seagrass species [16]. While a recent extensive review on seagrass species in Malaysia enlisted 18 species in different states and locations [12]. The previous studies suggested that, a total of 16.8 $km^2$ of land is dedicated to the seagrass ecosystem in Malaysia throughout the country [17] comprising 78 scattered sites [18]. As a proud member of the seagrass comprising country, Malaysia established legislation and research to protect and conserve the seagrass ecosystem in the coastal area [14].

The first seagrass species were reported by Beccari [19] from East Malaysia and Ridley [20] from Peninsular Malaysia which had already been scrutinized and assembled by a comprehensive historic review work by Bujang et al. [21]. In the 1960’s, the presence of seagrass was described by Henderson [23] and later on by Holttum [24], but they did not present any comprehensive work on the past times. However, the first comprehensive work was found in the study of Ismail [25]. During the ’80s and ’90s, some conference abstracts, book chapters, and presentations on seagrass research were found but those works were excluded from the current review of Malaysian seagrass due to their online unavailability and lack of comprehensiveness. Nevertheless, the history of seagrass research in Malaysia was well narrated by one of the pioneer academicians and researchers on the seagrass ecosystem in Malaysia, Prof. Dr. Japar Sidik Bujang [21]. While the collection of the herbarium of different seagrass species around Malaysia and the exploration of new sites were going on in the ’80s, the number of publications on seagrass research was very limited at that time. Nowadays, the trends and situations are changing rapidly as the research on seagrass sites, species, floral compositions, faunal compositions, ecosystem services, carbon sequestrations, mapping through satellite data, and genetic studies are conducted in different academic universities along with government departments that are subsidizing and encouraging to approach seagrass research in Malaysia [26–29]. This positive attitude of the government and universities enhanced the conservation efforts, and later on, extended the seagrass areas on the Malaysian coast, as can be predicted. Some review and research work focused on the seagrass knowledge gaps in South East Asian and the Coral Triangle countries [12, 30, 31]. A very comprehensive review work was conducted in China, which revealed different aspects of seagrass research on the mainland [32]. However, we did not find any comprehensive review work conducted in the Malaysian seagrass ecosystem that revealed the research trend of seagrass ecosystems; thus, this review work was initiated to provide an insight into the Malaysian seagrass ecosystem and research conducted. In this research, we focused on the research and conservation approaches that were taken by the Malaysian government, research institutions, academic institutions, universities, conservation units, and other organizations. We also focused on the previous research and reviews conducted on the Malaysian seagrass ecosystems. This research might help to understand the research gaps, trends, and possible research niches to be conducted in the Malaysian seagrass ecosystem. While, in broad, this review work would help to take decisions for the funding agencies for scrutinizing potential fund applications.

## Material and Methods

This review examined all research and review works on seagrass studies in Malaysia from Web-of-Science® (Clarivate Analytics), Google Scholar, and Scopus® from 1993 to 2022. The collection of literature and data was held from February 2019 to January 2022. The search of keywords (SK) on different bases (Web-of-Science®, Google Scholar, and Scopus®) were (‘seagrass’ AND ‘Malaysia’); by putting the keywords, we found 183 publications from all the bases, as the previous historic review was scrutinized and described [21]. The number of theses and books are excluded due to lack of abstracting in different databases, open access, and maybe non-digitalized. The conference abstracts were excluded unless they were full conference papers or proceedings. Most of the internationally published literature on

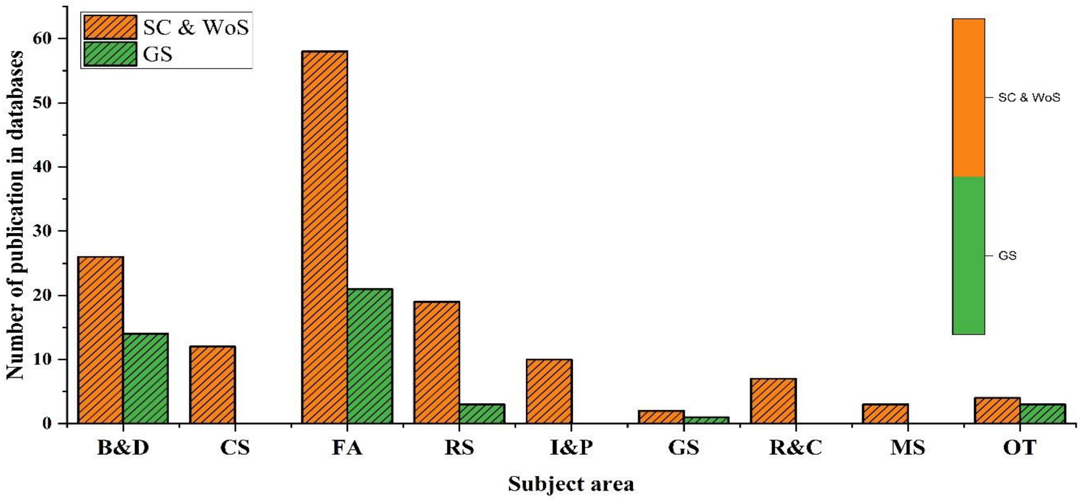


Figure 1. Number of publications in Scopus (SC), Web of Science (WoS), and google scholar (GS) (B&D= Biology and Distribution; CS= Carbon Sequestration; FA= Fauna; RS= Remote Sensing; I&P=Impact and Pollution; GS= Genetic Study; R&C= Restoration and Conservation; MS= Microbial Study; OT= Others).

Table 1. Categorization of Malaysian research publications

| No | Category | Code | Keywords |
|---|---|---|---|
| 1 | Biology and Distribution | B&D | Diversity, distribution, Biogeography, Morphology, Population |
| 2 | Carbon Sequestration | CS | Sediment, Biomass, Stock, organic matter |
| 3 | Fauna | FA | Epifauna, Fish larvae, gastropods, mollusk, Stock Assessment, Infauna |
| 4 | Remote Sensing | RS | Landsat, Satellite, changes detection |
| 5 | Impact and Pollution | I&P | Bioindicator, Metal contamination, Sedimentation, Siltation |
| 6 | Genetic study | GS | Genetic distance, RAPD, DNA |
| 7 | Restoration & conservation | R&C | Community knowledge, conservation, anthropogenic threats |
| 8 | Microbial study | MS | Anti-bacteria, microbes study, pathogens |
| 9 | Others | OT | Reviews and outlier topics |

the Malaysian seagrass research was collected from Scopus and Web of Science, while the domestic publications were collected through Google scholar search. There were 141 papers published in international journals that were abstracted on the Web of Science or Scopus, as well as 42 papers published in national journals (Figure 1) (Table 1S, 2S).

