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Reefs as Net Carbon Sources or Net Carbon Sink?

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Abstract. Debates on the role of coral reefs, whether as a carbon source or carbon sink, started in the early 1990s. These debates continue until today, especially with the increasing concern of global climate change and global warming. Although several studies have been done to calculate the flux of pCO_2 between reefs and the atmosphere, there is no clear evidence whether the coral reef is a source or sink. This paper reviews the development of studies of carbon flux of reefs, with how pCO_2 is different in several reef type habitats and assess if geographical latitude of reef affected the flux of CO_2. In general, coral reefs act as a carbon source to the atmosphere. However, this role depends on the habitat type of reef, whether they are coral-dominated or algal-dominated reef. The geographical location of reefs may also affect CO_2 flux between reefs and the atmosphere.

INTRODUCTION

Global warming is a very sensitive issue today. It is caused mainly by increasing the level of atmospheric CO_2, causing ocean acidification. In the pre-industrial revolution, CO_2 level was 280 ppm, increasing to approximately 416 ppm to date [1] and projected to increase rapidly. Increasing CO_2 levels make the ocean's pH level decrease, and impacted several coral reef biotas, including coral itself. When CO_2 levels reach approximately 450 ppm, calcification of coralline algae will probably be completely inhibited [2] and calcification of reef building corals will be reduced by up to 50% [3]. When CO_2 level reach 800 ppm, all calcification will cease [4]. High CO_2 have positive impact on coral photosynthesis, however, in some point, calcification will be decreased [5].

Many efforts have been made to reduce carbon emission into the atmosphere. In the ocean context, ocean nourishment or ocean fertilization has been introduced by using urea as an agent to increase nutrients in the ocean to be used by phytoplankton [6]. However, this concept still needs a lot of research, including benefits and consequences that may rise [7]. Another method proposed is to reduce some solar radiation absorbed by the earth [8].

In the Copenhagen meeting in 2009, the emission carbon trade was introduced, which will allow some countries to get funds to maintain the habitat and ecosystem that have important rules in preserving the atmospheric carbon level. The proposed trade includes ecosystems inland and the ocean. However, while it is true that the ability to absorb carbon in the land has been widely known, the magnitude of the carbon cycle in the ocean ecosystem is poorly understood [9].

As it is always associated with zooxanthellae, Coral reefs have become a potential ecosystem to sink the carbon. However, because of complex processes involving coral reefs, including the calcification process, debate has been arising whether reef is net carbon source or net carbon sink [10]. In the calcification process, inorganic carbon is used by coral in the form of calcium carbonate rock, making reefs sink [11]. However, because the present state of pH level is around 8.2, the inorganic carbon is in the form of bicarbonate instead of carbonate, the equation will shift. In contrast, for every mol of calcium carbonate produced, the reef also releases 1 mol of carbon dioxide.

Some coral reefs are carbon sources, while others are carbon sinks [10-17]. These debates give more doubt to stakeholders to decide if ocean or coral reef ecosystem in particular will be included in the carbon trade. This paper will summarize the global status of coral reef and carbonate system, assess the current development of the debate of source and sink, and give a clear picture of whether the coral reef is a carbon source and carbon sink and what major

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factor is driven the differences. This paper will have significance as follow: (1) overview of the global status of corals reefs and carbonate production, (2) assess the effect of reef degradation on carbon budget, and (3) assess if there is different partial pressure of CO_2 (pCO_2) between tropical and temperate reefs.

EXPERIMENTAL DETAILS

In order to answer the specific aim of this study, a literature review was used. This study used a metadata analysis method using secondary data from studies that have been published in journals. All papers and sources related to research in determining the role of reef in carbonate system were collected (Table 1) and analyzed.

TABLE 1. Location and data used in the literature review

Reefs	Reference
Majuro Atoll, Marshall Island	[18]
South Male Atoll, Maldives	[19]
Moorea Reef, French Polynesia	[20]
Palau Barrier Reef	[18]
Shiraho Reef, Ryukyu Island	[21]
Hog Reef Flat, Bermuda	[22]
Kaneohe Bay, Hawaii	[23]
Yongsu Reef, South China Sea	[17]
Yongxiang Island, South China Sea	[17]
Luhuitou Reef, South China Sea	[17]
Coroa Vermelha Reef, Brazil	[24]
Yongle Atoll, South China Sea	[25]
Great Barrier Reef	[26]
Pedra da Risca do Meio, Brazil	[27]
Iriomote Island, Japan	[28]

