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Potential for landscape-scale positive interactions among tropical marine ecosystems

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Supplement. Literature review of data showing fluxes (wave height, sediment and nutrients) between mangrove forests, seagrass beds and coral reefs

Wave heights

Table S1. Reports of field wave heights at (A) mangrove forests (from 1990 to 2011), (B) seagrass beds (from 2001 to 2012) and (C) coral reefs (from 1975 to 2012). The studies are in ascending order according to wave height (m). nd: no available data, NA: not applicable. The mean wave height across studies can be seen in Table 1 in the main article

Ecosystem and location	Ecosystem attributes	Depth (m)	Wave height (m)	Area of ecosystem (km^2)	State	Reference
(A) Mangrove forest						
Hinchinbrook Channel, Australia	nd	NA	0.2	164	Modified	Wolanski et al. (1990)
Flume	nd	NA	0.4	nd	nd	Suzuki et al. (2012)
Can Gio mangrove forest, Vietnam	nd	NA	0.4	757	nd	Phuoc & Massel (2006)
Tong King Delta, Vietnam	nd	NA	1	4.5	Re-planted	Mazda et al. (1997)
(B) Seagrass bed						
Whangapoua Estuary, New Zealand	*Zostera* sp.	1.2	0.02–0.1	>0.1	Fragmented	Bryan et al. (2007)
Duck Point Cove, USA	*Ruppia* sp.	1	0.1	nd	Recovered	Newell & Koch (2004)
Santa Rosa Island, USA	*Thalassia* sp.	1.5	0.1	nd	Stable	Bradley & Houser (2009)
South Bay, USA	*Zostera* sp.	1.4–2.3	0.2	0.0007	nd	Hansen & Reidenbach (2012)
Cala Millor, Majorca Island	*Posidonia* sp.	6–35	0.2–0.4	1.2	nd	Infantes et al. (2009)
Naruto, Japan	*Zostera* sp.	nd	2	nd	nd	Cited by Koch (2001)
(C) Coral Reef						
Hawaii, USA	Fringing reef	0.05	0.09	nd	nd	Filipot & Cheung (2012)
St. Croix, USA	Back reef	2	0.1	nd	nd	Roberts et al. (1988)
St. Croix, USA	Reef crest	3	0.1	nd	nd	Roberts et al. (1988)
St. Croix, USA	Reef crest	3	0.3	nd	nd	Roberts et al. (1988)
St. Croix, USA	Fore reef	5	0.5	nd	nd	Lugo-Fernández et al. (1998)
Torres Strait, Australia	Fore reef	2.5	0.5	nd	nd	Brander et al. (2004)
Margarita reef, Puerto Rico	Reef crest	0.3–6	0.6–1.5	nd	nd	Lugo-Fernández et al. (1994)
Grand Cayman Island, Barbados	Reef shelf	13	1	nd	nd	Roberts (1975)
Great Corn Island, Nicaragua	Reef crest	0.5	1	nd	nd	Suhayda & Roberts (1977)
Guam, USA	Reef edge	8	4	nd	nd	Pequignet et al. (2011)

Table S2. Studies showing a percentage reduction in wave height travelling across (A) coral reefs and (B) seagrass beds from ocean to shore. $H_{(enter)}$ denotes the wave height at the edge of the seaward side of the ecosystem. $H_{(exit)}$ represents the wave height after passing through the coral reef or seagrass bed. Reduction (R) (%) is the percentage reduction in the initial wave height after travelling over a given distance of the coral reef or seagrass bed. $H_{(exit)}$ was calculated by $H_{(enter)} - [H_{(enter)} \times (R/100)]$. Export/import ratio gives an inverse wave retention potential of the forest and bed. The studies are in ascending order according to distance (m)

