Marine biodiversity research in the Ryukyu Islands, Japan: Current status and trends

James D Reimer Corresp., [1,2] , **Piera Biondi** [1] , **Yee Wah Lau** [1] , **Giovanni Masucci** [1] , **Xuan Hoa Nguyen** [1] , **Maria E.A. Santos** [1] , **Hin Boo Wee** [1]

[1] Graduate School of Engineering and Science, University of the Ryukyus, Nishihara, Okinawa, Japan

[2] Tropical Biosphere Research Center, University of the Ryukyus, Nishihara, Okinawa, Japan

Corresponding Author: James D Reimer
Email address: jreimer@sci.u-ryukyu.ac.jp

In Japan, the subtropical Ryukyu Archipelago (RYS; also known as the Nansei Islands) with its coral reefs has been shown to harbor very high levels of marine biodiversity. This study provides an overview of the state of marine biodiversity research in the RYS. First, we examined the amount of scientific literature in the Web of Science (WoS; 1995-2017) on six selected representative taxa spanning from protists to vertebrates across six geographic sub-regions in the RYS. Our results show clear taxonomic and sub-region bias, with research on Pisces, Cnidaria, and Crustacea to be much more common than on Dinoflagellata, Echinodermata, and Mollusca. Such research was more commonly conducted in sub-regions with larger human populations (Okinawa, Yaeyama). Additional analyses with the Ocean Biogeographic Information System (OBIS) records show that within sub-regions, records are concentrated in areas directly around marine research stations and institutes (if present), further showing geographical bias within sub-regions. While not surprising, the results indicate the clear need to study 'understudied' taxa in 'understudied sub-regions' (Tokara, Miyako, Yakutane, Amami Oshima), and to study 'understudied areas' of some sub-regions away from marine research stations. Second, we compared the numbers of scientific papers on eight ecological topics for the RYS with numbers from selected major coral reef regions of the world; the Caribbean (CAB), Great Barrier Reef (GBR), and the Red Sea (RES). Not unexpectedly, the numbers for all topics in the RYS were well below numbers from all other regions, yet within this disparity, research in the RYS on 'marine protected areas' and 'herbivory' was an order of magnitude lower than numbers in other regions. Additionally, while manuscript numbers on the RYS have increased from 1995 to 2016, the rate of increase (4.0 times) was seen to be lower than those in the CAB, RES, and GBR (4.6 to 8.4 times). As the RYS are considered to contain among the most critically endangered coral reef biodiversity in the world due to high levels of both endemism and anthropogenic threats, much work is urgently needed to address

the areas of relative research weakness identified in this study.

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27029v1 | CC BY 4.0 Open Access | rec: 11 Jul 2018, publ: 11 Jul 2018

Marine biodiversity research in the Ryukyu Islands, Japan: Current status and trends

James Davis Reimer[1,2]*, Piera Biondi[1], Yee Wah Lau[1], Giovanni Masucci[1], Xuan Hoa Nguyen[1], Maria E. A. Santos[1], Hin Boo Wee[1]

All authors contributed equally to this publication

[1]Graduate School of Science and Engineering, University of the Ryukyus, 1 Senbaru, Nishihara, Okinawa 903-0213, Japan

[2]Tropical Biosphere Research Center, University of the Ryukyus, 1 Senbaru, Nishihara, Okinawa 903-0213, Japan

*corresponding author: jreimer@sci.u-ryukyu.ac.jp

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27029v1 | CC BY 4.0 Open Access | rec: 11 Jul 2018, publ: 11 Jul 2018

Abstract

In Japan, the subtropical Ryukyu Archipelago (RYS; also known as the Nansei Islands) with its coral reefs has been shown to harbor very high levels of marine biodiversity. This study provides an overview of the state of marine biodiversity research in the RYS. First, we examined the amount of scientific literature in the Web of Science (WoS; 1995-2017) on six selected representative taxa spanning from protists to vertebrates across six geographic sub-regions in the RYS. Our results show clear taxonomic and sub-region bias, with research on Pisces, Cnidaria, and Crustacea to be much more common than on Dinoflagellata, Echinodermata, and Mollusca. Such research was more commonly conducted in sub-regions with larger human populations (Okinawa, Yaeyama). Additional analyses with the Ocean Biogeographic Information System (OBIS) records show that within sub-regions, records are concentrated in areas directly around marine research stations and institutes (if present), further showing geographical bias within sub-regions. While not surprising, the results indicate the clear need to study ‘understudied’ taxa in ‘understudied sub-regions’ (Tokara, Miyako, Yakutane, Amami Oshima), and to study ‘understudied areas’ of some sub-regions away from marine research stations. Second, we compared the numbers of scientific papers on eight ecological topics for the RYS with numbers

from selected major coral reef regions of the world; the Caribbean (CAB), Great Barrier Reef (GBR), and the Red Sea (RES). Not unexpectedly, the numbers for all topics in the RYS were well below numbers from all other regions, yet within this disparity, research in the RYS on 'marine protected areas' and 'herbivory' was an order of magnitude lower than numbers in other regions. Additionally, while manuscript numbers on the RYS have increased from 1995 to 2016, the rate of increase (4.0 times) was seen to be lower than those in the CAB, RES, and GBR (4.6 to 8.4 times). As the RYS are considered to contain among the most critically endangered coral reef biodiversity in the world due to high levels of both endemism and anthropogenic threats, much work is urgently needed to address the areas of relative research weakness identified in this study.

Introduction

Biodiversity research provides the basis to guide ecosystem management, and consequently, to preserve services and goods that are critical to the economic value of the planet (Costanza *et al*. 1997; Mace *et al*. 2012). Moreover, a better knowledge of biodiversity patterns enables the prediction of possible outcomes from ongoing environmental changes (Bellard *et al*.

2012) and species extinctions (Chapin *et al*. 2000; Dunne *et al*. 2002). Analyses of species diversity and distribution also allow the determination of biodiversity hotspots. For example, the 'Coral Triangle' hotspot, located in central Indo-Pacific waters, is considered to be the coral reef area with the highest numbers of marine species in the world (Hughes *et al*. 2002; Toonen *et al*. 2016). Nevertheless, there is still a lack of diversity information for most marine taxa (Appeltans *et al. 2012*; Troudet *et al*. 2017), and this problem is especially prevalent in understudied localities including many in the Indo-Pacific. This data gap hampers our understanding of biodiversity patterns and the conservation of species, and is therefore an obstacle to accurate ecosystem function protection (Cardinale *et al*. 2012; Costello *et al*. 2013; Duffy *et al*. 2017).

