

SI Appendix. Supporting Information.

Table S1. Candidates for high-probability high-impact tipping points and tipping elements.

Area/tipping element	Driver	Physical-biogeochemical variables affected	Hazards concerning:	References and examples
Coastal acidification	C_{anthro} , V_{ocean}	DIC, pH, Ω_{calcite} , $\Omega_{\text{aragonite}}$	Coastal ecosystem functioning, key species, marine living resources	(1, 2)
Coastal deoxygenation	ΔT , V_{ocean}	O_2	Coastal ecosystem functioning, key species, marine living resources, further eutrophication, harmful algae blooms	(3, 4)
Open ocean deoxygenation	ΔT , V_{ocean}	O_2	Marine living resources	(5-7)
Arctic sea ice reduction	ΔT , V_{ocean}	Light availability, biological primary production, T	Shift in ecosystem intensification away from coast, warming, invasive species, species loss, marine living resources	(8, 9)
Marine permafrost thaw	ΔT , V_{ocean}	DIC, pH, Ω_{calcite} , $\Omega_{\text{aragonite}}$	CH ₄ outgassing, increase in ocean dissolved carbon, less ocean CO ₂ uptake, atmospheric CO ₂	(10)
Polar acidification	C_{anthro}	DIC, pH, Ω_{calcite} , $\Omega_{\text{aragonite}}$	Ecosystem functioning, key species, marine living resources	(11, 12)
Warm water coral reef degradation	ΔT , C_{anthro}	pH, T	Coral bleaching, ecosystem functioning, species loss, coastal erosion, key species, marine living resources	(13, 14)
Large-scale ocean circulation changes (deep convection, upwelling, overturning)	ΔT , ΔS	DIC, Alk, pH, Ω_{calcite} , $\Omega_{\text{aragonite}}$, O_2 , T, S, nutrients, biological primary production	Ecosystem functioning, ocean CO ₂ uptake, heat accumulation, pH change accumulation	(15-17)
El Niño and Monsoon alterations	ΔT , ΔS , V_{ocean}	DIC, Alk, pH, Ω_{calcite} , $\Omega_{\text{aragonite}}$, O_2 , T, S, nutrients, biological primary production	Ecosystem functioning, marine living resources, ocean CO ₂ uptake, heat accumulation, accumulation of pH changes	(18-20)
Open ocean warming and marine heat waves	ΔT	T, biological primary production	Ecosystem functioning, marine living resources, ocean CO ₂ uptake, heat accumulation	(21-23)
Open Ocean acidification	C_{anthro} , V_{ocean}	DIC, pH, Ω_{calcite} , $\Omega_{\text{aragonite}}$	Ecosystem functioning, key species, marine living resources, deep-sea ecosystems	(24-26)

See following pages for explanation of symbols and references.

Explanation of symbols:

v_{ocean} : ocean velocity field

C_{anthro} : additional ocean carbon from uptake of atmospheric excess CO_2

T: seawater temperature

ΔT : temperature change

S: salinity

ΔS : salinity change due to change in fresh water fluxes including ice melt

DIC: total dissolved inorganic carbon

Alk: alkalinity (ability of sea water to dissociate CO_2)

pH: ph-value, $\text{pH} = -\log_{10}([\text{H}^+])$.

Ω_{calcite} : saturation state for calcite (CaCO_3), the boundary between over- and undersaturation is at $\Omega_{\text{calcite}}=1$

$\Omega_{\text{aragonite}}$: saturation state for aragonite (CaCO_3), the boundary between over- and undersaturation is at $\Omega_{\text{aragonite}}=1$

O_2 : dissolved oxygen

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