1. To review the general global status of coral reef in carbonate system, we extract results found in peer reviewed publications and then summarized and concluded whether reefs generally as carbon sources or sinks.
2. To assess the effect of reef degradation in carbon budget in reef, we extract data from previous literature, including how much carbon is produced or released, and compare it side by side with the habitat status (i.e., coral-dominated reef and algal-dominated reef).
3. To answer a question if carbon production is affected by geographical location, we were comparing existing data and location in where the data had been collected (i.e., tropical and temperate regions)

RESULTS AND DISCUSSION

Global status of corals reefs and carbonates production

Although many research are devoted to the usefulness of CO_2 in the coral reef, only twelve publications have specifically reported and discussed whether the coral reef is a net carbon source or a net carbon sink. However, these papers are varied in terms of the habitat condition and geographical location. We can derive useful information to better understand the real role of coral reefs in global carbon debates.

Global overview of coral reefs and carbon intake and uptake

Although coral reef has been associated as a carbon sink in the past because there is dominant photosynthesis by zooxanthellae, many research reported that coral reefs are a potential carbon source. Ten out of twelve papers measure coral reefs as a source, while the other two reported coral reefs as a sink (Table 2).

TABLE 2. Overview of coral reefs role in carbon exchange with the atmosphere.

Reefs	Flux (mmol m^{-2} d^{-1})	Flux	Reef (Dominated)	Reference
Majuro Atoll	+0.4	Source	Coral	[18]
South Male Atoll	+0.2	Source	Coral	[19]
Moorea reef, French Polynesia	1.5	Source	Coral	[20]
Palau Barrier Reef	+3	Source	Coral	[18]
Shiraho Reef	-5	Sink	Algal	[21]
Kaneohe Bay	+6	Source	Coral	[22]
Yongsu Reef, South China Sea	+0.4	Source	Coral	[17]
Yongxiang Reef, South China Sea	+4.7	Source	Coral	[17]
Luhuitou Reef, South China Sea	+9.8	Source	Coral	[17]
Hog Reef Flat, Bermuda	+3.3	Source	Coral	[23]
Yongle Atoll, South China Sea	+3.2	Source	Coral	[25]
Great Barrier Reef	+1.44	Source	Coral	[26]
Pedra da Risca do Meio, Brazil	+8.4	Source	Coral	[27]
Iriomote Island, Japan	+0.4	Source	Coral	[28]
Coroa Vermelha Reef, Brazil	-6.9	Sink	Algal	[24]

Rates of carbon production may differ between different reef types. For example, Atoll and Barrier reefs tend to produce high CO_2 because they are near the oceanic and have less anthropogenic effects than fringing reefs. While infringing reefs type, there are only a few coral covers and low calcification processes, which make the CO_2 level low [10]. Examples are Kaneohe Bay, which has small CO2 efflux to the atmosphere compared to the Great Barrier Reef and Majuro Atoll. Review by [29] indicates that the ocean is generally divided into two groups in carbon production, continental shelves as a carbon sink and nearshore ecosystem including mangrove and coral reef as a source of carbon to the atmosphere. Nonetheless, [30] found that shallow coastal water is believed to be a carbon source to the atmosphere.

Carbon production in coral reefs is affected by two factors: photosynthesis (and/or respiration) and the calcification process [11]. As CO_2 level is projected to increase year by year [4], the calcification process will be reduced or inhibited [2,3, 11]. When the calcification process decreases, carbon production will be affected because every 1 mole of $CaCO_3$ produced will be accompanied by 1 mole of CO_2. This means that when CO_2 level increases, calcification decreases, carbon production in reefs decreases, and coral reefs can act as a carbon sink.

The carbon productions that make coral reefs a carbon source are not high and not significant compared to anthropogenic sources such as industrial factories or transportation since reefs still absorb a large portion of carbon estimated around 70 to 90 million tons Cy^{-1} [31]. However, the fact that coral reefs are a source is key in which coral reefs are not suitable for being included in the global carbon trade. However, if the CO2 level in the atmosphere is true, coral reefs are very potential to become carbon sinks in the future when the calcification process decreases.

Different reefs type plays a different role in carbon production

Carbon production rates also differ between coral-dominated and algal-dominated reefs (Figure 1). Coral-dominated reef tends to become a carbon source, while algal-dominated reef usually has less carbon production and becomes a carbon sink [10,11]. Carbon production in coral-dominated reef generally higher because of the high calcification process and balance between photosynthesis and respiration [10]. In coral-dominated reefs, coral produce CO_2 as by-product of $CaCO_3$. In algal-dominated reef, photosynthesis play a major role, and the product of O_2 produced is not used for the calcification process, resulting in less CO_2 level. Research done by [32] in the coral reef area of Houtman Abrolhos Islands of Western Australia found a 20-50 μATM difference in CO_2 partial pressure between coral transect and algal transect.

