Meta-study of carbonate sediment delivery rates to Indo-Pacific coral reef islands

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Key Points:

- We provide the first estimation of sediment delivery rates to 28 coral reef islands using all data available from the literature.
- Results point towards a sediment delivery rate of c. $0.1 m^3.m^{-1}.yr^{-1}$, but with substantial inter-island variability.
- Where island building has been continuous through island history, long-term delivery rates provide valuable estimates for contemporary rates.

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Abstract

Coral reef islands are amongst the most vulnerable environments to sea-level rise (SLR). Recent physical and numerical modelling studies have demonstrated that overwash processes may enable reef islands to keep up with SLR through island accretion. Sediment supply to these islands from the surrounding reef system is critical in understanding their morphodynamic adjustments, but is poorly constrained due to insufficient knowledge about sediment delivery rates. This paper provides the first estimation of sediment delivery rates to coral reef islands. Analysis of topographic and geochronological data from 28 coral reef islands indicates an average rate of sediment delivery of c. $0.1 m^3.m^{-1}.yr^{-1}$, but with substantial inter-island variability. Comparison with carbonate sediment production rates from census-based studies suggests that this represents c. 26% of the amount of sediment produced on the reef platform. Results of this study are useful in future modelling studies for predicting morphodynamic adjustments of coral reef islands to SLR

Plain Language Summary

Low-lying coral reef islands are under threat of sea-level rise. However, when these islands are flooded, ocean waves can bring in sediment that can increase the island elevation. This would enable coral reef islands to better withstand flooding in the future. Knowing how much sediment is brought in will help in our understanding of future changes to these islands due to sea-level rise. In this paper, we use data from 28 Indo-Pacific coral reef islands to compute sediment supply to the islands. We find that on average 0.1m3 of sediment (roughly 100 kg) is delivered each year for every meter of island shoreline. We further suggest that implies that only one quarter of the sediments produced by the coral reef system is delivered to the island shoreline. Most of the sediment produced remains on the reef flat or is exported to the ocean or the lagoon. Our results will help future studies to predict more accurately how coral reef islands will adjust to sea-level rise.

Supporting Information

- Figure 1: *Location of archipelagoes and reef region in which reef island formation has been studied.* Coral reef islands in this study are distributed across the Indo-Pacific regions and located in six atoll archipelagos and four barrier reef settings.
- Table 1: *Average and upper delivery rates calculated for 28 coral reef islands in the Indo-Pacific region.* Delivery rates in $m^3.yr^{-1}$ and normalised delivery rates in $m^3.m^{-1}.yr^{-1}$ are displayed for each island.
- Table 2: *Pearson correlation matrix calculated for thickness of sediment, island surface, island volume, island shoreline perimeter, accumulation period, average delivery rate and normalised average delivery rate.* P-value indicating statistical significance are displayed (p-val<5%: *; p-val<1%:**; p-val<0.1%: ***).
- Figure 2: *Average delivery rate versus island size.*
- Table 3: *Summary of islands characteristics:* nature of the island, number of radiometric ages, oldest and youngest ages and accumulation window.
- Table 4: *Summary of islands characteristics*: sediment thickness, island basis (used for computing the island thickness), island surface, reef and island perimeters and reef width.

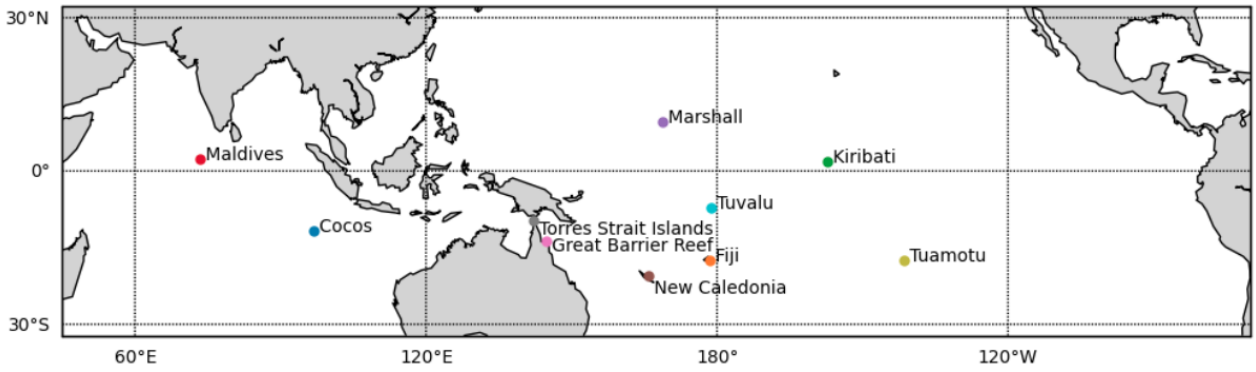

Figure 1: Location of archipelagoes and reef region in which reef island formation has been studied

