



# A Conceptual Approach towards Utilization of Technological Advancement for Coral Reef Conservation at India



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## Abstract

The unique coral reef ecosystem faces multiple stress factors from its surrounding coastal environment. Corals, an ancient marine form survived in many mass extinction events of geological past evolved to be the provider of many vital ecological services to our planet earth. Its fragility towards withstanding the pressures of fast developing coastal developments deserves conservation measures. This work conceptualizes the utility of technological advancements towards conservation of coral reef ecosystems.

## Introduction

Corals are found to be the ancient marine organisms, and they evolved 540 million years ago [1]. It is sensitive to light, and temperature levels, as well as corals, survived numerous mass extinction events in geological past [2-4]. Coral reefs are home for 25% of marine species and occupy less than 1% of the world's oceans, form a unique biodiversity reserve [5, 6]. This exceptional biodiversity has Net Primary Productivity (NPP) of 2500g C/ m<sup>2</sup>/year [7] and higher than tropical rainforest of 2200g C/m<sup>2</sup>/year [6] deserves conservation efforts. Its service to our planet earth has been classified in to four major heads regulating, provisional, cultural and supporting services. The regulating services includes carbon sequestration, ocean water filtration followed by provisioning of fish/shell fish protein for humans, jobs through fishing, building materials, medical and genetic research products. The cultural services includes Tourism, recreation, aesthetics to coast and supporting services like coastal erosion prevention and serves as nursery for fish juvenile continually maintaining fish stock. It is predicted that more than 75% worldwide coral reefs were under threat hence; a conceptual approach towards adopting modern technology for coral reef conservation has been studied.

## Coral Reef Health Status

According to WWF Living Planet Index [LPI,2016], a long-term measure of marine ecosystem health has declined by 36% between 1970 and 2012 with an average annual decline of 1 per cent (Figure 1). The health conditions were derived from summaries of 12,634 surveys conducted from 1975-2006 [8,9]. It suggests that coral reefs, sea-grass beds, and mangrove forests are slowly degraded

by the wide range of threats facing them. It might be caused by cumulative local and global pressures [10] various local and global pressures were consolidated and tabulated hereunder (Table 1). The Indian scenario of coral reef research as well as threats to coral reefs was summarized [11,12] and tabulated hereunder (Table 2). It is prominent that population pressure and associated effects, as well as siltation, contribute major threat to Indian coral reefs. Since coastal population pressure needs administrative controls through good management practices, sedimentation required technological interventions.

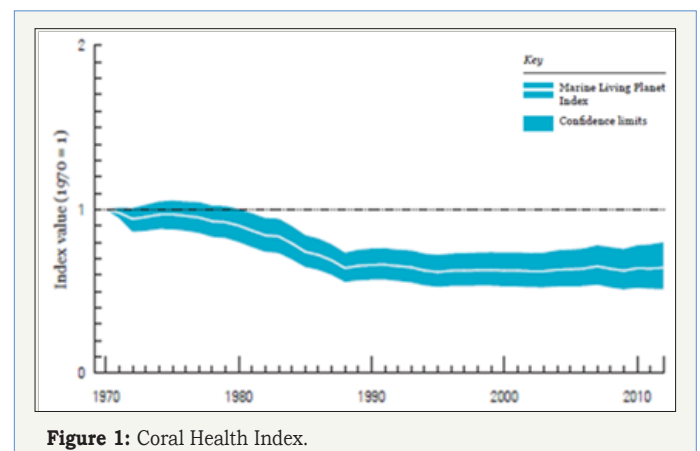


Figure 1: Coral Health Index.

## Impact of Sedimentation on Coral Reefs

The issues of turbidity and sedimentation at coral reefs have received increasing attention over the past decade [13-15]. Coral reefs are recognized as structures built by animal and plant forms

creates unique environment biologically. Their problem of siltation or sedimentation also found to be peculiar and not like most of the benthic ecosystem [16]. In general, sedimentation should be of exogenous origin from river runoff, wind or icebergs, or sediments from biological derivation such as the skeletons of plankton which settled from surface waters to the sea floor. On reef environment, the endogenous origin of sediment through death and decay of reef organism and physical, chemical and biological erosion of preexisting reef rock. This carbonate sediment spreads throughout the reef eco system and excess transported to the deep sea. However, the unprecedented coastal development along tropical shorelines is further augments the sediment load to the coral ecosystem. The exogenous sedimentation creates excess turbidity and reduces light intensity which is vital for photosynthesis and coral growth. By considering the sensitivity of corals to turbidity,

the effects of dredging has been prioritized. The deleterious effects of dredging in the lagoon and reefs of Lakshadweep were studied by [17] and some specific islands [18] along Indian coastal areas. However, the ever growing economic and societal demands necessitate activities like coastal constructions, land reclamation, beach nourishment and port construction along worldwide which are depending on dredging. The impact of dredging and other causes of sediment disturbances along corals reefs are primarily related to the concentration, duration, and frequency of exposure to elevated levels of turbidity and sedimentation [19]. In general, sedimentation leads to smothering of the reef, scouring of the reef by sediment laden waters, loss of bottom area suitable for settlement of larvae and reduction of light intensity due to turbidity. The elite responses of coral reef to sedimentations were documented [19] and tabulated (Table 3).

**Table 1:** Different threats to coral reef ecosystem.

S. Nos.	Local Pressures	Global Pressures
1	Overfishing, Destructive fishing (trawling, dynamite and cyanide fishing)	Alien species invasion, linked to changing Ocean temperatures
2	Tourism/diving damage	Coral bleaching due to rising global sea temperatures and stronger El Nino events
3	Siltation from onshore sediment flows, often linked to deforestation and farming erosion	Ocean acidification, due to increased ocean carbon dioxide levels, Weakening coral skeleton
4	Eutrophication from urban, industrial and farm pollution, Coral mining for building materials	Rising sea levels 'drowning' coral in deeper waters

**Table 2:** Different threats to Indian coral reef ecosystems.

Coral Reefs	Bio-Physical	Research	Perceived Threats
Palk Bay	Slow recovery from 60's coral mining	Mainly on Bio-physical aspects	Population pressure and associated effects
Gulf of Mannar	Slow recovery from 60's coral mining	Bio-physical aspects; associated fauna and Human activities damaging the reefs.	Population pressure and associated effects
Andaman & Nicobar	Fair Excellent, Problems around south island	Bio-physical aspects; associated fauna and Human activities damaging the reefs.	Siltation due to logging. Sand mining
Lakshadweep	Excellent off uninhabited islands and endangered along habited islands.	Bio-physical aspects; associated fauna and Human activities damaging the reefs.	Population pressure and associated effects
Gulf of Kutch	30% of the reefs are living	Bio-physical aspects; associated fauna and Human activities damaging the reefs.	Sedimentation and siltation due to cutting of mangrove forests, sand mining for industrial use. Population pressure
West coast	Unknown	Limited	Unknown

**Table 3:** Qualitative coral response to various environmental threats.

Coral Response	Sedimentation	Turbidity
<b>Stress</b>		
Photophysiological changes	Reduced photosynthetic efficiency zooxanthellae and autotrophic nutrition to coral	Reduced photosynthetic efficiency zooxanthellae and autotrophic nutrition to coral; switch to heterotrophic feeding, ingestion of sediment particles
Changes in polypactivity	Extrusion of mesenterial filaments following severe stress Increased ciliary or polyp activity and tissue expansion in some species, to remove sediment	Increased ciliary or polyp activity to feed
Mucus production	Increased mucus production or sheeting to remove sediment	Evidence of mucus production
Severe stress		

sediment accumulation	Accumulation of sediment on tissue of susceptible growth forms due to failure of mechanisms of rejection	
Change in coral colour	Change in coral colour arising from changes in the density of zooxanthellae and photosynthetic pigments  Paling of coral due to partial bleaching	Change in coral colour arising from changes in the density of zooxanthellae and photosynthetic pigments  Darkening of coral in response to reduced light due to photoacclimation
Bleaching	Considerable whitening of corals due to the expulsion of a large proportion of zooxanthellae from the colony  Injury to coral tissue, loss of polyps and partial mortality of the colony  Decrease in (live) coral cover	Not Known  Injury to coral tissue, loss of polyps and partial mortality of the colony Decrease in (live) coral cover
Partial mortality		
Mortality	Mortality of small-sized colonies and partial mortality of large corals	
	Mortality of susceptible species and size classes	
	Decreased density, diversity and coral cover	Decreased density ,diversity and coral cover
	Changes in community structure	Changes in community structure
	Wide-spread mortality of corals	Wide-spread mortality of corals
	Major decreases in density, diversity and coral cover	Major decreases in density, diversity and coral cover
	Dramatic changes in community structure ,and shifts towards the dominance of non-coral species, such as sponges and algae	Dramatic changes in community structure, and shifts towards the dominance of non-coral species, such as sponges and algae

