

## ***LITERATURE REVIEW OF CORAL REEF RESTORATION IN AND AROUND THE CORAL TRIANGLE FROM THE VIEWPOINT OF MARINE BIODIVERSITY***

Revisão da literatura sobre a restauração de recifes  
de coral dentro e ao redor do Triângulo de Coral  
do ponto de vista da biodiversidade marinha

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### **ABSTRACT**

The coral reefs of the Coral Triangle and nearby marine regions are the most biodiverse marine ecosystems in the world, providing ecosystem services to hundreds of millions of people. However, like coral reefs in other regions, these ecosystems are in decline due to a myriad of anthropogenically-induced stressors. To mitigate this decline, active coral reef restoration efforts have been increasing worldwide, including in this region. An important end-goal of coral reef restoration is the conservation of functional biodiversity of not only zooxanthellate scleractinian corals, but of all associated coral reef organisms. In this literature review, we collected papers from the Web of Science (1995-2021) focused specifically on coral reef restoration from six countries and regions around the Coral Triangle (Japan, Taiwan, mainland China, the Philippines, Malaysia, Indonesia) to examine how much coral reef restoration research has been performed in each area, when it was performed, what methodologies were used, what organisms were targeted, and whether any assessment of biodiversity was included. Our results show great disparity in the research efforts of each area, with the Philippines clearly leading research in the region with almost half of the literature examined, followed by Japan and Indonesia, with nascent efforts in mainland China, Taiwan, and Malaysia. Overall, for the region, research appears to be increasing with time. Research in most areas was concentrated in one or two locations, and almost exclusively focused only on corals. Only approximately 38% of

papers mentioned biodiversity in any manner, and only 14% included organisms other than scleractinian corals in their results. It is clear from this review that extensive research and data gaps exist regarding coral reef restoration in the western Pacific and Coral Triangle, particularly from the viewpoint of biodiversity. It is hoped that research can address these gaps before coral reef ecosystems in the region decline even further.

**Keywords:** coral reef ecosystems, knowledge gaps, East Asia, South-East Asia, Indo-Pacific.

## RESUMO

*Os recifes de coral do Triângulo de Coral e regiões marinhas próximas são os ecossistemas marinhos mais biodiversos do mundo, fornecendo serviços ecossistêmicos a centenas de milhões de pessoas. No entanto, como os recifes de coral em outras regiões, esses ecossistemas estão em declínio devido a uma miríade de estressores induzidos antropogenicamente. Para mitigar esse declínio, os esforços ativos de restauração de recifes de coral têm aumentado em todo o mundo, incluindo nessa região. Um objetivo final importante da restauração do recife de coral é a conservação da biodiversidade funcional não apenas dos corais escleractíneos zooxantelas, mas de todos os organismos associados do recife de coral. Nesta revisão de literatura, coletamos artigos da Web of Science (1995-2021) focados especificamente na restauração de recifes de coral de seis países e regiões ao redor do Triângulo de Coral (Japão, Taiwan, China continental, Filipinas, Malásia, Indonésia) para examinar como muitas pesquisas de restauração de recifes de coral foram realizadas em cada área, quando foram realizadas, quais metodologias foram utilizadas, quais organismos foram visados e se alguma avaliação da biodiversidade foi incluída. Nossos resultados mostram grande disparidade nos esforços de pesquisa de cada área, com as Filipinas claramente liderando as pesquisas na região com quase metade da literatura examinada, seguida pelo Japão e Indonésia, com esforços nascentes na China continental, Taiwan e Malásia. No geral, para a região, a pesquisa parece estar aumentando com o tempo. A pesquisa na maioria das áreas estava concentrada em um ou dois locais e quase exclusivamente focada apenas em corais. Apenas 38% dos artigos mencionaram a biodiversidade de alguma maneira e apenas 14% incluíram outros organismos além dos corais escleractíneos em seus resultados. É claro a partir desta revisão que existem lacunas de pesquisa e dados extensas sobre a restauração de recifes de coral no Pacífico ocidental e no Triângulo de Coral, particularmente do ponto de vista da biodiversidade. Espera-se que a pesquisa possa abordar essas lacunas antes que os ecossistemas de recifes de coral na região diminuam ainda mais.*

**Palavras-chave:** recifes de coral, lacunas do conhecimento, leste da Ásia, sudeste da Ásia, Indo-pacífico.

## INTRODUCTION

Subtropical and tropical coral reefs are among the most diverse marine ecosystems, and are estimated to contain approximately 25-50% of total marine biodiversity (e.g. Fisher *et al.*, 2015, states 38%), as well as provide important ecosystem services to hundreds of millions of people (Burke; Selig & Spalding, 2002). For humans, coral reefs have important functions in economic (Barton, 1994; Cesar, 2002) and cultural activities (Cinner; Marnane & McClanahn, 2005; Vaughan; Vitousek & Mahele, 2013), and also act as protective

breakwaters (Hongo; Kurihara & Golbuu, 2018). Coral reef biodiversity has been shown to be highest in the Coral Triangle region of the western Pacific Ocean, centered around the Philippines and Indonesia (Carpenter & Springer, 2005), and in general the diversity of Indo-Pacific reefs is considered to be higher than that of other regions (Hoeksema, 2007). Within East and Southeast Asia, many coral reefs are located next to growing urban areas (Heery *et al.*, 2018).

