

**Comparing CO₂ and CH₄ Fluxes in Prevailing
Saltmarsh Zones in the Southern Gulf of Saint
Lawrence**

By

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Abstract

Tidal saltmarshes are unique coastal ecosystems that have historically provided important ecosystem services, including efficient carbon sequestration. In the northwestern North Atlantic, salt water adapted vegetation species organize saltmarshes into vegetation zones distributed along a tidal gradient. In the southern Gulf of St. Lawrence, saltmarshes' primary low marsh vegetation zone is dominated by *Sporobolus alterniflorus*. Recently, significant community structure change has been observed in several southern Gulf of St. Lawrence saltmarshes. Particularly, an expansion of saltmarsh area bare of dominant vegetation has been observed. I have called these areas dead zones. Given that vegetation is a controlling factor in the flux of greenhouse gasses into and out of the soil environment, I compared the fluxes of carbon dioxide (CO₂) and methane (CH₄) in *S. alterniflorus* zones and dead zones. Simulating daytime (light) and night-time (dark) conditions, I collected 43 dead zone soil gas flux measurements between June 16 and September 25, 2023, and 24 *S. alterniflorus* zone soil gas flux measurements, between August 17 and September 25, 2023, using a soil gas chamber and a mobile gas concentration analyzer at five different saltmarshes. Following the analysis of my measurements, I found that the mean dark CO₂ fluxes of late growing season *S. alterniflorus* zones ($\bar{x} = 963.3 \pm 626.2 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$) was significantly greater ($F_{\text{stat}} = 7.161$, P-value = 0.001250) than that of dead zones ($\bar{x} = 200.1 \pm 259.9 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), but I found no significant difference between the mean light and daily net CO₂ fluxes of the two groups ($\bar{x} = -168.7 \pm 710.7 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, $F_{\text{stat}} = 1.474$, P-value = 0.2466; $\bar{x} = 89.03 \pm 382.7 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, $F_{\text{stat}} = 0.3313$, P-value = 0.8028; respectively). I also found no significant differences between the mean light, dark or net daily CH₄ fluxes of late growing season

S. alterniflorus zones and dead zones ($\bar{x} = 0.02832 \pm 0.4635 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, $F_{\text{stat}} = 0.06789$, P-value = 0.9765; $\bar{x} = 0.009973 \pm 0.2602 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, $F_{\text{stat}} = 2.033$, P-value = 0.1349; $\bar{x} = 0.01434 \pm 0.2858 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, $F_{\text{stat}} = 0.4226$, P-value = 0.7385; respectively). I did however observe seasonal normal-resembling magnitude curves of the light and dark CO₂ fluxes, and to lesser extent, light and dark CH₄ fluxes. Both light and dark CO₂ fluxes trended to be positive at the end of August and in September, after *S. alterniflorus* had senesced. As climate change warms autumns in Nova Scotia, this period of *S. alterniflorus* and dead zones being net sources of CO₂ may lengthen and intensify. My work characterizes dead zone CO₂ and CH₄ fluxes over the majority of one growing season. The greenhouse gas fluxes of dead zones should continue to be studied, along with how they change the community structure ecosystem function of saltmarshes.

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Introduction

Coastal tidal saltmarshes, referred to hereafter as saltmarshes, are grass dominated wetlands that are periodically inundated by tidal waters (Adam, 1993). In the southern Gulf of St. Lawrence, saltmarshes commonly occupy intertidal zones in estuaries or sheltered coasts along. In the north-northwestern Atlantic, the shoreward margin of saltmarshes, called the upper margin, closely follows the mean annual high tide mark (Davis and Browne, 1996). The waterward margin is called the lower margin. Being an ecosystem where freshwater and terrestrial environments meet the saltwater of the marine environment (Levin et al. 2001), saltmarsh plants are halo-tolerant and adapted to regular inundation (Kaiser et al. 2005).

Saltmarshes of the northwestern Atlantic are regularly divided into stratified vegetation zones with predictable members. An increase in elevation from the lower margin to the upper margin creates a gradient with other abiotic factors along which the vegetation zones are organised (Davis and Browne, 1996; Yando et al. 2023). There is little research characterising the vegetation zones of the southern Gulf of St. Lawrence in full. However, researchers of the saltmarshes of the southern Gulf of St. Lawrence have identified some notable zones (e.g. Watt et al. 2011). These zones are, from the high – or upper – marsh to the low marsh: the upper margin zones, the *Juncus* zones, the *Sporobolus pumilus* (Roth) P.M. Peterson et Saarela (= *Spartina patens*) and *Distichlis spicata* (Linnaeus) Greene zones, and the low marsh – or *Sporobolus alterniflorus* (Roth) P.M. Peterson & Saarela (= *Spartina alterniflora*) – zones. In addition, bare zones, which lack the dominant vascular plants of the other zones, can form by disturbance events that remove or kill the vegetation that would have been there (Shumway, 1995; van de

Plassche, 2006; Watt et al. 2011). These disturbances may include ice scouring, erosion, prolonged submersion underwater, anthropogenic hydrology changes, and nutrient enrichment, among others. Among the salt marshes of the southern Gulf of St. Lawrence, these bare zones have been increasing in proportion of total marsh area (Watt et al. 2010; Garbary per. com. 2023). Vegetation zones are dynamic, being subject to interspecific competition and succession (Bertness, 1991; van de Plassche, 2006). Naturally, the different vegetation zones offer different potentials as ecosystem services, like carbon sequestration (Comer-Warner et al. 2022) or erosion control (Leonard and Croft, 2006; Bass et al. 2022). These ecosystem services are not only achieved by vegetation, but vegetation regime also significantly affects microbial (Abbott et al. 2022) and animal (Watt et al. 2010) biodiversity and density in saltmarshes.

Taken in full, the unique biota and abiotic conditions of saltmarshes interact to reduce global warming potential (hereafter: GWP) with notable efficiency (McLeod et al. 2011). Like other wetlands, saltmarshes have anoxic soils, slowing decomposition (Wang et al. 1996) and allowing for highly positive net ecosystem production (hereafter: NEP) (McLeod et al. 2011). More, the regular deposition of sulfate (SO_4^{2-}) may allow sulfur reducing bacteria to outcompete some methanogens (Bartlett et al. 1987; Poffenbarger et al. 2011; Villa, 2020). This means that saltmarshes have the conditions of freshwater wetlands that increase the net rate carbon dioxide (CO_2) uptake, but produce methane (CH_4) – a potent greenhouse gas – at a lesser rate than freshwater wetlands.

Apart from their unique NEP and effect on GWP, saltmarshes are dynamic ecosystems that require particular sediment dynamics conditions to form (Davis and Browne, 1996) and are vulnerable to both human activity (Kennish, 2001; Coverdale et

al. 2013) and climate change (Watt et al. 2011). In the Gulf of St. Lawrence, saltmarshes have formed in the sheltered coastal areas of bays and harbours, like in barachois, behind baymouth bars, or nestled against tombolos, by the slowing of sediment escape with fibrous biomass during tidal cycles (Davis and Browne, 1996; Leonard and Croft, 2006; Faegin et al. 2009; Bass et al. 2022). Historically, they have persisted in a delicate state by capturing more sediment than is lost, year over year, building the saltmarsh (Nyman et al. 2006). If the saltmarsh were to lose more sediment than is captured, year over year, then it would shrink in size, eventually disappearing. For generations, human activities have changed sediment dynamics, by changing local hydrology and increasing the rate of sea level rise (Carey et al. 2017) through human induced climate change (IPCC, 2014).

Given rapid human caused climate change, the effect on GWP that wetlands have, may change (e.g., Hardy et al. 2023) and should be measured. Freshwater wetlands have already begun changing their greenhouse gas (hereafter: GHG) dynamics in the context of their changing climates. For example, melting permafrost, rising soil temperatures, and other factors are increasing CH₄ emissions from the Mackenzie River Delta (Burn and Kokelj, 2009) and are predicted to continue to do so (Wesley et al. 2023). In a tropical setting, emissions of CH₄ in the Sudd, a large tropical swamp in South Sudan, have increased by 3 Tg/yr between 2011 and 2015 (Lunt et al. 2019) linked to greater rainfall caused by climate change (Hardy et al. 2023). While saltmarshes have historically had lower CH₄ emission rates than freshwater ecosystems attributed to SO₄²⁻ deposition (Bartlett et al. 1987) and a rapid carbon burying rate (Chmura et al. 2003; McLeod et al. 2011), the increase in cover of bare zones may change soil gas fluxes and should be investigated.

Salt Marsh Vegetation Zones in the Southern Gulf of St. Lawrence

Vegetation is directly and indirectly responsible for GHG and sediment dynamics. Vegetation is a primary producer that incorporates the carbon from CO₂ into biomass and alters the physical structure of the environment, above and below ground. By altering the physical structure of the environment, both gas (Brix et al. 1992; Verville et al. 1998) and sediment dynamics (Leonard and Croft, 2006) change directly. Indirectly, either physically (Blum et al. 2004; Daodu, 2008; Honig et al. 2015) or chemically (Blum et al. 2004; Abbott et al. 2022), vegetation also has a significant effect on the microbial (Blum et al. 2004; Abbott et al. 2022) and animal (Daodu, 2008; Honig et al. 2015) communities in their ecosystem. The microbial and animal communities then in turn have their own effects on GHG and sediment dynamics.

High marsh zones

Upper margin zones

The upper margin is at the highest elevation of the marsh and, in the southern Gulf of St. Lawrence, is dominated by stands of *Sporobolus michauxianus* (Hitc.) P.M. Peterson & Saarela (= *Spartina pectinata*), *Solidago sempervirens* Linnaeus, *Myrica pensilvanica* Mirbel, and *Rosa virginiana* Miller. These stand-forming dominant plants here are often found outside of saltmarshes as well. In addition to dominant stand forming species of vegetation, this zone can also host non-dominant species, including *Argentina egedei* (Wormskjold) Rydberg (= *Potentilla egedei*) and *Sabatia stellaris* (Pursh) Britt (= *Sabatia simulata*). This zone is submerged minimally, only during the highest tides. Soil in this region is less often saturated with water by tides (Neily et al.

2017) and therefore perhaps more aerobic. More, the woody roots of *R. virginiana* likely offer different soil stabilizing properties than other saltmarsh species. If disturbances are rare enough, then this vegetation zone may undergo procession into being a part of a neighbouring terrestrial ecosystem (Chapman, 1959).

Juncus zones

The next zone down, near the high watermark, is the *Juncus* zone. This zone is dominated by stands of *Juncus gerardii* Loisel. and *Juncus balticus* Willd. Given that they occupy the same zone, it can be presumed that they have similar environmental tolerances. Given that presumption, these dominant species are halotolerant flood adapted rushes (Rozema and Blom, 1977). However, *J. gerardii* and *J. balticus* are poor competitors lower in the marsh where they would be waterlogged for longer periods (Rozema and Blom, 1977). These species are well adapted to the sandier soil of the high marsh (Montemayor et al. 2015). *Juncus* zones also host other common salt marsh, non-dominant, species, such as *Limonium carolinianum* (Walter) Britton and *Salicornia maritima* S.L. Wolff et Jefferies. As sea levels rise the *Juncus* zones of northeastern North America are being, and will continue to be, reduced in size or forced to migrate given rising sea levels (Watson et al. 2015a).

Sporobolus pumilus and *Distichlis spicata* zones

Further down, often taking up the central portion of the horizontal profile of the marsh, *Sporobolus pumilus* and *Distichlis spicata* form patchy stands, sometimes mixing with the *Juncus* zone above or the *Sporobolus alterniflorus* below. *S. pumilus* and *D. spicata* will form stands of thin stalked bent-down grasses. These species can form dense canopies and completely covering the sediment below. Where *S. pumilus* and *D. spicata*

stands are less dense, non-dominant species like *L. carolinianum* or *Salicornia maritima* are also present. While both *S. pumilus* and *D. spicata* are more adapted to longer submergence than the *Juncus* species, they also have less growth when submerged for great periods of time (Leonard et al. 2013; Watson et al. 2015b). Rising sea levels or abrupt changes in local hydrology can cause these longer submergences.

Low marsh zones

The low marsh is dominated by a keystone species of cordgrass, *Sporobolus alterniflorus*. This zone will stretch from the lower margin of the marsh to the *S. pumilus* and *D. spicata* zone, where there can often be mixed stands of the grasses. *S. alterniflorus* shoots can grow at the lower margin where it slows water flow, letting sediment settle (Leonard and Croft, 2006), building or protecting the edge of the marsh. It also forms mussel habitat, notably for *Geukensia demissa* (Watt et al. 2011; Honig et al. 2015). Along with *S. alterniflorus*, this zone also hosts *L. carolinianum* and *Salicornia maritima*. The expanse of this zone has increased in recent years, as sea level rise accelerates (Donnelly and Bertness, 2001; Garbary per com. 2023), pushing the higher zones into more narrow bands (Donnelly and Bertness, 2001; Watson et al. 2015b).

Dead zones

In the southern Gulf of St. Lawrence, areas bare of the previously mentioned dominant vegetation have reportedly been growing in recent years (Garbary per com. 2023). These have previously been called dead zones by Deveau (2007) and Watt et al. (2011). They include dead lower margins, expansive salt pannes, and limited salt pannes. However, there is little literature characterizing these zones in salt marshes in the northwestern North Atlantic. Dead zones are speculated to form following significant

disturbance (Deveau, 2007; Watt et al. 2011; Garbary per. com., 2023). Increased wave action, periods of extended inundations, sea ice scouring, peat displacement, accelerated sea level rise, and nutrient enrichment, are examples of such disturbances. Some are physical processes that will remove vegetation (e.g. wave action, ice scouring, and the displacement of peat) and some modify abiotic conditions (e.g. periods of extended inundations and sea level rise), which would affect community structure. The loss of vegetation in an area means the loss of its contributions to the ecosystem.