However, the sensitivity of a coral reef to dredging impacts and its resilience depends on the ambient conditions habitually experienced. To understand the background concentrations of sedimentation among undisturbed reef environments were studied by [20,21] it mean value ranges from less than 1 to about 110mg cm<sup>-2</sup> d<sup>-1</sup> or <10 mg L<sup>-1</sup> of suspended sediment concentration. In India, sedimentation rate studies are limited, and the pristine reefs

of Lakshadweep islands recorded 2.69 to 124.49mgcm<sup>-2</sup>d<sup>-1</sup> [21]. The highest value was related to monsoonal effects of terrigenous runoff [15]. The data from Palk Bay during May to October 2004 varied between 1 to 42mgcm<sup>-2</sup>d<sup>-1</sup> [18]. The highest value was recorded during June 2004 heavy precipitation period. However extreme event like a tsunami of 26 December 2004 has elevated the sedimentation rate to 54mgcm<sup>-2</sup>d<sup>-1</sup> in the Palkbay area [22].

**Table 4:** Quantitative coral response to turbidity.

Coral Species	Turbidity Level (Tested)	Response	Growth Form	Calyx (Mm)	References
Acropora cervicornis (Lamarck,1816)	Severe light reduction (shading) for 5 weeks	Mass bleaching (3 weeks), mortality/algal cover (7 weeks), no recovery (8 months)	B	1	Rogers [23]
Acropora cervicornis (Lamarck,1816)	50mg/l (96h)	No effect	B	1	Thompson [24]
Acropora cervicornis (Lamarck,1816)	150mg/l (96h)	Polyp retraction, mucus production but no mortality	B	1	Thompson [24]
Acropora cervicornis (Lamarck,1816)	476rng/l (96h)	Partial mortality after 96h.	B	1	Thompson [24]
Acropora cervicornis (Lamarck,1816)	Total shading (3 weeks)	Bleaching and mortality, no recovery	B	1	Nieuwaal [25]
Acropora cervicornis (Lamarck,1816)	25 mg/l (drilling mud) (24h)	62% Decrease in calcification rate	B	1	Kendall et al. [26]
Acropora cervicornis (Lamarck,1816)	100mg/l (drilling mud)(24h)	50% Decline in soluble tissue protein	B	1	Kendall et al. [26]
Acropora cervicornis (Lamarck,1816)	50 and 100mg/l (kaolin,24h)	Reduced calcification rate and free amino acids at 100 mg/l (recovery in 48h)	B	1	Kendall et al. [27]
Acropora cervicornis (Lamarck,1816)	1000mg/l (for 65h)	Mortality of colonies	B	1	Thompson & Bright [28]
Acropora digitifera (larvae)	50-100mg/l (lab and field tests)	Adverse effects on fertilisation, larval survival and settlement	-	1	Gilmour [29]

Coral Species	Turbidity Level (Tested)	Response	Growth Form	Calyx (Mm)	References
<i>Acropora millepora</i> (Ehrenberg,1834)	1-30mg/l SPM (hours)	Increased feeding capacity at high SPM concentrations	B	1	Anthony [30]
<i>Acropora millepora</i> (Ehrenberg,1834)	1-30mg/l SPM (days)	Increasing contribution of heterotrophy at high SPM concentration	B	1	Anthony [31]
<i>Acropora millepora</i> (Ehrenberg,1834)	1, 3, 10, 30 and to 0mg/l TSS (16 weeks)	Full colony mortality at to 0 mg/l for 12 weeks (50% mortality after 4 weeks)	B	1	Negri et al. [32] & Flores et al. [33]
<i>Acropora nobilis</i> (Dana, 1846)	10mg/l (42 days)	Increased survival from high temperature treatment compared to control	L	1.5	Anthony et al. [34]
<i>Acropora</i> spp.	170mg/l (hours) of marine snow/SPM	Mucus production in response to flocculation	-	-	Fabricius & Wolanski [35]
<i>Agaricia agaricites</i> (Linnaeus,1758)	Severe light reduction (shading) for 5 weeks	Partial bleaching after 5 weeks, recovery within weeks	L	5	Rogers [23]
<i>Agaricia agaricites</i> (Linnaeus,1758)	50mg/l (96h)	No effect	L	5	Thompson [24]
<i>Agaricia agaricites</i> (Linnaeus,1758)	150mg/l (96h)	Polyp retraction, mucus production but no mortality	L	5	Thompson [24]
<i>Agaricia agaricites</i> (Linnaeus,1758)	476mg/l (96h)	Mortality after 65 h	L	5	Thompson [24]
<i>Agaricia agaricites</i> (Linnaeus,1758)	<1% SI (several days)	33% Decrease in calcification rate (for >1 month),but survival	L	5	Bak [36]
<i>Agaricia agaricites</i> (Linnaeus,1758)	1000mg/l (for 65h)	Mortality of colonies	L	5	Thompson & Bright [28]
<i>Cladocora arbuscula</i> (Lesueur,1812)	49, to, 165 and 199mg/l (10-20 days)	No effect on growth rate or survival (to d), minor bleaching (20 d)	B	4	Rice & Hunter [37]
<i>Colpophy Uianatans</i> (Houttuyn,1772)	Severe light reduction (shading) for 5 weeks	Partial bleaching (5 weeks), limited recovery & some algal growth (15 weeks)	M	25	Rogers [23]
<i>Dichacaenia stokes</i> (Milne Edward & Haime, 1848)	0-2 NTU and 7-9 NTU (weeks)	No effect on P:R ratio	M	11	Telesnicki & Goldberg [38]
<i>Dichacaenia stokes</i> (Milne Edward & Haime, 1848)	14-16 NTU (weeks)	Mucus production, P:R ratio <1 after 6 days exposure	M	11	Telesnicki & Goldberg [38]
<i>Dichacaenia stokes</i> (Milne Edward & Haime, 1848)	28-30 NTU (weeks)	Mucus production, P:R ratio <1 after 3 days exposure	M	11	Telesnicki & Goldberg [38]
<i>Dichacaenia stokes</i> (Milne Edward & Haime, 1848)	50-150-476mg/l (96h)	No effect at 50 and 150 mg/l: extreme sublethal stress but survival at 476 mg/l	M	11	Thompson [24]
<i>Dichacaenia stokes</i> (Milne Edward & Haime, 1848)	1000mg/l (for 65h)	No mortality	M	11	Thompson & Bright [28]
<i>Diploria labyrinthiformis</i> (Linnaeus, 1758)	Severe light reduction (shading) for 5 weeks	Substantial bleaching (5 weeks), no recovery & so algal growth (15 weeks)	M	8	Rogers [23]
<i>Eusmilia fastigiata</i> (Pallas, 1766)	severe light reduction (shading) for 5 weeks	No visible effects	M	12	Rogers [23]
<i>Favia fava</i> (Forskal, 1775)	Light reduced to 50% and 25% PAR (surface)	Severely diminished productivity, increased carbon loss and mucus	M	14	Riegl & Branch [39]
<i>Favites pentagona</i> (Esper, 1794)	Light reduced to 50% and 25% PAR (surface)	Severely diminished productivity, increased carbon loss and mucus	M	7	Riegl & Branch [39]
Fungiidae (mushroom corals)		Adapted to highly turbid environments			Dikou & Van Woesik [40,41]