However, with increasing levels of anthropogenically-induced climate change, the threats to coral reefs and to their biodiversity and ecosystem functioning are thought to be rapidly increasing in severity (Guan *et al.*, 2020). Among the myriad of threats to coral reefs, coral bleaching induced by global warming (Sully *et al.*, 2019), over-exploitation (Zgliczynski & Sandin, 2017), increasing urbanization and decreasing water quality (Heery *et al.*, 2018), ecosystem unbalance (Reimer *et al.*, 2011; Plass-Johnson *et al.*, 2015), and invasive species (Soares *et al.*, 2020; Ruiz-Allais; Banayahu & Lano-Alcalá, 2021) are main concerns. The reefs of East and Southeast Asia are not immune from these threats. For example, low reef complexity and reef compression (i.e., narrowing of species' depth ranges) have been observed in reefs regions due to sediment pollution and resulting increases in turbidity caused by urbanization (Heery *et al.*, 2018).

One intervention strategy to help mitigate the negative effects of such threats is active coral restoration (Rinkevich, 1995). Coral restoration is the propagation of zooxanthellate scleractinian corals via human intervention with the goal of increasing their numbers in natural ecosystems (Rinkevich, 1995; Epstein; Bak & Rinkevich, 2001; Kaufman, 2006). Coral restoration efforts and research have exponentially increased in the last four decades as coral reefs decline (Rinkevich, 2005), and restoration has been performed via a wide variety of methods, including asexual (Rinkevich, 1995) or sexual propagation (Rinkevich, 1995; Pollock *et al.*, 2017), floating or isolated aquaria nurseries (Rinkevich, 1995; Omori, 2005; Omori; Iwao & Tamura, 2008; Shafir; van Rijn & Rinkevich, 2006; Shaish *et al.*, 2008; Levy *et al.*, 2010), and "replanting" at various stages of colony growth (Forrester *et al.*, 2012), among others (for reviews see Barton; Willis & Hutson, 2017; Randall *et al.*, 2020). While much research has been performed on coral restoration, results have often been mixed (Hein *et al.*, 2020). New approaches are being proposed to overcome present challenges (Van Oppen *et al.*, 2015, 2017), and the field can be considered, overall, as still developing, with results strongly dependent on the selected intervention methods and with assessment ability limited by the monitoring effort, which has often been too short-term to be effective (Hein *et al.*, 2020). Critics have argued that current approaches to coral restoration have been a pointless approach to conserving reefs in the Anthropocene, due to scale mismatches between the threat that reefs are facing and the much smaller scale of the management responses to the threat itself (Bellwood *et al.*, 2019). Thus far, the three major scale mismatches between the threat that coral reefs are facing and the current implementations of reef restoration have been temporal, spatial and functional (Bellwood *et al.*, 2019): major bleaching events can now occur faster than the time needed for transplanted corals to reach their full size (temporal mismatch, for example see Montero-Serra *et al.*, 2018), bleaching events occur on a global scale, while restorations happen on a local scale (hectares; spatial mismatch). Finally, reef restoration has been largely biased towards fast-growing branching corals (59% of studies; Boström-Einarsson *et al.*, 2020), and the most commonly transplanted species may not be the ones most critical to the reefs in order to maintain their functional redundancy (functional mismatch). Another important