The Ryukyu Islands (RYS; also known as the Nansei Islands) comprise the southernmost region of Japan and border the northern edge of the Coral Triangle, spanning 1200 km from Yakushima and Tanegashima Islands (Yakutane sub-region) in the north, acorss the Tokara, Amami, Okinawa, Miyako sub-regions to the Yaeyama Islands in the south (Figure 1, also Coral Reefs of Japan 2004; Fujita *et al*. 2015). These waters are all influenced by the warm Kuroshio Current that flows northwards along the west side of the island chain (Andres *et al*. 2008), and the RYS includes islands of different geological formation, ages, and sizes (Kizaki

1986; Table 1). Thus, the RYS are a marine region of exceptionally high diversity and endemism of species (Hughes *et al*. 2002; Cowman *et al*. 2017). Moreover, it has been calculated that southern Japan and Taiwan rank first in global marine conservation priority when considering high levels of multi-taxon endemism, their high risk of biodiversity loss due to overexploitation and coastal development, and thus need rapid conservation action (Roberts *et al*. 2002). More than one decade after this initial work, and despite some conservation successes (e.g. Okubo and Onuma 2015; establishment of Keramas National Park in 2016), the RYS are still threatened by rapidly increasing tourism pressure (Dal Kee 2015; Hirano and Kakutani 2015; Tada 2015; Toyoshima and Nadaoka 2015; Okinawa Prefectural Government 2016) and continuous ongoing coastal developmental (Veron 1992; Fujii *et al*. 2009; Reimer *et al*. 2015). In fact, the numbers of tourists visiting Okinawa exceeded those of Hawai'i for the first time in 2017 (Ryukyu Shinpo 2018; also FY2017 data on Okinawa Prefecture homepage http://www.pref.okinawa.jp/site/bunka-sports/kankoseisaku/h28nendo.html).

Although the RYS contain high levels marine species diversity, until now there has been no marine biodiversity overview that covers the archipelago in detail (but see Fujikura *et al*. (2010)'s general overview of marine biodiversity of Japan with a focus on Sagami Bay). Here, we conduct an extensive data-mining review to provide information on the status of marine biodiversity research within the RYS, with specific information on six sub-regions within the RYS for six important and representative marine taxa. Furthermore, we review and compare data of ecological studies in the RYS to those of other major reef regions (Caribbean, Great Barrier Reef, Red Sea). Finally, we discuss and highlight the trends of biodiversity related research in the RYS, emphasizing the need for continued research as the data gap hampers our understanding of marine biodiversity and conservation efforts in this important coral reef region.

Materials and Methods

The Ryukyu Islands (RYS)

We divided the RYS into six sub-regions based on geographical, historical, and administrative information (Table 1); the sub-regions generally follow those in Coral Reefs of Japan (2004) and as used by various levels of Japanese government. The sub-regions (south to north) are the island groups of Yaeyama, Miyako, Okinawa, Amami Oshima, Tokara, and Yakutane. The first three sub-regions are within Okinawa Prefecture, while the last three are within Kagoshima Prefecture, and are as follows:

a. Yaeyama Islands: the southernmost group of islands in the RYS, this group experiences the most tropical conditions, has the most well developed coral reefs (Coral Reefs of Japan 2004), including the Sekisei Lagoon, Japan's largest reef system, and is generally thought to have the highest biodiversity within the entire archipelago (Nishihira and Veron 1995; Roberts *et al*. 2002; Table 1). This sub-region includes the major islands of Ishigaki and Iriomote as well as several smaller islands.

b. Miyako Islands: includes the large island of Miyako as well as several surrounding smaller islands. This sub-region is notable for having a coral reef system with extensive cave systems and endemic species (e.g. Shimomura *et al*. 2012).

c. Okinawa Main Island and region: this sub-region is dominated by Okinawa Main Island, the largest and by far the most populous island in the RYS (Table 1). In addition, the island is surrounded by numerous smaller islands notable for their relatively pristine condition and protection within two national parks.

d. Amami Oshima Island and region: Amami Oshima is the second largest island in size and population in the RYS, but this region also includes other major islands such as Yoron, Okinoerabu, and Tokunoshima, as well as many smaller island groups. Notable for endemic terrestrial species, the marine life of this subregion is thought to be understudied when compared with regions further south (e.g. Fujii 2016; Nakae *et al*. 2018). The southernmost portion of Kagoshima Prefecture, this area was historically sometimes included within the former Ryukyu Kingdom (current Okinawa Prefecture).

e. Tokara Islands: the smallest and least populated sub-region within the RYS, this group is often considered part of the Yakutane Islands, but differs in several important ways, as it has more developed coral reefs than areas further north in the Yakutane sub-region and south around Amami Oshima (Coral Reefs of Japan 2004), and is heavily influenced by the Kuroshio Current. Consists of 12 small islands stretched across 160 km, with six islands having well-developed coral reefs (Coral Reefs of Japan 2004). As the least developed sub-region, this area, unlike all other sub-regions, is not easily reachable by major air transport systems, and is considered the least well-studied area in the RYS.

f. Yakutane Islands (also known as the Osumi Islands): consisting of the two major islands of Yakushima and Tanegashima along with neighboring smaller islands, the Kuroshio takes a sudden turn to the east south of Yakushima. This sub-region is considered the northern limit of modern coral reef development in the region (Coral Reefs of Japan 2004) and the northern limit of the subtropical region of Japan.

Web of Science taxa and sub-regions search

We searched within the Web of Science (WoS) for papers on six representative marine taxa within the RYS; Pisces, Mollusca, Crustacea, Echinodermata, Cnidaria, and Dinoflagellata, utilizing search strings (Electronic Supplementary Material Table S1). We determined the sub-region location of each paper of these six taxa within the WoS based on the title, key words, and abstract information. When the title and abstract only contained "Okinawa", "Ryukyu", or "Nansei", with no further information, we categorized these papers as "Ryukyu/Nansei unspecified", as "Okinawa" may refer to the entire Okinawa prefecture, and "Ryukyu" and "Nansei" may refer to anywhere within the RYS island chain. Additionally, deep-sea publications were not included in our examinations. Publication numbers were compiled for 1995-2017 for each taxon for each sub-region to examine what taxa have been investigated in what sub-region. The search was conducted on August/September of 2017.

Web of Science ecology search and comparison

We searched eight principal topics in ecological studies (apex predators, connectivity, coral bleaching, coral reproduction, herbivory, marine protected areas, Porifera, reef-associated bacteria) with in WoS following the search strings utilized by Berumen *et al*. (2013) in their review on biodiversity work in the Red Sea (see also Electronic Supplementary Material Table S1). Subsequently, we filtered and compared the data for four reef regions across the globe. The regions and search strings used to filter the data are the following: RYS (search string was "Ryukyus*" OR "Nansei" OR "Okinawa*"), Caribbean (CAB; search string was "Caribbean"), Great Barrier Reef (GBR; search string was "Great Barrier Reef"), and the Red Sea (RES; search string was "Red Sea"). Publication numbers were compiled annually (1995-2016) and by ecology topic (as above). The search was conducted on September 20, 2017.