Ecosystem and location	Ecosystem attributes	Distance (m)	Depth (m)	H_{enter} (m)	H_{exit} (m)	Reduction (R) (%)	Export/Import ratio	Reference	Study
(A) Coral reef									
St. Croix, USA	Back reef	30	2	0.07	0.02	74	0.3	Roberts et al. (1988)	1
St. Croix, USA	Reef crest	45	3	0.1	0.05	56	0.5	Roberts et al. (1988)	2
St. Croix, USA	Reef crest	55	3	0.1	0.07	46	0.7	Roberts et al. (1988)	3
St. Croix, USA	Fore reef	125	5	0.3	0.1	54	0.3	Lugo-Fernández et al. (1998)	4
Great Corn Island, Nicaragua	Reef crest	300	5	1	0.6	40	0.6	Suhayda & Roberts (1977)	5
Grand Cayman Island	Reef crest	400	13	1	0.8	20	0.8	Roberts (1975)	6
Ipan, Guam	Fore reef	500	8	4	0.1	97	0.03	Pequignet et al. (2011)	7
Torres Strait, Australia	Fore reef	556	3	0.5	0.3	58	0.6	Brander et al. (2004)	8
Margarita Reef, Puerto Rico	Reef crest	1000	0.3	1	0.2	72	0.3	Lugo-Fernández et al. (1994)	9
(B) Seagrass bed			Density (shoots m^{-2})						
Flume	*Zostera* sp.	1	875	0.04	0.01	81	0.3	Fonseca & Cahalan (1992)	1
Virginia Coast reserve, USA	*Zostera* sp.	1.4–2.3	560	0.2	0.08	58	0.4	Hansen & Reidenbach (2012)	2
Santa Rosa Island, USA	*Thalassia* sp.	50	110	0.1	0.07	30	0.7	Bradley & Houser (2009)	3

Sediment

Table S3. Reports of total suspended solid fluxes (g m^{-2} d^{-1}) for (A) mangrove forests (from 1990 to 2010), (B) seagrass beds (from 1995 to 2003) and (C) coral reefs (from 1974 to 2004). Mean total suspended solid fluxes (g m^{-2} d^{-1}) values across studies can be seen in Table 1 in the main article. The studies are in ascending order according to total suspended solid (TSS) flux values (g m^{-2} d^{-1}). *: mean values. nd: no available data

Ecosystem and location	Ecosystem attribute	TSS* (g m^{-2} d^{-1})	Area (km^2)	State	Reference
(A) Mangrove forest					
Ngerdorch, Palau	River	0.001	1.5	Developed catchment area	Victor et al. (2004)
Nudgee Creek, Australia	Tidal creek	0.09	~0.8	Extensively modified	Adame et al. (2010)
Bald Hills Creek, Australia	Tidal creek	0.1	0.8	Extensively modified	Adame et al. (2010)
Caboolture River, Australia	River	0.2	2.4	Modified	Adame et al. (2010)
Eprapah Creek, Australia	Tidal creek	0.2	1.3	Modified	Adame et al. (2010)
Tingalpa, Australia	River	0.3	1.3	Extensively modified	Adame et al. (2010)
Ngerikiil, Palau	River	0.5	0.7	Natural, but poor surrounding land use	Victor et al. (2004)
Mooloolah River, Australia	River	1	0.3	Modified	Adame et al. (2010)
Klong Ngao Estuary, Thailand	Tidal creek	12	11.5	Natural	Wattayakorn et al. (1990)
Pohnpei, Federated States of Micronesia	River dominated	62	~0.4	nd	Victor et al. (2006)
North Coast, Kenya	River	233	17	Moderately and extensively degraded	Kitheka et al. (2002)
Middle Creek, Australia	Tidal creek	675	6.5	Less developed catchment area	Furukawa et al. (1997)
(B) Seagrass bed					
China Sea, Hong Kong	*Zostera* sp.	0.003–0.02	nd	nd	Lee (1997)
Bay of Calvi, Mediterranean	*Posidonia* sp.	3.6	nd	nd	Dauby et al. (1995)
Silaqui, Pislatan, St. Barbara, Buenavista, Umalagan, Philippines	*Enhalus* sp. *Cymodocea* sp. *Halodule* sp. & *Thalassia* sp.	19–175	nd	nd	Gacia et al. (2003)
Fanals point, Spain	*Posidonia* sp.	1.5–500	nd	nd	Gacia & Duarte (2001)
Bai Tien, Dam Gia, My Giang, Vietnam	*Enhalus* sp. *Cymodocea* sp. *Halodule* sp. & *Thalassia* sp.	76–681	nd	nd	Gacia et al. (2003)