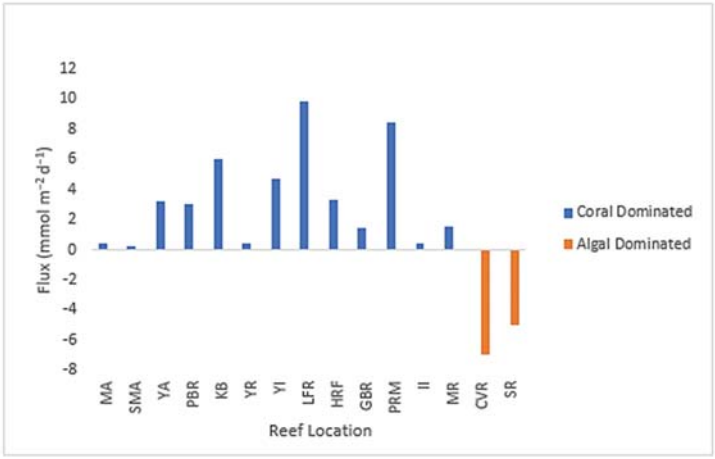

FIGURE 1. Net pCO2 flux in coral-dominated and algal-dominated reefs at several research locations. (Calculated from papers in Table 1).

Over time, with increasing threat to the coral reef, coral reef often shifts from coral dominated to algal dominated [32]. In Jamaica, the coral reef shifted from 50% coral cover to almost 90% algal covered [33]. This phenomenon also happens all over reefs in the world as coral cover decreases [34] and is expected to continue. If this coral cover decreases and phase shift continues, coral reefs will be shifted from carbon source to carbon sink because of lower CO_2 level than atmosphere CO_2 level.

Coral cavities absorb much atmospheric CO_2 [16]. More than 60% of the volume of coral reefs consists of cavities [35]. In Curacao and Berau (East Kalimantan, Indonesia), coral cavities and organisms inside of them absorbed a net carbon volume up to 3.6 µATM and 1.9 µATM, respectively. More studies in other places are needed to confirm if coral cavities are really a carbon sink and become a consideration in calculating pCO_2 in coral reefs.

Is geographical location affected CO_2 level?

The geographical location (i.e., latitude) plays an important role in coral photosynthesis. When the photosynthesis rate is high, it is expected that the calcification process is also high, thus increasing the CO_2 level. It is widely known that the photosynthesis rate is higher in the tropical than in the temperate region [37]. However, studies have done to measure CO2 level in coral reefs did not show significant differences between tropical and temperate regions. The net pCO_2 level in the tropical region is between -6.9-9.8 mmol m^{-2} d^{-1} and -5 to 6 mmol m^{-2} d^{-1} in the temperate region. However, it is observed that the result of -6.9 mmol m^{-2} d^{-1} in the tropical region and -5 mmol m^{-2} d^{-1} in the temperate region is derived from the algal-dominated reef.

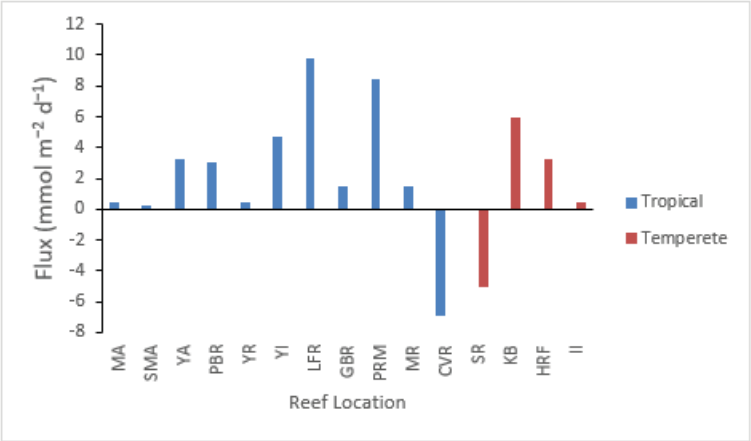

FIGURE 2. Net pCO_2 of reefs at different latitudes, tropical defined as between 0-20°N and temperate as >20°N. (Calculated from papers in Table 1)

Regression analysis between latitude and flux shows an increase of flux with increasing latitude, although the decrease is not significant (Figure 3). It is suggested that there is no difference of CO_2 level between tropical and temperate coral reefs, and the level of CO_2 is mainly affected by habitat structure (i.e., coral or algal) [11].