Table 1: Average and upper delivery rates calculated for 28 coral reef islands in the Indo-Pacific region

Archipelago	**Island**	**Delivery rate** $(m^3.s^{-1})$		**Normalised Delivery rate** $(m^3.m^{-1}.s^{-1})$		**Source**
		average	upper	average	upper	
Cocos	West Island	3700.0 +/- 500.0	3700.0 +/- 500.0	0.24 +/- 0.04	0.24 +/- 0.04	Woodroffe et al. (1999)
Fiji	Malamala	110.0 +/- 20.0	150.0 +/- 20.0	0.13 +/- 0.02	0.18 +/- 0.03	McKoy et al. (2010)
	Navini	66.0 +/- 10.0	67.0 +/- 10.0	0.072 +/- 0.01	0.073 +/- 0.01	McKoy et al. (2010)
Kiribati	Makin	3500.0 +/- 500.0	4100.0 +/- 600.0	0.24 +/- 0.04	0.29 +/- 0.05	Woodroffe and Morrison (2001)
Maldives	Baavanadhoo	52.0 +/- 8.0	64.0 +/- 9.0	0.04 +/- 0.006	0.05 +/- 0.008	East et al. (2018)
	Boduhini	25.0 +/- 4.0	44.0 +/- 6.0	0.026 +/- 0.004	0.047 +/- 0.007	East et al. (2018)
	Dhakandhoo	27.0 +/- 4.0	190.0 +/- 30.0	0.023 +/- 0.004	0.16 +/- 0.02	East et al. (2018)
	Galamadhoo	22.0 +/- 3.0	29.0 +/- 4.0	0.018 +/- 0.003	0.024 +/- 0.004	Kench et al. (2005)
	Hulhudhoo	15.0 +/- 2.0	49.0 +/- 7.0	0.017 +/- 0.003	0.057 +/- 0.009	Kench et al. (2005)
	Kandahalagalaa	85.0 +/- 10.0	110.0 +/- 20.0	0.068 +/- 0.01	0.091 +/- 0.01	Liang et al. (2022)
	Kondeymatheelaabadhoo	75.0 +/- 10.0	88.0 +/- 10.0	0.06 +/- 0.01	0.071 +/- 0.01	Liang et al. (2022)
	Mainadhoo	130.0 +/- 20.0	160.0 +/- 20.0	0.061 +/- 0.01	0.078 +/- 0.01	East et al. (2018)
	Thiladhoo	59.0 +/- 8.0	74.0 +/- 10.0	0.056 +/- 0.009	0.072 +/- 0.01	Kench et al. (2005)
	Vadhoo	860.0 +/- 100.0	900.0 +/- 100.0	0.13 +/- 0.02	0.14 +/- 0.02	Kench et al. (2020)
Marshall	Jabat	210.0 +/- 30.0	210.0 +/- 30.0	0.052 +/- 0.008	0.053 +/- 0.008	Kench et al. (2014)
	Jabnodren	200.0 +/- 30.0	230.0 +/- 30.0	0.072 +/- 0.01	0.081 +/- 0.01	Kench et al. (2022)
	Jeh	400.0 +/- 60.0	410.0 +/- 60.0	0.23 +/- 0.04	0.23 +/- 0.04	Ford et al. (2020) and Owen et al. (2016)
	Jin	320.0 +/- 50.0	340.0 +/- 50.0	0.18 +/- 0.03	0.19 +/- 0.03	Kench et al. (2022)
	Laura Island	2400.0 +/- 300.0	3400.0 +/- 500.0	0.37 +/- 0.06	0.53 +/- 0.08	Yasukochi et al. (2014)
New Caledonia	Mba	300.0 +/- 40.0	440.0 +/- 60.0	0.1 +/- 0.02	0.15 +/- 0.02	Yamano et al. (2014)
Torres Strait Islands	Bewick	1200.0 +/- 200.0	1200.0 +/- 200.0	0.17 +/- 0.03	0.18 +/- 0.03	Kench et al. (2012)
	Warraber	210.0 +/- 30.0	210.0 +/- 30.0	0.055 +/- 0.009	0.055 +/- 0.008	Woodroffe et al. (2007)
Tuamotu	Motu Aramu	120.0 +/- 20.0	120.0 +/- 20.0	0.028 +/- 0.004	0.028 +/- 0.004	Montaggioni et al. (2023)
	Motu Vainono	420.0 +/- 60.0	530.0 +/- 80.0	0.17 +/- 0.03	0.21 +/- 0.03	Montaggioni et al. (2023)
	Takapoto SE	1400.0 +/- 200.0	1500.0 +/- 200.0	0.2 +/- 0.03	0.21 +/- 0.03	Montaggioni et al. (2019)
	Takapoto SW	1900.0 +/- 300.0	1800.0 +/- 300.0	0.12 +/- 0.02	0.12 +/- 0.02	Montaggioni et al. (2019)
Tuvalu	Tepuka	260.0 +/- 40.0	450.0 +/- 70.0	0.31 +/- 0.05	0.53 +/- 0.08	Kench et al. (2014)
	Tugata	28.0 +/- 4.0	30.0 +/- 4.0	0.074 +/- 0.01	0.079 +/- 0.01	Kench et al. (2018)
	Mean	646	736	0.118	0.151	
	Standard deviation	1010	1132	0.092	0.127	