(C) Coral reef

Phuket, Thailand	*Acropora* sp. *Porities* sp.	0.02	nd	nd	Chansang et al. (1992)
Puerto Rico, USA	*Agaricia* sp. *Monstratea* sp.	0.03–0.2	nd	nd	Loya (1976)
Puerto Rico, USA	*Acropora* sp.	0.2	nd	nd	Rogers (1979)
Great Barrier Reef, Australia	*Acropora* sp.	0.5	nd	nd	Fabricius & Wolanski (2000)
Puerto Rico, Caribbean	*Porities* sp. *Siderastrea* sp.	1	nd		Torres & Morelock (2002)
Papua New Guinea	*Acropora* sp.	1.4	nd	nd	Kojis & Quinn (1984)
Puerto Rico, USA	*Monstratea* sp.	1.9	nd	nd	Torres (1998)
Discovery Bay, Jamaica	*Monstratea* sp.	1.9	nd	nd	Dodge et al. (1974)
Aquarium experiment	*Favia* sp.	2	nd	nd	Todd et al. (2004)
Great Barrier Reef, Australia	*Leptoria* sp. *Porities* sp.	2.5	nd	nd	Stafford-Smith (1992)
Palawan, Philippines	*Montipora* sp. *Porities* sp.	3	nd	nd	Hodgson (1990)
Natal, South Africa	*Favia* sp. *Favites* sp. *Gyrosmillia* sp. *Platygyra* sp.	20	nd	nd	Riegl (1995), Riegl & Bloomer (1995)
Dampier Archipelago, Australia	*Acropora* sp.	20–30	nd	nd	Simpson (1988)
Curacao, Caribbean	*Acropora* sp.	43	nd	nd	Bak & Elgershuizen (1976)
Laboratory experiment	*Astrangla* sp.	<60	nd	nd	Peters & Pilson (1985)

Table S4. Studies showing flux of total suspended solids (TSS; g m^{-2} d^{-1}) exported from a mangrove forest (column 4) compared to the initial import into the forest (Column 5) (g m^{-2} d^{-1}). Some fluxes were not based on a full year of observation, and this can cause large variability. Nevertheless, for simplicity, all fluxes have been expressed as g m^{-2} d^{-1}. Location indicates where the study was performed. Classification and area of the mangrove forest is information from the original data source except where indicated. Trapping capacity was calculated as 100 – (Import/Export × 100), which gives the percentage of the influx retained by the ecosystem. Column 7 is the export/import ratio, which gives an inverse retention potential of the forest. We also include the original units, how the export and import were calculated and the type/location of measurements for transparency, which are all taken from the original studies. The studies are in ascending order according to mangrove area (km^2). *: data were taken from www.ozcoasts.au. Data from Adame et al. (2010) are estimations because these data were taken during a spring tide when inundation was higher, and this could affect the sedimentation rates

Location and reference	Classification	Mangrove area (km^2)	Export (g m^{-2} d^{-1})	Import (g m^{-2} d^{-1})	Trapping capacity (%)	Export/import ratio	Original units	Calculated from	Type of measurement	Location of measurement	Study
Mooloolah River, Australia Adame et al. (2010)	River dominated	0.3*	0.9	1	8	0.9	mg cm^{-2} spring $tide^{-1}$	Sedimentation rate	Sediment traps	Depositional side of river/tidal creek	1
Ngerikiil, Palau Victor et al. (2004)	River dominated	0.7	0.4	0.5	25	0.7	tons km^{-2} yr^{-1}	Export rate	Sediment traps	Edge of river bank/perpendicular to river	2
Nudgee Creek, Australia Adame et al. (2010)	Tide dominated	~0.8*	0.090	0.094	5	1.0	mg cm^{-2} spring $tide^{-1}$	Sedimentation rate	Sediment traps	Depositional side of river/tidal creek	3
Bald Hills Creek, Australia Adame et al. (2010)	Tide dominated	0.8*	0.130	0.131	1	1.0	mg cm^{-2} spring $tide^{-1}$	Sedimentation rate	Sediment traps	Depositional side of river/tidal creek	4
Eprapah Creek, Australia Adame et al. (2010)	Tide dominated	1.3*	0.21	0.22	5	1.0	mg cm^{-2} spring $tide^{-1}$	Sedimentation rate	Sediment traps	Depositional side of river/tidal creek	5
Tingalpa Creek, Australia Adame et al. (2010)	River dominated	1.3*	0.2	0.3	37	0.6	mg cm^{-2} spring $tide^{-1}$	Sedimentation rate	Sediment traps	Depositional side of river/tidal creek	6