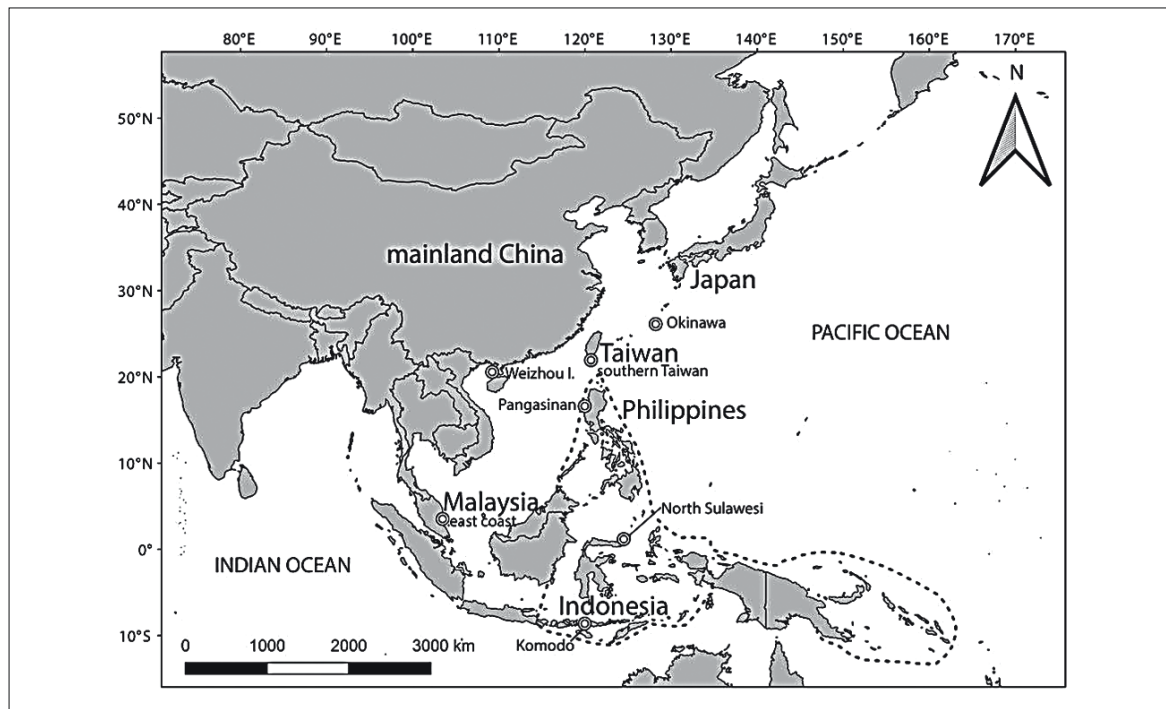
limitation is that the success of restoration projects has depended on the presence of nearby healthy or relatively healthy reefs (Hein *et al.*, 2020). Despite mixed success, coral reef restoration efforts are thought to be critical in our ability to conserve and protect coral reef ecosystems in the future (Possingham; Bode & Klein, 2015).

While most of the focus of coral reef restoration has been on the “ecosystem engineers” zooxanthellate scleractinian corals, the end goal of coral reef restoration is that by increasing these corals, not only corals but other associated organisms will also continue to exist amongst coral reefs and their complex structures. This would thereby protect not only corals, but the entire biodiversity and ecosystem functioning of coral reefs, which range across different size scales, from fish to cryptic organisms inhabiting coral skeletal frameworks (Biondi; Masucci & Reimer, 2020) that have been shown to be sensitive to environmental stressors and changes in habitat (Masucci; Biondi & Reimer, 2021). Following this, there is therefore a critical need to assess how coral restoration efforts affect the biodiversity of coral reefs beyond scleractinian corals.

In East and Southeast Asia, coral reef restoration and monitoring efforts vary widely from country to country, and even by region (Chou *et al.*, 2009). Many of the major coral reef restoration efforts in this area are generally well-known, but there is a myriad of projects under way, as well as governmental efforts at various levels that are not documented in peer-reviewed literature and/or in the English language. Given the recent economic development of many parts of the region (average economic growth rate for the Southeast Asian region from 2018 to the end of 2019 = 5.2%; Nasir; Huynh & Tram, 2019; Zeraibi; Balsalobre-Lorente & Murshed, 2021) combined with generally rapid population growth (average annual population growth rate in South-East Asia > 2.5%; United Nations, 2019), the success and failures of coral reef restoration in this region can be considered to hold valuable lessons for the entire field. However, until now, there have been few reviews on coral reef restoration efforts in this region (but see Chou *et al.*, 2009, focusing on methodologies), particularly from the viewpoint of coral reef biodiversity.

Therefore, in this review, we examine the available literature on coral reef restoration from the viewpoint of biodiversity for six regions in East and Southeast Asia: Japan, Taiwan, mainland China, the Philippines, Indonesia, and Malaysia (Figure 1). By “viewpoint of biodiversity”, we specifically examined if papers discuss or mention species other than any targeted scleractinian coral species, or if biodiversity indices of any kind were mentioned. In performing this review, we hope to provide an overview on the scientific literature on coral reef and biodiversity restoration for the West Pacific, identifying areas where research has been performed and also areas of concern or lacking data, to help guide future research efforts.

Figure 1 – Map showing countries and regions examined in this review. Double circles indicate areas of coral reef restoration focus within each region. Dotted line indicates Coral Triangle boundary



## MATERIALS AND METHODS

Between the period of August 16 and September 5, 2021, we searched the following terms on the Web of Science: “coral, restoration, XXX”, where “XXX” was represented by a country or region name, namely “Japan”, “Taiwan”, mainland “China”, the “Philippines”, “Malaysia”, or “Indonesia”. All records from each of these six searches were downloaded as a spreadsheet file. The Web of Science covers research literature from 1995 to current.