Ocean Biogeographic Information System search

As a supplementary examination, we searched the six sub-regions of the RYS within the Ocean Biogeographic Information System (OBIS) for the six representative marine taxa (Cnidaria, Crustacea, Dinoflagellata, Echinodermata, Mollusca, and Pisces) with the aim of examining spatial differences in the research of these taxa within sub-regions. Using the highest grid resolution of OBIS, we examined all square grids that covered the coastline of each island of the RYS and noted the number of records for each quadrat for each taxon. The number of quadrats examined in each sub-region ranged from 11 in Miyako to 50 in Okinawa (Table 1). The search was conducted in August 2017.

Results

Web of Science taxa and sub-regions search

In total, from our WoS searches for papers between 1995-2017, we examined 980 papers, which contained information for 1023 sub-region occurrences (some papers had >1 sub-region in their content). Of these occurrences, 420 were from the Okinawa Main Island sub-region, 307 from an unspecified area in the RYS, 199 from Yaeyama, 48 from Amami Oshima, 29 from Yakutane, 16 from Miyako, and 4 from Tokara (Figure 1).

By taxa, the groups Pisces (n=346), Cnidaria (n=233), and Crustacea (n=225) had the most occurrences, with all other groupings <100 occurrences (Mollusca n=92, Echinodermata n=51, Dinoflagellata n=44; Figure 1). Of note was the fact that ~80% of both Echinodermata and Dinoflagelleta papers were from Okinawa (40 of 51 papers, 36 of 44, respectively). Papers dealing with Pisces were most numerous for Yakutane (n=12), Okinawa (n=82), and Yaeyama (n=80), while papers on Cnidaria were most numerous for Amami (n=19) and Okinawa (n=169), and Cnidaria and Crustacea were equally numerous for Tokara (n=2 each) and Miyako (n=6 each). For unspecified sub-regions, Pisces (n=118) and Crustacea (n=108) were the most numerous taxa (Figure 1).

Web of Science ecology search and comparison

Our WoS search results showed that the RYS had less publications overall (n=1288; Figure 2) when compared to the three other coral reef regions examined for the same time period (GBR n=6242, CAB n=6990, RES n=4493). Additionally, RYS publication numbers were lower for all eight ecological topics analyzed (Figure 3). In particular, numbers for RYS were comparatively very low for herbivory and marine protected areas (Figure 3b and 3d, respectively). Temporally, the number of papers published for all regions increased noticeably between 1995 and 2016 (Figure 2), with the number of RYS papers increasing approximately 4.0 times (1995 n=24 publications vs. 2016 n=97), CAB papers increasing 4.6 times (1995 n=100 vs. 2016 n=460), GBR papers increasing approximately 7.6 times (1995 n=66 vs. 2016 n=504), and RES papers increasing approximately 8.4 times (1995 n=47 vs. 2016 n=397).

Ocean Biogeographic Information System results

OBIS results examining the numbers of records of different taxa within the sub-regions showed great variation, with some general trends appearing. In general, the three more northern sub-regions within Kagoshima Prefecture had fewer records than those in Okinawa Prefecture for Cnidaria, Crustacea, Echinodermata, Mollusca, and Pisces. Within Okinawa Prefecture (and the RYS), Okinawa consistently had the highest numbers of records, with the highest numbers observed around Akajima (Crustacea, n=200-500) and the west coast of Okinawa-jima Island (Cnidaria, Crustacea, Echinodermata, Mollusca, and Pisces). Conversely, even within the Okinawa sub-region, some areas such as the northeast coast of Okinawa-jima Island had none or only few records (Electronic Supplementary Material Figure S1a). Additionally, there was only one record for the entire RYS within OBIS for Dinoflagellata in shallow water (Electronic Supplementary Material Figure S1b).

Discussion

From the WoS and OBIS analyses of sub-regions and taxa occurrences it became clear, as in many other marine regions (Hughes *et al*. 2002), that serious taxonomic and geographic bias is present in marine research in the RYS. Some of this taxonomic bias may stem from the commercial importance of Pisces and Crustacea in Japan, which has resulted in many studies on various species' lifecycles and aquaculture methodologies. Research on these topics, while often conducted somewhere in the RYS, generally did not include field observations or sampling information as the focus was more on *ex situ* analyses and model species, and this was reflected in these two groups' dominance of the "unspecified RYS sub-region" category (Figure 1).

Overall, most work in the RYS has been conducted on Pisces, Crustacea, and Cnidaria, with the large majority (57.94%, n=135/233) on Scleractinia hard corals, and surprisingly far less work on other commercially important groups such as Echinodermata and Mollusca. While Mollusca research was somewhat evenly spread around the RYS, approximately 80% of Echinodermata research was conducted in the Okinawa sub-region (Figure 1). Due to recent commercial pressure and reported large drops in abundances of some echinoderms (Soliman *et al*. 2016a, 2016b), it is clear that more research is urgently needed in other sub-regions; this is also the case for Dinoflagellata. Hughes *et al*. (2002) suggested nearly two decades ago that more work is needed on understudied taxa in understudied locations, and this is clearly still true for the RYS.

From the analyses of records of various taxa in OBIS, research patterns within each sub-region become clear. While generally understudied sub-regions such as Tokara had a lack of research for all taxa across all areas inside the sub-region, in the case of more well-studied sub-regions, these areas were often directly adjacent to marine research stations (e.g. 200-500 Crustacea records on Akajima, containing Akajima Marine Station, active until 2017; Electronic Supplementary Material Figure S1a) and have had much more research conducted than in other areas. Thus, while Okinawa and Yaeyama can be considered to be comparatively well-studied inside RYS, there are areas within both sub-regions that are almost completely uninvestigated. As conservation studies require data on not only exploited or well-studied areas, but neighboring relatively 'pristine' areas as well, research on these uninvestigated areas are an urgent necessity. Additionally, the presence of marine research stations is obviously a driving force for research, and this can be demonstrated by the OBIS records for the Miyako sub-region, which despite a relatively large human population, has no research-focused marine station (Table 1), and a corresponding general lack of scientific publications and data available (e. g. Figure 1).

While the WoS obviously does not include all scientific publications from each region of the world as it does not index all scientific journals, and its coverage in some fields is less complete than in others, the problem is particularly acute when examining marine science publications from Japanese waters. Japan has a long history of marine biodiversity and coral reef science (e.g. Kawaguti 1940), and even today much research is published in Japanese, the large majority of which are in journals that do not appear in the WoS. An exception is Nippon Suisan Gakkaishi, and even though it appears in the WoS, some articles in this journal list title and authors only, with no abstract available in English, and the journal even occasionally contains articles with no English at all. Such domestic journals are still held in high regard in many scientific fields within Japan, including marine and fisheries sciences, and contain much valuable and important data. Failure to access these journals and their contents undoubtedly results in not gaining a complete picture of marine sciences in Japan, including our examination here of marine biodiversity in the RYS. We suggest that Japanese language science publications make the effort to include translations of the title, authors, and abstract to allow more access from the international science community, as is already performed by such journals as Nippon Suisan Gakkaishi (for most articles, in the WoS) and Fauna Ryukyuana (for all articles, not in the WoS). Also, for aquaculture or model species studies, listing the exact location from where specimens were collected would be helpful for mapping records and distributions of species in the Oceanographic Biology Information System (OBIS 2018) or other databases.