Ngerdorch, Palau Victor et al. (2004)	River dominated	1.5	0.005	0.01	64	0.4	tons km^{-2} yr^{-1}	Export rate	Sediment traps	Edge of river bank/perpendicular to river	7
Caboolture River, Australia Adame et al. (2010)	River dominated	2.4*	0.1	0.2	31	0.7	mg cm^{-2} spring tide^{-1}	Sedimentation rate	Sediment traps	Depositional side of river/tidal creek	8
Pohnpei, Federated States of Micronesia Victor et al. (2006)	River dominated	~4	37.3	62	40	0.6	mg cm^{-2} d^{-1}	Export rate	Oceanographic instruments	Bay	9
Middle Creek, Australia Furukawa et al. (1997)	Tide dominated	6.5*	135	675	80	0.2	mg cm^{-2} d^{-1}	Sedimentation rate	Sediment traps	Along boardwalk	10
Klong Ngao Estuary, Thailand Wattayakorn et al. (1990)	Tide dominated	11.5	1	12	90	0.1	kg d^{-1}	Export rate	Water samples	In estuary at 3 different depths	11
Mwache mangrove, Kenya Kitheka et al. (2002)	River dominated	17	107	233	54	0.5	g m^{-2} tide $^{-1}$	Sedimentation rate	Water samples	Along tidal creek	12

Nutrients

Table S5. Reports of fluxes in the water column (g N or P m^{-2} d^{-1}) for (A) coral reefs (1983 to 2011) and (B) seagrass beds (1985 to 2010) of total dissolved nitrogen (N) and phosphorous (P). Mean nutrient flux (g N or P m^{-2} d^{-1}) values across studies can be seen in Table 1 in the main article. The studies are in ascending order according to the year of the study. *: average values; nd: no available data

Location and ecosystem	Type	Nutrient* (g m^{-2} d^{-1})		Study
		N	P	
(A) Fluxes in the water column at coral reefs				
Guam, Mariana Islands	Fringing reef	0.02	0.0004	Matson (1993)
Florida, USA	Offshore reef	0.004	0.00002	Corbett et al. (1999)
Yucatan, Mexico	Barrier reef	0.002	0.00007	Hernández-Terrones et al. (2010)
(B) Fluxes in the water column at seagrass beds				
Chesapeake Bay, USA	*Zostera* sp.	0.01	nd	Adapted from Lee & Olsen (1985)
Long Island, USA	*Zostera* sp.	0.02	nd	Adapted from Lee & Olsen (1985)
Long Island, USA	*Zostera* sp.	0.03	nd	Adapted from Lee & Olsen (1985)
Long Island, USA	*Zostera* sp.	0.02	nd	Adapted from Lee & Olsen (1985)
Buttermilk Bay, USA	*Zostera* sp.	0.02	nd	Valiela & Costa (1988)
Chincoteague bay, USA	*Zostera* sp.	0.01	nd	Boynton et al. (1996)
Sage Lot Pond, USA	*Ruppia* sp.	0.003	nd	McClelland et al. (1997)
Sage Lot Pond, USA	*Zostera* sp.	0.02	nd	Hauxwell et al. (1998)
Charlestown Pond, USA	*Zostera* sp.	0.02	nd	Adapted from Nixon et al. (2001)
Great South Bay, USA	*Zostera* sp.	0.004	nd	Adapted from Nixon et al. (2001)
Great Bay, USA	*Zostera* sp.	0.01	nd	Adapted from Nixon et al. (2001)
Great Bay, USA	*Zostera* sp.	0.09	nd	Adapted from Nixon et al. (2001)
Buttermilk Bay, USA	*Zostera* sp.	0.05	nd	Adapted from Nixon et al. (2001)
Kertinge Nor, USA	*Zostera* sp.	0.01	nd	Adapted from Nixon et al. (2001)
Florida, USA	*Thalassia* sp.	0.001	nd	Cornelisen & Thomas (2006)
Florida, USA	*Thalassia* sp.	0.002	nd	Cornelisen & Thomas (2006)
Spermonde Archipelago, Indonesia	*Cymodocea* sp.	0.1	nd	Vonk & Stapel (2008)
Spermonde Archipelago, Indonesia	*Halodule* sp.	0.1	nd	Vonk & Stapel (2008)
Spermonde Archipelago, Indonesia	*Thalassia* sp.	0.1	nd	Vonk & Stapel (2008)
Sonion, Greece	*Posidonia* sp.	0.04	0.002	Apostolaki et al. (2010)