Dead zones are not truly dead; animal and microbial communities remain. However, without the dominant vegetation the animal and microbial communities would change, at least somewhat (Watt et al. 2011; Abbott et al. 2022). Watt et al (2011) noted that *G. demissa* did persist in a dead zone. There is a lack of literature describing other invertebrate species', e.g. *Cancer irroratus* or *Littorina littorea*, use of dead zones. The microbial community in dead zones is likewise, uncharacterised in the southern Gulf of St. Lawrence. I suspect that the microbial communities in dead zones are like those in tidal mudflat ecosystems, other areas of the saltmarsh, or the recently restored saltmarshes described by Abbott et al. (2022), which were lower in microbial density but comparable in diversity. Conspicuous microbial colonies found in the rest of the marsh, such as green, pink, and white sulfur metabolizing bacteria or dark velvety cyanobacterial colonies, can easily be identified here (Dyer, 2003).

Dead Lower Margin

A band bare of vegetation along the lower margin of some southern Gulf of St. Lawrence saltmarshes has recently developed (Deveau, 2007; Watt et al. 2011). This dead zone, hereafter called the dead lower margin, can be described as peat mats at the

lower margin with intact root and rhizome networks, but without living *S. alterniflorus* above-ground stalks (Garbary per. com. 2023). This peat is often dense (Deveau, 2007). The stalks may have been removed by ice scouring stripping shoots from the sediment, wrack covering young shoots, or rising sea levels inundating the margin for longer than *S. alterniflorus* could survive. Live and dead mussels, namely *G. demissa* and *Mytilus edulis*, snails (e.g. *L. littorea*), and algal colonies can be found on or attached to the peat here. Smaller *S. alterniflorus* shoots may be seen where it meets the *S. alterniflorus* zone.

Expansive Salt Pannes

Alternatively, unpublished observations of saltmarshes in Chéticamp Harbour note interior mudflats persisting for several years (Garbary per. com. 2023). These dead zones, hereafter called extensive salt pannes, could have formed by interior portions of the marsh being scoured by sea ice, waterlogged for extended periods, or simply inundated for a greater proportion of a tidal cycle than usual. In Chéticamp Harbour saltmarshes, extensive salt pannes have formed wide and long bands. The work of sulfate-reducing and sulfide-oxidizing bacteria is apparent here by the blacks, pinks, and whites that colour the extensive salt panne soil (Dyer, 2003). Like in the dead lower margin, mussels and algal colonies may be present, sometimes forming felt-like mats. *L. carolinianum* and *Salicornia maritima* may be present too, potentially having survived the disturbance that removed the formerly dominant vegetation or by having colonised the zone more quickly in its succession.

Limited Salt Pannes

A third type of dead zone, hereafter called limited salt pannes, are similar to extensive salt pannes, but are differentiated by their small size. Limited salt pannes have

previously been studied among in Louisiana saltmarshes (Macreadie et al. 2013). In the southern Gulf of St. Lawrence more unpublished observations have noted limited salt pannes in saltmarshes in Antigonish Harbour, Chéticamp Harbour, and near Judique. They are interior to the saltmarsh, within several square meters in size, and have many of the same characteristics and biota as extensive salt pannes (Roberts and Robertson, 1986). I have chosen to distinguish limited salt pannes from extensive salt pannes primarily because of their smaller size because I believe their smaller size may cause other notable differences to extensive salt pannes.

Net Ecosystem Production

What is Net Ecosystem Production

Net ecosystem production (NEP) can be understood as the net flux of carbon into and out of an ecosystem. An ecosystem with a positive NEP takes in more carbon than it releases and is a carbon sink. An ecosystem with a negative NEP releases more carbon than it takes in and is a net carbon source. Broadly speaking, carbon can enter or leave an ecosystem as an inorganic gas (e.g. CO₂ and CH₄) – by photosynthesis and respiration respectively – or by the transfer of organic matter to or from another ecosystem. To calculate NEP the following formula can be used:

$$NEP = (GPP - R_{autotrophs} - R_{heterotrophs}) + (B_{import} - B_{export})$$

Where gross primary production (GPP) is the total photosynthetic activity of the ecosystem, $R_{autotrophs}$ and $R_{heterotrophs}$ are the respired carbon of all the autotrophs and heterotrophs in the ecosystem, respectively, and B_{import} and B_{export} are the total imported and exported biomass, respectively. GPP and $R_{autotrophs}$ is also often combined into net primary production (NPP), the total metabolism of autotrophs.

Components

Net Primary Production

Primary production in saltmarshes is achieved by flowering plants, multicellular algae, and photosynthetic microbes. These groups of primary producers are importantly distinguished from each other by their respective contributions to productivity and structure in saltmarshes.

Flowering plants are likely the primary contributors to the NPP and structure of saltmarshes. The stalks of grasses allow for photosynthetic activity in three dimensions. Roots anchor plants into the soil; they resist displacement from tidal cycles and create structural complexity in the soil environment. Because of their higher carbon to nitrogen ratio, flowering plants decomposes more slowly (Abbott et al. 2022; Taylor et al. 1989) than multicellular algae and photosynthetic microbes, retaining biomass in the ecosystem.

Multicellular algae could be the secondary contributors to the NPP and structure of saltmarshes. Multicellular algae have less permanent biomass than flowering plants, on account of less defensive tissue, but their multicellularity allows them to form structures like mats, that persist in a location for some time. These structures are flat on the sediment during low tide and are removed by tidal action more easily than those of flowering plants (e.g. Chalmers et al. 1985). Their lesser ratio of carbon to nitrogen ratio, allows them to be decomposed more easily than flowering plants too (Taylor et al. 1989).

Photosynthetic microbes, like cyanobacteria and unicellular eukaryotes, are likely the lesser contributor to NPP and structure in saltmarshes. While the biomass of photosynthetic microbes is generally more efficient and can exploit more photosynthetic pathways than flowering plants and multicellular algae, their small size allows them to be

transported out of saltmarshes or decomposed comparatively easily, limiting their contribution to the NPP and macrostructure of saltmarshes. Notably though the abundance of H₂S supports a significant quantity of H₂S oxidizing photolithoautotrophic cyanobacteria (Thomas et al. 2014) apparent by their purple, brown, and other-coloured colonies. H₂S oxidizing photolithoautotrophic cyanobacteria produce SO₄²⁻ as a product of their photosynthesis. While it is not presumed that H₂S oxidizing photolithoautotrophs contribute significantly to NPP, they do support microbes that are competitive with methanogenic decomposers.

Heterotroph Respiration

Heterotroph respiration is performed by two groups: animals and microbiota.

Southern Gulf of St. Lawrence saltmarshes support significant invertebrate and fish populations in or on the sediment, in ponds, or near the lower margin. Snails, like *Littoreia*, mussels, like *M. edulis* and *G. demissa*, and a variety of larval invertebrates, can be found in southern Gulf of St. Lawrence saltmarshes. Local fish species, such as *Gasterosteus aculeatus*, *Menidia menidia*, and *Fundulus heteroclitus*, use the waters in and around saltmarshes as nurseries, and as permanent or temporary habitats (Nordlie, 2003; Daodu, 2006). Animals are concentrated points of respiration compared to the soil community, but there is not much literature on their ecosystem wide effect in saltmarshes of the northwestern North Atlantic. Rather, most of the heterotrophic respiration is assumed to be performed by microbial life (e.g. Bartlett et al. 1985; Chmura et al. 2011).

Microbes in the anoxic, saline soils of saltmarshes have diverse metabolisms. As there is a lack of terrestrial macrofauna in saltmarshes – even more so than in freshwater wetland habitats (Greenberg et al. 2006) – most digestion of plant biomass is performed

by microbes. In a saltmarsh's anoxic soil environment there is significant niche space for anaerobic microbes (Abbott et al. 2022), like in freshwater wetlands (Wang et al. 1996). Because anaerobic metabolisms (e.g. methanotrophy, nitrogen fixation, SO_4^{2-} respiration, etc.) are less efficient than aerobic metabolism, decomposition happens slower, and biomass can accumulate faster (McLeod et al. 2011). This keeps carbon in the system. More, in saltmarshes the regular deposition of SO_4^{2-} from the tides and the production of SO_4^{2-} by H_2S oxidizing autotrophic bacteria support SO_4^{2-} reducing heterotrophic bacteria that outcompete acetoclastic and hydrogenotrophic methanogens (Villa, 2020).

Organic Matter Transport

Most of the organic matter transport in the saltmarshes of the Gulf of St. Lawrence is likely facilitated by the tide (Greenberg et al. 2006). While Atlantic Canadian saltmarshes are sometimes used to graze cattle (Roberts and Robertson, 1986) there is little research on native macro- and megafaunal grazers. As saltmarshes are likely to fracture in the future (Watt et al. 2011) it may be useful to measure organic matter transport to understand the NEP of southern Gulf of St. Lawrence saltmarshes better.

Measurement

To estimate NEP, several methods can be employed to measure its components. NPP can be estimated by measuring the change in above- and belowground biomass over a growing season (Connor and Chmura, 2000; Tripathee and Schäfer, 2015). To estimate organic matter transport in a saltmarsh, the flux of biomass by an inlet can be measured (e.g. Chalmers et al. 1985). NPP and heterotroph respiration, is often estimated by soil gas flux measurements (e.g. Chmura et al. 2011). These methods are not comprehensive of NEP however and must be combined to understand the NEP of any given saltmarsh.

Saltmarsh Persistence and Decline

Persistence

For a saltmarsh to persist in the same location it must maintain a pace of soil accretion greater than or equal to the rate of sea level rise. When the pace accretion is greater than sea level rise soil surface elevation will rise, desalination will occur, and give rise to a completely terrestrial environment, such as a coastal forest (Neily et al. 2017). However, this greater pace of accretion must be maintained over long periods to be sufficient for procession (Orson et al. 1985). Otherwise, a saltmarsh's brief lead obtained in a marathon of elevation change may simply be dynamic equilibrium. In those cases, or when marsh accretion matches sea level rise closely, the upper margin of a saltmarsh will remain near the high-water mark (Orson et al. 1985; Davis and Browne, 1996).

The process of saltmarsh accretion is controlled by persistent biomass accretion and wave energy. Nyman et al. (2006) found that there was a positive correlation between the accretion of elevation and accumulation of organic matter, even when the soil was as much as 80% sediment. The traits of plant matter like leaf and stem roughness, length, and mass, canopy height, and leaf size are positively correlated to greater vertical accretion (Bass et al. 2022). Conversely, wave energy is negatively correlated with the rate of vertical accretion. Therefore, saltmarshes with greater vegetation cover and less wave energy will accrete elevation more quickly.

Decline

In recent years, saltmarshes have been degrading, shrinking, or disappearing entirely. This is a trend globally (McLeod et al. 2011; Yando et al. 2023) including in the southern Gulf of St. Lawrence (Deveau, 2007; Watt et al. 2011). Deveau (2007)

demonstrated that southern Gulf of St. Lawrence saltmarshes had deviated from their *pristine state* by degradation. A saltmarsh's *pristine state* being its botanical, faunal, and microbial communities and general appearance, prior to intensive anthropogenic changes like dyking, road building, and enriching the atmosphere with GHGs from fossil fuels. Saltmarshes are degrading by losing their typical vegetation (Watt et al. 2011; Donnelly and Bertness, 2001) and fauna (e.g. *C. irroratus*), and having their usual ecological processes altered (Macreadie et al. 2013). The increase of dead zone total cover in southern Gulf of St. Lawrence saltmarshes is a prime example of degradation. Given that degraded saltmarshes are more susceptible to erosion (Kennish, 2001) saltmarshes may lose sediment year over year or even fracture (Deveau, 2007). The conclusion of degradation for a saltmarsh is its drowning or complete erosion (Orson et al. 1985).

Global and local human activity, occurring with natural phenomena, are offered as significant drivers of saltmarsh degradation (Kennish, 2001). Deveau (2007) notes that crustal subsidence, geologically driven sea level rise, and naturally occurring climate change in the southern Gulf of St. Lawrence places saltmarshes' *pristine state* in a context of dynamic equilibrium. However, human activity in the recent past is pushing saltmarshes over the edge, metaphorically speaking. Globally, rapid anthropogenic climate change from increasing GHG concentrations has accelerated the rate of sea level rise (Donnelly and Bertness, 2001; IPCC, 2014). Locally, the manipulation of the natural hydrology, like concentrating flow through a culvert, and the construction of barriers to saltmarsh retreat – a phenomenon termed 'coastal squeeze' (Garbary per. com. 2023) – introduces novel stresses and constraints to saltmarshes. Without mitigating human activity saltmarsh shrinking and disappearance will continue and perhaps accelerate.

Effects on Global Warming Potential

Balance of Global Warming Potential

To understand a saltmarsh's effect on global warming we cannot only consider its NEP; its net CO₂ flux must be balanced against those of other GHGs. In short, different GHGs contribute more or less than CO₂, molecule to molecule. Each CH₄ molecule causes 25 to 28 more warming than a CO₂ molecule over a 100-year period and 84 to 90 times more warming over a 20-year period (IPCC, 2013; Etminan et al. 2016). Each N₂O molecule causes 265 to 298 time more warming than a CO₂ molecule over a 100-year period (IPCC, 2012; IPCC, 2013). Greenhouse gasses (GHGs) are defined as gasses that absorb the energy radiating from Earth's surface and radiate it back – in a phenomenon called radiative forcing – causing the Greenhouse Effect. To compare the relative radiative forcing of different GHGs driving the Greenhouse Effect – sometimes called their potency – we often use a unit called carbon dioxide equivalents (CO₂e) (US EPA, 2023). CO₂e is a unit that represents the radiative forcing gasses would produce equivalent to that many molecules of CO₂. For example, if one molecule of some gas were to produce 100 times the radiative forcing of CO₂, its radiative forcing could be expressed as 100 CO₂e. CO₂e allows for the synthesis of the radiative forcing of multiple gasses in one digestible number. Other than CO₂, CH₄ and N₂O are the primary GHGs of biotic significance. To understand the effect of saltmarshes on GWP, we must weigh the total CO₂e going into the system against the total CO₂e leaving.