From the WoS search on ecological topics, the relative and comparative lack of research in the RYS compared to the 'major' coral reef areas of CAB, GBR, and the RES is apparent. While our results were not unexpected, particularly given the relatively small size of the RYS (approximately 4642 km^2 area and c. 1200 km in length) in comparison to these other regions than GBR, CAB and RES (17,400 km^2 area c. 2300 km length; 10,530km^2 area; 8890 km^2 area c. 2000 km^2 length; respectively, data from Berumen *et al*. (2013)), it should be noted that in terms of human populations immediately adjacent to reefs, the RYS could be considered to have higher numbers than those the GBR or even the RES, particularly given that the other three regions have continental landmasses much larger than those of the RYS islands.

When examining the trends for the different ecological topics, the deficiencies of research in the RYS become starkly clear, with almost no research conducted on ecosystem sciences such as herbivory, or on marine protected areas. Historically, Japan and Okinawa have been somewhat slow to adopt marine conservation measures with legal strength (Reimer *et al*. 2015) but it also appears that scientists based in the region have been equally slow to adopt research on these topics, despite a clear public need for such third-party research given the controversy over continuing coastal development in Okinawa (McCormack 1999; Hook 2010). Additionally and somewhat surprisingly, there has been little research on apex predators, despite clear public interest in Japan in this group (e.g. large shark displays at Churaumi Aquarium in Okinawa). Given the high rates of marine endemism and biodiversity in this region (Roberts *et al*. 2002), more efforts should be made to conduct research on these topics in the RYS.

Most worryingly, the pace at which scientific research in the RYS has increased has not kept pace with the other three regions we examined (Figure 2). While the number of publications from the RYS (and all other regions) is increasing, given the large number of coral reef, fisheries, and marine science researchers in Japan (e.g. the Japanese Coral Reef Society created in 1997 has over 600 members [JCRS homepage http://www.jcrs.jp]), we expected the gap between the RYS and other regions to be smaller. At current rates and based on these data from the past twenty-one years, compared to other regions the RYS are comparatively less studied now than in 1995.

In conclusion, marine biodiversity and ecology research in the RYS, while steadily advancing, lags behind the progress of other major coral reef regions in the world. In particular, research levels on conservation topics are dramatically lower than in other coral reef regions, despite the stark need for conservation and protection of these ecosystems. Additionally, despite the large amount of marine research infrastructure including numerous research facilities and a large population base, and despite the comparatively small area of the RYS (Table 1), there are taxa in both sub-regions and smaller areas within sub-regions that are almost completely unstudied. Moving forward, local, prefectural, and national governments and stakeholders should focus on addressing the clear gaps in our knowledge base. Such work combined with a more robust legal framework and the establishment of functioning no-take and marine protected areas should be able to better conserve and protect RYS coral reef ecosystems and their valuable ecosystem services for future generations.

Acknowledgements

Data in this study were generated as part of a doctoral level class entitled “Advanced Marine Biodiversity”, taught by the first author in 2017, and part of the Okinawa International Marine Science Program (OIMAP) at the Graduate School of Engineering and Science at the University of the Ryukyus (UR). This work was partially inspired by a Red Sea biodiversity research overview by Berumen *et al*. (2013). XHN, MEAS, and HBW were supported by Japanese Government (MEXT) scholarships. We thank Drs. T. Naruse (UR) and T. Fujii (Kagoshima University) for information on marine research institutes in the RYS.

References

Andres M, Park JH, Wimbush M, Zhu XH, Chang KI, Ichikawa H (2008) Study of the Kuroshio/Ryukyu current system based on satellite-altimeter and in situ measurements. J Oceanogr 64:937–950. doi: 10.1007/s10872-008-0077-2

Appeltans W, Ahyong ST, Anderson G, Angel MV, Artois T, Bailly N, Bamber R, Barber A, Bartsch I, Berta A, Błażewicz-Paszkowycz M, Bock P, Boxshall G, Boyko CB, Brandão SN, Bray RA, Bruce NL, Cairns SD, Chan TY, Cheng L, Collins AG, Cribb T, Curini-Galletti M, Dahdouh-Guebas F, Davie PJ, Dawson MN, De Clerck O, Decock W, De Grave S, de Voogd NJ, Domning DP, Emig CC, Erséus C, Eschmeyer W, Fauchald K, Fautin DG, Feist SW, Fransen CH, Furuya H, Garcia-Alvarez O, Gerken S, Gibson D, Gittenberger A, Gofas S, Gómez-Daglio L, Gordon DP, Guiry MD, Hernandez F, Hoeksema BW, Hopcroft RR, Jaume D, Kirk P, Koedam N, Koenemann S, Kolb JB, Kristensen RM, Kroh A, Lambert G, Lazarus DB, Lemaitre R, Longshaw M, Lowry J, Macpherson E, Madin LP, Mah C, Mapstone G, McLaughlin PA, Mees J, Meland K, Messing CG, Mills CE, Molodtsova TN, Mooi R, Neuhaus B, Ng PK, Nielsen C, Norenburg J, Opresko DM, Osawa M, Paulay G, Perrin W, Pilger JF, Poore GC, Pugh P, Read GB, Reimer JD, Rius M, Rocha RM, Saiz-Salinas JI, Scarabino V, Schierwater B, Schmidt-Rhaesa A, Schnabel KE, Schotte M, Schuchert P, Schwabe E, Segers H, Self-Sullivan C, Shenkar N, Siegel V, Sterrer W, Stöhr S, Swalla B, Tasker ML, Thuesen EV, Timm T, Todaro MA, Turon X, Tyler S, Uetz P, van der Land J, Vanhoorne B, van Ofwegen LP, van Soest RW, Vanaverbeke J, Walker-Smith G, Walter TC, Warren A, Williams GC, Wilson SP, Costello MJ (2012) The magnitude of global marine species diversity. Curr Biol 22(23):2189-2202.