	thickness of sediment	island surface	island volume	island shoreline perimeter	accumulation period (to present)	average delivery rate	normalised average delivery rate
thickness of sediment	1.0***	-0.22	-0.07	-0.24	0.09	-0.16	0.04
island surface	-0.22	1.0***	0.98***	0.9***	0.15	0.96***	0.51**
island volume	-0.07	0.98***	1.0***	0.88***	0.2	0.95***	0.55**
island shoreline perimeter	-0.24	0.9***	0.88***	1.0***	0.19	0.91***	0.44*
accumulation period (to present)	0.09	0.15	0.2	0.19	1.0***	0.07	-0.33
average delivery rate	-0.16	0.96***	0.95***	0.91***	0.07	1.0***	0.66***
normalised average delivery rate	0.04	0.51**	0.55**	0.44*	-0.33	0.66***	1.0***

Table 2: Pearson correlation matrix calculated for thickness of sediment, island surface, island volume, island shoreline perimeter, accumulation period, average delivery rate and normalised average delivery rate. P-value indicating statistical significance are displayed (p-val<5%: *; p-val<1%:**; p-val<0.1%: ***).

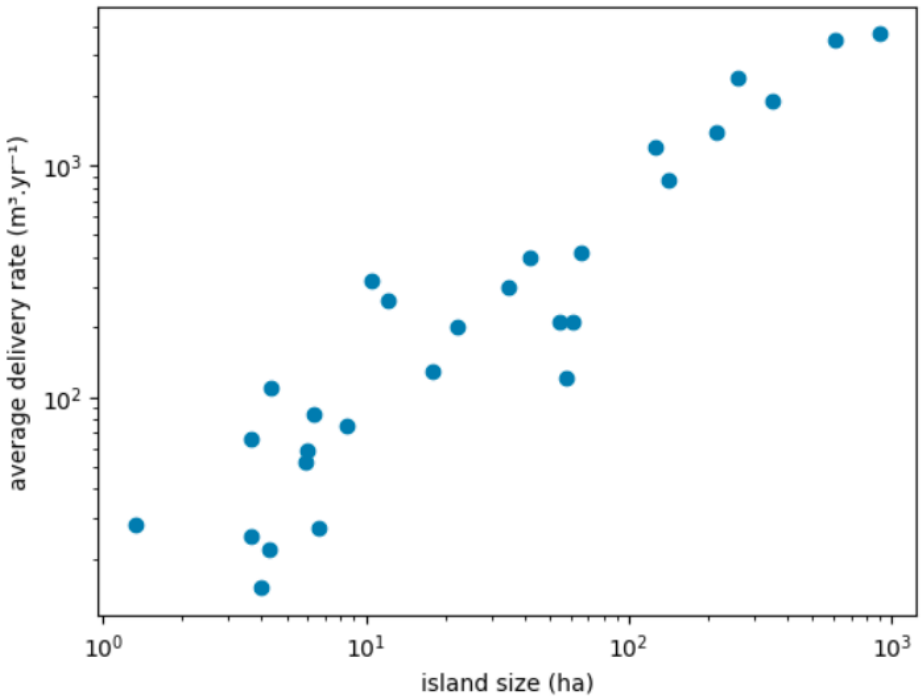

Figure 2: Average delivery rate versus island size

Table 3: Summary of islands characteristics: Nature of the island, number of radiometric ages, oldest and youngest ages and accumulation window