Historically, saltmarshes have had a mitigating effect on global warming (Chmura et al. 2003; McLeod et al. 2011). The slow rate of decomposition and lack of large, native herbivores, allows plant biomass to accumulate each year. The carbon in plant biomass

becomes buried and forms peat. Thus, the net flux of CO₂ has often historically been relatively large and into a saltmarsh's soil. Previous Atlantic Canadian studies found that at two saltmarshes, net N₂O fluxes were negligible to their net CO₂e flux (Chmura et al. 2011; Chmura et al. 2016). CH₄ however, is sometimes notable and has been reported to have large emissions from *S. alterniflorus* zones (Comer-Warner, 2022) perhaps through the grass's aerenchyma tissue (Brix et al. 1992). However, CH₄ emission is often comparably lesser from saltmarshes than freshwater wetlands (Poffenbarger et al. 2011).

Anoxic soils, typical of wetlands, create niche space for anaerobic heterotrophs. In freshwater wetlands, soil biogeochemistry can often host enough methanogens to produce substantial CH₄ emissions (Wang et al. 1996; Hardy et al. 2023). In saltmarshes, ubiquitous SO₄²⁻ supposedly allows SO₄²⁻ reducing soil microbes to largely outcompete acetoclastic and hydrogenotrophic methanogens (Bartlett et al. 1985; Poffenbarger et al. 2011; Villa, 2020). This significantly reduces CH₄ production and emission, offering saltmarshes as having particularly negative effects on GWP, mitigating global warming.

Variation

GHG flux varies amongst vegetation zones and across abiotic condition gradients.

Vegetation zone

The biology and ecology of the vegetation in each zone is a significant driver of GHG fluxes. Comer-Warner et al. (2022) found comparably lesser CH₄ emissions from mudflats, *S. pumilus*, and *Phragmites australis* than from *S. alterniflorus*, proposing that aerenchyma tissue of *S. alterniflorus* may facilitate CH₄ transfer to the atmosphere (Brix et al. 1992), bypassing soil methanotrophs. More, different vegetation zones generate

biomass at different rates (Connor and Chmura, 2000; Tripathee and Schäfer, 2014; Ampuero and Reyes 2022) suggesting varied CO₂ flux amongst vegetation zones too.

Abiotic conditions

The flux of greenhouse gasses is also controlled by abiotic environmental conditions. Abdul-Aziz et al. (2018) found that soil temperature and photosynthetically active radiation were positively correlated, and salinity was negatively correlated with the uptake of CO₂ and emission of CH₄ at four saltmarshes in Waquoit Bay, Massachusetts. Interestingly, they also found that magnitude of fluxes were significantly greater during high tide as opposed to low tide. Soil temperature was a 2 and 4 to 5 times greater influence on the CO₂ and CH₄ fluxes compared to photosynthetically active radiation and salinity, respectively. Salinity is often used as a proxy for the concentration of SO₄²⁻. While high salinity is often associated with lesser CH₄ emissions (Bartlett et al. 1987; Poffenbarger et al. 2011; Abdul-Aziz et al. 2018), greater CH₄ emissions have sometimes still been reported highly saline marshes and saltmarsh zones (Martin and Moseman-Valtierra, 2017; Emery and Fulweiler, 2017; Comer-Warner et al. 2022). Comer-Warner et al (2022) suggests that this could be due to other environmental factors superseding the effect of salinity, interacting with and negating it, or causing CH₄ to be emitted in a different location from where it is produced.

Novel Saltmarsh Changes

The degradation of saltmarshes is cause for concern with respect to their role as mitigators of global warming. Increasing global temperatures and loss of vegetation cover will increase saltmarsh soil temperatures, potentially increasing CH₄ production and emission (Abdul-Aziz et al. 2018). The loss of saltmarsh vegetation could also decrease

CO₂ uptake and the permanence of organic matter in saltmarshes. As climate change continues to progress, conditions conducive to dead zone formation (e.g. accelerating sea level rise, more weather events causing high wave energy, etc.) will be amplified (IPCC, 2014). It is possible that dead zone formation and expansion will continue or accelerate in the southern Gulf of St. Lawrence. To understand the degree to which the changing community structure of saltmarshes will also change the effect of saltmarshes as global warming mitigating ecosystems, we must measure the difference in GHG fluxes between the historically dominant *S. alterniflorus* zones of the low marsh and the expanding dead zones. There have been few previous studies in the southern Gulf of St. Lawrence examining dead zones in saltmarshes. Therefore, this study may be regionally important to describing dead zones and understanding their capacity for CO₂ sequestration and CH₄ emission.

Intent

Therefore, I have set out with this thesis to compare these dead zones to live *S. alterniflorus* zones. Specifically, I am comparing the CO₂ and CH₄ flux rates, under light and dark conditions, between *S. alterniflorus* zones, dead lower margins, expansive salt pannes, and limited salt pannes. I did this by sampling directly from the soil using light and dark soil gas flux chambers, and a mobile gas analyzer. I then compared the rates of flux to determine the difference in magnitude and direction of the CO₂ and CH₄ fluxes. I predict that the *S. alterniflorus* zone will absorb significantly more CO₂ and emit significantly more CH₄ than the dead zones. I also predict that the magnitude of mean net CO₂ and CH₄ fluxes from all dead zones will be lesser than those from the *S. alterniflorus* zones.

Materials and Methods

Between June 8 and September 25, 2023, I sampled the flux of carbon dioxide (CO₂) and methane (CH₄) from saltmarsh soils using a Soil Air Nature Description Instrument (SANDI) (Figure 1) at five tidal saltmarshes in the southern Gulf of St. Lawrence. These samples were usually taken in *Sporobolus alterniflorus* and dead zones of these saltmarshes. For this study, I defined dead zones as areas of the saltmarsh which lacked any historically-zone-defining, dominant plant species of the saltmarshes of the southern Gulf of St. Lawrence (i.e. *S. alterniflorus*, *S. pumilus*, *D. spicata*, *J. balticus*, *J. gerardii*, or any of the dominant high marsh species). The dead zones examined were the dead lower margins, extensive salt pannes, and the limited salt pannes.

To complement these soil CO₂ and CH₄ flux measurements, I also took two categories of environmental measurements. The first category, called the ‘condition measurements,’ were taken with every single soil gas flux measurement. Condition measurements were the temperature, pore water salinity, and compressibility of the soil that was being measured for CO₂ and CH₄ flux. The second category, called the ‘contextual measurements,’ were taken sporadically to understand general qualities of saltmarshes. Contextual measurements consisted of personally taken and accessed photography, GPS delimited marsh zones, and observational notes.

Study areas

The five saltmarshes I studied were located along the southern shore of the Gulf of St. Lawrence (Figure 2). Two saltmarshes, Boy Scout Beach and Captain’s Pond Inlet saltmarshes, were on Nova Scotia’s mainland, in Antigonish County, and three

saltmarshes, the Chéticamp Mainland, Chéticamp Island, and Michael's Landing saltmarshes, were along the western shore of Cape Breton Island.

Nova Scotia Mainland

Boy Scout Beach Saltmarsh

The first site, the Boy Scout Beach saltmarsh (Figure 3), was in Antigonish County, on the east side of Antigonish Harbour, inside Captain's Pond at the end of Scout Camp Road. The specific portion of the saltmarsh sampled from is south of 45.6780° N, north of 45.6772° N, east of 61.8519° W, and west of 61.8493° W. This saltmarsh's northern, eastern, and western edges met the shoreward side of a beach dune system and its southern edge meets Captain's Pond, a barachois. This saltmarsh was relatively expansive compared to others in this study with a wide profile in most places. It contained many pools, sparse limited salt pannes, no extensive salt panne, and thin and infrequent dead lower margins. This site had a wide *S. alterniflorus* zone in the lower marsh with spongy and compressible peat.

Captain's Pond Inlet Saltmarsh

The second site, the Captain's Pond Inlet saltmarsh (Figure 4), was also in Antigonish County, on the east side of Antigonish Harbour, but it was accessed near the end of Southside Harbour Road, where the eastern-most portion of Antigonish Harbour fed into Captain's Pond. The portion of the saltmarsh that I sampled from was south of 45.6810° N, north of 45.6800° N, east of 61.8682° W, and west of 61.8669° W. This saltmarsh was somewhat continuous along the western edge of Captain's Pond becoming very thin in many parts. The upper margin of the Captain's Pond Inlet saltmarsh bordered coastal Acadian forest, with species such as black spruce (*Picea mariana*), quaking aspen

(*Populus tremuloides*), and red maple (*Acer rubrum*). This saltmarsh had no pools, small limited pannes, found near the lower edge of the *S. alterniflorus* zone, no extensive salt panne, and a continuous dead lower margin that was relatively wide in some areas and thin in others. The *S. alterniflorus* zone varied from around 10 - 20m wide to being non-existent between the dead lower margin and mid-marsh zones. The peat in my study area was relatively less compressible than the Boy Scout Beach saltmarsh.

Western Cape Breton Island

Chéticamp Mainland Saltmarsh

The third site, the Chéticamp Mainland saltmarsh (Figure 5), is in Inverness County, south of the village of Chéticamp, nestled in the southern-most, narrow portion of a small basin in Chéticamp Harbour. The Chéticamp Mainland saltmarsh formed a U-shape along the shore of this small basin, from its northeastern edge (46.5981° N, 61.026° W), stretching southward on the east side to roughly 46.5931° N, then west to 61.029° W and north to 46.5972° N. The sampling area however was south of 46.5978° N, north of 46.5964° N, east of 61.2078° W, west of 61.0267° W. Roads bordered the saltmarsh's upper margin on all sides. It was accessible by a dirt road, La Roach, from the east and by Chéticamp Island Road from the west. There was little area between the saltmarsh's upper margin and the roads for non-saltmarsh vegetation, except for a stand of bigtooth aspen (*Populus grandidentata*) at the southeast upper margin. This saltmarsh had a moderate number of pools and limited salt pannes in its southeast area, a large expansive salt panne at its northeast extent, and a moderately wide dead lower margin along its eastern side. Most of the band of *S. alterniflorus* zone was relatively wide but sometimes varying thinner or interrupted by drainage streams. The peats in these *S.*

alterniflorus and dead zones were less compressible than at the Boy Scout Beach saltmarsh, but slightly more compressible than at the Captain's Pond Inlet saltmarsh.

Chéticamp Island Saltmarsh

The fourth site, the Chéticamp Island saltmarsh (Figure 6), was located northwest of the Chéticamp Mainland Saltmarsh, at the southeast of Chéticamp Island, northeast of a causeway. The specific sampling area was south of 46.6048° N, north of 46.6036° N, east of 61.0362° W, and west of 61.0342° W. This saltmarsh was partially protected behind a barrier beach to its southeast that hosted saltmarsh vegetation on its shoreward side and, although much less, on its harbour side as well, where scarp could be seen. The saltmarsh's southern portion opens to the harbour, concentrating tidal water inflow and outflow. The shore-side's upper saltmarsh backs into Chéticamp Island Road to the southwest, a road, Du Phare, to the northwest, and a residential property's lawn to the northeast. The Chéticamp Island saltmarsh has deep channels that flow freshwater from culverts to the sea. The Chéticamp Island saltmarsh had deep and shallow pools, few limited salt pannes, a single extensive salt panne near its southeast extent, and a dead lower margin of varying width. The *S. alterniflorus* zones were roughly half the saltmarsh's profile's width and sometimes interrupted by the deep channels and less halo-tolerant species, such as *S. michauxianus*. The peat of the *S. alterniflorus* and dead zones was comparably compressible to those of the Captain's Pond Inlet saltmarsh.

Michael's Landing Saltmarsh Complex

The fifth site, the Michael's Landing saltmarsh complex (Figure 7), is two kilometers north of the community of Judique; accessible from the Ceilidh Trail. The sampling area was part of a peninsula south of 45.8976° N, north of 45.8961° N, east of

61.4883° W, and west of 61.4862° W. A barrier dune system with an inlet created a barachois and concentrated tidal flow through its inlet. Freshwater inflow primarily came from Judique Intervale Brook to the north, along with a few small streams. This saltmarsh complex's upper margin mostly bordered mixed-wood forest except a lawn next to the Michael's Landing parking area and a residential lawn near 45.8972° N and 61.4835° W. The study area of this saltmarsh complex had two notable pools, a relatively moderate number of limited salt pannes, no extensive salt pannes, and a dead lower margin that was wide to non-existent varying across areas of the saltmarsh complex peninsula. The peat in the *S. alterniflorus* zones was less compressible than at the Boy Scout Beach saltmarsh, but more compressible than at the Chéticamp Mainland saltmarsh.

Field Measurement

Soil Gas Flux Measurements

Standard Soil Gas Flux Measurements

To measure CO₂ and CH₄ flux, soil gas chambers (Figure 8), connected to the SANDI, were placed on top of the soil for roughly twenty minutes, encapsulating plants if there were any, and the temperature probe was inserted into the soil near the chamber. I used four variations of soil gas chamber: a small-light chamber, a small-dark chamber, a large-light chamber, and a large-dark chamber. The light chambers were intended to simulate daytime conditions, allowing both photosynthesis and respiration, while dark chambers were intended to simulate nighttime conditions, allowing only respiration. Twenty minutes was selected to allow sampling artifacts to dissipate and because it was short enough to collect several samples in a day.

On August 17th, 2023, I switched from using small to large chambers because as the shoots of *S. alterniflorus* grew, I began breaking more and more stems under my small chambers, compromising their natural photosynthetic rate.

During these twenty minutes of sampling, the SANDI pumped air into and out of its analyzers at the same rate. Maintaining equal inflow and outflow was important to maintain a stable air pressure inside the chambers. Figure 9 shows a diagram illustrating the path of air during a measurement.