All the publications were arranged and sorted into nine categories, and they were: biology and distribution, carbon sequestration, fauna, remote sensing, impact and pollution, genetic study, restoration, microbial study, and others (Table 1). Others referred to previous review works and were not comparable to the previously listed categories. If the publication was multidisciplinary, the major focus of the article was given priority in the categorization.

The journal quartiles were assessed through the Scimago Journal and Country Rank database websites. The trends in the number of international seagrass publications from Malaysia over the last three decades were assessed in Web-of-Science® and Scopus using "seagrass AND Malaysia" as keywords. The top ten most cited publications on Malaysian seagrasses in Scopus were selected and discussed based on average citations per year.

## Results and Discussion

### *Trends in seagrass research and conservation in Malaysia*

The number of seagrass research and conservation in Malaysia was very general and closed to botany at an early age, which was described by Bujang et al. [21]. In the early days, British explorers and scientists reported different seagrass species and their morphology, biology, and physiology from different parts of Malaysia, mostly from the Malacca Strait and adjacent locations, as the Malacca Strait is an international shipping route that directs merchant marines from the South China Sea to the Andaman Sea. From East Malaysia, Beccari [19] published a book on the flora and fauna of Borneo Island, and there he described the presence of *Halophila beccarii* in the East part of Malaysia. The number of publications, which included books, journals, and proceedings from conferences, was determined to be insufficient, and the researchers mostly focused on describing the biology and distribution of the seagrass. However, as time went on, a dramatic shift took place in the scenario. Academicians and researchers gained more attention when it was revealed, and the study that focused on the ecological relevance, economic importance, and carbon burial capability of the seagrass ecosystem gained more attention [33–38]. The number of papers published between the beginning of substantial seagrass study in 1993 and the end of the century in 1999 was 0.86 ± 0.34; these numbers are quite low, and the majority of the publications were related to seagrass biology and its distribution. But at the turn of the twenty-first century, everything changed quickly; new subfields of research were established, such as the study of the various species of flora and fauna that can be found in seagrass meadows. The use of remote sensing to determine the area and distribution of seagrass, the genetic study of seagrass plants. While the study of carbon sequestration gained attention very recently, where the first publication was found in 2013 [36] but this study stated the preliminary and potential carbonate burial source in Malaysia. Whereas the first extensive study on carbon sequestration was found in the study of Rozaimi et al. [39]. The trends in the number of publications from 2000 to 2020 found drastic change, and it was 7.70 ± 1.16. The average number of publication trends found from 1993 to 2020 was 6.78 ± 1.08 (Figure 2).

The historical review of seagrass research in Malaysia before 2001 revealed that the number of journal publications was very low; whereas the number of books and conference publications was very high, but the abstracts in conference proceedings which had a lack of full-length data and information [21].

The data of top-cited publications in Scopus was also collected and it revealed that the publication by Morton & Blackmore [40] got the highest citations with 245 citations in 21 years. Whereas research on marine epibenthic dinoflagellates got more attraction in Malaysia (73 citations) [41]. The first extensive work on the biology and distribution of seagrass conducted in 2006, where the number of seagrass sites, areas, and conservation measures were described, received 62 citations which was the third highest position in terms of number of citations according to the highest cited documents found in Malaysia [18] (Table 3S). The very first publication to be discovered in Scopus was carried out in 1995 by Bujang et al. [42]. For the very first time, the authors reported seagrass *Halophila decipiens* and its physiology from the state of Negeri Sembilan in Malaysia.