Coral Species	Turbidity Level (Tested)	Response	Growth Form	Calyx (Mm)	References
<i>Galaxea fascicularis</i> (Linnaeus,1767)	>40 NTU (cAD d), at times up to 175 NTU	Shift from autotrophy to heterotrophy (reversible)	C	8	Larcombe et al. [42]
<i>Goniastrea retiformis</i> (Lamarck,1816)	Shading (equivalent to 16 mg/l <sup>2</sup> ) months	Increased particle feeding & heterotrophy; survival and tissue gains	M	4	Anthony & Fabricius [43]
<i>Goniastrea retiformis</i> (Lamarck.1816)	1-30mg/1 SPM (weeks)	Gained tissue & skeletal mass (all treatments); increasing heterotrophy	M	4	Anthony & Fabricius [43]
<i>Goniastrea retiformis</i> (Lamarck.1816)	1-16mg/l suspended matter (8 weeks)	Increased growth rate as function of SPM concentration	M	4	Anthony [44]
<i>Goniastrea retiformis</i> (Lamarck.1816)	Shading (equiv. 16mg/l at 4m) (8 weeks)	Significant reduction in growth rate	M	4	Anthony [44]
<i>Gorgonia flabellum</i> (Linnaeus, 1758)	Severe light reduction (shading) for 5 weeks	No visible effects	So		Rogers [23]
Gorgonians & soft corals	-	Very tolerant to high turbidity	-	-	Fabricius & Dommissie [45]
<i>Gyrosmlia interrupta</i> (Ehrenberg. 1834)	Light reduced to 50% and 25% PAR (surface)	Severely diminished productivity. Increased carbon loss and mucus	M/E	16	Riegl & Branch [39]
<i>Isophyllia sinuosa</i> (Ellis & Selander, 1786)	49.101.165 and 199mg/l (10-20 days)	No effect on growth rate or survival after 10 d. minor bleaching after 20 d	N	15	Rice & Hunter [37]
<i>Leptastrea</i> sp.	-	Well adapted to turbid waters	-	-	Dikou & Van Woesik [40,41]
<i>Lophytum depress</i> (Tixier Durivault, 1957)	Light reduced to 50% and 25% PAR (surface)	Severely diminished productivity, increased carbon loss and mucus	So	-	Riegl & Branch [39]
<i>Lophytum depress</i> (Tixier Durivault, 1957)	Light reduced to 50% and 25% PAR (surface)	Severely diminished productivity, increased carbon loss and mucus	So	-	Riegl & Branch [39]
<i>Madracis auretenra</i> (Locke, Well & Coates, 2007)	<1% SI (several days)	33% Decrease in calcification rate (for >1 month), but survival	B	1	Bak [36]
<i>Manicina Areolata</i> (Linnaeus, 1758)	49.101,165 and 199mg/l (10-20 days)	No effect on growth rate or survival after 10 d. minor bleaching after 20 d	M	14	Rice & Hunter [37]
<i>Meandrina meandrites</i> (Linnaeus, 1758)	0-2 NTU and 7-9 NTU (weeks)	No effect on P:R ratio	M/E	15	Telesnicki & Goldberg [38]
<i>Meandrina meandrites</i> (Linnaeus, 1758)	14-16 NTU (weeks)	Mucus production, P:R ratio < 1 after 6 days exposure	M/E	15	Telesnicki & Goldberg [38]
<i>Meandrina meandrites</i> (Linnaeus, 1758)	28-30 NTU (weeks)	Mucus production, P:R ratio < 1 after 3 days exposure	M/E	15	Telesnicki & Goldberg [38]
<i>Millepora alcornis</i> (Linnaeus,1758)	Severe light reduction (shading) for 5 weeks	Partial bleaching (5 weeks). algal growth (6 weeks). no recovery of damaged tissue	B	0.5	Rogers [23]
<i>Montastraea annularis</i> (Ellis & Selander, 1786)	Severe light reduction (shading) for 5 weeks	Substantial bleaching (5 weeks). partial recovery (6-8 weeks). some algae/mucus	M/E	5	Rogers [23]
<i>Montastraea annularis</i> (Ellis & Selander, 1786)	50m/l (96h)	No effect	M/E	5	Thompson [24]
<i>Montastraea annularis</i> (Ellis & Selander, 1786)	150mg/l (96h)	Polyp retraction. mucus production but no mortality	M/E	5	Thompson [24]
<i>Montastraea annularis</i> (Ellis & Selander, 1786)	476mg/l (96h)	Mortality after 65 h	M/E	5	Thompson [24]
<i>Montastraea annularis</i> (Ellis & Selander, 1786)	100mg/l (6-weeks)	Major sublethal effects (photosynthesis, respiration. calcification & nutr.uptake)	M/E	5	Szman-Froelich et al. [46]

Coral Species	Turbidity Level (Tested)	Response	Growth Form	Calyx (Mm)	References
Montastraea annularis (Ellis & Selander, 1786)	1-10mg/l (6 weeks)	Only (some) effect on feeding response	M/E	5	Szmant-Froelich et al. [46]
Montastraea annularis (Ellis & Selander, 1786)	525mg/l	Decreased net production & tissue Chl, increased respiration & mucus	M/E	5	Dallmeyer et al. [47]
Montastraea annularis (Ellis & Selander, 1786)	1000 mg/l (for 65h)	Mortality of colonies	M/E	5	Thompson & Bright [28]
Montastraea cavernosa (Linnaeus, 1767)	Severe light reduction (shading) for 5 weeks	No visible effects	M	11	Rogers [23]
Montipora aequituberculata (Bernard, 1897)	-	Common on shallow. turbid inshore fringing reefs	F	0.6	Stafford-Smith [48]
Montipora aequituberculata (Bernard, 1897)	1, 3, 10, 30 and 100 mg/l TSS (16 weeks)	Full colony mortality at 30 mg/l after 12 weeks (50% mortality after 4 weeks)	F	0.6	Negri et al. [32] & Flores et al. [33]
Montipora capitata (Dana, 1846)	Light reduction from 57 to 44% SI (field; hours)	Photophysiological sublethal response; 1.4 times lower rETR, higher Fv/Fm	B	1	Piniak & Storlazzi [49]
Montipora digitata (Dana, 1846)	1-30mg/l SPM (hours)	Increased feeding capacity at high SPM concentrations	B	1	Anthony [30]
Montipora digitata (Dana, 1846)	>95% shading (transplanted Hoegh into caves)	Survival/acclimation, reduced photosynthetic rate	L	1	Anthony & Hoegh-Guldberg [50]
Montipora digitata (Dana, 1846)	70% light reduction (permanent transplantation)	Complete photo acclimation within 3 weeks	L	1	Anthony & Hoegh-Guldberg [50]
Montipora verrucosa (Lamarck, 1816)	8 and 20 mg/l (modelling)	Reduced photosynthesis at 8 mg/l; negative energy balance at 20 mg/l	M/L	1	Te [51]
Montipora sp.	-	Well adapted to turbid waters	-	-	Dikou & Van Woesik [40,41]
Mussaangulosa (Pallas, 1766)	Severe light reduction (shading) for 5 weeks	No visible effects (1 colony showing minor bleaching after 8 weeks)	M	40	Rogers [23]
Pectinialactuca (Pallas, 1766) (larvae)	6, 43 and 169 mg/l (lab test)	Adverse effects on fertilisation success and embryo development	-	-	Erfteimeijer et al. [52]
Pectinia sp.	-	Well adapted to turbid waters	-	-	Dikou & Van Woesik [40,41]
Phyllangia Americana (Milne Edwards & Hairne, 1849)	49, 101, 165 and 199 mg/l (10-20 days)	No effect on growth rate or survival after 10 d, minor bleaching after 20 d	E	9	Rice & Hunter [37]
Platygyra daedalea (Ellis & Solander, 1786)	Light reduced to 50% and 25% PAR (surface)	Severely diminished productivity, increased carbon loss and mucus	M	5	Riegl & Branch [39]
Pocilloporadamicomis (Linnaeus, 1758)	1-30 mg/l SPM (hours)	Increased feeding capacity at high SPM concentrations	B	1.1	Anthony [30]
Pocilloporadamicomis (Linnaeus, 1758)	1-30mg/l SPM (days)	Increasing contribution of heterotrophy at high SPM concentration	B	1.1	Anthony [31]
Pocilloporadamicomis (Linnaeus, 1758) (larvae)	10, 100, 1000 mg/l (modelling)	Reverse metamorphosis (reduced settlement success) at 100 and 1000 mg/l	B	1.1	Te [51]
Pocilloporadamicomis (Linnaeus, 1758)	-	Characteristic of turbid waters	B	1.1	Dikou & Van Woesik [40,41]