On top of these data, we added additional information available from each paper’s Abstract, and if needed, from reading the paper. Additional data columns populated into the spreadsheet were:

- 1) Include in our analyses? (Yes/No);
- 2) Restoration study? (Yes/No);
- 3) Target organisms, with as much detail as possible;
- 4) Country/region: Japan, Taiwan, mainland China, the Philippines, Malaysia, Indonesia;
- 5) Local location (as much detail as possible);
- 6) Objectives of the restoration (as much detail as possible);
- 7) Method of restoration (as much detail as possible);
- 9) Does the paper mention biodiversity? (Yes/No);
- 10) Funding source (if available);
- 11) Finally, any biodiversity results were cut and pasted from the abstract into the spreadsheet.

After this, we performed simple quality control on our dataset, excluding review papers and including instead only active restoration papers from scientific journals that were focused on coral reef ecosystems.



Once the dataset was amassed, we examined the following information for each country or region; numbers of papers, mentions of biodiversity, years of publication, target organisms, methods employed, and locations of research. We then performed the same analyses for the combined dataset of all six regions.

We also generated a wordcloud from the keywords of each paper, adding in the name of each country or region once for each paper included in our study. We used R 4.1.0 (R Core Team, 2021) with the packages tm (Feinerer & Hornik, 2020) and wordcloud2 (Lang & Chien, 2018).

## RESULTS

### Japan

After our initial search, we recovered 63 papers. Twenty-two of them dealt with coral reef restoration in Japan, and after filtering, we kept 11 publications that focused only on active restoration and excluded modeling studies (Table I, Supplementary Material). Of these 11 papers, six mentioned biodiversity (= 55%) (Table I, Supplementary Material). The included research spanned from 2008 to 2021 (Table I, Supplementary Material). Corals were the target organisms for all 11 papers (eight out of 11 dealt with *Acropora* spp.), with one paper also focused on rubble cryptofauna. Settlement substrate methods (n = 8), coral and rubble collection (n = 3), sexual reproduction methods (n = 3), and fragmentation (n = 2) were mentioned in multiple papers (Supplementary Material). Ten publications were about Okinawa Prefecture, southwest Japan (six were around Ishigaki Island, two were in Onna Village, one in Sesoko Island and one in Naha) and one paper was in Okinotorishima (Table I, Figure 1, Supplementary Material). Funding for Japanese restoration projects were supported by a wide variety of entities. While the majority of papers mentioned the national Japanese Society for the Promotion of Science (JSPS) and the Fisheries Agency, other funding sources included private corporations (Mitsubishi) and foundations (JCG-S Foundation) as well as Okinawa Prefecture.

Table I - Summary of coral reef restoration work in six East/Southeast Asian countries and regions

Country/region	Number of papers	Earliest paper	Number mentioning biodiversity	Number focused on coral	Number of papers focused on other taxa	Other notes
Japan	11	2008	54% (6/11)	100% (11/11)	9% (1/11)	Often large-budget or artificial methodologies implemented, focused in Okinawa
Taiwan	3	2003	33% (1/3)	100% (5/5)	33% (1/3)	Highly varied methods, little literature, possible repository in Chinese language? Likely much more on artificial reefs
Mainland China	4	2006	50% (2/4)	75% (3/4)	50% (2/4)	Little research yet conducted; possible large repository of information in Chinese language
The Philippines	27	2003	18% (5/27)	100% (27/27)	7% (2/27)	Majority of research focused on sites in Pangasinan
Indonesia	8	2003	50% (4/8)	100% (8/8)	0% (0/8)	Little focus on other taxa despite mentioning biodiversity; at least two central regions of research
Malaysia	3	2013	66% (2/3)	100% (3/3)	66% (2/3)	Little research, likely much more on artificial reefs
<b>Total</b>	<b>56</b>	<b>2003</b>	<b>35% (20/56)</b>	<b>98% (55/56)</b>	<b>14% (8/56)</b>	<b>Clear disparity in research effort and methodologies among countries</b>

Supplemental Table I - Spreadsheet of raw data from the Web of Science and all related data used in this review



634 million USD, although the amount for coral reef work was not shown ([http://zyhj.mof.gov.cn/zxzyzf/hyst/202105/t20210507\\_3697663.htm](http://zyhj.mof.gov.cn/zxzyzf/hyst/202105/t20210507_3697663.htm), [http://zyhj.mof.gov.cn/zxzyzf/zdstbhxf/202007/t20200707\\_3544806.htm](http://zyhj.mof.gov.cn/zxzyzf/zdstbhxf/202007/t20200707_3544806.htm)).