The SANDI's datalogger (Model CR1000, Campbell Scientific, Inc., Logan, UT) created a sample record every ten seconds which could be monitored through the Campbell Scientific computer program, LoggerNet (Campbell Scientific, 2024). Each sample record included an instantaneous timestamp, record number, latitude (in degrees minutes), and longitude (in degrees minutes), and a ten second mean battery voltage (in volts), datalogger temperature (in °C), CH₄ concentration (in ppm), CO₂ concentration (in ppm), and soil temperature (in °C). Each measurement's start and end times were recorded in a field notebook. A file for each measurement was later retrieved from the datalogger, using LoggerNet, and saved as comma separated value files (.csv files).

Measurements were done in sets, with a standard 'measurement set' containing one dark chamber measurement and one light chamber measurement. Every measurement in a single measurement set was done in the exact same location, one measurement followed as immediately as practically possible by the next.

Measurement Sets with Cutting Treatments

To verify the assumption that the light chambers and dark chambers were adequate simulations of daytime and nighttime conditions, respectively, some

measurement sets of *S. alterniflorus* zones included two more measurements using a cutting treatment. These measurement sets were called ‘cut measurement sets.’ The first two measurements in a cut measurement set were a light chamber measurement and a dark chamber measurement, taken as they would have been in a standard measurement set. These were called the ‘uncut measurements.’ Then, using garden shears, the vegetation was removed and placed in a plastic bag to later be weighed. The third and fourth measurements, called ‘cut measurements,’ were then taken; a dark chamber measurement and a light chamber measurement. All measurements in a cut measurement set would be used for testing the assumption that light and dark chamber measurements simulated of day and night, respectively, but only the first and second measurements would be used for the comparison of *S. alterniflorus* zones and dead zones.

Measurement Sets with a Replicated Measurement

Near the middle of August, it was brought to my attention that unpublished work done by Dr. Douglas Campbell at Mount Allison University on tidal mudflats had similar methods to my own and had persistent sampling artifacts (Garbary per com. 2023). Dr. Campbell had found that placing a soil gas chamber on the soil of tidal mudflats caused an acute increase in CH₄ concentration before CH₄ concentrations then stabilized. I then consulted documentation for commercial soil gas chambers, the Eosense © eosAC-LT/LO and eosMX/MX-P user manual (2021). I also consulted a previous user of the SANDI, Sarah Kennedy, MSc (Hachmen et al. 2023). I found that this artifact was not unusual and could be accounted for in processing. I nonetheless determined that I should add a verification of this into my experimental design to verify that my processing could account for artifacts. Therefore, in some measurement sets, the first measurement was

repeated, making the measurement set contain three measurements. The first measurement and second measurement (the first measurement's repeat) would be processed as usual, but then tested for significant difference between them.

In measurement sets with three measurements, called 'repeated measurement sets,' the first measurement, whether it was a light or dark chamber measurement, was immediately repeated. That repeated measurement was then followed by the chamber measurement type, light or dark, that had not yet been taken. Accordingly, the first two measurements, near exact replicates, represented the first measurement of a standard set, and the third measurement represented the second measurement of a standard set.

Benchmarking

To ensure the SANDI was measuring properly, I benchmarked the instrument's gas concentration accuracy, and inflow and outflow rates four times during my sampling period. I started each benchmarking session by turning the SANDI on for five minutes to warm up the sensors (I would do the same in the field when taking measurements).

To benchmark the instrument's gas concentration accuracy, I would fill 4 1-L Tedlar bags, connected together by vinyl tubing and fittings, with calibration gas of known CO₂ and CH₄ concentrations (516.54 ± 0.01 ppm and 4.5254 ± 0.00002 ppm respectively), to be fed into the instrument. I would then connect the Tedlar bags to the SANDI and note the time. Once the Tedlar bags were empty, I would disconnect them and note the time. I would then download the data between the start and end and calculate the mean CO₂ and CH₄ recorded concentrations from the first record within 20% lesser or greater of the known respective gas concentrations to the file's final record using R statistical software (v4.3.2; R Core Team 2023). The difference between the calculated

mean concentrations and the true gas concentrations were the drifts of the CO₂ and CH₄ sensor accuracies.

Following this test, an Aalborg GFM mass flow meter (2022) would be attached to the inlet tube and then outlet tube, to ensure that inflow and outflow rates were the same. If the difference between inflow and outflow rates was greater than 0.1 L/min, then the line of tubing would be checked for leaks, repaired if needed, and then retested.

Environmental Measurements

Soil Gas Flux Measurement-tied Environmental Measurements

With as many soil gas measurements as possible, position, soil pore water salinity, soil compressibility, and soil temperature were also recorded. Position was obtained from a GARMIN eTrex® 22x GPS for most soil gas measurements but was otherwise determined by the SANDI's GPS. Soil pore water salinity was obtained using a handheld analog refractometer to sample pore water extracted adjacent to the soil gas measurement chamber. Soil compressibility was sampled using a Humbolt Manufacturing Company Pocket Penetrometer with a low-strength soil adapter foot on the soil under the soil gas chamber following all soil gas chamber measurements. Soil temperature was sampled using the SANDI's thermistor temperature probe, which was inserted into the soil, approximately 10 cm, next to the soil gas chamber measurement.

Contextual Measurements

Throughout the field season, I wrote additional notes and recorded additional measurements in my field notebook. The purpose of these was to better understand the saltmarshes and therefore the context in which my soil gas measurements were produced. These field notes are included as Appendix A.

Sample Processing

Calculating Sample Means

CO₂ and CH₄ Flux Rates

To obtain the CO₂ and CH₄ flux rates from my soil gas chamber measurements I first had to obtain the average change in CO₂ and CH₄ concentration per unit time. Using RStudio (v2023.12.1) and R (v4.3.2, R Core Team 2023) I wrote a script, available on GitHub (Kennedy, 2024), to process measurement files from the SANDI and output the mean change in CO₂ and CH₄ concentration over time.

In short, the script's process was the following: first, one measurement .csv file and one benchmarking .csv file were introduced into the RStudio environment. Then, the CO₂ and CH₄ concentrations (in ppm) from the measurement .csv file were corrected using the benchmarking .csv file. The corrected CO₂ and CH₄ concentrations of the measurement file were each plotted against time which were used, with field notes, to determine the time frame and concentration ranges from which mean rates of CO₂ and CH₄ concentration change would be calculated. Selecting the time frame and concentration ranges was intended to exclude sampling artifacts, such as negative concentrations, concentrations outside of the sensors' respective calibrations ranges, or evidently discontinuous data points (Figure 10). The mean rates CO₂ and CH₄ concentration change were then calculated and standardized to the volume and basal surface area of the soil gas chamber that was used to take that measurement; this was the final output. The outputted mean rates of CO₂ and CH₄ concentration change were then put in a Microsoft Excel file.

Inside the Excel file, I used the ideal gas law to convert the mean rates of concentration change into fluxes (in g/m²hr). Hourly air temperature and air pressure from nearby Environment and Climate Change Canada (2023) weather stations were assumed as the gas temperature and pressure inside the soil gas chamber. In sum, after determining the mean rates of CO₂ and CH₄ concentration change the following equation was used to calculate the CO₂ and CH₄ fluxes of each measurement:

$$J_{i,a} = \frac{x_i * V_i}{SA_i} * \left(\frac{1 \text{ part}}{1\,000\,000 \text{ parts}} \right) * \left(\frac{P_i}{R * T_i} \right) * M_a * \left(\frac{3600s}{1hr} \right)$$

Where ‘J_{i,a}’ is the flux of gas ‘a’ (in g/m²hr) from measurement ‘i’, ‘x’ is the mean rate of concentration change (in Δ in ppm/s) of gas ‘a,’ ‘V’ is the volume of the soil gas chamber (in m³), ‘SA’ is the surface area of the soil that the soil gas chamber covers (in m²), ‘P’ is pressure (in Pa), ‘R’ is the ideal gas constant (in kg*m²*s⁻²*K⁻¹*mol⁻¹), ‘T’ is temperature (in K), and ‘M_a’ is the molar mass of gas ‘a’.

Mean Soil Temperature

The measurement file processing script also calculated the mean soil temperature of each measurement. To calculate the mean soil temperature, the soil temperature was plotted over time and assessed. If the soil temperature appeared to behave regularly, as it nearly always did, the mean soil temperature was calculated between the start and end times I had recorded in my field book.

Organising Measurement Sets

After calculating each measurement’s CO₂ and CH₄ fluxes, I arranged them into a new table according to the measurement set they belonged to. Each column in this measurement set table contained all light chamber CO₂ flux(es), light chamber CH₄ flux(es), dark chamber CO₂ flux(es), and dark chamber CH₄ flux(es) from the same

measurement set. Standard measurement sets would have one of each flux, whereas repeated measurement sets would have an extra CO₂ flux and an extra CH₄ flux, from the chamber measurement type that had been repeated, and cut measurement sets would have two of each flux. Each column also contained the number of hours between sunrise and sunset on the measurement set's day of collection.

Each column would only have one of each flux that would be used for statistical testing, unless otherwise specified below. For repeated measurement sets, the mean of the replicated fluxes would be used. For cut measurement sets, only the fluxes of the uncut measurements would be used.

Calculating Net Fluxes

To synthesize the simulated daytime and nighttime fluxes of CO₂ and CH₄ into a number representative of a 24-hour period, I calculated net fluxes of CO₂ and CH₄ for each measurement set. The equation used to calculate these net fluxes is as follows:

$$J_{net,x} = \left(J_{light,x} * \left(\frac{t_{daylight,x}}{24 \text{ hours}} \right) \right) + \left(J_{dark,x} * \left(1 - \frac{t_{daylight,x}}{24 \text{ hours}} \right) \right)$$

Where 'J_{net,x}' is the net flux (in g/m²hr), 'J_{light,x}' is the light chamber flux, and 'J_{dark,x}' is the dark chamber flux of measurement set 'x,' and 't_{daylight,x}' is the number of hours between sunrise and sunset the day of measurement set 'x.'

Tests to Support Assumptions

An outline of all tests to support assumptions can be found in Table 1.

Testing Accurate Simulation of Night and Day Conditions

Dark Chambers and Light Chambers

To verify my assumption that dark chamber measurements and light chamber measurements accurately simulated nighttime and daytime, respectively, I first tested for

significant difference between their mean fluxes. I used two Single Factor Analysis of Variance (ANOVA) tests and the light and dark chamber measurement CO₂ and CH₄ fluxes of each measurement set. The first single factor ANOVA (Test 1) tested for significant difference between the mean CO₂ fluxes of light chamber measurements and dark chamber measurements ($\alpha = 0.05$). The second single factor ANOVA (Test 2) tested for significant difference between the mean CH₄ fluxes of light chamber measurements and dark chamber measurements ($\alpha = 0.05$). The null hypothesis of both ANOVAs was that there would be no significant difference in the mean fluxes of the two groups.

Cutting Treatments

To further support that light chamber measurements and dark chamber measurements accurately simulated daytime and nighttime conditions, respectively, I had to test if light chambers allowed photosynthetic activity, and that dark chambers did not. Using the cut measurement sets, I performed two Single Factor ANOVAs. The first (Test 3) tested for significant difference amongst the mean CO₂ fluxes of the uncut light chamber measurements, cut light chamber measurements, uncut dark chamber measurements, and cut dark chamber measurements ($\alpha = 0.05$). The second Single Factor ANOVA (Test 4) tested for significant difference in the mean CO₂ fluxes of only the cut light chamber measurements, uncut dark chamber measurements, and cut dark chamber measurements ($\alpha = 0.50$). The null hypothesis being tested for both ANOVAs was that no mean CO₂ flux of any group would be significantly different from the others.

If the null hypothesis for either Single Factor ANOVA were rejected, I would then perform a Tukey Test for Honestly Significant Difference (Tukey HSD Test) on the tested groups. My assumption – that the light chambers allowed photosynthetic activity,

and the dark chambers did not – would be supported if only the mean CO₂ flux of the uncut light measurements was significantly different from the other groups, was the most negative, and if the mean CO₂ fluxes of the other three groups were relatively similar.

Testing for Sampling Artifacts

Small Chambers Versus Large Chambers

To test that changing chamber sizes during my sampling campaign did not significantly alter my method of measurement, I needed to test for significant difference between the mean CO₂ and CH₄ fluxes of the small chamber and the large chamber measurements. For this I performed two Single Factor ANOVAs ($\alpha = 0.05$). The first (Test 5) tested for significant difference between the mean CO₂ fluxes of dead zone small and large chamber measurements. The second Single Factor ANOVA (Test 6) tested for significant difference in the mean CH₄ fluxes of dead zone small and large chamber measurements. For both Single Factor ANOVAs, the null hypothesis being tested was that there would be no significant difference between the mean fluxes of dead zone small and large chamber measurements. Small and large chamber measurements from the *S. alterniflorus* zone were excluded from these tests because the small chamber measurements in the *S. alterniflorus* zone were known to be flawed.

Test for Artificial Emission

To test the assumption that my processing methods sufficiently accounted for sampling artifacts, I tested significant difference between the mean CO₂ and CH₄ fluxes of the first and second measurements from repeated measurement sets, using two Two-Sample t-Tests, assuming equal variance ($\alpha = 0.05$). The first (Test 7) tested for significant difference between the mean CO₂ fluxes of the first measurement and the

second measurement. The second (Test 8), tested for significant difference between mean CH₄ fluxes of the first measurement and the second measurement. For both t-Tests, the null hypothesis being tested was that there would be no significant difference between the mean fluxes of the first and second measurements.

Testing for Difference Amongst Zones

If all assumptions were verified, my goal was then to determine if there were significant differences amongst the mean CO₂ and CH₄ fluxes of my saltmarsh vegetation zones of interest; the *Sporobolus alterniflorus* zone, the dead lower margin, the limited salt pannes, and the expansive salt pannes.