Coral Species	Turbidity Level (Tested)	Response	Growth Form	Calyx (Mm)	References
Porites astreoides (Lamarck, 1816)	50-150-476mg/l (96 h)	No effect at 50 and 150 mg/l: extreme sublethal stress (but survival) at 476 mg/l	M/E	1.5	Thompson [24]
Porites astreoides (Lamarck, 1816)	<1% SI (several days)	Bleaching and mortality	M/E	1.5	Bak [36]
Porites astreoides (Lamarck, 1816)	1000mg/l (for 65 h)	No mortality	M/E	1.5	Thompson & Bright [28]
Porites cylindrica (Dana, 1821)	Shading (equivalent to 16mg/l) - 2 months	Energy deficiency/C-loss not compensated by particle feeding; sublethal stress	M	1.5	Anthony & Fabricius [43]
Porites cylindrica (Dana, 1821)	1-30mg/l SPM (weeks)	Skeletal growth sustained, tissue biomass decreased at high SPM	M	1.5	Anthony & Fabricius [43]
Porites cylindrica (Dana, 1821)	1-30mg/l SPM (hours)	Increased feeding capacity at high SPM concentrations	M	1.5	Anthony [30]
Porites cylindrica (Dana, 1821)	1-16mg/l suspended matter (8 weeks)	No effect on growth rates	M	1.5	Anthony [44]
Porites cylindrica (Dana, 1821)	Shading (equiv. 16mg/l at 4m) (8 weeks)	Significant reduction in growth rate	M	1.5	Anthony [44]
Porites divaricate (Lesueur, 1821)	50-150-476mg/l (96 h)	No effect at 50 and 150 mg/l: extreme sublethal stress (but survival) at 476 mg/l	B	1.2	Thompson [24]
Porites divaricate (Lesueur, 1821)	1000mg/l (for 65 h)	No mortality	B	1.2	Thompson & Bright [28]
Porites utcata (Lamarck, 1816)	50-150-476mg/l (96 h)	No effect at 50 and 150 mg/l: extreme sublethal stress (but survival) at 476 mg/l	B	2	Thompson [24]
Porites utcata (Lamarck, 1816)	1000mg/l (for 65h)	No mortality	B	2	Thompson & Bright [28]
Porites lobata (Dana, 1846)	-	Dominant in turbid waters	-	-	Stafford-Smith [48]
Porites lutea (Milne Edwards & Haime, 1851)	-	Dominant in turbid waters	M	1.5	Stafford-Smith [48]
Porites lutea (Milne Edwards & Haime, 1851)	Increased turbidity up to 286mg/l (4 months)	Partial mortality of 25% of colonies, recovery within 22 months	M	1.5	Brown et al. [53]
Porites (Pallas, 1766)	Significant light reduction due to eutrophication	Reduced reproductive success (ova maturation, larval development)	M	2	Tomascik & Sander [54]
Porites sp.	General increase in SPM	Decreasing tissue thickness from nearshore to offshore	-	-	Barnes & Lough [55]
Porites sp.	General increase in SPM	Decreasing skeletal density, linear extension, increasing calcification	-	-	Lough & Barnes [56,57]
Sarcophytonglaucum (Quoy & Gaimard, 1833)	Light reduced to 50% and 25% PAR (surface)	Severely diminished productivity, increased carbon loss and mucus	So	-	Riegl & Branch [39]

Coral Species	Turbidity Level (Tested)	Response	Growth Form	Calyx (Mm)	References
<i>Scolymiacubensis</i> (Milne Edwards & Haime, 1849)	49,101,165 and 199mg/l (10-20 days)	No effect on growth rate or survival after 10 d, minor bleaching after 20 d	S	91	Rice & Hunter [37]
<i>Scolymiacubensis</i> (Milne Edwards & Haime, 1849)	49-199mg/l (10 days)	Partial polyp death and partial bleaching (in some individuals)	S	91	Rice [58]
<i>Siderastrea radians</i> (Pallas, 1766)	49-199mg/l (10 days)	Partial polyp death and partial bleaching (in some individuals)	M/E	5	Rice [58]
<i>Siderastreasiderea</i> (Ellis & So/ander, 1786)	Severe light reduction (shading) for 5 weeks	Partial bleaching after 5 weeks, partial recovery in 6-8 weeks	M	3	Rogers [23]
<i>Sinularia dura</i> (Pratt, 1903)	Light reduced to 50% and 25% PAR (surface)	Severely diminished productivity, increased carbon loss and mucus	So	-	Riegl & Branch [39]
<i>Sinularialeptoelados</i> (Ehrenberg, 1834)	Light reduced to 50% and 25% PAR (surface)	Severely diminished productivity, increased carbon loss and mucus	So	-	Riegl & Branch [39]
<i>Solenastrea hyades</i> (Dana, 1846)	49,101,165 and 199mg/l (10-20 days)	No effect on growth rate or survival after 10 d, minor bleaching after 20 d	M	5	Rice & Hunter [37]
<i>Solenastrea hyades</i> (Dana, 1846)	49-199mg/l (10 days)	Partial polyp death and partial bleaching (in some individuals)	M	5	Rice [58]
<i>Stephanocoenia intersepta</i> (Lamarck, 1816)	49,101,165 and 199mg/l (10-20 days)	No effect on growth rate or survival after 10 d, minor bleaching after 20 d	M	3	Rice & Hunter [37]
<i>Stephanocoenia intersepta</i> (Lamarck, 1816)	49-199mg/l (10 days)	Partial polyp death and partial bleaching (in some individuals)	M	3	Rice [58]
<i>Turbinaria mesenterina</i> (Lamarck, 1816)	-	Tolerant to high turbidity	L	1.5	Nieuwaal [25]
<i>Turbinaria reniformis</i> (Bernard, 1896)	-	Tolerant to high turbidity	L	2	Nieuwaal [25]
<i>Turbinaria</i> spp.	-	Most tolerant to high turbidity and sedimentation			Stoddart & Stoddart [59]

Abbreviations used in the tables are B-Branching; C-Columnar; (including digitate); E-Encrusting; F-Foliaceous; L-Laminar (including plate & Tabular); M-Massive; S-Solitary (Free-living); So-Soft corals & Gorgonians. Calyx diameter measured on museum specimens, supplemented with data from Stafford-Smith & Ormond (1992).

**Table 5:** Quantitative coral response to sedimentation

Coral species	Sedimentation rate (tested)	Response	Growth form	Calyx (mm)	References
<i>Acropora cervicornis</i> (Lamarck, 1816)	200 mg/m <sup>2</sup> /d (daily for 45 days)	No effect (not even on growth rate) even after 45 days	B	1	Rogers [23]
<i>Acropora cervicornis</i> (Lamarck, 1816)	200mg cm <sup>-2</sup> d <sup>-1</sup> (daily)	No effect	B	1	Rogers [21]
<i>Acropora cervicornis</i> (Lamarck, 1816)	430 mg cm <sup>-2</sup> d <sup>-1</sup> (>1 day)	Physiological stress	B	1	Bak & Elgershuizen [63]



Coral species	Sedimentation rate (tested)	Response	Growth form	Calyx (mm)	References
<i>Acropora cervicornis</i> (Lamarck, 1816)	Burial (10-12cm of reef sand)	Sublethal stress within 12 h; 100% mortality within 72 h	B	1	Thompson [64]
<i>Acropora formosa</i> (Dana, 1846)	Up to 14.6 mg/m <sup>2</sup> /d (fine silt) due to dredging	No effect on growth rate (in situ)	B	1.2	Chansang et al. [65]
<i>Acropora formosa</i> (Dana, 1846)	200-300 mg cm <sup>-2</sup> d <sup>-1</sup> (up to 7 days)	Decreased growth	B	1.2	Simpson [66]
<i>Acropora millepora</i> (Ehrenberg, 1834) (larvae)	0.5-325 mg cm <sup>-2</sup> d <sup>-1</sup> (2 days)	Reduction of larval settlement	-	-	Babcock [67]
<i>Acropora millepora</i> (Ehrenberg, 1834)	83 mg cm <sup>-2</sup> d <sup>-1</sup> (up to 16 weeks)	Onset mortality after 4 weeks, full mortality after 12 weeks	B	1	Negri et al. [32] & Flores et al. [33]
<i>Acropora palifera</i> (Lamarck 1816)	Field site comparison (<1 versus 13.5mg cm <sup>-2</sup> d <sup>-1</sup> )	Reduced fecundity at the site with higher sedimentation	L	2	Kojis &Quinn [68]
<i>Acropora palmata</i> (Lamarck, 1816)	Up to 600 mg cm <sup>-2</sup> d <sup>-1</sup> (natural events)	Poor rejection ability; sediment accumulation	B	2	Abdel-Salam & Porter [69]
<i>Acropora palmata</i> (Lamarck, 1816)	430 mg cm <sup>-2</sup> d <sup>-1</sup> (>1 day)	Physiological stress	B	2	Bak & Elgershuizen [63]
<i>Acropora palmata</i> (Lamarck, 1816)	200 mg cm <sup>-2</sup> d <sup>-1</sup> (once)	Partial mortality	B	2	Rogers [70]
<i>Acropora palmata</i> (Lamarck, 1816)	200 mg cm <sup>-2</sup> d <sup>-1</sup> (field application)	Death of underlying tissue	B	2	Rogers [21]