island	nature of the island	number of radiometric dates	oldest age	youngest age	accumulation window
West Island	linear reef rim island	43	4280	0	4280
Malamala	reef platform island	8	1446	355	1091
Navini	reef platform island	6	2185	33	2152
Makin	reef platform island	17	2690	410	2280
Baavanadhoo	reef rim island	7	2703	524	2179
Boduhini	reef rim island	4	2827	1253	1574
Dhakandhoo	reef rim island	6	5330	4560	770
Galamadhoo	reef rim island	10	4203	1284	2919
Hulhudhoo	reef platform island	9	4965	3445	1520
Kandahalagalaa	reef platform island	23	1840	466	1374
Kondeymatheelaabadhoo	reef platform island	18	2353	595	1758
Mainadhoo	reef rim island	16	2912	640	2272
Thiladhoo	reef rim island	7	2590	545	2045
Vadhoo	reef rim island	24	2667	123	2544
Jabat	reef platform island	22	4800	51	4749
Jabnodren	reef rim island	27	1213	128	1085
Jeh	reef platform island	23	1807	35	1772
Jin	reef rim island	10	603	35	568
Laura Island	linear reef rim island	23	2210	650	1560
Mba	reef platform island	26	4460	1370	3090
Bewick	reef platform island	17	4880	0	4880
Warraber	reef platform island	10	3893	0	3893
Motu Aramu	reef platform island	26	5042	108	4934
Motu Vainono	reef platform island	35	4026	42	3984
Takapoto SE	linear reef rim island	30	2635	156	2479
Takapoto SW	linear reef rim island	21	2843	71	2772
Tepuka	reef platform island	7	1140	482	658
Tugata	reef platform island	20	778	345	433

Table 4: Summary of islands characteristics: Sediment thickness, island basis, island surface, reef and island perimeters and reef width

island	sediment thickness	island basis	island surface	outer reef perimeter	island perimeter	reef width
West Island	1.75	reef flat or conglomerate platform	8978090	15113	14987	229
Malamala	3.78	bottom of the deepest core	43361	2791	844	82
Navini	3.96	bottom of the deepest core	36612	2443	921	76
Makin	1.55	bottom of the deepest core	6072840	17643	14269	250
Baavanadhoo	2.36	underlying reef flat	59236	641	639	524
Boduhini	1.91	underlying reef flat	36350	188	305	709
Dhakandhoo	2.17	top of the velu infill	66293	665	490	81
Galamadhoo	2.13	underlying reef flat	42790	504	568	540
Hulhudhoo	1.88	top of the velu infill	39926	1375	866	31
Kandahalagalaa	2.47	top of the velu infill	63222	2784	1255	120
Kondeymatheelaabadhoo	2.09	top of the velu infill	84410	3523	1240	119
Mainadhoo	2.06	underlying reef flat	179321	495	906	786
Thiladhoo	2.55	top of the velu infill	59524	2003	1039	205
Vadhoo	1.62	top of the velu infill	1412480	2477	2913	484
Jabat	1.84	top of the conglomerate platform	548588	4981	4003	77
Jabnodren	1.11	top of the conglomerate platform	223623	1111	1963	76
Jeh	1.72	bottom of the deepest core	420083	1717	1741	97
Jin	1.84	top of the conglomerate platform	105296	1113	1287	86
Laura Island	2.04	bottom of the deepest core	2580212	6347	6433	195
Mba	3.89	bottom of the deepest core	349962	4860	2999	59
Bewick	4.58	underlyng reef flat	1251985	7611	6793	81
Warraber	1.32	underlying reef flat	611208	15124	3747	660
Motu Aramu	1.07	top of the conglomerate platform	578752	1981	4448	134
Motu Vainono	2.56	top of the conglomerate platform	662838	3295	2504	167
Takapoto SE	1.75	top of the conglomerate platform	2156275	6871	7101	286
Takapoto SW	1.5	top of the conglomerate platform	3516647	27078	15516	322
Tepuka	2.45	bottom of the deepest core	121844	918	850	249
Tugata	1.62	underlying reef flat	13317	217	378	24

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