All Measurement Sets

Light Chamber Measurements

To test if my four vegetation zones of interest had significantly different daytime fluxes of CO₂ and CH₄, I performed two Single Factor ANOVAs ($\alpha = 0.05$). The first (Test 9) tested for significant difference amongst the mean light chamber CO₂ fluxes of the *S. alterniflorus* zones, dead lower margins, limited salt pannes, and extensive salt pannes. The second Single Factor ANOVA (Test 10) tested for significant difference amongst the mean light chamber CH₄ fluxes of the *S. alterniflorus* zones, dead lower margins, limited salt pannes, and extensive salt pannes. The null hypothesis of both Single Factor ANOVAs was that no vegetation zone would have a significantly different mean light chamber flux from the other vegetation zones.

If the null hypothesis of one of those Single Factor ANOVAs, testing for significantly different mean light chamber fluxes, would have been rejected, I would have then performed a Tukey HSD test for the mean light chamber fluxes determined to not all

be the same. The Tukey HSD test would show which vegetation zone or zones had significantly different mean light chamber fluxes from the rest.

Dark Chamber Measurements

To test if my four vegetation zones of interest had significantly different nighttime fluxes of CO₂ and CH₄, I performed two Single Factor ANOVAs ($\alpha = 0.05$). The first (Test 11) tested for significant difference amongst the mean dark chamber CO₂ fluxes of the *S. alterniflorus* zones, dead lower margins, limited salt pannes, and extensive salt pannes. The second Single Factor ANOVA (Test 12) tested for significant difference amongst the mean dark chamber CH₄ fluxes of the *S. alterniflorus* zones, dead lower margins, limited salt pannes, and extensive salt pannes. The null hypothesis of both Single Factor ANOVAs was that no vegetation zone would have a significantly different mean dark chamber flux from the other vegetation zones.

If the null hypothesis of one of those Single Factor ANOVAs, testing for significantly different mean dark chamber fluxes, would have been rejected, I would have then performed a Tukey HSD test for the mean dark chamber fluxes determined to not all be the same. The Tukey HSD test would show which vegetation zone or zones had significantly different mean dark chamber fluxes from the rest.

Net Fluxes

To test if my four vegetation zones of interest had significantly different net fluxes of CO₂ and CH₄, I performed two Single Factor ANOVAs ($\alpha = 0.05$). The first (Test 13) tested for significant difference amongst the mean net CO₂ fluxes of the *S. alterniflorus* zones, dead lower margins, limited salt pannes, and extensive salt pannes. The second Single Factor ANOVA (Test 14) tested for significant difference amongst the

mean net CH₄ fluxes of the *S. alterniflorus* zones, dead lower margins, limited salt pannes, and extensive salt pannes. The null hypothesis of both Single Factor ANOVAs was that no vegetation zone would have a significantly different mean net flux from the other vegetation zones.

If the null hypothesis of one of those Single Factor ANOVAs, testing for significantly different mean net fluxes, would have been rejected, I would have then performed a Tukey HSD test for the mean net fluxes determined to not all be the same. The Tukey HSD test would show which vegetation zone or zones had significantly different mean net fluxes from the rest.

August Measurement Sets

Because measurement sets throughout the summer were not evenly distributed across vegetation zones for most of the summer, the above-described statistical tests, performed on all measurement sets to compare the mean fluxes of different vegetation zone, were repeated using only the measurement sets collected in August (Tests 15 through 20, accordingly). August had the largest abundance of measurements of any month during the summer, in addition to the best evenness. These results of these tests, performed only on measurement sets collected in August, would complement, not negate, the results of the tests performed on all measurement sets.

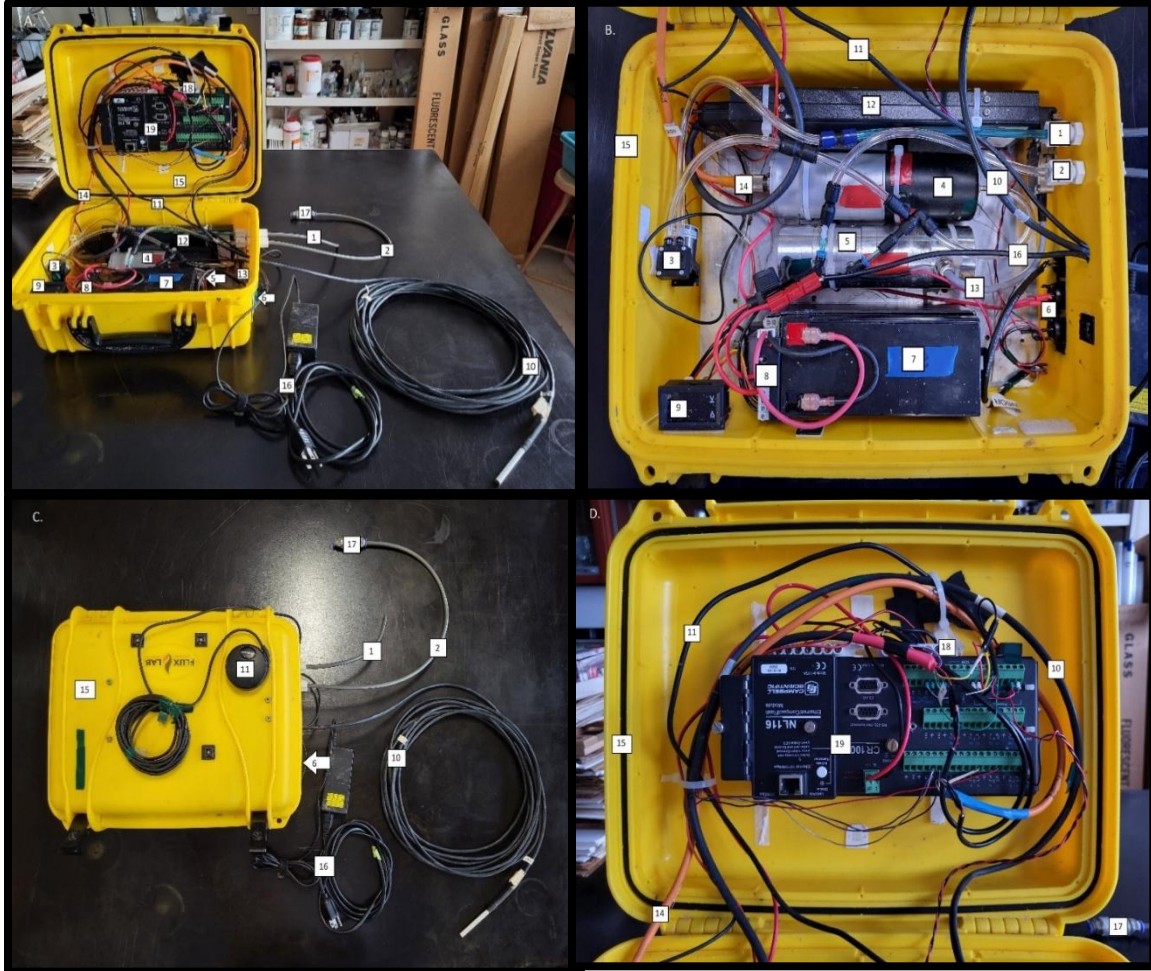


Figure 1. The Soil Air Nature Description Instrument (SANDI), pictured here, is an originally manufactured multi-instrument enclosure. It is capable of measuring CO₂ and CH₄ gas concentrations, soil temperature, and position. Air is pumped out of the (1.) out-going tubing and in through the (2.) in-coming vinyl tubing by a (3.) small diaphragm pump at a rate of approximately 2.2 L/min. Air traveling the through line of tubing passes through a (4.) Vaisala CARBOCAP® Carbon Dioxide Probe GMP343 and an (5.) Axetris Laser Gas Detection (LGD) Compact-A CH₄ sensor. An (6.) external power switch controls the powering of the enclosure by a (7.) 12-volt batter that is connected to an (8.) internal master power switch. The current voltage and amperage can be read from an (9.) digital display. A (10.) thermistor temperature probe runs out of the enclosure to measure soil temperatures. A (11.) Garmin ETREX 22x handheld GPS also runs to the external of the enclosure. An (12.) analog to serial signal adapter is connected to the CH₄ sensor by a (13.) serial cable. Another (14.) serial cable connects to the CO₂ probe. Running out of the (15.) Pelican Case enclosure is an (16.) AC/DC power adapter to charge the 12-volt battery. A (17.) filter at the in-coming tubing prevented moisture and particulate matter from entering the system. A (18.) circuit connector connected the power from the 12-volt battery to all components. A (19.) Campbell Scientific CR1000 Data Logger is connected to all the instruments and compiles all information from the instruments into timestamped files.

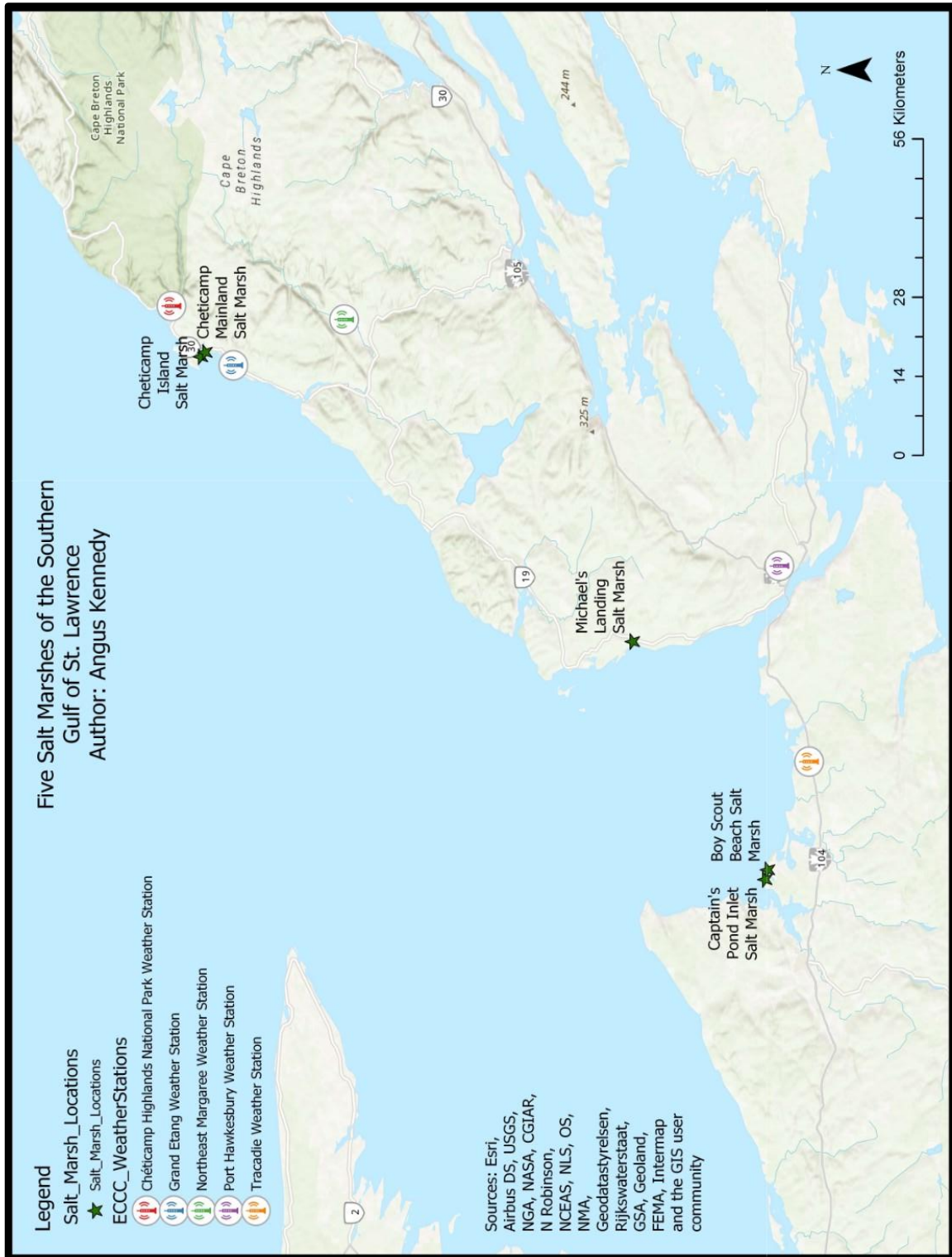


Figure 2. Five Salt Marshes of the Southern Gulf of St. Lawrence. Five saltmarshes in the Southern Gulf of St. Lawrence were study sites in a 2023 study of CO₂ and CH₄ fluxes from *Sporobolus alterniflorus* zones and ‘dead zones.’ Five weather stations are also shown from which weather data was gathered for analysis in the study.