Bellard C, Bertelsmeier C, Leadley P, Thuiller W, Courchamp F (2012) Impacts of climate change on the future of biodiversity. Ecol Lett 15:365–377. doi: 10.1111/j.1461-0248.2011.01736.x.Impacts

Berumen M, Hoey A, Bass W, Bouwmeester J, Catania D, Cochran JEM, Khalil MT, Miyake S, Mughal MR, Spaet JLY, Saenz-Agudelo P (2013) The status of coral reef ecology research in the Red Sea. Coral Reefs 32:737–748. doi: 10.1007/s00338-013-1055-8

Cardinale BJ, Duffy JE, Gonzalez A, Hooper DU, Perrings C, Venail P, Narwani A, Mace GM, Tilman D, Wardle DA, Kinzig AP, Daily GC, Loreau M, Grace JB, Larigauderie A, Srivastava DS, Naeem S (2012) Biodiversity loss and its impact on humanity. Nature 489:326–326. doi: 10.1038/nature11373

Chapin FS, Zavaleta ES, Eviner VT, Naylor RL, Vitousek PM, Reynolds HL, Hooper DU, Lavorel S, Sala OE, Hobbie SE, Mack MC, Díaz S (2000) Consequences of changing biodiversity. Nature 405:234–242.

Costanza R, Arge R, de Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neil RV, Paruelo J, Raskin RG, Sutton P, van den Belt M (1997) The value of the world's ecosystem services and natural capital. Nature 387:253–260. doi: 10.1038/387253a0

Costello MJ, May RM, Stork NE (2013) Can we name Earth's species before they go extinct? Science (339:413–416. doi: 10.1126/science.1230318

Cowman PF, Parravicini V, Kulbicki M, Floeter SR (2017) The biogeography of tropical reef fishes: Endemism and provinciality through time. Biol Rev 92:2112-2130. doi: 10.1111/brv.12323

Dal Kee H (2015) Sustainability of ecotourism in Yakushima, Japan. Japanese Cultural Studies 54:331-352.

Duffy JE, Godwin CM, Cardinale BJ (2017) Biodiversity effects in the wild are common and as strong as key drivers of productivity. Nature 549:261. doi: 10.1038/nature23886

Dunne J, Williams RJ, Martinez ND (2002) Network structure and biodiversity loss in food webs: robustness increases with connectance. Ecol Lett 5:558–567. doi: 10.1046/j.1461-0248.2002.00354.x

Fujii T (2016) Preliminary report of diversity of order Zoantharia and Actiniaria in the Satsunan Islands, Kagoshima. Kagoshima University Occasional Papers 57:87-88 (in Japanese).

Fujii S, Kubota Y, Enoki T (2009) Resilience of stand structure and tree species diversity in subtropical forest degraded by clear logging. J For Res 14:373–387. doi: 10.1007/s10310-009-0151-7

Fujikura K, Lindsay D, Kitazato H, Nishida S, Shirayama Y (2010) Marine biodiversity in Japanese waters. PLoS One 5:e11836. doi: 10.1371/journal.pone.0011836

Fujita K, Arakaki T, Denda T, Hidaka M, Hirose E, Reimer JD (eds) (2015) Nature in the Ryukyu Archipelago: coral reefs, biodiversity, and the natural environment, Faculty of Science, University of the Ryukyus, Nishihara.

Hirano N, Kakutani N (2015) Improvements of systems for accepting tourists to Okinawa in accordance with increases in LCC users. Northeast Asia Tourism Research 11:241-266.

Hook GD (2010) Intersecting risks and governing Okinawa: American bases and the unfinished war. Japan Forum 22:195-217.

Hughes TP, Bellwood DR, Connolly SR (2002) Biodiversity hotspots, centres of endemicity, and the conservation of coral reefs. Ecol Lett 5:775–784. doi: 10.1046/j.1461-0248.2002.00383.x

Kawaguti S (1940) Materials for the study of reef-building corals (1). Science of the South Sea (Kagaku Nanyo) 2:159-169. In: S. Kawaguti Working Group of the Japanese Coral Reef Society (JCRS) (eds) Reports by Dr. Siro Kawaguti during his stay in the Palao (Palau) Tropical Biological Station in 1936-1940 (English translation). Galaxea JCRS 14S:13-25.

Kizaki K (1986) Geology and tectonics of the Ryukyu Islands. Tectonophysics 125:193–207.

doi: 10.1016/0040-1951(86)90014-4
Mace GM, Norris K, Fitter AH (2012) Biodiversity and ecosystem services: A multilayered relationship. Trends Ecol Evol 27:19–25. doi: 10.1016/j.tree.2011.08.006
McCormack G (1999) From the sea that divides to the sea that links: contradictions of ecological and economic development in Okinawa. Capitalism Nat Socialism 10:3–40.
OBIS (2018) Ocean Biogeographic Information System. Intergovernmental Oceanographic Commission of UNESCO. www.iobis.org.
Okinawa Prefectural Government (2016) A summary of inbound tourist statistics in 2015 Department of Culture, Tourism and Sports, Tourism Policy Division (in Japanese). Accessed in September 2017. http://www.pref.okinawa.jp/site/bunka-sports/kankoseisaku/kikaku/statistics/tourists/documents/h27-f-gaikyou.pdf
Okubo N, Onuma A (2015) An economic and ecological consideration of commercial coral transplantation to restore the marine ecosystem in Okinawa, Japan. Ecosyst Serv 11:39–44. doi: 10.1016/j.ecoser.2014.07.009
Nakae M, Motomura H, Hagiwara K, Senou H, Koeda K, Yoshida T, Tashiro S, Jeong B, Hata H, Fukui Y, Fujiwara K, Yamakawa T, Aizawa M, Shinohara G, Matsuura K (2018) An annotated checklist of fishes of Amami-Oshima Island, the Ryukyu Islands, Japan. Mem Natl Mus Nat Sci Tokyo 52: 205-361
Nishihira M, Veron JE (1995) Hermatypic corals of Japan. Kaiyusha, Tokyo. 439 pp.
Reimer JD, Yang SY, White KN, Asami R, Fujita K, Hongo C, Ito S, Kawamura I, Maeda I, Mizuyama M, Obuchi M, Sakamaki T, Tachihara K, Tamura M, Tanahara A, Yamaguchi A, Jenke-Kodama H (2015) Effects of causeway construction on environment and biota of subtropical tidal flats in Okinawa, Japan. Mar Pollut Bull 94:153–167. doi: 10.1016/j.marpolbul.2015.02.037
Roberts CM, Mittermeier CG, Schueler FW (2002) Marine biodiversity hotspots and conservation priorities for tropical reefs. Science 295:1280–1285. doi: 10.1126/science.1067728
Ryukyu Shinpo (2018) Okinawa tourists exceeding Hawaii, last year 93.9 million people, foreigners increased significantly. February 2, 2018. https://ryukyushimpo.jp/news/entry-657773.html (in Japanese)
Shimomura M, Fujita Y, Naruse T (2012) First record of the genus *Thetispelecaris* Guţu & Illife, 1998 (Crustacea: Peracarida: Bochusacea) from a submarine cave in the Pacific Ocean. In:

Naruse T, Chan TY, Tan HH, Ahyong ST, Reimer JD (eds), Scientific results of the Kumejima Marine Biodiversity Expedition—KUMEJIMA 2009. Zootaxa 3367:69–78.

