**Supplemental Information 5. Descriptions and examples of stressors to seagrasses, umbrella categories.**

**5.1 Stressor Descriptions**

Light

* This stressor has multiple impacts and could be light affecting seagrass as a limiting factor, or in excess. This is seen as an abiotic impact in studies looking at seasonal light availability, in the field or simulated (usually associated with temperature (Verhagen & Nienhuis, 1983 and Conover, 1958). Light was also commonly mentioned in studies as limited by a nutrient (commonly associated stressor) influx which caused a macroalgae bloom resulting in light limitation (van Lent et al., 1995).

Temperature

* This is seen as an abiotic impact in studies looking at seasonal temperature fluxes, in the field or simulated (usually associated with light) (Sand-Jensen, 1975). This could also be associated with rising water temperatures discussed in relation to climate warming (Johnson et al., 2021).

Sediment

* Sediment can be associated with seagrass in contributing to water turbidity, studied for its characteristics of accumulation in meadows, or development of anoxic or toxic patches (Terrados et al., 1999). Sediment was often tagged as a stressor in addition to light due to it’s light limitation capability (McGlathery *et al*., 2013).

Salinity

* Extreme salinities both low and high were studied in field and mesocosm studies
looking at how the stressor limited distribution and growth. Could be from
greater evaporation (high salinity) or looking at Zostera growth in brackish
waters. (Sola et al., 2020). This is also often associated with hydrodynamics and temperature (Kotta *et al.,* 2014).

Nutrients

* Nutrients were measured as an anthropogenic input such as runoff or fertilizer, causing macroalgal blooms (Harlin & Thorne-Miller, 1981), or seasonally looking at nitrogen as a limiting nutrient for plant growth (Zimmerman, Smith, & Alberte, 1987). Nutrients can also be a stressor in tissue and plant breakdown (Pellikaan & Nienhuis, 1988).

Acidification

* (Ocean) acidification is the decrease in pH mainly due to increases in carbon dioxide inputs to the system. The acidification could be studied as a stressor to the community surrounding seagrass, or as impacting the productivity of seagrass (Miller, Yang, & Love, 2018 and Collier et al., 2018). Acidification was a stressor often recorded in conjunction with carbon and hydrodynamics (Egea et al., 2018).

Carbon

* Carbon was studied in two main regards as a stressor, one as a limitation to seagrass growth, and another within the realm of carbon dioxide as a contributor to ocean acidification (Palacios & Zimmerman, 2007 and Jiang et al., 2017). Carbon was also often studied with an interest in seagrass blue carbon stocks, related to the study of limiting growth factors (Ferguson et al., 2017).

Aquaculture Impacts

* Studied as a stressor of seagrass related to the farming of fish, shellfish, and other aquatic organisms for commercial use. The stressor often stems from the releases of nutrients due to this activity (De Casabianca, Laugier, & Marinho-Soriano, 1997)

Hydrodynamics

* Hydrodynamic stressors of seagrass include wave action, storms, and water flow impacts on seagrass (Paulo et al., 2019). This can also be related to hydrodynamics and sediment, which can alter light and water turbidity (Hansen & Reidenbach, 2013).

Oxygen

* Oxygen stressors include hypoxic environments that may alter seagrass growth or survival (Lemley, Snow, & Human, 2014). Also studied could be sulfide toxins that reduce oxygen in seagrass tissues, studied in relation to metabolism (Pedersen, Binzer, & Borum, 2004).

Herbivory

* Herbivory as a stressor can be related to herbivores eating epiphytes off of seagrass leaves, altering growth (Hootsmans & Vermaat, 1985). Or, herbivory can be a stressor where herbivores are consuming seagrass (Lewis & Boyer, 2014).

Pathogens

* Pathogens can be found as stressors typically having to do with seagrass wasting disease, a protist pathogen, *Labyrinthula zosterae* (Brakel et al., 2019). This stressor is known to historically contribute to large seagrass die-offs and lower distribution. It is important to distinguish between pathogens and the microbiome, although they may be associated and both be selected. The seagrass wasting disease is most often associated with *Zostera marin*a (McKone & Tanner, 2009).

Habitat Fragmentation

Habitat fragmentation is often a stressor that interrupts connectivity between seagrass meadows, and destroys parts of the meadow, decreasing functionality (Beem & Short, 2009). This also includes disturbance/recovery experiments. Sometimes habitat fragmentation can be a study of function in bare vs. seagrass vegetated sites or as the removal of seagrass in a manipulative experiment (Aoki & McGlathery 2018). Furthermore, edge effects may play a key role in this dynamic, since the proportion of edge habitat is increased (Carroll et al., 2018)

Invasion

* Invasion stressors result from invasive species impacts to seagrass meadows, this can be in the form of another seagrass species, such as *Zostera japonica* (Hahn, 2003). Invasion can also be colonization by a non-invasive species such as tunicates (Carman et al., 2019).