### **The Philippines**

After our initial search, we recovered 69 papers. 37 of these papers dealt with coral reef restoration, and after filtering, we kept 27 papers that focused on coral reef restoration in the Philippines (Table I, Supplementary Material). Of these 27 papers, five mentioned biodiversity (= 18.5%) (Table I, Supplementary Material). The included papers spanned from 2003 to 2021, but only three of them were published before 2008. From 2008, there was an increase in studies on coral restoration in the Philippines, with peaks observed in 2010 and 2020 (= four papers each) (Supplementary Material). Corals were the target organisms for all 27 publications, with one paper each also focused on gastropods and giant clams (Table I, Supplementary Material). Transplantation methods were mentioned in 10 studies, with gardening (n = 4), outplanting (n = 4), sexual reproduction (n = 3), and nurseries (n = 2) also mentioned in multiple publications (Figure 2, Supplementary Material). We were able to determine locations of the coral reef restoration for 27 papers. Of these, 19 were in Bolinao, and seven were in Anda, both in the province of Pangasinan (also mentioned in 14 papers) (Figure 1, Table I, Supplementary Material). Funding for these works included national government agencies (Department of Science and Technology) as well as overseas agencies (Global Environment Facility, World Bank, Australian Centre for International Agricultural Research).

### **Malaysia**

After our initial search, we recovered 16 papers. 10 of these papers dealt with coral reef restoration, and after filtering, we kept three that focused on coral reef restoration in Malaysia (Table I, Supplementary Material). Of these three, two mentioned biodiversity (= 66%) (Table I, Supplementary Material). The included papers spanned from 2013 to 2015. Corals were the target organisms for all three papers, with two also focused on other benthic organisms as well (Table I, Supplementary Material). Xin *et al.* (2013) studied the feasibility of a selected species of hard coral as an ideal subject for restoration projects, monitoring the growth rate and survivability of *A. formosa* in the nursery environments. The other two papers (Mohd *et al.*, 2013; Hamizan *et al.*, 2015) focused on the biodiversity of benthic settlement (including hard corals) on artificial reefs/ structures. We were able to determine locations of the coral reef restoration for all three papers; they were all conducted around islands of the east coast of Peninsular Malaysia, specifically Tioman Island (n = 2) and Bidong Island (n = 1) (Figure 1, Table I, Supplementary Material). Funding came from collaboration between the Department of Fisheries and its Division of Marine Park Malaysia (Bin; Salleh & Bin, 2020).

### **Indonesia**

After our initial search, we recovered 32 papers. Eight dealt with coral reef restoration, and after filtering, we found that all focused on Indonesia and thus we kept all of them (Table I, Supplementary Material). Of these eight papers, four mentioned biodiversity (= 50%) (Table I, Supplementary Material). Papers spanned from 2003 to 2019, but there were only two studies published before 2010. Corals were the target organisms for all eight



papers (Table I, Supplementary Material). Transplantation methods were mentioned in five papers, with gardening ( $n = 4$ ), artificial reefs of some kind ( $n = 3$ ), and substrate stabilization ( $n = 2$ ) also mentioned in multiple papers (Figure 2, Supplementary Material). We were able to determine locations of the coral reef restoration for all eight papers. Of these, one was in Aceh province (Weh Island), four were in East Nusa Tenggara province (Komodo National Park), and three were in North Sulawesi province (Bunaken National Park, Gangga Island, and Meras District) (Figure 1, Table I, Supplementary Material). Indonesian coral reef restoration work was funded via private (Newmont Mining) and overseas (United States National Science Foundation) sources, with recent work funded by the Coral Reef Rehabilitation and Management Project (COREMAP), a collaboration among the Indonesian government, Conservation Trust Funds, and the World Bank (Hidayat; Muawana & Pabuayan, 2017).

### Combined results

Our combined dataset included 56 papers. Overall, the highest number of papers were from the Philippines (48%, 27/56), followed in order by Japan (19%, 11/56), Indonesia (14%, 8/56), mainland China (7%, 4/56), and Taiwan and Malaysia (each 5%, 3/56) (Table I). The oldest papers dated from 2003 for Taiwan, the Philippines, and Indonesia, while the oldest paper from mainland China was published in 2006, Japan in 2008, and Malaysia in 2013 (Table I). The large majority of papers (98%, 55/56) focused on hard corals, and only eight studies (= 14%) dealt with other taxa. 35% of papers (20/56) mentioned biodiversity in some form (Table I; Supplementary Material).

Notably, there were clear differences in the research conducted in each region, with the Philippines and Indonesia focused on transplantation, while Japan, Taiwan, Malaysia, and Indonesia included varying amounts of focus on implementing artificial substrates or devices (Figure 2). There were clear regional biases within all countries, with most research in the Japan (Okinawa), Taiwan (southern Taiwan), mainland China (Weizhou Island), Philippines (Pangasinan), and Malaysia (east coast of Peninsular Malaysia) focused on one single region, while Indonesia had research conducted mainly in two regions (Komodo, North Sulawesi).

Overall, there was an increasing trend in the amount of papers focused on coral reef restoration. Although the Web of Science covers publications from 1995, the first papers on restoration appeared in 2003, and the trend increased over time to peaks in 2019 and 2020 (seven papers in each year) (Figure 3).