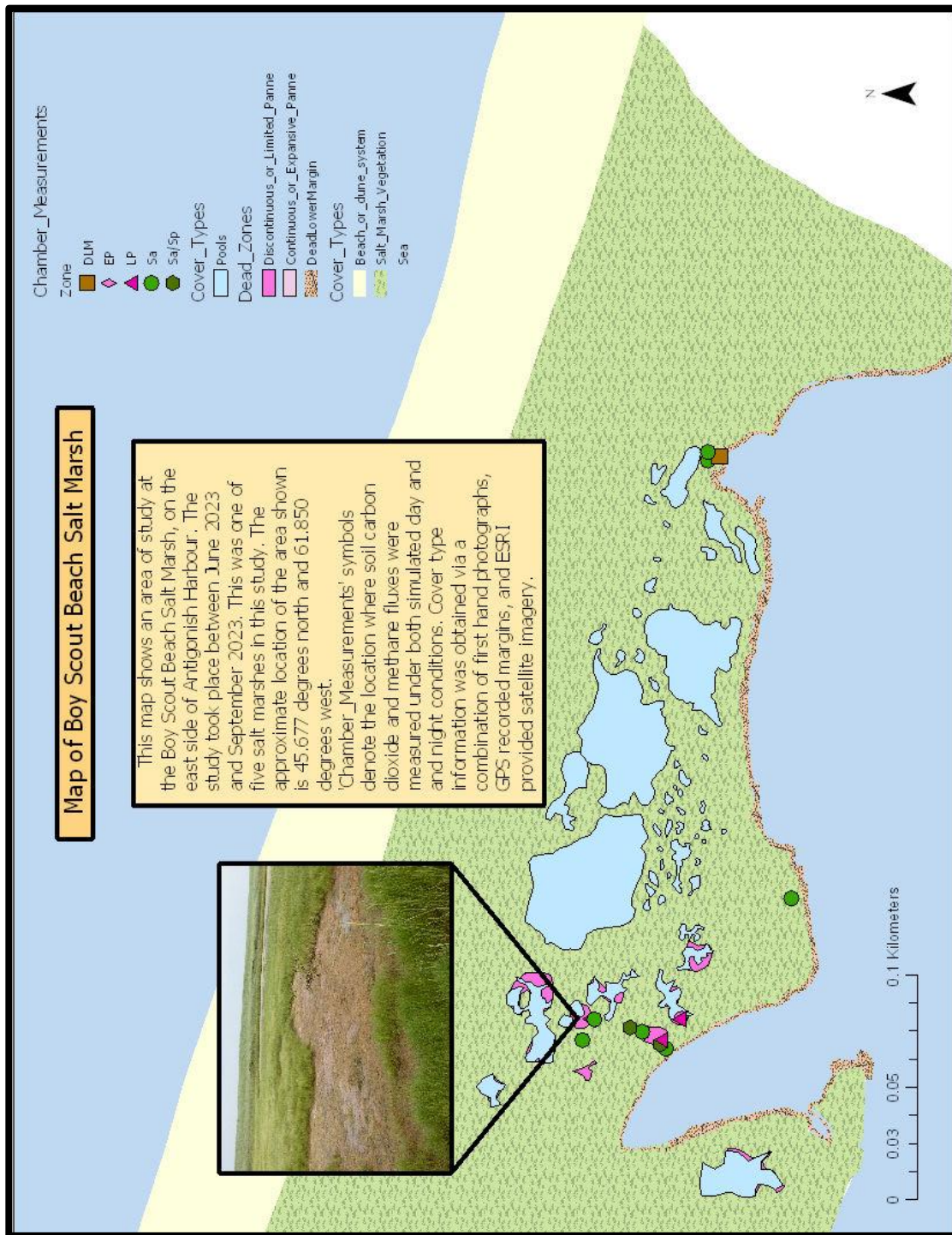


Figure 3. Boy Scout Beach saltmarsh. This map shows the eastern end of the Boy Scout Beach saltmarsh near approximately **45.677° north and 61.850° west**. Interior pools and dead zones are shown on top of the vegetated areas of the saltmarsh. Locations of measurement sets and an image of a **limited salt panne** are shown too. This map does not show the true extent of limited pannes in this area of the saltmarsh but nonetheless can be useful as a guide.

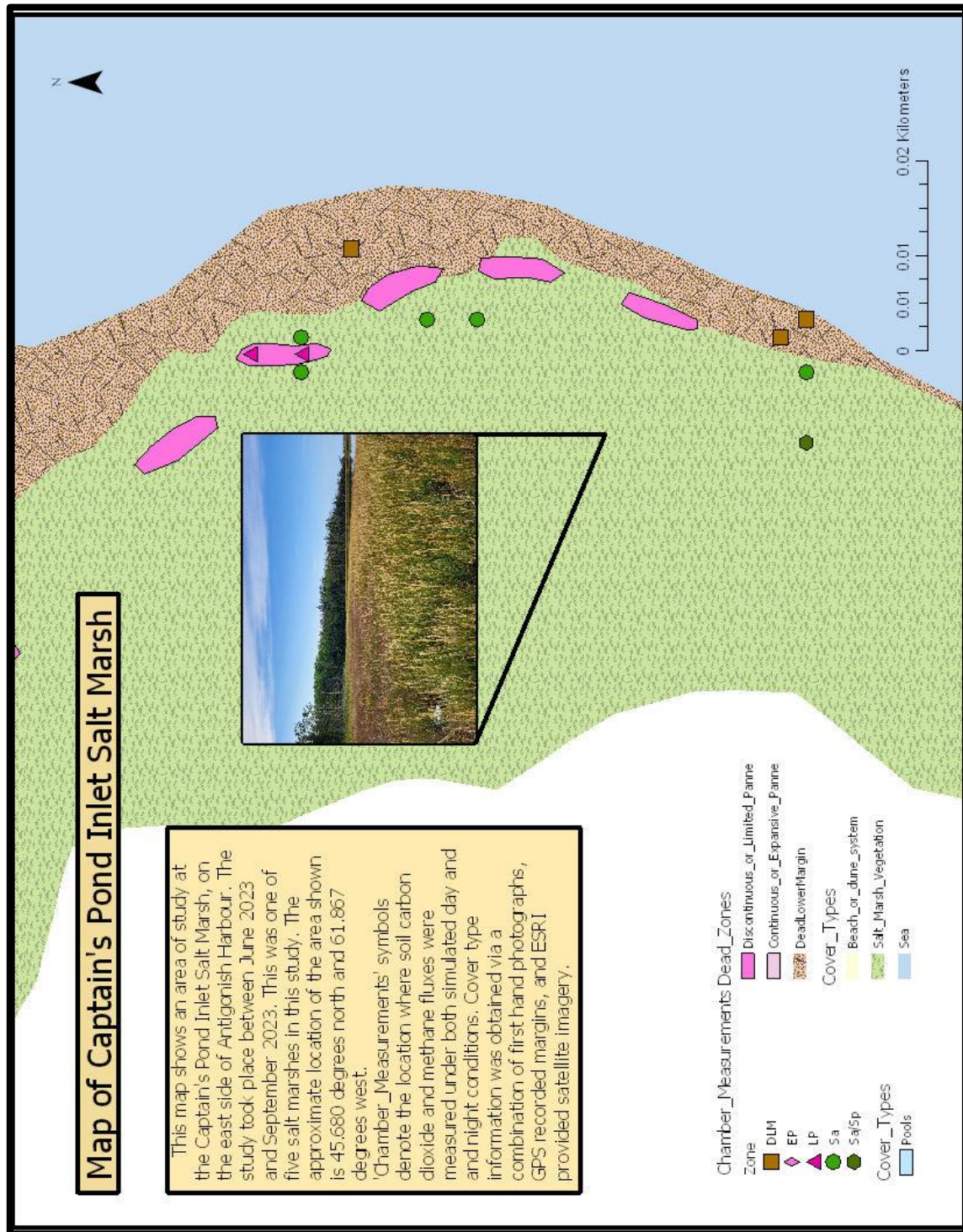


Figure 4. Captain's Pond Inlet saltmarsh. This map shows the eastern end of the Captain's Pond Inlet saltmarsh near approximately **45.680° north and 61.867° west**. Interior pools and dead zones are shown on top of the vegetated areas of the saltmarsh. Locations of measurement sets and an image of a *Sporobolus alterniflorus* zone are shown too. This map does not show the true extent of limited pannes in this area of the saltmarsh, but nonetheless can be useful as a guide.

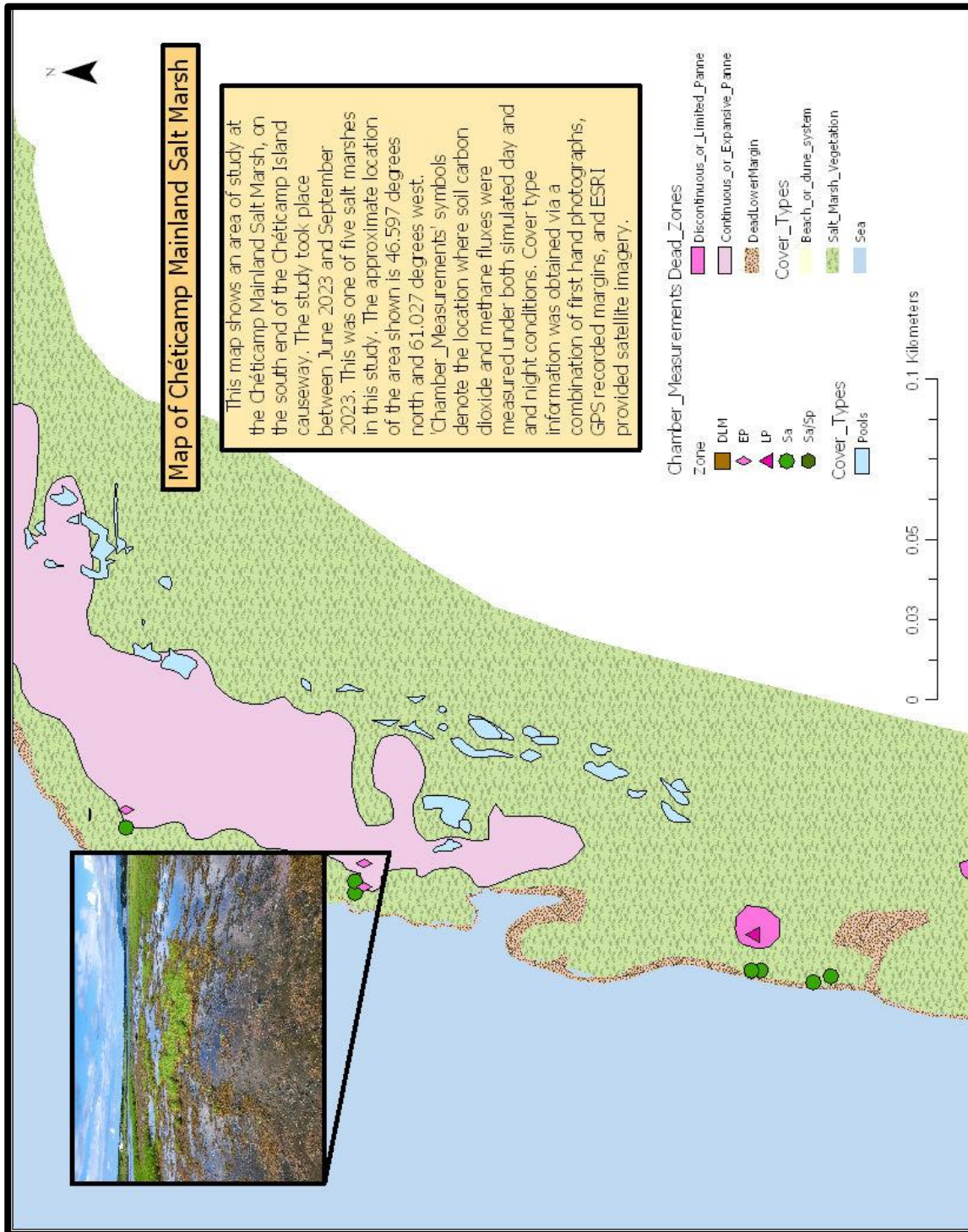


Figure 5. Chéticamp Mainland saltmarsh. This map shows the middle portion of the east side of the saltmarsh, accessible from La Roach, approximately **46.597° north and 61.027° west**. Interior pools and dead zones are shown on top of the vegetated areas of the saltmarsh. Locations of measurement sets and an image of an **expansive salt panne** are shown too. This map does not show the true extent of limited pannes in this area of the saltmarsh but nonetheless can be useful as a guide.

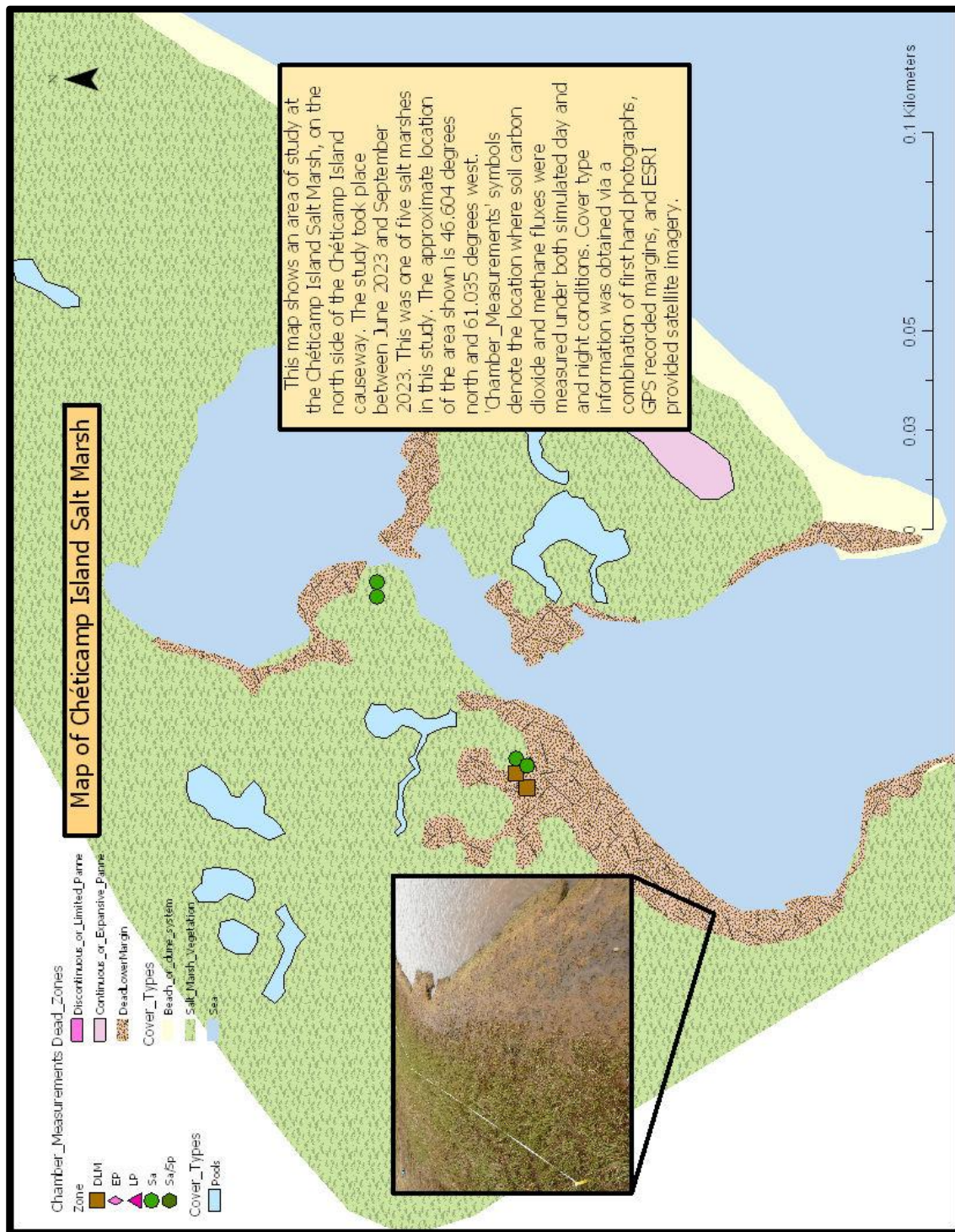


Figure 6. Chéticamp Island saltmarsh. This map shows the majority of the Chéticamp Island saltmarsh near approximately **46.604° north and 61.035° west**. Interior pools and dead zones are shown on top of the vegetated areas of the saltmarsh. Locations of measurement sets and an image of a **dead lower margin** are shown too. This map does not show the true extent of limited pannes in this area of the saltmarsh but nonetheless can be useful as a guide.