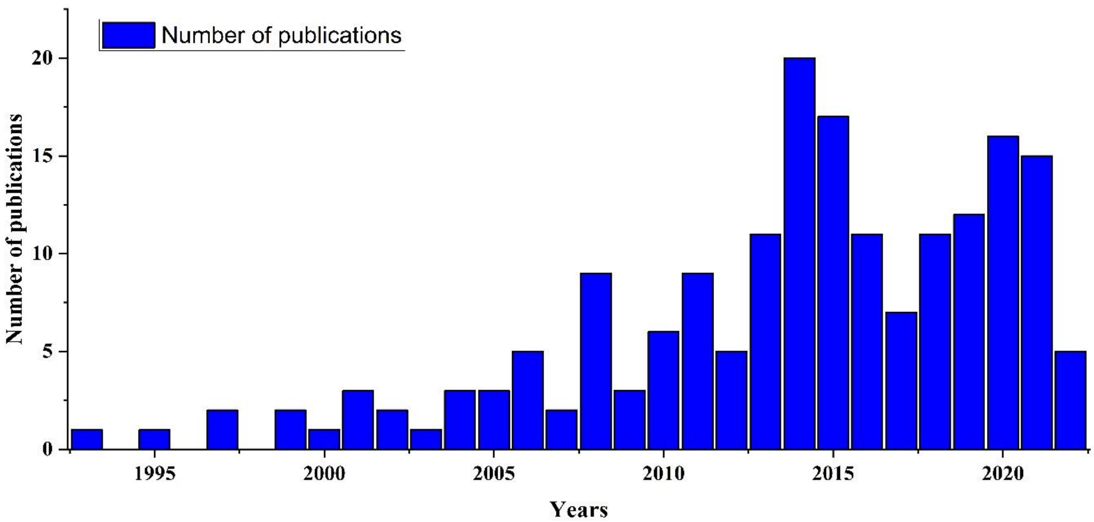


Figure 2. The number of seagrass research publications based on years

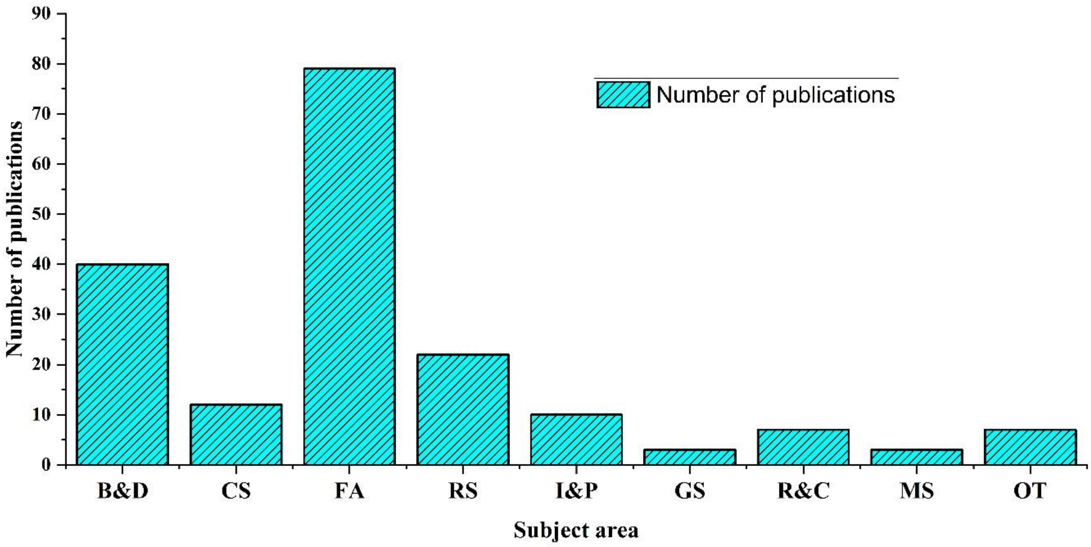


Figure 3. The number of seagrass research publications based on different categories

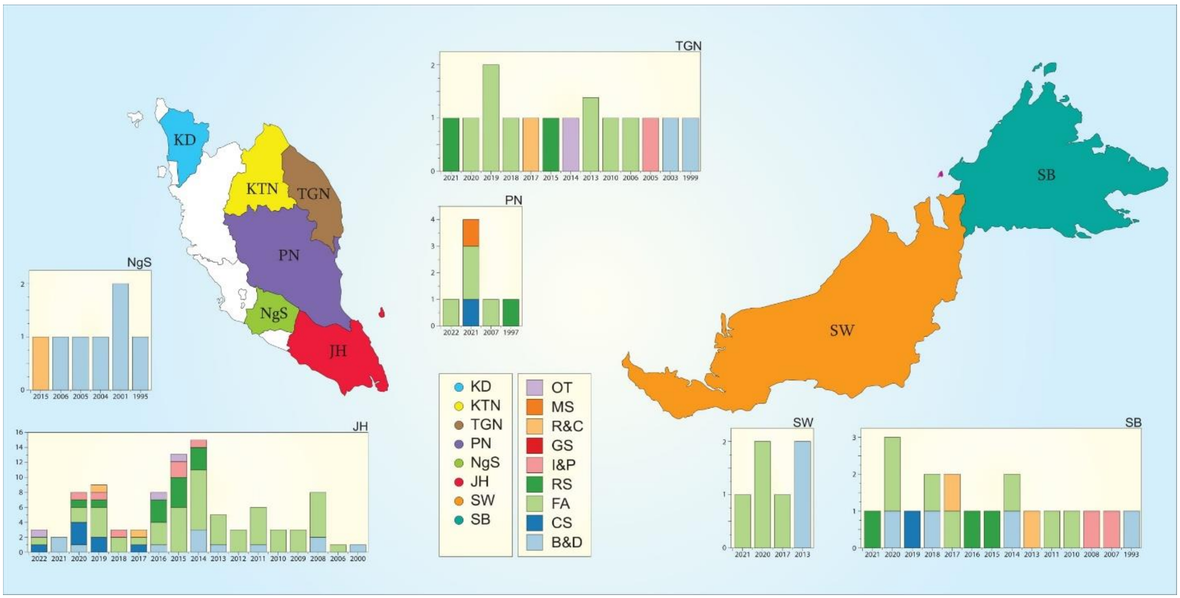


Figure 4. Number of published papers in different states and years (KD=Kedah; KTN=Kelantan; TGN=Terengganu; PN= Pahang; NgS=Negeri Sembilan; JH=Johor; SW=Sarawak; SB=Sabah).

The papers on biology and distribution (40 papers) were found in the second-highest research category on the Malaysian seagrass ecosystem (21.85%) (Figure 3). Since the commencement of the seagrass study that was carried out in Malaysia, an extremely high number of articles on biology and distribution have been published [43–46]. When the extensive study on seagrass started in the early '90s, the main focus was on seagrass plant biology and their distribution in peninsular Malaysia and East Malaysia, but the research focus was turned into the faunal study then. The available fauna in seagrass meadows was studied well, including epibenthic dinoflagellates [41], fish [47, 48], bivalves [49, 50], amphipods [51], gastropods [52]. The faunal studies that were carried out in the many seagrass meadows located throughout Malaysia accounted for the highest part of the overall number of seagrass investigations in a number of different years (Figure 4).

However, Merambong shoals, Johor and Sungai Pulai were the most extensively studied

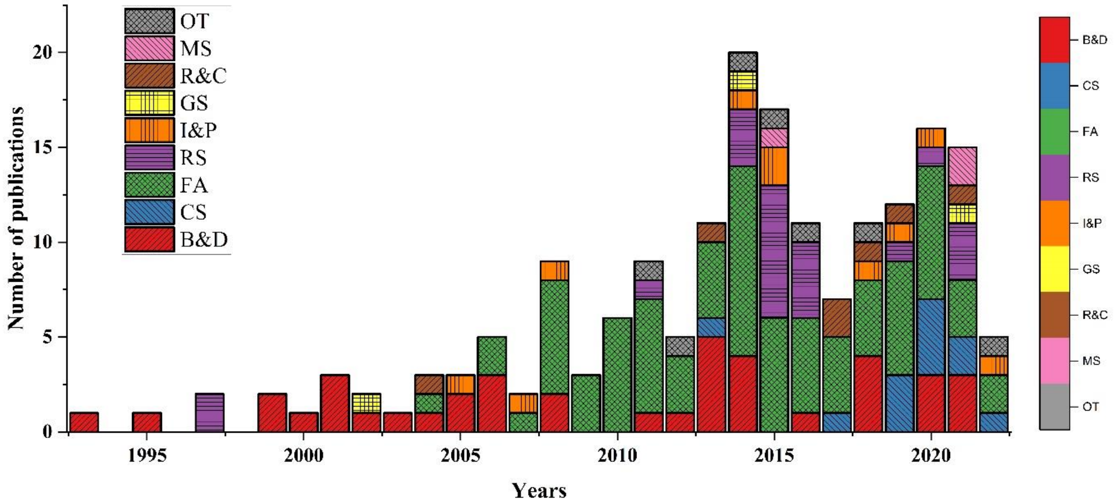


Figure 5. The number of seagrass research publications based on categories and years