## DISCUSSION AND CONCLUSIONS

The observed trends in terms of total papers and research focuses within the field of coral reef restoration for each country and region can be considered informative on their restoration situations and approaches. For example, research from the Philippines accounted for almost half of the papers we examined, and the Philippines have a long history of coral reef conservation and restoration (e.g. Yap; Alino & Gomez, 1992), with numerous active researchers focusing on these topics. In this regard, we feel the Philippines can act as a role model country for coral reef restoration research in the Coral Triangle and western Pacific region. While there is much to be admired about the coral reef restoration science that has come out of the Philippines, our review pinpointed areas where future

research could focus. Research in the Philippines has been largely concentrated in one province, and expanding conservation to other regions, when possible, could provide for additional information and scientific opportunities. As well, while one of the only restoration papers not focused on scleractinian corals is from the Philippines (focused on *Trochus*; Villanueva; Edwards & Bell, 2010), research from the Philippines including non-coral taxa or solely focused on biodiversity were relatively rare.

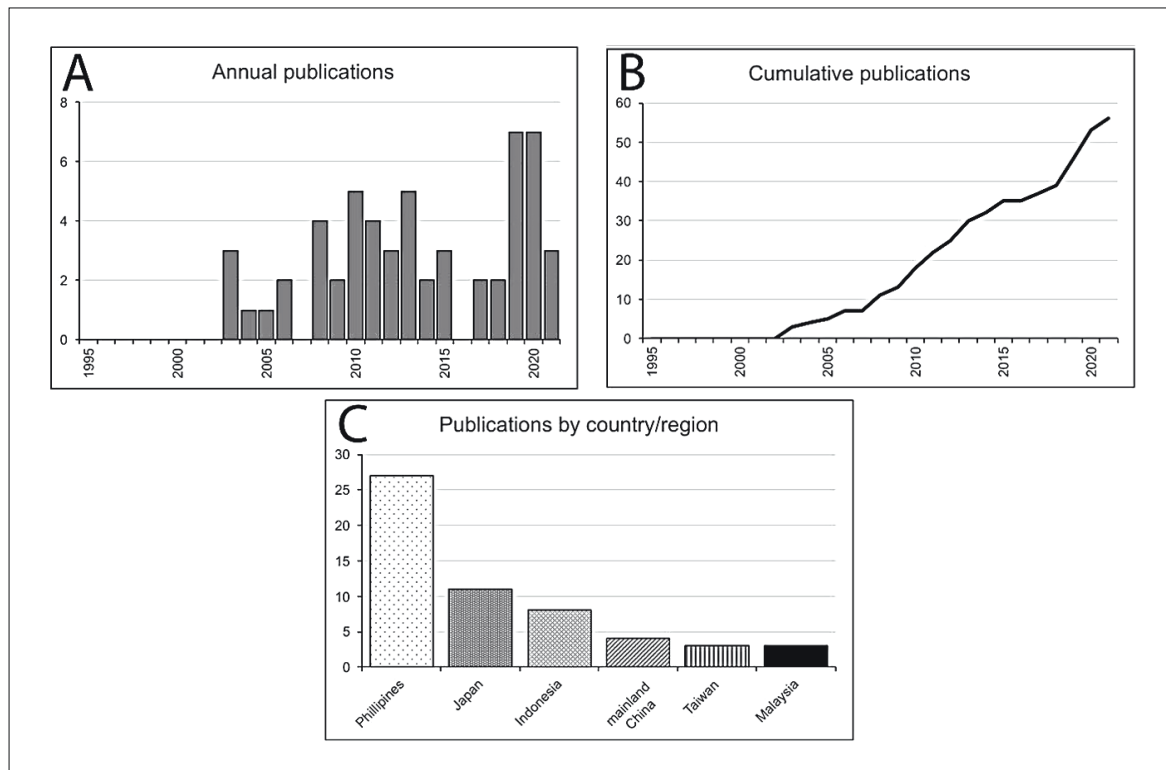
Research in Indonesia was not numerous (n = 8) and also focused almost exclusively only on hard corals (Table I), despite being the estimated center of marine biodiversity (Hutomo & Moosa, 2005; Hoeksema, 2007). Research in Indonesia mostly focuses on ecological research, monitoring, and social impact. A possible reason for focusing on these topics is that reef restoration is generally expensive, requires a long time period, and is technically challenging, making it difficult for developing nations to undertake without financial support (Fadli *et al.*, 2012), which may be the case for parts of Indonesia. On the positive side, it appears there are at least two central regions of coral reef restoration, one in the Coral Triangle region and one location in the west of the Indonesian archipelago.