Soliman T, Fernandez-Silva I, Reimer JD (2016a) Genetic population structure and low genetic diversity in the over-exploited sea cucumber *Holothuria edulis* Lesson, 1830 (Echinodermata: Holothuroidea) in Okinawa Island. Cons Gen 17:811-821

Soliman T, Takama O, Fernandez-Silva I, Reimer JD (2016b) Extremely low genetic variability within and among locations of the greenfish holothurian *Stichopus chloronotus* Brandt, 1835 in Okinawa, Japan. PeerJ 4:e2410

Tada O (2015) Constructing Okinawa as Japan's Hawaii: from honeymoon boom to resort paradise. Japanese Stud 35:287–302. doi: 10.1080/10371397.2015.1124745

Toonen RJ, Bowen BW, Iacchei M, Briggs JC (2016) Biogeography, Marine. In: Kliman RM (ed) Encyclopedia of Evolutionary Biology, 1st edn. pp 166–178

Toyoshima J, Nadaoka K (2015) Importance of environmental briefing and buoyancy control on reducing negative impacts of SCUBA diving on coral reefs. Ocean Coast Manag 116:20–26. doi: 10.1016/j.ocecoaman.2015.06.018

Troudet J, Grandcolas P, Blin A, Vignes-Lebbe R, Legendre F (2017) Taxonomic bias in biodiversity data and societal preferences. Sci Rep 7:9132. doi: 10.1038/s41598-017-09084-6

Veron JEN (1992) Conservation of biodiversity: a critical time for the hermatypic corals of Japan. Coral Reefs 11:13–21. doi: 10.1007/BF00291930

Tables

Table 1 – Information on the six sub-regions investigated in this study in the Ryukyu Islands (RYS).

Figures

Figure 1 – Map of the Ryukyu Islands (RYS) with sub-regions used in this study, and total number of publications (1995-2017) in the Web of Science for six different marine taxa.

Figure 2 – (a) Numbers of ecological publications per year, and (b) the total number of publications for the Ryukyus (RYS; blue), Red Sea (RES, red), Great Barrier Reef (GBR, grey), and Caribbean (CAR, yellow) from 1995 to 2016 in the Web of Science.

Figure 3 – Number of ecological publications per year for four regions from 1995 to 2016 in the Web of Science; the Ryukyus (RYS; blue), Red Sea (RES, red), Great Barrier Reef (GBR, grey), and Caribbean (CAR, yellow) by topic. (a) apex predators, (b) herbivory, (c) connectivity, (d) marine protected areas, (e) coral bleaching, (f) Porifera, (g) coral reproduction, and (h) reef-associated bacteria.

Electronic Supplementary Material

Electronic Supplementary Material Table S1 – search terms for Web of Science and numbers of publications per year (1995-2017) for the Ryukyus, Red Sea, Great Barrier Reef, and Caribbean.

Electronic Supplementary Material Figure S1 – Example images of the Okinawa sub-region of the RYS within the Ocean Biogeographic Information System (OBIS) for (a) Crustacea, and (b) Dinoflagellata, showing spatial differences in the records of these taxa. Crustacea have most numerous records (n=200-500) in the square that contains Akajima Marine Station. On the other hand, there are almost no data at all for Dinoflagellata. The search was conducted in August

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27029v1 | CC BY 4.0 Open Access | rec: 11 Jul 2018, publ: 11 Jul 2018

2017.

Table 1(on next page)

Information on the six sub-regions investigated in this study in the Ryukyu Islands (RYS).

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27029v1 | CC BY 4.0 Open Access | rec: 11 Jul 2018, publ: 11 Jul 2018

Table 1 – Information on the six sub-regions investigated in this study in the Ryukyu Islands (RYS).

Sub-region	Yakutane	Tokara	Amami	Okinawa	Miyako	Yaeyama	RYS total	Reference(s
Major islands	Yakushima, Tanegashima, Kuchinoerabu, others	Nakanoshima, Suwanose, Kuchinoshima, Taira, Takara, Kodakara, Akuseki, others	Amami-Oshima, Kikai, Tokunoshima, Okinoerabu, Yoron, others	Okinawa Main Island, Kume, Izena, Iheya, Kerama Islands, Ikei Islands, Aguni, Ie, Sesoko, Kouri, others	Miyako, Ikema, Tarama, others	Ishigaki, Iriomote, Taketomi, others	198 islands (not including <0.01 km2)	Wikipedia
Notable marine research stations & institutes	Yakushima Umigane-kan	none	Kagoshima University Amami Station, Seikai National Fisheries Research Institute Amami Station, Kikai Coral Reef Research Institute (from 2014), Kagoshima U. Fac. Fisheries Yoron Station	Akajima Marine Science Laboratory (closed 2017), Okinawa Institute of Science and Technology (from 2011), Okinawa National College of Technology, University of the Ryukyus Tropical Biosphere Research Center Sesoko Station, University of	Miyako City Museum	University of the Ryukyus Iriomote Field Station, Ishigaki Pref. Exp. Station, Ishigaki MoE Parks Station, Kuroshima Sea Turtle Station		Various homepages, pe comm, with T Naruse, T. Fu

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27029v1 | CC BY 4.0 Open Access | rec: 11 Jul 2018, publ: 11 Jul 2018

				the Ryukyus Main Campus, Itoman Pref. Exp. Center, Meio University				
OBIS cover (# squares)	27	14	36	50	11	26	164	OBIS
Land area (km2)	1030	101.35	1231.47	1418.59	226.5	587.16	4595.07	Wikipedia
Population	46,500	784	118,773	1,285,003	53,270	53,405	1,557,735	Wikipedia
Population density (/km2)	45.1	7.7	96.4	905.8	235.2	91.0	339.0	Wikipedia
Geological formation	volcanic, sedimentary, granite uplift	volcanic, coral reefs	volcanic, sedimentary, uplift, coral reefs	volcanic, sedimentary, uplift, coral reefs	volcanic, coral reefs	volcanic, sedimentary, uplift, coral reefs	N/A	Coral Reefs o Japan (2004) Fujita et al. (201 Wikipedia
Annual average SST (°C)	24.3		24.5	25.0	25.8	25.2	N/A	Coral Reefs o Japan (2004
Reef perimeter (km)	local coral reef flats only	19	420.3	382.2	121.6	268.4	1211.5	Coral Reefs o Japan (2004
Coral community	118		5951.2	6980	1957.1	19231.5	34237.8	Coral Reefs o