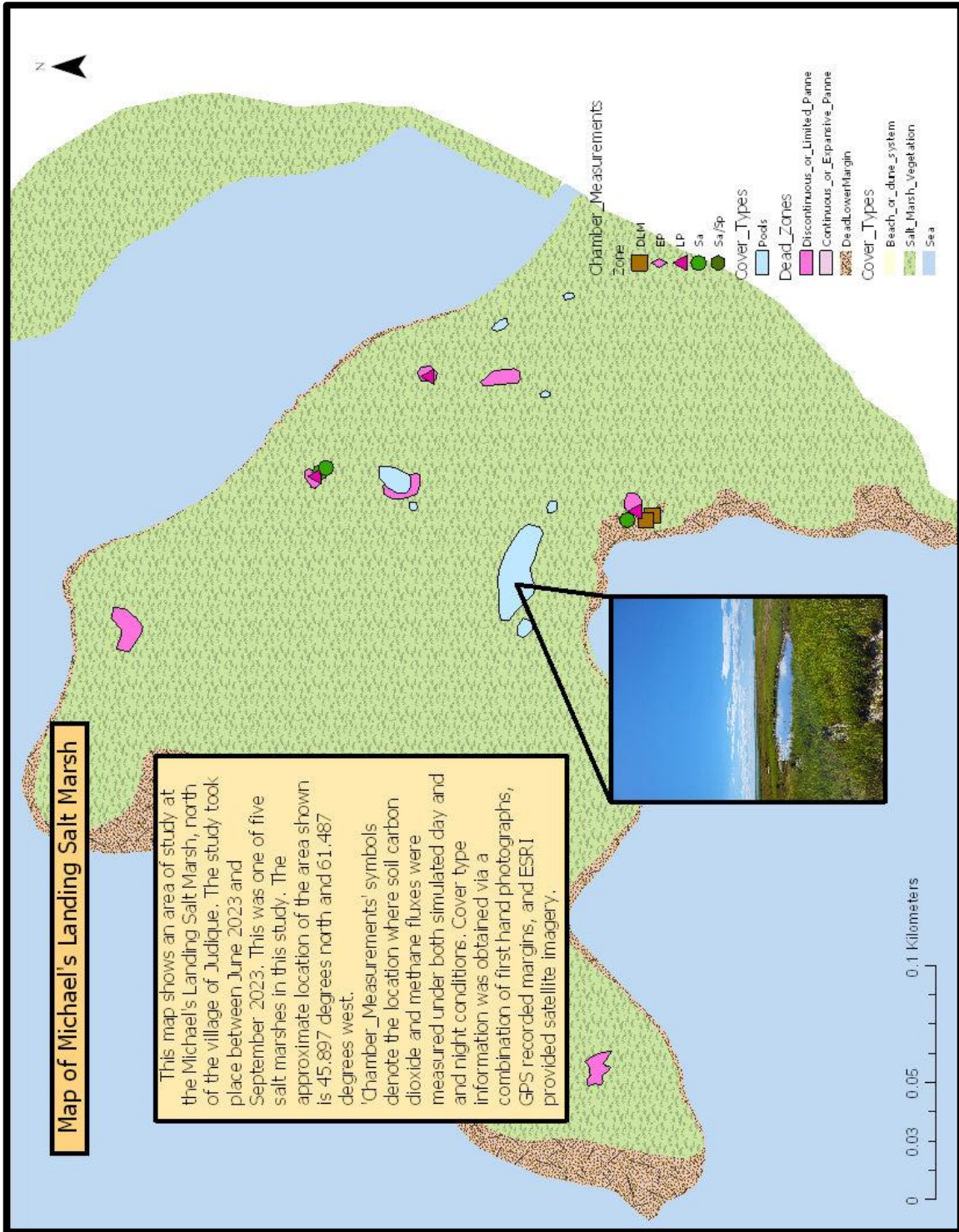


Figure 7. Michael's Landing saltmarsh complex. This map shows a portion of a saltmarsh complex at Michael's Landing, accessible from Route 19, the Ceilidh Trail, at approximately **45.897° north and 61.487° west**. Interior pools and dead zones are shown on top of the vegetated areas of the saltmarsh. Locations of measurement sets, and an image of a **pool** are shown too. This map does not show the true extent of limited pannes in this area of the saltmarsh, but nonetheless can be useful as a guide.



Figure 8. Four variations of simple soil gas chamber. The **upper left** image shows the ‘**small-dark chamber**,’ which is 8.3439 L in volume and 0.05726 m² in basal surface area. The **upper right** image shows the ‘**small-light chamber**,’ which has the same dimensions. The **lower left** image shows the ‘**large-dark chamber**,’ which is 17.599 L in volume and 0.05726 m² in basal surface area. The **lower right** image shows the ‘**large-light chamber**,’ which is 17.349 L in volume and 0.05683 m² in basal surface area. Chambers were made of polycarbonate. Black or red electrical tape attaches vinyl tubing to the chambers and functionally block exterior air exchange. Black electrical tape and duct tape were also used to block light from entering the dark chambers. During a soil gas measurement, one of these chambers would be attached to a portable gas concentration analyzer, using ‘quick-connect tube fittings,’ and placed on a soil surface.

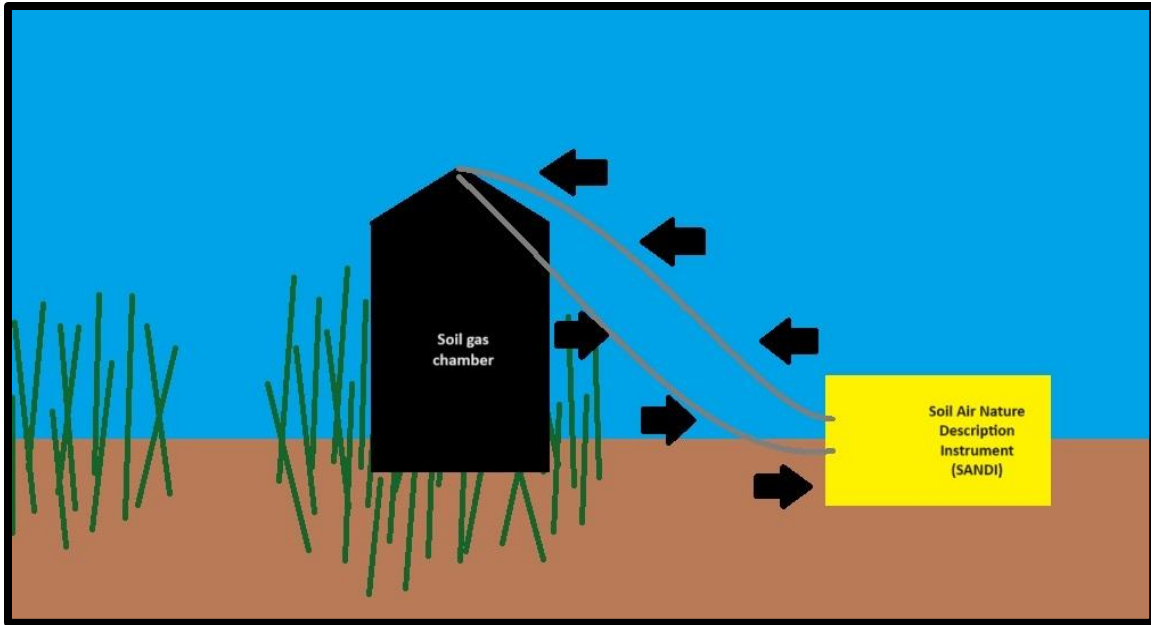


Figure 9. A diagram illustrating the path of air being pumped into and out of a soil gas chamber during a soil gas flux measurement. The soil gas chamber (represented by the black, irregular pentagon) is placed on the peat surface, enveloping vegetation (represented by the green strands) if intended, and a functionally closed system is created. The soil gas analyzer (represented by the yellow rectangle) is attached to the soil gas chamber by vinyl tubing (represented by the grey strands). The soil gas analyzer pumps air in and out of the soil gas chamber at equal rates, maintaining constant pressure. Every ten seconds, the soil gas analyzer records the average CO₂ and CH₄ concentrations from the past ten seconds. A time series can be created by plotting the average CO₂ and CH₄ concentrations over time.

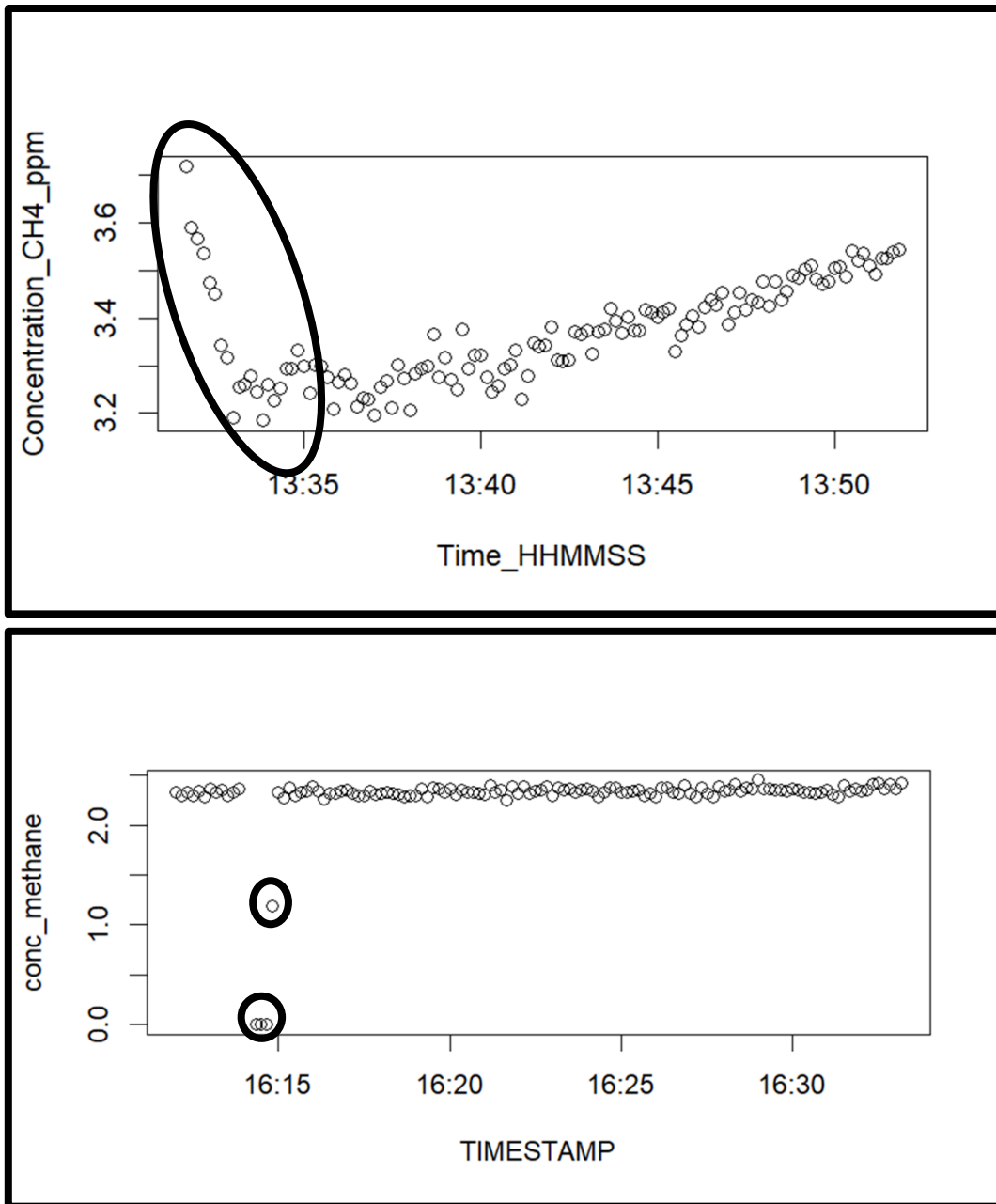


Figure 10. Two types of soil gas chamber artifacts from continuous sampling. (Top) A common artifact of placing a soil gas chamber on a soil surface is a rush of gasses out of the soil environment, creating an artificially high concentration measurements of gasses like CO₂ and CH₄. After some time, the concentration measurements return to a concentration near what would be more reasonably expected. The concentration measurements will then follow the trend of the gas's actual concentration, following the air pressure's return to near equilibrium within the soil gas measurement chamber. **(Bottom)** Due to the imperfection of gas concentration sensors, they may sometimes produce artificial values that are impossibly discontinuous. Here, the concentration read by the CH₄ concentration was impossibly discontinuous for four records where it was much lower than the CH₄ concentrations being read before and after.