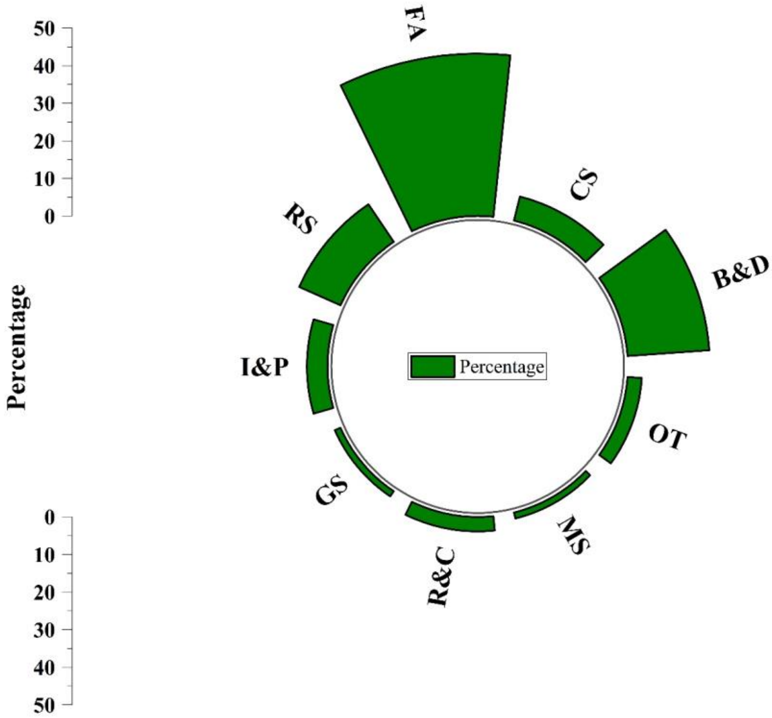


Figure 6. Percentage of seagrass research categories in Malaysia

seagrass meadows in Peninsular Malaysia [49, 50, 53, 54], while Abu Hena et al. [55-57] found Negeri Sembilan was also extensively studied. Whereas, Lawas and Punang Sari estuary are also found the most extensively studied seagrass meadows in East Malaysia [4, 26, 58]. The year-wise categorization of research publications in the Malaysian seagrass meadows is shown in Figure 5.

The number of papers on microbial ecology [59], genetic study [60], and restoration and conservation [61] found low in number and percentage and they are 1.64%, 1.64%, and 3.83% respectively. According to the review, the number of studies and the attention that can be focused on these subjects are the least explored topics in the near future in Malaysian seagrass beds (Figure 6).

Based on the findings of the state-by-state seagrass study, it was determined that the majority of seagrass research was carried out in the state of Johor. This was due to the presence of previously researched areas such as Merambong Shoal and Pulau Tinggi, and most importantly, the proximity

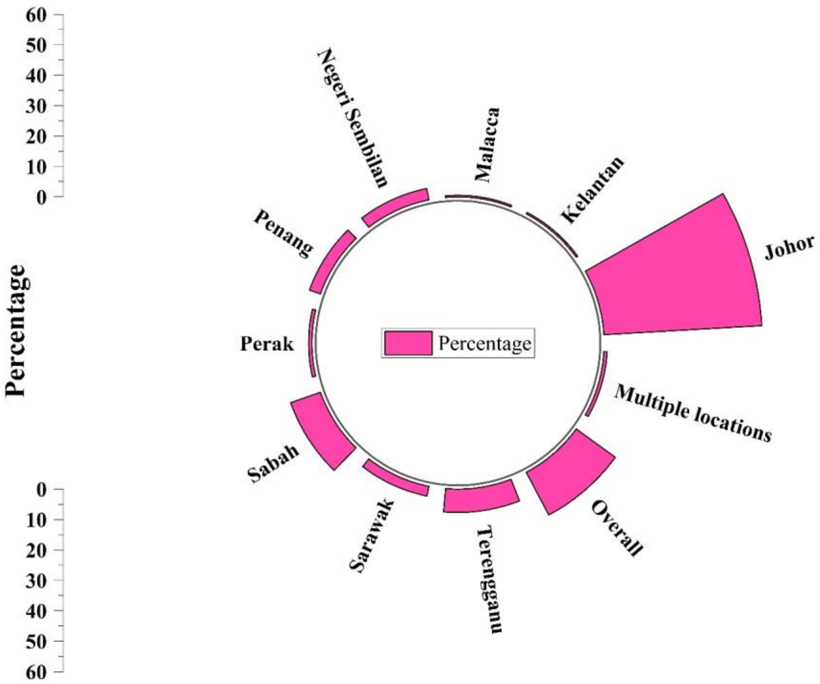


Figure 7. State-wise seagrass research in Malaysia

of the strait of Johor to Singapore. According to the results of the bibliometric study, the state of Johor was credited with a total of 95 studies or reports (51.91%), followed by overall (29 reports; 15.85%) and Sabah (19 reports; 10.38 %) (Figure 7).