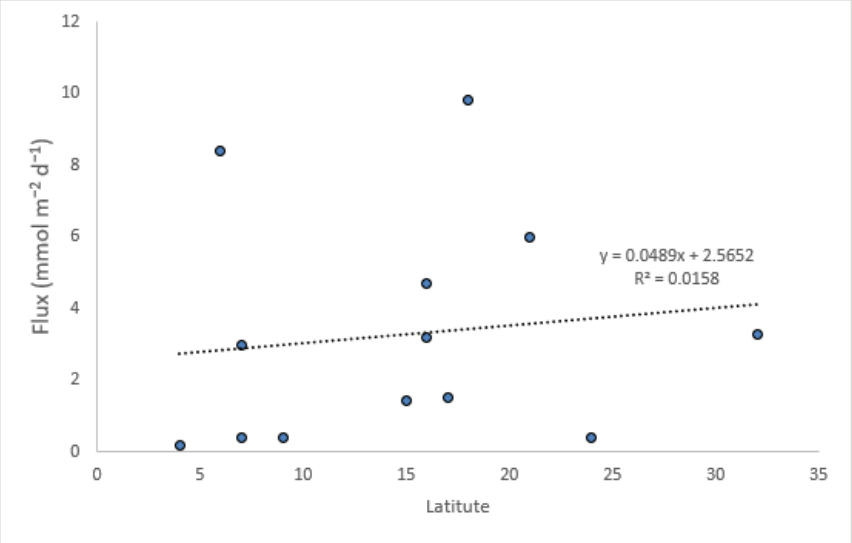

FIGURE 3. Regression analysis between net pCO_2 of coral-dominated reef and reef location (° latitude). (Calculated from papers in Table 1)

Hermatypic corals normally occur between 30ºN and 30ºS [38]. The photosynthesis rate is almost uniform in this geographical range, although slightly higher near the equator [39]. If we assume that coral cover status is the same in this geographical range, we will get a similar calcification rate and, in the end, there is a paucity of research of CO_2 production. The geographical location of the coral reef did not contribute to the differences in carbon production is reasonable because, according to the global map produced by NASA, this region has a similar photosynthesis rate and carbon volume.

CONCLUSION

There is still no clear answer whether the coral reef is a carbon source or sink, although many reefs act as carbon source rather than sink. This role mainly depends on the reef condition and habitat structure: whether reef is classified as coral-dominated or algal-dominated, whether reef is classified as coral-dominated or algal-dominated, or whether reef is classified as coral-dominated or algal-dominated. In coral-dominated reefs, higher CO_2 production tends to flux to the atmosphere, while in algal-dominated reefs, they absorb carbon from the ocean surface to fulfill the demand of photosynthesis need. In general, two factors are affecting the production of carbon in the coral reef, (1) photosynthesis and respiration and (2) habitat structure. There is no evidence yet that geographical location or latitude has impacted the carbon production in the coral reef. There is a need for deeper research to compare the carbon production in different latitudes with the same method and similar coral reef conditions to understand if there is a strong relationship between latitude and carbon production of coral reef. It is also suggested that coral reef is very potential for carbon sink in the future because of the continuing decrease of coral cover and major shifts of coral to algal in all over the world. It is also concluded that while the coral reef is a carbon source at present, the ocean itself is a carbon sink.

REFERENCES

1. E. Dlugokencky and P. Tans, NOAA/GML (gml.noaa.gov/ccgg/trends/)
2. K.R. Anthony, D.I. Kline, G. Diaz-Pulido, S. Dove, and O. Hoegh-Guldberg, Proc. Natl. Acad. Sci. 105, 17442 (2008).
3. J. Silverman, B. Lazar, L. Cao, K. Caldeira, and J. Erez, Geophys. Res. Lett. 36, 1 (2009).