Table S6. Studies showing water column fluxes (g N or P m^{-2} d^{-1}) of dissolved (A) nitrogen (N, TN, DON + DIN) and (B) phosphorus (TP, SRP + PO_4, DIP, DOP) to and from a mangrove forest. All data are expressed as fluxes per day, but not all studies covered a full year, which will give rise to variability. Different studies are also variable because of differences in methodology. Import flux (column 6) indicates the nutrient being fluxed into the mangrove forest, and export flux (column 5) is nutrients, which are being fluxed out from or within a mangrove. Location (and reference) indicate where and by whom the study was completed. Export/import ratio (column 7) gives an inverse retention potential of the forest. The studies are in ascending order according to mangrove area inundated (km^2). We also included the original units, how the import & export was calculated and the type/location of measurements for transparency, which are all taken from the original studies. nd: no available data, *:wetland area, not inundation area

Location and reference	Mangrove area inundated (km^2)	Type of nutrient	State	Export g m^{-2} d^{-1}	Import g m^{-2} d^{-1}	Export/ import ratio	Original units	Calculated from	Type of measurements	Location of measurements	Study
(A) Nitrogen											
Shenzhen, South China Li (1997)	1.1	N	Relatively undisturbed	0.01	0.02	0.5	kg ha^{-1} yr^{-1}	Uptake & Export rate	Nutrients in woody components	In mangrove trees	1
Taylor River, America Davis et al. (2001)	2.5	TN	nd	0.001	0.004	0.3	μmoles m^{-2} h^{-1}	Uptake & Export rate	Water samples	River	2
Coral Creek, Australia Boto & Wellington (1988)	5	DIN + DON	nd	0.001	0.003	0.5	kg d^{-1}	Export & Import	Water samples	Creek water column	3
Bahía de Lobos, Mexico Sánchez-Carrillo et al. (2009)	14	TN	Eutrophication problems	0.02	0.002	10	kg ha^{-1} d^{-1}	Export & Import	Water samples	Mouth of channel	4
Sarasota Bay, USA Cited from Valiela & Cole (2002)	17*	N	nd	0.1	0.2	0.5	kg ha^{-1} yr^{-1}	Export & Import	nd	nd	5
Tampa Bay, USA Cited from Valiela & Cole (2002)	85*	N	nd	0.12	0.13	0.9	kg ha^{-1} yr^{-1}	Export & Import	Suspended and dissolved N	Bay	6
Moreton Bay, USA Cited from Valiela & Cole (2002)	95*	TN	nd	0.1	0.12	0.8	kg ha^{-1} yr^{-1}	Export & Import	Water samples	River mouth, plumes and ocean	7
Red river, Vietnam	107	DIN +	nd	0.03	0.1	0.2	kmol d^{-1}	Export &	Water samples	Estuary	8

Wösten et al. (2003)		DON						Import			
Charlotte Harbour, USA Cited from Valiela & Cole (2002)	261*	N	nd	0.06	0.07	0.9	kg ha^{-1} yr^{-1}	Export & Import	nd	nd	9
Tapi Estuary, Thailand Wattayakorn et al. (2001)	480	DIN + DON	nd	0.4	0.1	4	mol m^{-2} d^{-1}	Export & Import	Water samples	Estuary	10
(B) Phosphorus											
Shenzhen, South China Li (1997)	1.1	P	Relatively undisturbed	0.002	0.004	0.5	kg ha^{-1} yr^{-1}		Nutrients in woody components	In mangrove trees	1
Taylor River, America Davis et al. (2001)	2.5	TP	nd	0.0001	0.0002	0.5	µmoles m^{-2} h^{-1}		Water samples	River	2
Coral Creek, Australia Boto & Wellington (1988)	5	DOP + PO_4	nd	0.0005	0.001	0.5	kg d^{-1}		Water samples	Creek water column	3
Bahía de Lobos, Mexico Sánchez-Carrillo et al. (2009)	14	TP	Eutrophication problems	0.001	0.1	0.001	kg ha^{-1} d^{-1}		Water samples	Mouth of channel	4
Red river, Vietnam Wösten et al. (2003)	107	P	nd	0.06	0.09	0.7	kmol d^{-1}		Water samples	Estuary	5
Tapi Estuary, Thailand Wattayakorn et al. (2001)	480	DOP + DIP	nd	0.017	0.02	0.9	mol m^{-2} d^{-1}		Water samples	Estuary	6