### *Biology and distribution*

A total of 18 seagrass species were acknowledged from Malaysian states, islands and territories. However, we scrutinized all the seagrass species reports based on states while most of the reports were from the state of Johor (Table 2; Figure 8). The category biology and distribution comprised: new species report; physiology; morphology; new seagrass meadow report [62], fiber characteristics of seagrass [63], spatial distribution study through remote sensing and GIS [64], seagrass monitoring [65], etc. The first extensive research on seagrass in Sabah, as well as Malaysia, was conducted by Ismail [25], and the author described the number of species, their morphology, and meadow characteristics of seagrass meadows from Sabah. Bujang et al. [42] reported a new seagrass, *Halophila decipiens*, from Malaysia. Whereas, Zakaria et al. [46] discussed the flowering, fruiting, and seedling behavior of *Halophila beccarii* [66]. The number of *Halodule* species, their distribution, and morphological variation were described by Bujang et al. [43].

At the start of the current century, Abu Hena et al. [56] provided insight into the photosynthetic, respiration responses, and biomass studies of *Thalassia hemprichii* [57] and *Cymodocea serrulata* [55]. Wong [45] provided a detailed description and number of seagrass species available in Malacca and Johore Straits.

The other descriptions and distribution of seagrass species were reported from the East Coast of Peninsular Malaysia [44], and the South China Sea [40]. The co-existence of seagrasses and seaweed was first reported by Jillian et al. [67]. The major distribution and species records of seagrass were first described by Bujang et al. [18], where the revisions and challenges were also described after 12 years by the same author [15]. Another shading response of seagrass [68] and a photosynthetic study of wild and cultured *Halophila ovalis* were conducted by Jamaludin et al. [69]. The burial rates of different tropical seagrass species were studied by Ooi et al. [70]. The algal collection during the marine biodiversity mini expedition in Negeri Sembilan reported the seagrass species [71]. The overall seagrass biodiversity in Johor was assessed by Sabri et al. [72]. Japar Sidik & Zakaria [73] reported the cause of purple colo-

Table 2. Distribution of seagrass species with their IUCN red list status in the Malaysian states

| Family | Species | IUCN | JH | KD | TGN | SB | PN | SW | KTN | NSM | NgS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Hydrocharitaceae | *Enhalus acoroides* | LC | 1,3,8,13-15,17,19,20,22,23,26,28,32,34, 36-38, 40, 42, 43, 45,48, 49, 50, 51, 56-58, 62, 64, 66, 76, 77, 79,80,81,85,87,88 | | 31,54,66 | 24,44,66,72-75,97 | 7,12,35 | 11,16,53 | | # | 41,66 |
| | *Thalassia hemprichii* | LC | 1,13,15,17,26,32,34,43,50,56,58,66, 80,81,85,87 | | | 44,52,63,66,73,97 | 12 | 11,16,39,53,66 | | # | 41,66, 92,96 |
| | *Halophila beccarii* | VU | | | 39,66,70 | | 89 | 11,16,53,82 | 39,68 | # | |
| | *Halophila decipiens* | LC | 18,87 | | 6,31,54,66,93 | 44,66 | | | | # | 66,71 |
| | *Halophila major* | LC | 1,29 | | | 5, 33,46 | | | | # | |
| | *Halophila minor* | LC | 26,43,50,56,66,80,81,87 | | 6,31,54,66,67,93 | 66 | | 11,16,39,53,66 | | # | |
| | *Halophila ovalis* | LC | 1-4,9,15,17,19,20-22, 25, 26, 32, 34, 36, 37, 40, 42, 43, 45, 46, 48-50, 56, 57, 59, 60-62, 66, 76, 78-81, 84, 86-88, 94 | 4 | 4,31,54,61,66,90 | 24,44,46,63,66,72, 73,74,97 | 7,10,12, 89 | 11,16,39,46,53,66 | | # | 65,66, 91 |
| | *Halophila ovata* | LC | | | | | 89 | | | # | |
| | *Halophila spinulosa* | LC | 1,26,34,43,48,50,56,57,60,62,66,76, 78,80,81,87 | | | 44,66 | 89 | | | # | |
| | *Halophila* sp. | - | 13,30,47,51,58,64,77,85 | | | 29,44 | | | | # | |
| | *Halophila tricostata* | LC | | | | 29 | | | | | |
| Cymodoceaceae | *Cymodocea rotundata* | LC | 26,66,80,87 | | | 24,44,52,63,66,72-75,97 | | 11,16,39,53,66 | | # | 41 |
| | *Cymodocea serrulata* | LC | 1-3, 13, 15, 17, 22, 25, 26, 32, 34, 36, 43, 45, 47, 49, 50,59,60,64,66,79-81,84,85,87 | | | 24,44,63,66,72,74, 75,97 | | | | # | 66,95 |
| | *Halodule pinifolia* | LC | 1,15,17,22,26,32,56,58,66,69,80,81, 87 | | 6,27,31,39,54,66,67,69,90,93 | 24,66,69,73,97 | | 11,16,39,53,66,69 | 39,69 | # | 66 |
| | *Halodule uninervis* | LC | 1-3, 17, 21, 25, 26, 36, 43, 45, 47, 49, 50, 59, 60, 66, 69,78-80,87 | | 61,69 | 24, 44, 61, 63, 66, 69, 72-74, 97 | | 11,16,53,69 | | # | 66 |
| | *Syringodium isoetifolium* | LC | 2,3,17,25,26,47,57,59,62,66,80 | | | 44,97 | | | | # | 66 |
| | *Thalassodendron ciliatum* | LC | | | | 83 | | | | *,66, # | |
| Ruppiaceae | *Ruppia maritima* | LC | 83 | | | | | | | *,66, # | |

LC= Least concern; VU= Vulnerable; NE= Not evaluated; DD= Data deficient; JH=Johor; KD=Kedah; TGN=Terengganu; SB=Sabah; PN=Penang; SW=Sarawak; KTN=Kelantan; NSM=No State Mentioned; NgS=Negeri Sembilan