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27029v1 | CC BY 4.0 Open Access | rec: 11 Jul 2018, publ: 11 Jul 2018

area (ha)								Japan (2004)
Fishing activities	recreational, commercial	recreational, some commercial	recreational, commercial	recreational, commercial	recreational, commercial	recreational, commercial	N/A	Coral Reefs of Japan (2004)
Agricultural activities	sugarcane, rice, sweet potatoes, vegatables, other fruits, flowers, tobacco, others	minimal	sugarcane, pineapple, potatoes, vegatables, other fruits, flowers, tobacco, others	sugarcane, vegatables, pineapple, other fruits, flowers, tobacco, others	sugarcane, vegatables, other fruits, flowers, tobacco, others	sugarcane, vegatables, pineapple, other fruits, flowers, tobacco, others	N/A	Prefectural homepages
Other activities/issues	local tourism	minimal	local tourism	extensive tourism, red soil runoff, landfill, military bases、local pollution & eutrophication	extensive tourism	extensive tourism, red soil runoff, landfill	N/A	Coral Reefs of Japan 2004, prefectural homepages
COTS outbreaks	none	none	1970s onwards	1970s onwards	1957-59, 1970s-1980s, 2004~	1970s-1980s, 2007~	N/A	Coral Reefs of Japan (2004) Ministry of Environment
Water quality notes	oligotrophic oceanic	oligotrophic oceanic	oligotrophic oceanic with turbid bays	oligotrophic oceanic with turbid bays, local pollution & eutrophication	oligotrophic oceanic with turbid bays	oligotrophic oceanic with turbid bays	N/A	Coral Reefs of Japan (2004)
Recent years of level 2 bleaching	1998, 2001, 2016-7	1998	1998, 2016-7	1998, 2001, 2016-7	1998, 2001, 2016-7	1998, 2001, 2010, 2016-7	N/A	Coral Reefs of Japan (2004)

events								NOAA, Ministry Environment
National parks	Yakushima	None	Amamigunto	Yanbaru, Keramashoto	None	Iriomote-Ishigaki	5 parks	Coral Reefs c Japan (2004) Ministry of Environment
Number of coral species	151	>151	200	340	302	363	N/A	Nishihira & Ve (1995), Cora Reefs of Japa (2004)

3

Figure 1(on next page)

Map of the Ryukyu Islands (RYS) with sub-regions used in this study, and total number of publications (1995-2017) in the Web of Science for six different marine taxa.

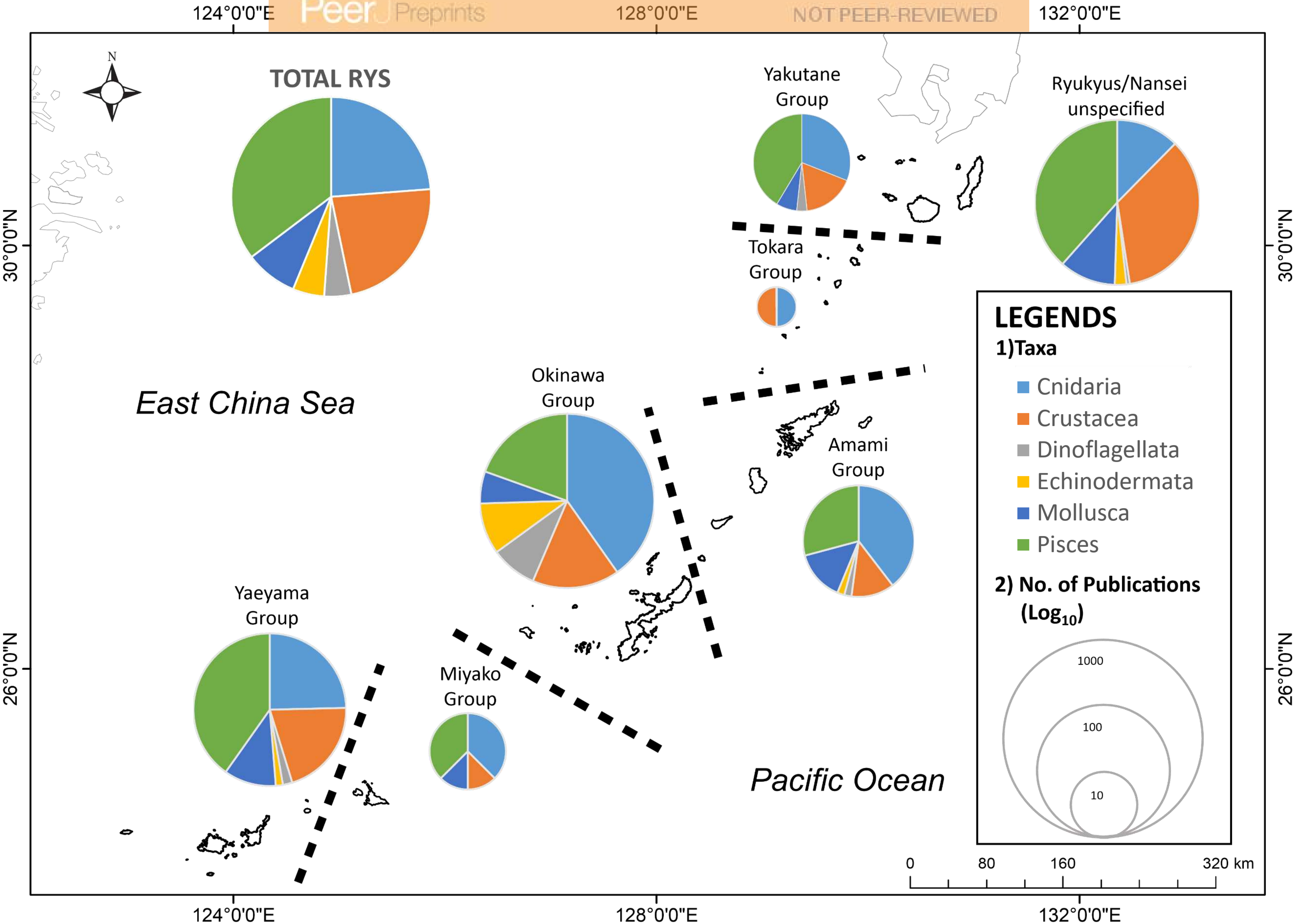
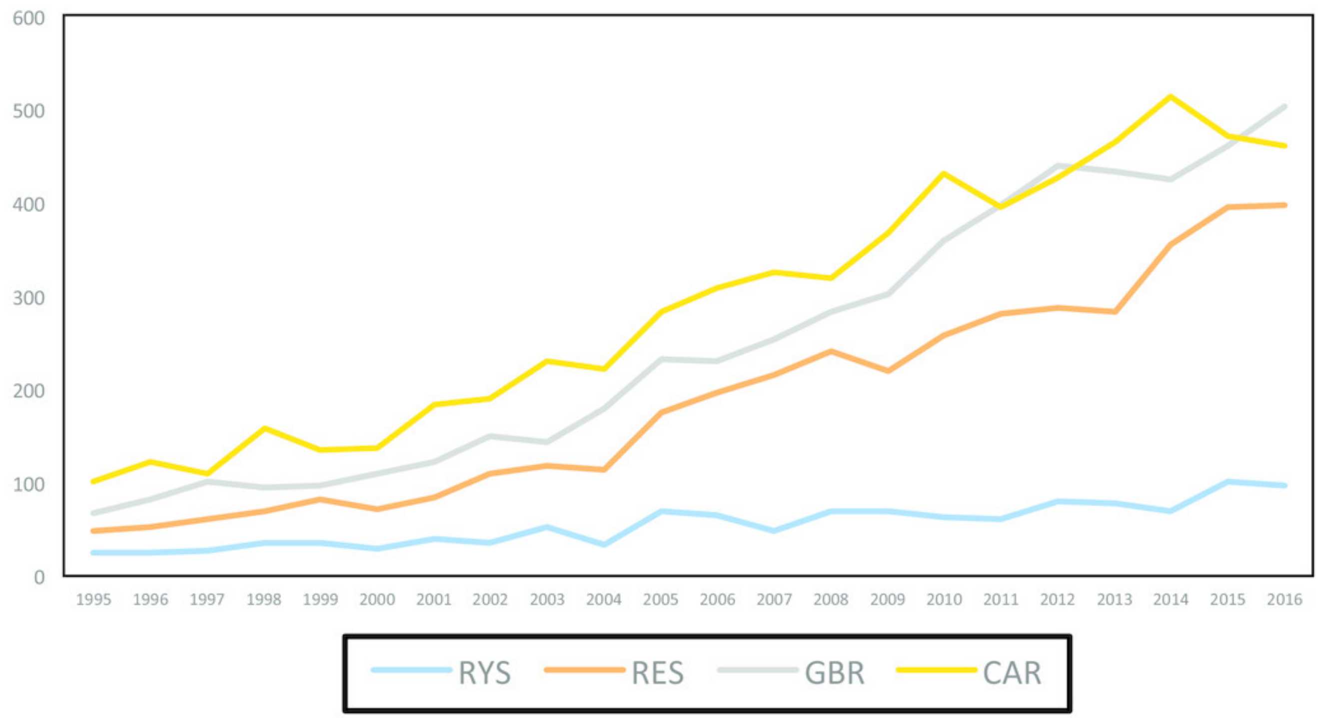