Research from Malaysia and Taiwan was relatively rare (n = 3 papers each), perhaps reflective of the often sandy marine ecosystems surrounding these two areas. Further support for this theory can be seen in the apparently large amount of research and capital spent on artificial reefs. For example, in Taiwan, in order to promote commercial fishing, greater than 230 km<sup>2</sup> of artificial reefs were reported to have been built during the last 40 years (Chuang *et al.*, 2010). These artificial reefs may recruit and support growth of many coral species, but existing ecological impact assessments have been mainly focused on fish communities (Lu *et al.*, 2021). It is not clear if local or higher level governments distinguish between artificial reefs for fishing development and providing habitat for corals and other reef organisms, but the goals of these two methods may be different. From the viewpoint of this literature review, it is hoped that active coral reef restoration of existing coral reefs continues to grow in both Taiwan and Malaysia. Although not included in this study, research from Singapore has recently examined the creation of artificial reefs to replace former reefs lost to land reclamation (e.g. Loke *et al.*, 2014), and research from this country could serve as a template for other areas targeting the same goals.

Similarly, Malaysia also had the lowest number of research papers specifically focused on coral reef restoration. However, we noted that there were additional studies that focused on artificial reefs; an auxiliary search with “artificial reef” included in the search string for Malaysia found an additional seven papers focused on artificial reefs. Those papers did not specifically mention coral reef restoration in the title or in the abstract, but artificial reefs can promote the resettlement of benthic communities and reef fish (Salleh *et al.*, 2017; Rosdi & Syed, 2018). However, the creation of artificial reefs can be differentiated from the restoration of existing coral reefs. As each of these regions only had three papers on coral restoration, it is clear much work remains to be done in both areas.

Research from mainland China was also not numerous (n = 4 papers), but given the country’s few coral reef regions and only recent focus on ecological research (Wu *et al.*, 2012; Cybulski *et al.*, 2020), we can expect research in this field to grow rapidly in the near future, particularly given the overall general increase in coral reef restoration literature (Figure 3; also Hein *et al.*, 2021).

Figure 3 – Publications in this review from the Web of Science. A. Publication per year for all countries and regions combined. B. Cumulative total publications by year. C. Total publications per country/region covered in this review



Another reason for the low numbers of papers from many countries in this literature review is that for many local government and NGO organizations, scientific publication and dissemination of results on an international scale may not be a priority. For four of six regions examined in this review, the national government supported the majority of coral restoration work (Japan, Taiwan, mainland China, Malaysia). Thus, reports, if submitted for publication, may be in government reports, or local scientific journals, perhaps without peer review, or at the least not listed in the Web of Science, and thus harder to find for international researchers. Such problems may be compounded by many reports being created for national audiences, and thus in the local language, and not English. We believe such issues exist to some degree or another in Taiwan, mainland China, Japan and Indonesia, where a large portion of university theses, governmental, and NGO reports are produced in non-English formats. One example of this is from Taiwan, where 135 research reports on coral restoration exist within the Government Research Bulletin ([www.grb.gov.tw](http://www.grb.gov.tw)). Similarly, with the Chinese search term “珊瑚礁修复” (coral restoration), we found 143 papers from a Chinese literature database (cnki.net). Of these papers, 30 of them dealt with coral reef restoration, and nine of these papers mentioned biodiversity. Additionally, Okinawa in southern Japan has a long history of coral reef restoration (e.g. Okubo & Onuma, 2015; Omori *et al.*, 2016; Biondi; Masucci & Reimer, 2020), but much of the literature does not appear in the Web of Science. It should be noted that much of the research within Indonesia and the Philippines was supported by overseas or international agencies, which may have more stringent requirements for scientific publication of results, but may also indicate a lack of government support or prioritization for coral restoration, although the situation appears to be changing in recent years (e.g. Hidayat; Muawana & Pabuayan, 2017).

There are also various local conditions within each region that may make coral reef restoration research difficult. An example of this is Japan, where the large majority of such investigations are conducted in southern Okinawa (Table I). Coral reef restoration is made difficult in Okinawa by the regular occurrence of typhoons (e.g. White *et al.*, 2013) and large waves that can dislodge newly outplanted coral colonies. Potential solutions can include raising corals in more sheltered “farming” nurseries or tanks (Higa & Omori, 2014; Omori & Iwao, 2015) followed by commercial transplantation (discussed in Okubo & Onuma, 2015), but given the destructive power of such storms, risks to restoration efforts may not be completely avoidable. Such problems may not occur on such a large scale in much of Malaysia or Indonesia, for example, as they are closer to the equator with less frequent and weaker storms. Similarly, in some regions, while initially it appeared as if there was extensive literature on coral restoration (e.g. Japan with 63 papers), upon examination a clear lack of field work reporting was noted (only 11 papers kept in our analyses on Japan), with many excluded papers focusing on modelling or artificial reef construction. Thus, in such areas, there is a need for more continued practical coral restoration field work and subsequent reporting into the international literature.

Overall, initially we found the relative lack of coral reef restoration literature to be somewhat surprising, given the importance of coral reef ecosystems in East and South-East Asia. However, upon consideration, we believe these results accurately reflect the current situation of coral reef restoration in the Coral Triangle and the western Pacific. Based on our analyses, we can suggest several paths forward to help increase scientific information on coral reef restoration in this region.