4. J.E. Veron, O. Hoegh-Guldberg, T.M. Lenton, J.M. Lough, D.O. Obura, P. Pearce-Kelly, C.R. Sheppard, M. Spalding, M.G. Stafford-Smith, and A.D. Rogers, Mar. Pollut. Bull. 58, (2009).
5. M. Holcomb, D. McCorkle, and A.C. Marine, J. Exp. Mar. Bio. Ecol. 386, (2010).
6. I. Jones and H. Young, Environ. Conserv. 24, (1997).
7. J. Shepherd, Geoengineering the Climate: Science, Governance and Uncertainty (Royal Society, London, 2009).
8. D. Battisti, J.J. Blackstock, K. Caldeira, D.E. Eardley, J.I. Katz, D.W. Keith, S.E. Koonin, A.A.N. Patrinos, D.P. Schrag, and R.. Socolow, in IOP Conf. Ser. Earth Environ. Sci. (2009), p. 452015.
9. Y. Malhi, Philos. Trans. R. Soc. London. Ser. A Math. Phys. Eng. Sci. 360, 2925 (2002).
10. J.P. Gattuso, M. Frankignoulle, and S. V. Smith, Proc. Natl. Acad. Sci. 96, 13017 (1999).
11. S. Tambutté, M. Holcomb, C. Ferrier-Pagès, S. Reynaud, É. Tambutté, D. Zoccola, and D. Allemand, J. Exp. Mar. Bio. Ecol. 408, 58 (2011).
12. D. Kinsey and D. Hopley, Palaeogeogr. Palaeoclimatol. Palaeoecol. 89, 363 (1991).
13. J.R. Ware, S. V. Smith, and M.L. Reaka-Kudla, Coral Reefs 11, 127 (1992).
14. H. Kawahata, A. Suzuki, and K. Goto, Geochem. J. 33, 295 (1999).
15. A. Suzuki and H. Kawahata, Glob. Environ. Chang. Ocean L. 229 (2004).
16. J.M. De Goeij and F.C. Van Duyl, Limnol. Oceanogr. 52, 2608 (2007).
17. H.Q. Yan, K.F. Yu, Q. Shi, Y.H. Tan, H.L. Zhang, M.X. Zhao, S. Li, T.R. Chen, L.Y. Huang, and P.X. Wang, Chinese Sci. Bull. 56, 676 (2011).
18. H. Kawahata, A. Suzuki, and K. Goto, Coral Reefs 16, 261 (1997).
19. A. Suzuki and H. Kawahata, J. Oceanogr. 55, 731 (1999).
20. J.P. Gattuso, M. Pichon, B. Delesalle, and M. Frankignoulle, Mar. Ecol. Prog. Ser. 96, 259 (1993).
21. H. Kayanne, A. Suzuki, and H. Saito, Science (80-.). 269, 214 (1995).
22. N.R. Bates, Limnol. Oceanogr. 47, 43 (2002).
23. K. Fagan and F. Mackenzie, Mar. Chem. 106, 174 (2007).
24. C. Longhini, M. Souza, and A. Silva, Estuar. Coast. Shelf Sci. 166, 13 (2015).
25. H. Yan, K. Yu, Q. Shi, Z. Lin, M. Zhao, S. Tao, G. Liu, and H. Zhang, Cont. Shelf Res. 165, 71 (2018).
26. C. Lønborg, M.L. Calleja, K.E. Fabricius, J.N. Smith, and E.P. Achterberg, Mar. Chem. 210, 24 (2019).
27. L.C. Cotovicz Jr, R. Chielle, and R. V. Marins, Cont. Shelf Res. 204, 104175 (2020).
28. A. Akhand, K. Watanabe, A. Chanda, T. Tokoro, K. Chakraborty, H. Moki, T. Tanaya, J. Ghosh, and T. Kuwae, Sci. Total Environ. 752, 142190 (2021).
29. C.T.A. Chen and A. V. Borges, Deep Sea Res. Part II Top. Stud. Oceanogr. 56, 578 (2009).
30. A.J. Andersson, F.T. Mackenzie, and L.M. Ver, Geology 31, 513 (2003).
31. M. Frankignoulle and J.P. Gattuso, in Interact. C, N, P S Biogeochem. Cycles Glob. Chang. (Springer, Berlin, Heidelberg, 1993), pp. 233–248.
32. S. V. Smith, Science. 211, 838 (1981).
33. T.J. Done, Hydrobiologia 247, 121 (1992).
34. T.P. Hughes, Science. 265, 1547 (1994).
35. Z. Dubinsky and N. Stambler, Coral Reefs: An Ecosystem in Transition (Springer Science & Business Media, 2010).
36. S. Scheffers, Benthic-Pelagic Coupling in Coral Reefs: Interaction between Framework Cavities and Reef Water, Ph.D Thesis, University of Amsterdam (2005).
37. R. Rodolfo-Metalpa, Y. Huot, and C. Ferrier-Pagès, J. Exp. Biol. 211, 1579 (2008).
38. J. Veron, Corals of the World (Australian Institute of Marine Science, 2000).
39. R. Pinker and I. Laszlo, J. Clim. 5, 56 (1992).