Drought

* Drought as a stressor is often studied in relation to hydrodynamics, both can reduce freshwater or nutrient inputs to the seagrass meadows (Hirst et al., 2016).

Epiphytes

* Stressors that can grow on top of seagrass leaves and limit light penetration, and in turn growth (Hootsmans & Vermaat, 1985). Epiphytes can be algae, crustaceans, bacteria and can also be altered and affect seagrass via grazers (Jaschinski & Sommer, 2010).

Invertebrates

* Invertebrates often reside in seagrass ecosystems and include organisms such as crustaceans, mollusks, and echinoderms. They can be defined as the impact of one invertebrate on seagrass as a plant or community; or defined as the impact of abundance/diversity on a process.  Common incidences of invertebrates as stressors seagrass include consumption of seagrass, harvesting of invertebrates, as epiphytes, or as invasive species, altering the seagrass ecosystem. (Borowitzka, Lavery, & Keulen, 2006, Lewis & Anderson, 2012, Nakaoka, 2005, Liu, Pearce, & Dovey, 2015, and Ruesink et al., 2006). With this, sometimes herbivory, predation, and invasion will also be selected with the invertebrate stressor because the invertebrate fits into one of these categories as well (Amundrud et al., 2015 and Momota & Nakaoka, 2017)

Herbicides

* Herbicides are toxic to plants, commonly used in agriculture, and make up the majority of pesticides utilized worldwide (Dayan, 2019). Herbicides can be stressors to seagrass when runoff carries herbicides into meadows, inhibiting photosynthesis, and in large concentrations can cause plant mortality (McMahon et al., 2005). Hydrodynamics can often be studied in conjunction with herbicides as a stressor.

Genetic Diversity Loss

* Genetic diversity can be a stressor in that the diversity of a meadow or population determine resilience, or greater restoration success (Procaccini, Olsen, & Reusch, 2007).  Also, certain traits in the genetic makeup of seagrasses may be indicative of some species ability to tolerate/not tolerate certain environmental conditions (Pazzaglia et al., 2021).  Loss of diversity can have synergistic effects with other stressors, as well as decreasing reproductive success, and increased risk of extinction (Williams, 2001 and Elso, Manent., & Robaina, 2018).

Toxins

* Often found in sediments, or released into the water column, toxins can cause seagrass mortality and limited growth. Toxins to seagrass are often metals, or sulfides and can be pollutants, including runoff (Lee & Dunton, 2000 and Mylona et al., 2020).

Seagrass competition

* Seagrass competition can be intra- or inter-specific, as the result of either high-density meadows limiting production, competition with another species of seagrass for resources, or an invasive species competing with a native seagrass meadow (Rose & Dawes, 1999, Ruesink et al., 2010, and Sugimoto et al., 2017).

Microbial Dysbiosis

* The microbiome can be looked at in the scope of seagrass within the plant was well as directly surrounding the plant. Fungi, microalgae, and bacteria can associate with seagrasses and make up the plant microbiome: they can form mutualistic relationships that protect the plant from environmental extremes, or increase productivity (Hurtado-McCormick, 2019). Microbes can also be pathogenic to seagrasses or promote a worsening of stressor effects on the seagrass plants when the community is altered (Inaba et al., 2017 and Seymour et al., 2018).

Anthropogenic Use

* Anthropogenic uses of seagrass can include fishing, tourism, boating, oil spills, dredging, or building, all spanning of human uses acting directly or indirectly on seagrass meadows. Fishing can reduce fish diversity, while boat blades can scour seagrass blades, tourism may result in unintended consequences of human presence/usage in seagrass meadows, and oil spills can cause seagrass mortality (Icarella et al., 2018, Turschwell et al., 2021).

**5.2 Umbrella categories of stressors.**

Note, these stressors may be able to fit more than one category, however were classified in the category which the authors agreed was the best fit. Stressors can occur in isolation, or together. Umbrella categories were formed based off of categories from Kappel (2005)’s list of marine threats.

Pollution

* Description: abiotic stressors related to contamination, agricultural runoff, debris, often resulting in poor water quality.
	+ Nutrients
	+ Sediment
	+ Toxins
	+ Herbicides

Climate Change

* Description: Stressors that are either direct or indirect effects of global climate change (anthropogenic caused).
	+ Light
	+ Temperature
	+ Hydrodynamics
	+ Salinity
	+ Oxygen
	+ Invasion
	+ Acidification
	+ Drought

Increased Anthropogenic Presence

* Description: stressors to seagrasses derived from increases in human activity. These can typically occur from direct actions harming seagrasses.
	+ Aquaculture Impacts
	+ Habitat Fragmentation
	+ Anthropogenic Use

Intrinsic Factors

* Description: stressors to seagrasses that may occur “naturally,” or exist as typical ecosystem processes but may result in seagrass loss, and/or be exacerbated by other stressors.
	+ Herbivory
	+ Invertebrates
	+ Genetic Diversity Loss
	+ Seagrass Competition
	+ Pathogens
	+ Microbial Dysbiosis

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