Firstly, having researchers in each area collate and report on restoration efforts in international journals, such as a review of the domestic restoration situation, utilizing local knowledge and networks, to list the various projects and researchers within each region could help to form a coral reef restoration database, allowing better information exchange and accessibility to datasets and critical thinking. If feasible, the creation of a network or international-level homepage or information depository could be helpful in this regard. Secondly, even in government reports or local journals, having a title and abstract in English would be greatly beneficial to international researchers, along with depositing reports on publicly available internet sites. Given the increasing emphasis on international collaboration in coral reef restoration (e.g. Selmoni *et al.*, 2020), this action would provide immediate benefits with little effort.

Looking to the future, besides from the clear need to address the issues of upscaling (Bellwood *et al.*, 2019) and temporal time-scales (Montero-Serra *et al.*, 2018) of restoration efforts, it would be in each country and region’s interest to promote restoration across a wider geographic scale. Currently, all areas we examined had coral reef restoration centered on one or two locations, and while concrete reasons related to logistics and the availability of funding, researchers, facilities, and boats may apply, this approach can be a somewhat risky approach if a dramatic event such as extreme warming or a typhoon, etc. was to hit such an area and potentially damage or destroy years of restoration work. As well, conducting active restoration across a wider geographic range would provide more information on the importance of environmental variables and local conditions, as well as more statistical power when modeling outcomes to larger areas, and potentially allow the formulation of more effective and less risky restoration efforts (e.g. portfolio theory; Hoegh-Guldberg *et al.*, 2018).

Finally, with regards to research, it is clear from our analyses that more non-scleractinian taxa, as well as more biodiversity datasets, need to be included in scientific analyses in order to better judge the effectiveness of restoration projects. Even within scleractinian corals, there was a clear bias in the literature towards certain coral genera, for example in this review an overwhelming focus on *Acropora* spp. was evident. There are several underlying explanations behind this trend. *Acropora* is a common, diverse, and fast-growing genus, which responds relatively well to being displaced, fragmented, and transplanted (e.g. Yap; Alino & Gomez, 1992). It is also common in the region, and easy to identify to at least genus, which is an important advantage as numerous restoration projects rely on the help from volunteers or non-expert collaborators. Finally, *Acropora*'s rapid growth provides results which are clearly visible and thus can be appreciated by not only stakeholders but also the general public, making this genus a popular candidate for outreach initiatives, marketing, and social media communication. This, while being a positive outcome, and potentially resulting in an increase both in donations, volunteers, and funds for restoration projects, has the side effect of making the true outcomes of restoration projects unclear or unreliable, while bona-fide efforts can become increasingly harder to tell apart from marketing-driven speculation. A case could also be made that projects heavily centered on the availability of short-term unpaid work may struggle to scale-up, and in including other genera and techniques requiring more specialized knowledge, vision, and long-term stability. The bias towards *Acropora* is certainly not unique for the East and South-East Asian regions (see Boström-Einarsson *et al.*, 2020) but, unfortunately, the low number of publications from this area on other corals means that the absolute amount of restoration research focused on coral genera other than *Acropora* is insufficient, and this research gap is in urgent need of being addressed. Recent methods such as isogenic fusion (e.g. Forsman *et al.*, 2015) also have not yet been applied at a large scale in this region. From our review, it is clear there is a need for much more restoration work on scleractinian corals with different life strategies in East and Southeast Asia.

As restoration efforts in the region increase, we believe it is important to properly organize available relevant information within the context of published peer-reviewed literature. Access to such literature will be critical for the successful implementation of restoration projects, allowing to more quickly identify methodological dead-ends and avoid unneeded duplication of inconclusive efforts. Even "failures" can be of great help, if appropriately documented and published, and such works would not only to save money, time, and resources, but also avoid causing lasting negative impacts on the same reefs that are under restoration. We noted that papers examined in this review generally did not comment on the success or failure of projects, and it is clear more transparency and evaluations of restoration efforts are needed. At the same time, clearly documenting efforts conducted with taxpayers' money will increase transparency and reduce possible speculative schemes. Finally, our review showed little literature on the discourse and motivations of coral reef restoration (see Hein *et al.*, 2017; Ounanian *et al.*, 2018), and more transparency and discussion on this point should help focus and improve regional and national efforts, which are likely to become critically needed into a future under increasing coral reef decline.

As we enter the United Nations Decade on Ecosystem Restoration (2021-2030), and given the increasing pressures on subtropical and tropical coral reef ecosystems, it is clear



a large push in the research efforts on coral reef restoration in East and Southeast Asia is needed. Reviews of knowledge gaps such as this current paper should help in the formulation of clear paths forward, and it is hoped that such efforts supersede national boundaries and interests to become international collaborative projects. Given the ecosystem services derived from the high biodiversity of coral reefs of this region, we look forward to the next decade and advancements in not only coral restoration, but in the restoration and protection of coral reef biodiversity.

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