Coral species	Sedimentation rate (tested)	Response	Growth form	Calyx (mm)	References
<i>Acropora palmata</i> (Lamarck, 1816)	Burial (10-12cm of reef sand)	100% mortality within 72 h	B	2	Thompson [64]
<i>Acropora</i> sp.	5 mg cm <sup>-2</sup> d <sup>-1</sup>	Massive mucus production (within 1 h). Sublethal	-	-	Fabricius & Wolanski [35]
<i>Acropora</i> sp.	Burial for 20 h	Mortality of all colonies	-	-	Wesseling et al. [71]
<i>Acropora</i> sp.	39.6 mg cm <sup>-2</sup> d <sup>-1</sup> (for 2 weeks)	Partial bleaching (less affected)	-	-	Fabricius et al. [72]
<i>Agaricia agaricites</i> (Linnaeus, 1758)	Heavy sedimentation event (>1 cm)	Reduced growth but survival	L	5	Bak [36]
<i>Agaricia agaricites</i> (Linnaeus, 1758)	430 mg cm <sup>-2</sup> d <sup>-1</sup> (sand)	Mortality after 1 day	L	5	Bak & Elgershuizen [63]
<i>Agaricia agaricites</i> (Linnaeus, 1758)	Burial (10-12 cm of reef sand)	60% Tissue loss within 24 h; 100% mortality after 72 h	L	5	Thompson [64]
<i>Agaricia lamarcki</i> (Milne Edwards & Haime, 1851)	140 mg/m <sup>2</sup> /d (mean) for several weeks	Mass mortality (4 years after the steep decline in growth)	L	8	Van 't Hof [73]
<i>Agaricia</i> sp.	30 mg/m <sup>2</sup> /d (natural)	No effect: dominant species	-	-	Loya [74]
<i>Atveopora</i> sp.	-	Can survive high sedimentation rates	-	-	Stafford-Smith & Ormond [75]
<i>Astrangia poculata</i> (Ellis Solander, 1786)	<600 mg cm <sup>-2</sup> d <sup>-1</sup>	Survival	S	6	Peters & Pilson [76]

Coral species	Sedimentation rate (tested)	Response	Growth form	Calyx (mm)	References
<i>Catalaphyllia jardinei</i> (Saville-Kent, 1893)	-	Survive high sedimentation rates	M	40	Stafford-Smith & Ormond [75]
<i>Cladocora arbuscula</i> (Lesueur, 1812)	Complete burial	50% Survival after 15 days	B	4	Rice & Hunter [37]
<i>Ctenactis echinata</i> (Pallas, 1766)	Continuously repeated burial (sand)	Tissue mortality and colony death after 24-72h	S	200	Schuhmacher [77]
<i>Cycloseris costulata</i> (Ortmann, 1889)	Continuously repeated burial (sand)	Survival (endurance with no apparent effect)	S	15	Schuhmacher [77]
<i>Cycloseris costulata</i> (Ortmann, 1889)	40 mm <sup>3</sup> /cm <sup>2</sup> /d	Maximum rate tolerated (field gradient)	S	15	Schuhmacher [77]
<i>Cycloseris distorta</i> (Michelin, 1842)	-	Efficient sediment rejector (polyp inflation)	S	7.5	Schuhmacher [77]
<i>Cycloseris</i> spp.	-	Can actively dig through overlying sediment	-	-	Stafford-Smith & Ormond [75]
<i>Danafungta horrida</i> (Dana, 1846)	Continuously repeated burial (sand)	Tissue mortality and colony death after 24-72h	S	215	Schuhmacher [77]
<i>Danajungia scruposa</i> (Klunzinger, 1879)	Continuously repeated burial (sand)	Tissue mortality and colony death after 24-72h	S	380	Schuhmacher [77]
<i>Dichococnia stokes</i> (Milne Edwards & Haime, 1848)	430 mg cm <sup>-2</sup> d <sup>-1</sup> (sand + oil)	Mortality after 1 day	M	11	Bak & Elgershuizen [63]

Coral species	Sedimentation rate (tested)	Response	Growth form	Calyx (mm)	References
<i>Diploastrea ellopora</i> (Lamarck, 1816)	20 mg cm <sup>-2</sup> d <sup>-1</sup> (mixed sand)	Survival (4 months)	M	14	Todd et al. [78]
<i>Diporia clivosa</i> (Ellis & Solander, 1786)	Repeated application of 200 mg/ cm <sup>2</sup>	Extensive damage	M	9	Rogers [79]
<i>Diploria labyrinthiformis</i> (Linnaeus, 1758)	High sedimentation rates (dredging)	Survival (no effect)	M	8	Dodge & Vaisnys [80]
<i>Diploria strigosa</i> (Dana, 1846)	Up to 600 mg cm <sup>-2</sup> d <sup>-1</sup> (natural events)	High sediment clearing rate	M	8	Abdel-Salam & Porter [69]
<i>Diploria strigosa</i> (Dana, 1846)	200 mg cm <sup>-2</sup> d <sup>-1</sup> (daily)	No effect	M	8	Rogers [21]
<i>Diploria strigosa</i> (Dana, 1846)	High sedimentation rates (dredging)	Mass mortality (4 years after the steep decline in growth)	M	8	Dodge & Vaisnys [80]
<i>Diploria strigosa</i> (Dana, 1846)	Burial (10-12cm of reef sand)	Partial bleaching and sub lethal stress within 24 h	M	8	Thompson [64]
<i>Duncanopsammia axifuga</i> (Milne Edwards & Halme, 1848)	-	Can survive high sedimentation rates	B	14	Stafford-Smith & Ormond [75]
<i>Ecitonopora</i> spp.	-	Active sediment rejecter	-	-	Stafford-Smith & Ormond [75]
<i>Echinopora mammiformis</i> (Nemenzo, 1959)	-	Active sediment rejecter	L	5	Stafford-Smith & Ormond [75]

Coral species	Sedimentation rate (tested)	Response	Growth form	Calyx (mm)	References
Euphyllia spp.	-	Can survive high sedimentation rates	-	-	Stafford-Smith & Ormond [75]
Favia favaus (Forskal, 1775)	200 mg cm <sup>-2</sup> d <sup>-1</sup> (6 weeks)	Minor tissue damage, mucus production, no bleaching	M	14,0	Riegl [81] & Bloomer [82]
Favia speciosa (Dana, 1846)	20 mg cm <sup>-2</sup> d <sup>-1</sup> (mixed sand)	Survival (4 months)	M	12	Todd et al. [78]
Favia sp.	(0.9-1.3 mg/m <sup>2</sup> /day)	Described as relatively 'sensitive' to sedimentation	-	-	McClanahan & Obura [93]
Favia stelligera (Dana, 1846)	200 mg cm <sup>-2</sup> d <sup>-1</sup>	Mortality within 1-2 days	M	6	Stafford-Smith [48]
Favites pentagona (Esper, 1794)	200 mg cm <sup>-2</sup> d <sup>-1</sup> (6 weeks)	Tissue damage, mucus production	M	7	Riegl [81] & Bloomer [82]
Favites spp.	(between 1.3 and 4 mg cm <sup>-2</sup> d <sup>-1</sup> )	Tolerance to sedimentation described as 'intermediate.'	-	-	McClanahan & Obura [83]
Fungia fungites (Linnaeus, 1758)	Continuously repeated burial (sand)	Tissue mortality and colony death after 24-72 h	S	310	Schuhmacher [77]
Fungia fungites (Linnaeus, 1758)	10 mm <sup>3</sup> /cm <sup>2</sup> /d	Maximum rate tolerated	S	310	Schuhmacher [77]
Galaxea fascicularis (Linnaeus, 1767)	39.6 mg cm <sup>-2</sup> (for 2 weeks)	Sublethal (sed.accum.), act removal (polyp), recovery	M	8	Fabricius et al. [72]