1[86]; 2[87]; 3[37]; 4[88]; 5[89]; 6[64]; 7[90]; 8[91]; 9[92]; 10[93]; 11[94]; 12[95]; 13[96]; 14[97]; 15[27]; 16[4]; 17[99]; 18[62]; 19[100]; 20[28]; 21[101]; 22[102]; 23[61]; 24[103]; 25[104]; 26[105]; 27[106]; 28[107]; 29[30]; 30[108]; 31[109]; 32[39]; 33[110]; 34[63]; 35[111]; 36[112]; 37[113]; 38[65]; 39[114]; 40[115]; 41[59]; 42[116]; 43[117]; 44[118]; 45[119]; 46[60]; 47[76]; 48[123];49[121]; 50[122]; 51[120]; 52[75]; 53[58]; 54[74]; 55[73]; 56[72]; 57[124]; 58[125]; 59[70]; 60[126]; 61[51]; 62[127]; 63[128]; 64[50]; 65[69]; 66[18]; 67[130]; 68[66]; 69[43]; 70[46]; 71[42]; 72[131]; 73[132]; 74[79]; 75[133]; 76[134]; 77[135]; 78[54]; 79[81]; 80[136]; 81[137]; 82[83]; 83[21]; 84[138]; 85[49]; 86[84]; 87[139], 88[140]; 89[141]; 90[142]; 91[68]; 92[57]; 93[143]; 94[29]; 95[55]; 96[56]; 97[25]; *[15]; #[12]

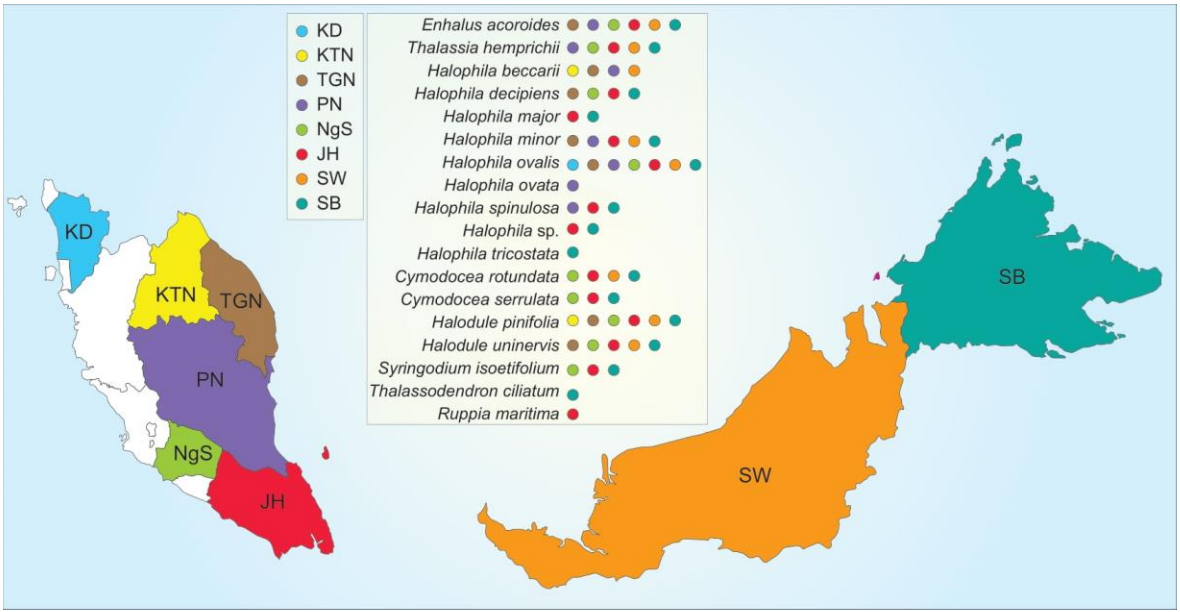


Figure 8. State-wise seagrass species distribution in Malaysian waters

ration in leaves of seagrass, *Halophila*, from Merambong shoal of Sungai Pulai estuary, Johore and Merchang, Terengganu, Malaysia, where lack of pigmentation caused the purple coloration. Zakaria & Japar Sidik [74] reported the presence of seagrass from Perhentian island archipelago, Malaysia; whereas Ahmad-Kamil et al. [58] conducted the first extensive study on Lawas seagrass bed from Sarawak states and described the baseline water quality parameters and biomass of seagrass. The monitoring and decline trends of seagrasses were described by Short et al. [75], whereas Ooi et al. [76] studied the spatial structure of seagrass in tropical multispecies meadows. In very recent years, the study trends of phycology and distribution of different seagrass species were discussed [77], and one new distribution of seagrass was reported [62]. Sudo and Nakaoka [78] described the distribution of South Asian seagrasses. The seagrass coverage [79] and meadow impact [80] in the Malaysian state of Sabah was reported recently. In the last seven years, the biomass and water quality parameters of extensively studied meadows in Merambong Shoal and Malacca Strait have been studied [81, 82]. Fakhrulddin et al. [83] studied the impact of salinity on seagrass meadows, which was the first approach to salinity gradient research, where previous studies were based on photosynthesis or shade gradients. But the first approach to the culture of seagrass in lab and confined conditions was reported by Bujang et al. [84]. Sudo et al. [85] conducted a recent study through remote sensing suggested that seagrass beds throughout Southeast Asia were declining; they also revealed the temporal changes in seagrass bed area that were analyzed for 68 sites in nine countries/regions that the area of more than 60% of seagrass beds decreased at an average rate of 10.9% per year.

***Carbon sequestration***

The study of carbon in seagrass beds was found to be a very new approach in Malaysia. The first study on carbon sequestration was found in 2013 [36]. But the first study stated the preliminary and potential carbonate burial source in Malaysia. Nonetheless, Rozaimi et al. [39] discovered the first extensive study on carbon sequestration in some densely populated areas, such as the Johor and Malacca Strait; they demonstrated that anthropogenic disturbance may hinder seagrass carbon storage. Gallagher et al. [103] discussed a very interesting topic from Sabah seagrass beds, where they showed that black carbon storage in seagrass meadows in Malaysia was lower than the previous prediction. This might have happened due to different sampling factors; the death of a good number of plants in studied meadows; changes in seasons; precipitation during sampling; and many other factors. Some other research that looked at different components of seagrass carbon and nitrogen sequestration or dynamics was also uncovered, which focused on different species and various states or regions in Malaysia [27, 98, 99, 102, 144, 145]. A recent study comparing the inorganic and black carbon between seagrass and saltmarsh ecosystems revealed that inorganic and black carbon might hamper the blue carbon deposition capacity [90]. A study by Stankovic et al. [38] quantified the organic carbon stock and its possible price in united states dollar; on the other hand, Hidayah et al. [37] demonstrated, organic matter that originates from mangroves and macroalgae may be significant contributions to the estuary's ability to store carbon dioxide. We found all the publications on seagrass carbon sequestration were from either Web of Science or Scopus sources, which also indicates the publications were published in the international journal. We did not find any publication on carbon sequestration that was published in a local or non-indexed journal.