Table S7. Studies showing seagrass bed import and export of dissolved nitrogen sources (nitrate/nitrate, ammonium and urea) and phosphorus (g m^{-2} d^{-1}) fluxes. Site and species indicates the location and type of seagrass of each individual study; each study looked at different dissolved nitrogen sources. To understand fluxes of import and export of nutrients, we totaled all of the types of nutrient (NH_4^+, NO_3^-, urea) as an import; we understand this is a coarse estimation, but it allowed us to compare export of nutrients. Nutrient export denotes the concentration flux in the water column at the end of the experiment; nutrient import represents the concentration flux at the beginning of the experiment. The export/import ratio is an indication of the inverse retention potential of the seagrass bed (column 7). The reduction (%) is the percentage of nutrient and phosphorus retained by the seagrass plants and is calculated as 100 – (export/import × 100). Type of measurement and the original units are taken from each study. The studies are in ascending order according to alphabetical order of the names of seagrass species. NA: not applicable

Site	Species	Area m^2	Type of nutrient	Nutrient export g m^{-2} d^{-1}	Nutrient import g m^{-2} d^{-1}	Export/ import ratio	Reduction %	Type of measurements	Original units	Study
Cadiz, Spain Van Engeland et al. (2013)	*C. nodosa*	NA	NH_4^+ NO_3^- Urea	1.5	2	0.7	30	Incubations	μgN m^{-2} h^{-1}	1
Spermonde Archipelago, Indonesia Vonk & Stapel (2008)	*C. rotundata*	0.5	N	0.09	0.1	0.8	22	Model verified with litterbags	μmol l^{-1} h^{-1}	2
Spermonde Archipelago, Indonesia Vonk & Stapel (2008)	*H. uninervis*	0.5	N	0.106	0.112	1.0	5	Model verified with litterbags	μmol l^{-1} h^{-1}	3
Sitia, Greece Apostolaki et al. (2012)	*P. oceanica*	0.08	NH_4^+ NO_3^-	0.0001	0.0003	0.3	60	Incubations	μgN m^{-2} h^{-1}	4
Psaromoura, Greece Apostolaki et al. (2012)	*P. oceanica*	0.08	NH_4^+ NO_3^-	0.0002	0.001	0.2	79	Incubations	μgN m^{-2} h^{-1}	5
Spermonde Archipelago, Indonesia Vonk et al. (2008)	*T. hemprichii*	0.5	N	0.1	0.1	0.9	67	Model verified with litterbags	μmol l^{-1} h^{-1}	6
Florida, USA Cornelisen & Thomas (2006)	*T. testudinum*	3.7	NH_4^+ NO_3^-	0.0002	0.0006	0.4	57	Flume	gN $(gDW)^{-1}$ $s^{-1} \times 10^{-9}$	7
Florida, USA Cornelisen & Thomas (2006)	*T. testudinum*	3.7	NH_4^+ NO_3^-	0.0008	0.002	0.4	58	Flume	gN $(gDW)^{-1}$ $s^{-1} \times 10^{-9}$	8
Cadiz, Spain Van Engeland et al. (2013)	*Z. noltii*	NA	NH_4^+ NO_3^- Urea	1.1	1.5	0.7	30	Incubations	μgN m^{-2} h^{-1}	9
Algeciras Bay, Spain Pérez-Lloréns & Niell (1995)	*Z. noltii*	NA	P	0.00004	0.0001	0.7	35	Incubations	μgN m^{-2} h^{-1}	10

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