Coral species	Sedimentation rate (tested)	Response	Growth form	Calyx (mm)	References
<i>Galaxea fascicularis</i> (Linnaeus, 1767)	Burial for 20 h	Tissue bleaching, recovery after 4 weeks	M	8	Wesseling et al. [71]
<i>Galaxea</i> spp.	(4 mg/m <sup>2</sup> /day)	Tolerance to sedimentation described as 'intermediate'	-	-	McClanahan & Obura [83]
<i>Gardineroseris planulata</i> (Dana, 1846)	200 mg cm <sup>-2</sup> d <sup>-1</sup>	Partial mortality after 6 days	M	7	Stafford-Smith [48]
<i>Goniastrea retiformis</i> (Lamarck, 1816)	-	Common on reefs affected by sedimentation	M	4	Brown & Howard [84]
<i>Goniopora lobate</i> (Milne Edwards & Haime, 1860)	-	Active sediment rejecter	s	4	Stafford-Smith & Ormond [75]
<i>Goniopora</i> spp.	-	Survive high sedimentation rates	-	-	Stafford-Smith & Ormond [75]
<i>Gyrosmlia nterrupta</i> (Ehrenberg, 1834)	200 mg cm <sup>-2</sup> d <sup>-1</sup> (6 weeks)	Tissue damage, mucus production, no bleaching	M/E	16	Riegl [81] & Riegl and Bloomer [82]
<i>Heliofungia actiniformis</i> (Quoy & Gaimard, 1833)	-	Efficient sediment rejecter (polyp inflation)	S	210	Schuhmacher [77]
<i>Helioporu coerulea</i> (Pallas, 1766)	Burial for 20 h	Tissue bleaching, recovery after 4 weeks	B	0.8	Wesseling et al. [71]
<i>Heteropsammia cochlea</i> (Spengler, 1783)	-	Obligate commensal sipunculid prevents burial	S	7	Stafford-Smith & Ormond [75]

Coral species	Sedimentation rate (tested)	Response	Growth form	Calyx (mm)	References
Hydnophora spp.	(4 mg/m <sup>2</sup> /day)	Tolerance to sedimentation described as 'intermediate.'	-	-	McClanahan & Obura [83]
Isopora polifera (Lamarck, 1816)	10-15 mg cm <sup>-2</sup> d <sup>-1</sup>	50% Reduction in fecundity	C	2	Kojis & Quinn [68]
Isophyllia sinuous (Ellis & Solander, 1786)	Complete burial	50% Survival after 7.2 days	M	15	Rice & Hunter [37]
Leptoria phrygia (Ellis & Solander, 1786)	25 mg cm <sup>-2</sup> d <sup>-1</sup>	Minor tissue damage within 3 weeks	-	4.1	Stafford-Smith [85]
Leptoria phrygia (Ellis & Solander, 1786)	50-100 mg cm <sup>-2</sup> d <sup>-1</sup>	Major tissue damage and bleaching after 4 days	M	4.1	Stafford-Smith [85]
Leptoria phrygia (Ellis & Solander, 1786)	100-200 mg cm <sup>-2</sup> d <sup>-1</sup>	Partial mortality and bleaching after 4 days	M	4.1	Stafford-Smith [85]
Leptoria phrygia (Ellis & Solander, 1786)	>200 mg cm <sup>-2</sup> d <sup>-1</sup>	Mortality within 1-2 days	M	4.1	Stafford-Smith [85], [48]
Lobophytum depressum (Tixier-Durivault, 1966)	200 mg cm <sup>-2</sup> d <sup>-1</sup> (6 weeks)	Tissue damage, bleaching, and partial mortality	So	-	Riegl [81] & Riegl & Bloomer [82]
Lobophytum venustum (Tixier-Durivault, 1957)	200 mg cm <sup>-2</sup> d <sup>-1</sup> (6 weeks)	Minor tissue damage and bleaching	So	-	Riegl [81] & Riegl & Bloomer [82]
Madracis auretenra (Locke, Well & Coates, 2007)	Heavy sedimentation event (>1 cm)	Reduced growth but survival	B	1	Bak [36]

Coral species	Sedimentation rate (tested)	Response	Growth form	Calyx (mm)	References
Manicina areolata (Linnaeus, 1758)	Complete burial	50% Survival after 10 days	M	23	Rice & Hunter [37]
Meandrina meandrites (Linnaeus, 1758)	-	Produces copious amounts of mucus to remove silt	M	15	Dumas & Thomassin [86]
Millepora spp.	(4 mg/m <sup>2</sup> /day)	Tolerance to sedimentation described as 'intermediate.'	-	-	McClanahan & Obura [83]
Montastraea annularis (Ellis & Solander, 1786)	-	High sediment clearing rate	M/E	5	Abdel-Salam & Porter [69]
Montastraea annularis (Ellis & Solander, 1786)	200 mg cm <sup>-2</sup> d <sup>-1</sup> (daily applications)	Tolerant for at least 38 days	L/E	5	Rogers [23]
Montastraea annularis (Ellis & Solander, 1786)	400-800 mg cm <sup>-2</sup> d <sup>-1</sup> (single application)	Mortality	M	5	Rogers [23]
Montastraea annularis (Ellis & Solander, 1786)	19 mg cm <sup>-2</sup> d <sup>-1</sup> (permanent)	Reduced growth rate	M/E	5	Torres [87]
Montastraea annularis (Ellis & Solander, 1786)	200 mg cm <sup>-2</sup> d <sup>-1</sup> (daily)	No effect	M/E	5	Rogers [21]
Montastraea annularis (Ellis & Solander, 1786)	400 mg cm <sup>-2</sup> d <sup>-1</sup>	Temporary bleaching	M/E	5	Rogers [21]



Coral species	Sedimentation rate (tested)	Response	Growth form	Calyx (mm)	References
Montastraea annularis (Ellis & Solander, 1786)	800 mg cm <sup>-2</sup> d <sup>-1</sup>	Death of underlying tissue	M/E	5	Rogers [21]
Montastraea annularis (Ellis & Solander, 1786)	800 mg cm <sup>-2</sup> d <sup>-1</sup> (single application)	Mortality	M/E	5	Rogers [21]
Montastraea annularis (Ellis & Solander, 1786)	430 mg cm <sup>-2</sup> d <sup>-1</sup> (sand + oil)	Mortality after 1 day	L/M	5	Bak & Elgetshuizen [63]
Montastraea annularis (Ellis & Solander, 1786)	10 mg cm <sup>-2</sup> d <sup>-1</sup> (natural)	Reduced %cover	M	5	Torres & Morelock [87]
Montastraea annularis (Ellis & Solander, 1786)	19 mg cm <sup>-2</sup> d <sup>-1</sup> (resuspended carbonate mud)	Reduced growth rate	M	5	Dodge et al. [28]
Montastraea annularis (Ellis & Solander, 1786)	Burial (10-12 cm of reef sand)	40% Tissue loss within 24 h; 90% tissue loss within 72 h	M	5	Thompson [64]
Montastraea annularis (Ellis & Solander, 1786)	-	Produces little mucus; removes silt by ciliary action	M	5	Dumas & Thomassin [86]
Montastraea cavernosa (Linnaeus, 1767)	<1390 mg cm <sup>-2</sup> d <sup>-1</sup>	Survival	M	11	Lasker [89]
Montastraea cavernosa (Linnaeus, 1767)	150 mg/m <sup>2</sup> /d (natural)	Survival/dominance	M	11	Loya [74]
Montastraea cavernosa (Linnaeus, 1767)	Burial (10-12cm of reef sand)	30% Tissue loss after 72 h: remaining tissue in decay	M	11	Thompson [64]