***Seagrass-associated fauna***

The study of the seagrass-associated fauna was started after all the biology and distribution were revealed, as the seagrass meadows provide shelter to a high number of marine creatures. According to the current and previous literature, studies on seagrass-associated fauna in meadows in different locations and states were found to be very extensive and the number of publications was 79, which comprised 43.17% of the total number of published documents on seagrass research. However, the first published documents on seagrass-associated fauna were found in 2004 by Mohammad-Noor et al. [41] and the number of publications on this topic has grown over time. Sea cucumbers from Penang island [93, 146], zooplankton from Lawas, Sarawak [94], dugong feeding grounds from the Sibu Archipelago, Malaysia [87], and Molluscan communities from Penang, Malaysia [95] were all reported in recent documents. The previously published documents suggested that fauna, for instance, fishes [4, 47, 48, 97, 104, 106, 142, 147–150], different fish larvae [131, 151–160] are the most abundant group of fauna observed from seagrass meadows in Malaysia, where the artificial seagrass meadows in east Malaysia recorded the highest number of fish species. Other faunal studies, for example, epibenthic dinoflagellates [41], bivalves [26, 49, 50, 97, 129, 133, 137, 140, 161–165], gastropods [26, 52, 97, 108, 120, 123, 125, 136, 166], benthic community [26, 96, 127, 140, 141, 167–170], amphipods [51, 126, 171], shrimp [138, 172–174], porcellidiidae [124], crabs [175, 176], polychaeta [170], seahorse [111, 177], plankton [97, 101, 132, 135, 178–181], dugong [182, 183], turtle [109, 184] and sea star [185–187] were also reported from Malaysian seagrass meadows. Most of the research was conducted to assess the diversity, population dynamics, ecological relations, and seasonal abundance of infauna, epifauna including fishes, gastropods, and bivalves; the parasitic study of gastropods and bivalves found in seagrass meadows; and different morphological, physiological, and behavioral features of any animal that was available in seagrass meadows.

***Remote sensing***

Although the studies on remote sensing in Malaysia are not new, remote sensing study was implemented in seagrass research comparatively late periods. The first research on remote sensing and mapping of seagrass beds was published in 1997 [188]. The first paper was published in a local journal where the first Scopus indexed publication was found in the year 2011, and the publications were based on the mapping of coastal seagrass meadows using ALOS AVNIR-2 satellite data [189].

According to Misbari & Hashim [121], the majority of the early work on submerged seagrass meadows related to remote sensing were published as conference abstract or conference papers. However, the year 2015 is the most productive and golden time for the publication of remote sensing papers, with seven major papers published this year on different seagrass habitats, Malaysian states, methods, and aspects [114–116, 118, 190–192]. Other research includes a satellite-based assessment of the above-ground blue carbon sequestration capacity of Sungai Pulai estuary seagrass meadows [113]. The decline of submerged seagrass biomass in shallow coastal water using the satellite-based method [112] and the ability of light penetration of the satellite band for seagrass detection using Landsat 8 OLI satellite data were assessed by Misbari & Hashim [193]. Different ecosystem mapping in the Malaysian Coral Triangle Initiative area [110]; coastal reclamation of seagrass meadows using satellite data [28]; and mapping of above-ground seagrass carbon [100] are other aspects of remote sensing study. Recent research conducted by Hashim et al. [194] measured the seagrass above-ground biomass (AGB) from all seagrass sites in peninsular Malaysia using satellite data. The results of this research showed that the AGB of different sites was changing over time and seasons due to variations in nutritional factors, seasonal water quality, and fishery harvest fluctuations in nearby locations of seagrass sites. Along with the distribution study, the satellite mapping of seagrass, land reclamation, and above and below-ground carbon study approaches are very important for the conservation and restoration of seagrass. As a result, this study justifies a larger budget and calls for additional research on various aspects of Malaysian seagrass meadows.

***Impact and pollution***

The impact study mainly focused on different threats: pollution, anthropogenic physical and climatic stress, heavy metals, and climate change described in Malaysian seagrass meadows. The first impacts and threats assessment research was published in 2005 from Setiu wetlands, where some seagrass species are available [130]. This is despite the fact that recent research suggests that both micro and macro plastic could be another substantial source of pollution that might alter the physiology, ecology, and development of seagrass plants [195]. However, the number of impact assessment publications is not ample to make a legislative decision and more research concentration on this topic can be performed. Another major impact assessment publication was from Sabah state, where the coastal management plan for their ecosystem and pollution is well described, including some major limiting factors for seagrass distribution, for instance, siltation, sedimentation, eutrophication, and shading effects of seagrass due to previously mentioned threats. Local conservation knowledge, public awareness, and consciousness about garbage and waste disposal from the local level to the state level were recommended to mitigate the pollution and impact [196]. In the year of 2008, Freeman et al. [128] published an extensive work where they blamed sedimentation, turbidity, and siltation for the decline of seagrass abundance and diversity in Sabah state on the river beds, estuary, and seagrass beds due to soil runoff from different sources, where human intervention plays as a catalyst force. The presence of mercury (Hg) and lead (Pb) in the Pulai estuary in Johor was reported from seagrass meadows, and the negative impact of the Hg and Pb polluted water was affecting the seagrass species, including *Enhalus acoroides* and *Halophila ovalis*. The Pulai Estuary in Johor is located in highly anthropogenic disturbed areas where industries and ocean-going merchant vessels may dump chemicals into the ocean water, and it is predicted that the seagrasses will be lost within a few years or decades [122]. Another research paper on different trace elements in the same estuary of Johor indicated the presence of heavy metals including As, Cu, and Cd, indicating the seagrass species are very sensitive to these pollutants and heavy metals; however, the pollution negatively impacts them. They suggested using the seagrass species *Halophila ovalis* and *Halophila minor* as bio-indicators for metal pollution [65]. A similar bio-monitoring and bio-indication study was conducted in the Johor area where they worked on As, Cd, Cu, Hg, and Pb metals and found a negative impact of seagrass species. They suggested using seagrass as a bio-indicator species [117]. A similar study from Merambong shoal also suggested tape seagrass might be used as a bio-indicator [107]. The study of lead accumulation and its impact on seagrass physiology [197], and the impact of organotin and booster biocides [198], suggested that seagrass beds were disturbed by these above-mentioned chemical factors. However, because seagrass provides economic support and has a monetary value, its decline may disrupt the economic cycle for fishermen and, on a large scale, the nation [53].