124°0'0"E
128°0'0"E
132°0'0"E
30°0'0"N
26°0'0"N
N
TOTAL RYS
Yakutane Group
Ryukyus/Nansei unspecified
Tokara Group
East China Sea
Okinawa Group
Amami Group
Yaeyama Group
Miyako Group
Pacific Ocean
LEGENDS
1)Taxa
Cnidaria
Crustacea
Dinoflagellata
Echinodermata
Mollusca
Pisces
2) No. of Publications (Log10)
1000
100
10
0
80
160
320 km

Figure 2

(a) Numbers of ecological publications per year, and (b) the total number of publications for the Ryukyus (RYS; blue), Red Sea (RES, red), Great Barrier Reef (GBR, grey), and Caribbean (CAR, yellow) from 1995 to 2016 in the Web of Science.

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27029v1 | CC BY 4.0 Open Access | rec: 11 Jul 2018, publ: 11 Jul 2018

a


600
500
400
300
200
100
0
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
RYS
RES
GBR
CAR

b

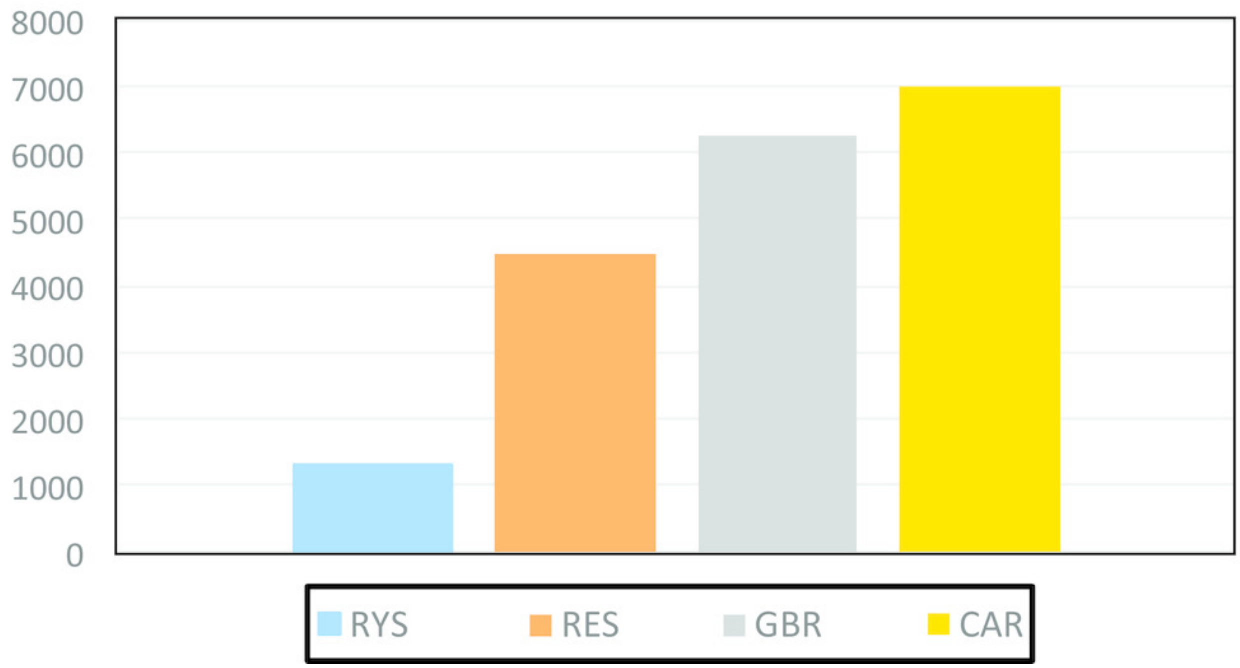

8000
7000
6000
5000
4000
3000
2000
1000
0
RYS
RES
GBR
CAR

Figure 3

Number of ecological publications per year for four regions from 1995 to 2016 in the Web of Science; the Ryukyus (RYS; blue), Red Sea (RES, red), Great Barrier Reef (GBR, grey), and Caribbean (CAR, yellow) by topic.

(a) apex predators, (b) herbivory, (c) connectivity, (d) marine protected areas, (e) coral bleaching, (f) Porifera, (g) coral reproduction, and (h) reef-associated bacteria.


a
b
c
d
e
f
g
h
RYS
RES
GBR
CAR