Coral species	Sedimentation rate (tested)	Response	Growth form	Calyx (mm)	References
<i>Montipora aequituberculata</i> (Bernard, 1897)	200 mg cm <sup>-2</sup> d <sup>-1</sup>	Bleaching after 6 days (but no mortality)	L	0.6	Stafford-Smith [48]
<i>Montipora aequituberculata</i> (Bernard, 1897)	25 mg cm <sup>-2</sup> d <sup>-1</sup> (up to 16 weeks)	Onset mortality after 4 weeks, full mortality after 12 weeks	F	0.6	Negri et al. [90] & Flores et al. [33]
<i>Montipora capdata</i> (Dana, 1846)	Burial (2.2-2.8 g/cm <sup>2</sup> for 45 h)	sub lethal effects after 30 h, little recovery after 90 h	B	2	Pinlaic [91]
<i>Montipora foliosa</i> (Pallas, 1766)	-	Active sediment rejecter	L	0.7	Stafford-Smith & Ormond [75]
<i>Montipora peltifortnis</i> (Bernard, 1897)	33-160 mg/cm <sup>2</sup> (silt) exposure for 36 h	Reduced photosynthesis within 12- 60 h	F	1	Weber et al. [92]
<i>Montipora peltifortnis</i> (Bernard, 1897)	79-234 mg/cm <sup>2</sup> (up to 36 h)	Significant decline in photosynthesis (quantum yield)	M/L	1	Philipp & Fabricius [93]
<i>Montipora</i> spp.	(0.9-1.3 mg/m <sup>2</sup> /day)	Described as 'sensitive' to sedimentation	-	-	McClanahan & Obura [83]
<i>Montipora verrucosa</i> (Lamarck, 1816)	30 mg cm <sup>-2</sup> d <sup>-1</sup> (daily applications)	Survived (10 days of application)	M	1.5	Hodgson [94]
<i>Mycetophyllia aliciae</i> (Wells, 1973)	430 mg cm <sup>-2</sup> d <sup>-1</sup> (sand + oil)	Mortality after 1 day	L	14	Bak & Eigershulzen [63]
<i>Oxypora giabra</i> (Nemenzo, 1959)	30 mg cm <sup>-2</sup> d <sup>-1</sup> (daily applications)	Total mortality within 10 days	L/E	5	Hodgson [94]
<i>Pectinia lactuca</i> (Pallas, 1766)	-	Active sediment rejecter	L	18	Stafford-Smith & Ormond [75]

Coral species	Sedimentation rate (tested)	Response	Growth form	Calyx (mm)	References
<i>Pectinia paeonia</i> (Dana, 1846)	-	Active sediment rejecter	L	15	Stafford-Smith & Ormond [75]
<i>Pectinia</i> sp.	-	Active sediment rejecter	-	-	Stafford-Smith & Ormond [75]
<i>Platygyra daertalea</i> (Ellis & Solander, 1786)	200 mg cm <sup>-2</sup> d <sup>-1</sup> (6 weeks)	Minor tissue damage, mucus production, no bleaching	M	5	Riegl [81] & Riegl & Bloomer [82]
<i>Platygyra sinensis</i> (Milne Edwards & Haime, 1849)	Complete burial	Bleaching and tissue damage after 48 h	M	4	Wong [95]
<i>Platygyra</i> spp.	(4 mg/m <sup>2</sup> /day)	Tolerance to sedimentation described as 'intermediate.'	-	-	McClanahan & Obura [83]
<i>Pteuractis granulosa</i> (Klunzinger, 1879)	Continuously repeated burial (sand)	Survival (high endurance with no apparent effect)	S	185	Schuhmacher [77]
<i>Pteuractis granulosa</i> (Klunzinger, 1879)	15 mm <sup>3</sup> /cm <sup>2</sup> /d	Maximum rate tolerated	S	185	Schuhmacher [77]
<i>Pteuractis moluccensis</i> (Van der Horst, 1919)	-	Adapted to withstand considerable sedimentation rates	S	19	Schuhmacher [77]
<i>Pocillopora damicornis</i> (Linnaeus, 1758)	50-95% sediment cover	Complete inhibition of larval settlement	B	1	Hodgson [96]
<i>Pocillopora damicornis</i> (Linnaeus, 1758)	67 and 186 mg cm <sup>-2</sup> d <sup>-1</sup> (fine silt; 83 days)	50-100% Mortality of transplanted (esp. small)	B	1	Sakai et al. [97]

Coral species	Sedimentation rate (tested)	Response	Growth form	Calyx (mm)	References
<i>Pocillopora darnicomis</i> (Linnaeus, 1758)	11-490 mg cm <sup>-2</sup> d <sup>-1</sup> (11 months)	The reduced growth rate of transplanted	B	1	Piniak & Brown [98]
<i>Pocillopora meandrina</i> (Dana, 1846)	30 mg cm <sup>-2</sup> d <sup>-1</sup> (daily applications)	Mortality within 10 days	B	1	Hodgson [94]
<i>Pocillopora</i> sp.	Increased sedimentation (dredging)	Considerable mortality	-	-	Hudson et al. [99]
<i>Pocillopora</i> app.	(0.9-1.3 mg/m <sup>2</sup> /day)	Described as 'sensitive' to sedimentation	-	-	McClanahan & Obura [83]
<i>Porites astreoides</i> (Lamarck, 1816)	Heavy sedimentation event (>1 cm)	Mortality (inability to reject sediment)	L	1.5	Bak [36]
<i>Porites astreoides</i> (Lamarck, 1816)	-	Abundant in heavily sedimented areas	M	1.5	Cortes & Risk [100]
<i>Porites astreoides</i> (Lamarck, 1816)	430 mg cm <sup>-2</sup> d <sup>-1</sup> (sand)	Mortality after 1 day	M/E	1.5	Bak & Elgershuizen [63]
<i>Porites astreoides</i> (Lamarck, 1816)	10 mg cm <sup>-2</sup> d <sup>-1</sup> (natural)	No effect	M/E	1.5	Torres and Morelock [87]
<i>Porites astreoides</i> (Lamarck, 1816)	Burial (10-12 cm of reef sand)	Bleaching within 24 h; 70% tissue loss after 72 h	M/E	1.5	Thompson [64]
<i>Porites lobata</i> (Dana, 1846)	30 mg cm <sup>-2</sup> d <sup>-1</sup> (daily applications)	Mortality within 10 days	M	1.5	Hodgson [94]
<i>Porites lobata</i> (Dana, 1846)	Burial (1.5-1.6 g/cm <sup>2</sup> for 45 h)	Sub lethal effects after 30 h, little recovery after 90 h	M	1.5	Piniak [91]

Coral species	Sedimentation rate (tested)	Response	Growth form	Calyx (mm)	References
Porites lobata (Dana, 1846)	200 mg cm <sup>-2</sup> d <sup>-1</sup>	Bleaching after 6 days (but no mortality)	M	1.5	Stafford-Smith [48]
Porites lobata (Dana, 1846)	Complete burial (48 h)	Bleaching; full recovery after sediment removal	M	1.5	Yeung [101]
Porites lutea Milne (Edwards & Haime, 1851)	200 mg cm <sup>-2</sup> d <sup>-1</sup>	Bleaching after 6 days (but no mortality)	M	1.5	Stafford-Smith [48]
Porites lutea Milne (Edwards & Haime, 1851)	-	Common on reefs affected by sedimentation	M	1.5	Brown and Howard [84]
Porites lutea Milne (Edwards & Haime, 1851)	Increased sedimentation (dredging)	Survival	M	1.5	Hudson et al. [99]
Porites lutea Milne (Edwards & Haime, 1851)	Up to 14.6 mg/m <sup>2</sup> /d (fine silt due to dredging)	No effect on growth rate (in situ)	M	1.5	Chansang et al. [65]
Porites parties (Pallas, 1766)	-	Uses tentacles to remove larger sediment particles	M	2	Meyer [102]
Porites porites (Pallas, 1766) fania furcata	Burial (10-12 cm of reef sand)	90% bleaching within 24 hrs.; 70% tissue loss after 72 hrs.	B	2	Thompson [64]
Porites rus (Forsk., 1775)	39.6 mg cm <sup>-2</sup> d <sup>-1</sup> (for 2 weeks)	Massive mortality (anoxia)	M	0.5	Fabricius et al. [22]
Porites sp.	-	Persists in areas of heavy sedimentation	-	-	Fabricius [100]
Porites sp.	Burial for 6h	No effect	-	-	Wesseling et al. [71]
Porites sp.	Burial for 20 h	Discoloration & bleaching after 3 weeks	-	-	Wesseling et al. [71]
Porites sp.	39.6 mg cm <sup>-2</sup> d <sup>-1</sup> (for 2 weeks)	Mucus production, survival (most tolerant)	-	-	Fabricius et al. [72]