***Genetic study***

The genetic study on seagrass species and the adjacent fauna was found to be very limited in Malaysia. This review found only two published documents on seagrass species. One revealed the polymorphic DNA sequence of *Halophila ovalis* [29], which was published in a local journal. The other published document referred to the seagrass species *Halophila major*, which was previously identified as *Halophila ovalis* by the morphological keynotes. Most interestingly, the study also suggested the Malay Peninsula is a geographic barrier between *H. ovalis* populations in the Western Pacific and the Eastern Indian Ocean regions [60].

***Restoration and conservation***

The first conservation and restoration study was conducted in 2014 [199], where the author suggested establishing a coastal and marine resource information system (CMARIS) for conserving and restoring biodiversity. Some conservation and restoration studies stated the use of community and fishers' knowledge, and awareness of seagrass associated fauna, such as Dugong [200, 201], whereas mutualism characteristic of symbiotic relationships between seagrass and fungal community may help to increase survivability and sustainability of seagrass restoration projects [61]. However, different stakeholders, from local level fishers to academic institutions, and finally, from local government to federal government, have a critical role to play in conserving Malaysia's seagrass sites [202]. While the discussion began with the restoration and conservation, policy and legislation can play an important role in conserving the seagrass ecosystem through various declarations such as marine protected zone, national reserve area, regional reserve area, marine protected area, Ramsar site, and so on. A comprehensive policy and legislative frameworks were proposed by Tan et al. [105], where priority-based conservation efforts were proposed based on the significance and condition of the site and point-oriented ecosystem conservation approaches needed to be implemented by different authorities, including local government, state government, regional government, and the federal government.

***Microbial study***

We found the only microbial study on seagrass meadows from Malaysia, where 3 species of seagrass were put under experimentation from the Negeri Sembilan and revealed that *Thalassia hemprichii* is the potential species as antibacterial agents [59]. A very recent study by Quek et al. [88] discussed the fungal community that exists in the *Halophilia ovalis* seagrass meadows. A study by Yeoh et al. [203] isolated Vibrio-predatory filamentous bacteria (VPFB) from seagrass plants from the coastal area of Penang, and later on they tested the efficiency of these isolates on Vibrio. As a result, they found three bacteria that can be used for controlling acute hepatopancreatic necrosis disease (AHPND) disease in shrimp. Despite the fact that we were only able to find a small number of works on microorganisms and microbial ecology that were undertaken in Malaysian seagrass meadows, this research field contains loopholes that a significant number of studies have the potential to address.

***Others***

This category comprised the papers which are not under the niche of the previously described eight categories; for example, review papers described Malaysian seagrass meadows, history, carbon sequestration, ecology, and associated biodiversity. Ooi et al. [31] published a major review work on the knowledge gap in Southeast Asian seagrass meadows where they mainly revealed and scrutinized the core information of seagrass biomass in different Southeast Asian countries, including Malaysia. Since the paper was published 10 years ago, most of the gaps in the described matter might be filled by different research from Southeast Asian countries. However, a recently published review paper demonstrated the distribution of seagrasses, biodiversity of fishery resources, blue carbon, threats, climate change, knowledge gap, sociocultural studies, and research trends in Coral Triangle countries, including Malaysia [12]. A major review of historic seagrass research was described by Bujang et al. [21]. This extensive historical review work mainly focused on the first published documents on seagrass species [19] to the publications until 2001. Bujang et al. [21] included books, conference abstracts, papers, proceedings, local and international journals. The work of Reba et al. [204] did not fall under the above-mentioned eight categories, where they described the impact of soil moisture and salinity on seagrass meadows, and how the ecology affects the distributional change and population. Macro and micronutrition play a very important role in seagrass plant growth, survivability, and growth. The impact of four seagrass species (*Halophila ovalis*, *H. major*, *H. spinulosa*, and *Halodule*) on macronutrients like N, P, K, Ca, Mg, and micronutrients like Zn, Fe, Mn, and Cu were studied, for four seagrass species and positive correlations of growth on micro and micronutrients were discovered [54]. Some other works in these categories are: food web and food chain identification and tracing the structure using stable isotopes ($\delta 13^{C}$ and $\delta 15^{N}$) in Johor [134]; knowledge gaps and conservation efforts of seagrass meadows from Southeast Asia [30]. Fortes et al. [30] and Al-Asif et al. [12] provided detailed information on the size and distribution of seagrass meadows in Malaysia, the number of species, knowledge gaps, and conservation efforts. For the first time, they provided research trends on the Malaysian seagrass ecosystem and discussed how the number of publications and research has increased since 2010, indicating a positive attitude of the government, institutions, and academicians.

## Conclusion

This study sheds light on a number of previously unexplored facets of seagrass research carried out in the seas around Malaysia. The comprehensive presentation of the search niche and the classification of the topic area contained nine elements of the seagrass investigations that were carried out in the waters of Malaysia. The related fauna in seagrass beds and sites has been recorded in the greatest number of publications. Nonetheless, the state of Johor in Malaysia has had the most research done on its seagrass locations. There are now researchers working in the eastern regions of Malaysia (Sarawak and Sabah), but the number of researchers working there might be boosted by giving research funding and training younger researchers. However, we discovered that there is a significant research vacuum in the area of genetic analysis of seagrass and the species that are linked with it. Furthermore, microbial research has also attracted less attention. The extent of seagrass sites in Malaysia was determined to be relatively insignificant in comparison to the other habitats. Thus, the declaration of conservation sites and marine protected areas may safeguard these unique ecosystems from pollution and other threats.

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