Coral species	Sedimentation rate (tested)	Response	Growth form	Calyx (mm)	References
Porites spp,	(between 1.3 and 4 mg cm <sup>-2</sup> d <sup>-1</sup> not quoted)	Tolerance to sedimentation described as 'intermediate.'	-	-	McClanahan & Obura [83]
Sarcophyton glaucum (Quay & Gaimard, 1833)	200 mg cm <sup>-2</sup> d <sup>-1</sup>	Tissue damage and partial mortality within 6 weeks	So	-	Riegl [81]
Scolymia cubensis (Milne Edwards & Haime, 1849)	Complete burial	50% Survival after 7 days	S	75	Rice & Hunter [37]
Scolymia cubensis (Milne Edwards & Haime, 1849)	3 g of 3 grain-sizes: 62 µm, 250 µm, 2 mm (24 h)	Sediment-shedding efficiency related to calicle angle	S	75	Logan [106]
Siderastrea radians (Pallas, 1766)	Complete burial	50% Survival after 13,6 days	M/E	5	Rice & Hunter [37]
Siderastrea radians (Pallas, 1766)	Total burial	Survival for more than 73 h	M/E	5	Mayer [107]
Siderastrea radians (Pallas, 1766)	Burial (chronic)	Reduced growth and some mortality	M/E	5	Lirman et al. [108]
Siderastrea siderea (Ellis & Solander, 1786)	10 mg cm <sup>-2</sup> d <sup>-1</sup> (natural)	No effect	M	3	Torres & Morelock [87]
Siderastrea siderea (Ellis & Solander, 1786)	0.3-64 mg cm <sup>-2</sup> d <sup>-1</sup>	Partial mortality	M	3	Nugues & Roberts [109]
Siderastrea siderea (Ellis & solander, 1786)	Burial (10-12 cm of reef sand)	50% Bleaching and sub lethal stress within 24 hr.	M	3	Thompson [64]
Sinularia tiara (Pratt, 1903)	200 mg cm <sup>-2</sup> d <sup>-1</sup> (6 weeks)	Minor tissue damage and bleaching	So	-	Riegl [81] & Riegl & Bloomer [82]

Coral species	Sedimentation rate (tested)	Response	Growth form	Calyx (mm)	References
<i>Sinularia leptoclados</i> (Ehrenberg, 1834)	200 mg cm <sup>-2</sup> d <sup>-1</sup> (6 weeks)	Minor tissue damage and bleaching	So	-	Riegl [81] & Riegl & Bloomer [82]
<i>Solenastrea hyades</i> (Dana, 1846)	Complete burial	50% Survival after >15 days	M	5	Rice & Hunter [37]
<i>Stephanocoenia iniersepta</i> (Lamarck, 1816)	Complete burial	50% Survival after 16.2 days	M	3	Rice & Hunter [37]
<i>Trachyphyllia geoffroyi</i> (Audouin, 1826)	-	Actively dig through overlying sediment	S	45	Stafford-Smith & Ormond [75]
<i>Turbinaria mesenterina</i>	110 mg/cm <sup>2</sup> (5 weeks)	No significant sub lethal physiological effects	L	1.5	Sofonia and Anthony [110]
<i>Turbinarta</i> (several spp.)	-	Active sediment rejecter	-	-	Stafford-Smith & Ormond [75]

However, the background concentration derived by Caroline [60] found to be suitable for the earlier studies of at Palk bay & Lakshadweep recorded minimum of 1 to 2.69 mg cm<sup>-2</sup> d<sup>-1</sup> during the fair-weather periods. Investigations on effects of sediment stress in 89 coral species provided a generic understanding of tolerance levels, response mechanisms, adaptations and threshold levels of corals to the effects of natural and anthropogenic sediment disturbances Paul et al. [19]. The algal symbionts of coral polyps undergo stress from high suspended sediment concentrations and the subsequent effects on light attenuation. The bare minimum light requirements of corals reef ranges from <1% to as much as 60% of surface irradiance Paul et al. [19]. However, the chronic levels of suspended sediment load range between <10 mg L<sup>-1</sup> in pristine offshore reef areas to >100 mg L<sup>-1</sup> in marginal near shore reefs Paul et al. [19]. But the tolerance level of exogenous sedimentation rates for different corals species ranged between <10 mg cm<sup>-2</sup> d<sup>-1</sup> to >400 mg cm<sup>-2</sup> d<sup>-1</sup>. The exposure duration of high sedimentation rates varied from <24 h for sensitive species to a few weeks (>4 weeks of high sedimentation or >14 days complete burial) for very tolerant species. This quantification of sensitivity between different coral species was accounted by the growth form of coral colonies and the size of the coral polyp or calyx. These observations were derived from the 77 published studies on the

effects of turbidity and sedimentation on 89 coral species Paul et al. [19] and presented in tabular form [Table 4 & 5]. Most of the case studies depict discrete turbidity or sedimentation events which produce stress on coral reefs [21]. In India, existing knowledge indicates that inshore corals in certain regions like Gulf of Kutch region may have adapted to high turbidity regimes. According to Anthony & Larcombe [61], coral resilience to turbidity might be of rapid replenishment of energy reserves between periods of sublethal turbidity events, interchanging between phototrophic and heterotrophic dependence, rapid rates of photo-acclimation and energy conservation through reduced respiratory and excretory losses. The current record of the occurrence of *Symbiodinium* spp. at Gulf of Kutch express the physiological resilience is also documented Koushik et al. [62]. These stress response of Indian coral reefs necessitates a comprehensive scientific approach towards solving the siltation problem through technological intervention. The precursor for any technological intervention requisite understanding of the different process governing the sedimentation shall be carried out by numerical modelling. The modeling effort has been warranted only to reef environment where the exogenous sedimentation from the natural environment exceeds endogenous sedimentation from the reef itself.

## Technological Interventions

In general, standard engineering modeling tool shall be used to quantitatively simulate sediment transport and deposition within a system [109]. Hence, conceptual site specific modelling for various sites in India needs to be developed to understand dynamic sediment transport along coral reef systems. As coral reefs have a unique environment, comprehensive understandings of the physical, chemical and biological processes influencing the fate and transport of sediments laden with contaminants of potential concern from sources to exposure media (i.e. coral reefs). Hence, a conceptual numerical model shall be developed comprising vital components like hydrodynamic and sediment transport. These components were adequately described by various processes like terrigenous matter inflow through rivers, tidal forcing, meteorological conditions, sediment size gradation, sediment bed properties, advection, dispersion, aggregation, settling, consolidation, erosion transport in suspension, water quality and particle-to-particle interactions and anthropogenic activities of current as well as historical condition. Accounting all these components a numerical model using Mike21, Delf 3D shall be set up to mimic natural conditions. The dynamics of these components shall be simulated using the numerical modelling and calibrated against observed values. Latter validated against the time series field data set collected in a specific manner as per the model requirement. The model output will be of the scenarios of the current, historical and future condition of sedimentation in a reef environment under consideration. The output of the modeling exercise will reveal the impact of siltation due to anthropogenic input (industrial discharge) or other factors like river runoff, bank erosion, etc. If the anthropogenic input predominates the other means of sedimentation, government departments like state pollution control boards and central pollution control boards shall be informed to curb the input through legislative means. However, the exogenous sedimentation rate found to be higher and segregate possible input areas of sediment load shall be mapped within the model domain, and suitable technological intervention may be suggested.

Sediment movement may be arrested by established technologies by providing geotube dykes along the eroding banks to prevent leach outs. As this technology found to be eco friendly and standardized by NIOT for coastal erosion prevention [110]. The model scenario of future condition after technological intervention also been simulated and try to achieve the sedimentation levels of  $>100\text{mg L}^{-1}$  or  $>400\text{mg cm}^{-2} \text{d}^{-1}$  as reported in the literature. Further studies are required to validate the maximum tolerable level of sedimentation level on coral reefs of Indian coast. The floating macro algal mass settlement on coral reefs of [111] was also reported during January to March. It may be prevented by floating barrier capable of filtering macro algae and not entangle fish as well as turtles. The further large scale is floating algae; garbage netting and collection by [112] may be adopted. This innovative boat capable of collecting floating macro algae materials with its foldable arms covering a width of 4m span and collection rate of

$98\text{m}^3 \text{day}^{-1}$  during operation. Further, coral reef rehabilitation shall be achieved through Biorock technology which uses mineral accretion process developed by Thomas Goreau, a marine biologist and Wolf Hilbertz, an engineer and architect [113-117] through electro deposition of calcium from sea water enhances the coral growth and the technology found to be viable at certain pockets of world reefs [48,118,119].

## Conclusion

Conservation efforts also been achieved through judicial utilization of current technological means.

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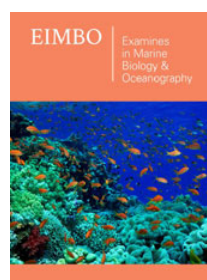
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