Results

Summarizing Measurements

After seventeen days surveying in the field, I had collected 114 individual soil gas measurements belonging to forty-nine measurement sets. Ninety-six of these individual soil gas measurements were standard measurements. Eighteen individual soil gas measurements were non-standard measurements: six were repeated measurements and twelve were cut measurements. However, due to surveying in the wrong vegetation zone and the small chamber breaking *S. alterniflorus* stalks, thirty-one standard measurements, belonging to sixteen total measurement sets, were unusable. Table 2 shows a summary of the number of measurements taken under each treatment. Table 3 shows a summary of the number of measurement sets taken under each treatment. Five surveying days were spent at the Boy Scout Beach saltmarsh, where twenty-eight measurements of thirteen measurement sets were taken. Four surveying days were spent at the Captain's Pond saltmarsh where twenty-four measurements of eleven measurement sets were taken. Two surveying days were spent at the Chéticamp Island saltmarsh where seventeen measurements of six measurement sets were taken. Four surveying days were spent at the Chéticamp Mainland saltmarsh where twenty-five measurements of eleven measurement sets were taken. Two surveying days were spent the Michael's Landing saltmarsh complex where twenty measurements of eight measurement sets were taken. Sixty-five soil gas measurements were taken in *S. alterniflorus* zones, but the thirty-three standard small chamber measurements were excluded from analysis. Six measurements, not included in any analysis, were taken in *S. alterniflorus*, *S. pumilus*, and *D. spicata* mixed

zones. Forty-three soil gas-flux measurements were taken in dead zones: seventeen in dead lower margins, nineteen in limited salt pannes, and seven in expansive salt pannes.

In total, seventy-five measurement files were useable for analysis. Twenty-nine and twenty-eight measurement files were standard measurements using a dark chamber and light chamber, respectively. Six measurement files were repeated measurements: two with a dark chamber and four with a light chamber. Twelve measurement files were cut measurements: six using a dark chamber and six using a light chamber.

Of the forty-nine measurement sets, twenty-nine were able to be used for comparing the CO₂ and CH₄ fluxes of vegetation zones. Twenty-two measurement sets were standard measurement sets. Five measurement sets were repeated measurement sets. One measurement set was a cut measurement set. One measurement set was both a repeated measurement set and a cut measurement set. The fluxes CO₂ and CH₄ used to compare vegetation zones are plotted against time in Figures 11 and 12. Another four cut measurement sets were used only for Test 3, Test 3.a, and Test 4.

Two important notes: (1) a negative flux indicates net absorption of a gas over the course of a measurement, where a positive flux indicates net emission, and (2) there were no usable measurements in *S. alterniflorus* zones until August 17, 2023, except for those used in the comparison the treatments of cut measurement sets.

Fluxes of CO₂

Light Chamber Measurements

The light chamber measured CO₂ fluxes across all zones (Table 4) had a range of 3678 mg¹m⁻²hr⁻¹ and a mean (n = 28) of -168.7 ± 710.7 mg¹m⁻²hr⁻¹. June's one usable light chamber measured CO₂ flux was -102.8 mg¹m⁻²hr⁻¹, recorded June 29, in the dead

lower margin. July's light chamber measured CO₂ fluxes had a range of 98.65 mg¹m⁻²hr⁻¹ and a mean (n = 5) of -19.58 ± 37.01 mg¹m⁻²hr⁻¹. August's light chamber measured CO₂ fluxes had a range equal to that of the entire sampling period, but a mean (n = 16) of -322.0 ± 913.0 mg¹m⁻²hr⁻¹. September's light chamber measured CO₂ fluxes had a range 529.2 mg¹m⁻²hr⁻¹ and a mean (n = 6) of 104.9 ± 194.3 mg¹m⁻²hr⁻¹. The largest magnitude light chamber measured CO₂ flux was -2833 mg¹m⁻²hr⁻¹, measured August 17, in a *S. alterniflorus* zone at the Chéticamp Island saltmarsh. The smallest magnitude light chamber measured CO₂ flux was -1.001 mg¹m⁻²hr⁻¹, measured September 24, in on a dead lower margin at the Captain's Pond Inlet saltmarsh.

The light chamber measured CO₂ fluxes in *S. alterniflorus* zones had a range of 3356 mg¹m⁻²hr⁻¹, and a mean (n = 9) of -547.5 ± 1152 mg¹m⁻²hr⁻¹. August's light chamber measured CO₂ fluxes in *S. alterniflorus* zones had the same range, but a mean (n = 6) of -914.1 ± 1269 mg¹m⁻²hr⁻¹. September's light chamber measured CO₂ fluxes in *S. alterniflorus* zones had a range of 529.2 mg¹m⁻²hr⁻¹ and a mean (n = 3) of 185.8 ± 271.5 mg¹m⁻²hr⁻¹. The largest magnitude light chamber measured CO₂ flux in a *S. alterniflorus* zone was -2833 mg¹m⁻²hr⁻¹, measured August 17, at the Chéticamp Island saltmarsh. The smallest magnitude light chamber measured CO₂ flux in a *S. alterniflorus* zone was 115.6 mg¹m⁻²hr⁻¹, collected September 25, at the Boy Scout Beach saltmarsh.

The light chamber measured CO₂ fluxes in dead zones (i.e. the dead lower margins, limited salt pannes, and expensive salt pannes) had a range of 547.8 mg¹m⁻²hr⁻¹ and a mean (n = 19) of -112.3 ± 249.1 mg¹m⁻²hr⁻¹. The ranges and means from the light chamber measured flux rates of CO₂ in dead zones in June and July were the same as across all zones. August's light chamber measured CO₂ fluxes in dead zones had a range

of $1320.4 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ and a mean ($n = 10$) of $33.21 \pm 347.4 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$. September's light chamber measured CO_2 fluxes in dead zones had a range of $60.53 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ and mean ($n = 3$) of $23.93 \pm 31.65 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$. The greatest magnitude light chamber measured CO_2 flux in a dead zone was $844.5 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, measured August 24, on a dead lower margin of the Michael's Landing saltmarsh. The smallest magnitude light chamber measured CO_2 flux in a dead zone was $-1.001 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, measured September 24, on a dead lower margin at the Captain's Pond Inlet saltmarsh.

Dark Chamber Measurements

The dark chamber measured CO_2 fluxes (Table 5) had a range $2185 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ and a mean ($n = 29$) of $452.1 \pm 535.7 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$. June's dark chamber measured CO_2 fluxes had a range of $258.2 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ and a mean ($n = 2$) of $141.7 \pm 182.6 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$. July's dark chamber measured CO_2 fluxes had a range of $958.6 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ to and a mean ($n = 5$) of $235.8 \pm 399.1 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$. August's range of dark chamber measured CO_2 fluxes was the same as the summer's overall range, but August's mean ($n = 16$) was $612.2 \pm 630.3 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$. September's dark chamber measured CO_2 fluxes had a range of $649.8 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ and a mean ($n = 6$) of $235.6 \pm 243.1 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$. The largest magnitude dark chamber measured CO_2 flux was $2135 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, measured August 17, in a *S. alterniflorus* zone at the Chéticamp Island saltmarsh. The smallest magnitude dark chamber measured CO_2 flux was $12.55 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, measured June 16, in a limited salt panne at the Chéticamp Mainland saltmarsh.

The dark chamber measured CO_2 fluxes in *S. alterniflorus* zones had a range of $1958 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ and a mean ($n = 9$) of $963.3 \pm 626.2 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$. August's dark chamber measured CO_2 fluxes had a range of $1473 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ and a mean ($n = 6$) of 1252 ± 542.7

mg¹m⁻²hr⁻¹. September's dark chamber measured CO₂ fluxes had a range 530.5 mg¹m⁻²hr⁻¹ and a mean (n = 3) of 385.1 ± 283.0 mg¹m⁻²hr⁻¹. The largest magnitude dark chamber measured CO₂ flux in a *S. alterniflorus* zone was 2135 mg¹m⁻²hr⁻¹, measured August 17, at the Chéticamp Island saltmarsh. The smallest magnitude dark chamber measured CO₂ flux in a *S. alterniflorus* zone was 176.8 mg¹m⁻²hr⁻¹, taken September 25, at the Boy Scout Beach saltmarsh.

The dark chamber measured CO₂ fluxes in dead zones had a range of 984.9 mg¹m⁻²hr⁻¹ and a mean (n = 20) of 200.1 ± 259.9 mg¹m⁻²hr⁻¹. The ranges and means from the dark chamber measured CO₂ fluxes in dead zones in June and July were the same as across all zones. August's dark chamber measured CO₂ fluxes in dead zones had a range of 827.1 mg¹m⁻²hr⁻¹ and a mean (n = 10) of 228.1 ± 247.5 mg¹m⁻²hr⁻¹. September's dark chamber measured CO₂ fluxes in dead zones had a range of 52.3 mg¹m⁻²hr⁻¹ and a mean (n = 3) of 86.18 ± 26.52 mg¹m⁻²hr⁻¹. The greatest magnitude dark chamber measured CO₂ flux in a dead zone was 935.1 mg¹m⁻²hr⁻¹, from July 26, in a Captain's Pond Inlet saltmarsh limited salt panne. The smallest magnitude dark chamber measured CO₂ flux in a dead zone was 12.55 mg¹m⁻²hr⁻¹, from June 16, in a Chéticamp Mainland saltmarsh limited salt panne.

Net Fluxes

Adding the light and dark measurements of a measurement set together, corrected by each day's daylight hours, produced net CO₂ fluxes (Table 6) that had range of 1846 mg¹m⁻²hr⁻¹ and a mean (n = 28) of 89.03 ± 382.7 mg¹m⁻²hr⁻¹. June's one net CO₂ flux was 26.89 mg¹m⁻²hr⁻¹, from June 29, on the Boy Scout Beach saltmarsh's dead lower margin. July's net CO₂ fluxes had a range of 378.0 mg¹m⁻²hr⁻¹ and a mean (n = 5) of 76.13 ±

254.6 mg¹m⁻²hr⁻¹. August's range of net CO₂ fluxes equaled the summer's range, but its mean (n = 16) was 66.63 ± 488.6 mg¹m⁻²hr⁻¹. September's net CO₂ fluxes had a range 560.2 mg¹m⁻²hr⁻¹ and a mean (n = 6) of 169.9 ± 212.6 mg¹m⁻²hr⁻¹. The largest magnitude net CO₂ flux was -1030 mg¹m⁻²hr⁻¹, measured August 17, in a *S. alterniflorus* zone at the Chéticamp Island saltmarsh. The smallest magnitude net CO₂ flux was -4.993 mg¹m⁻²hr⁻¹, from August 24, in a limited salt panne at the Michael's Landing saltmarsh.

In *S. alterniflorus* zones, the net CO₂ fluxes had a range of 1640 mg¹m⁻²hr⁻¹ and a mean (n = 9) of 87.49 ± 625.6 mg¹m⁻²hr⁻¹. August's net CO₂ fluxes in *S. alterniflorus* zones had the same range, but it's mean (n = 6) was -11.23 ± 749.8 mg¹m⁻²hr⁻¹. September's net CO₂ fluxes in *S. alterniflorus* zones had a range of 482.2 mg¹m⁻²hr⁻¹ and a mean (n = 3) of 284.9 ± 269.4 mg¹m⁻²hr⁻¹. The largest magnitude net CO₂ flux in a *S. alterniflorus* zone was -1030 mg¹m⁻²hr⁻¹, collected August 17, at the Chéticamp Island saltmarsh. The smallest magnitude net CO₂ flux in a *S. alterniflorus* zone was 113.3 mg¹m⁻²hr⁻¹, collected September 25, at the Boy Scout Beach saltmarsh.

The net CO₂ fluxes in dead zones had a range of 918.7 mg¹m⁻²hr⁻¹ and a mean (n = 19) of 89.76 ± 213.8 mg¹m⁻²hr⁻¹. The June and July ranges and means of the net CO₂ fluxes in dead zones are the same as those across all zones for those months. August's net CO₂ fluxes in dead zones had the same range as the dead zones' range over the entire summer, but their mean (n = 10) was 11.33 ± 281.2 mg¹m⁻²hr⁻¹. September's net CO₂ fluxes in dead zones had a range of 49.14 mg¹m⁻²hr⁻¹ and a mean (n = 3) of 54.84 ± 26.08 mg¹m⁻²hr⁻¹. The largest and smallest magnitude net CO₂ fluxes in a dead zone were 815.7 mg¹m⁻²hr⁻¹, from August 24, and -4.993 mg¹m⁻²hr⁻¹, from August 25, respectively; both from limited salt pannes at the Michael's Landing saltmarsh.

Flux Rates of CH₄

Light Chamber Measurements

The light chamber measured CH₄ fluxes across all zones (Table 7) had a range of 2.713 mg¹m⁻²hr⁻¹ and a mean (n = 28) of 0.02832 ± 0.4635 mg¹m⁻²hr⁻¹. June had only one usable light chamber measured CH₄ flux, -0.07531 mg¹m⁻²hr⁻¹, recorded June 29, on a dead lower margin at the Boy Scout Beach saltmarsh. July's light chamber measured CH₄ fluxes had a range of 0.1200 mg¹m⁻²hr⁻¹ and a mean (n = 5) of -0.01795 ± 0.04395 mg¹m⁻²hr⁻¹. August's light chamber measured CH₄ fluxes had the same range as over the entire sampling period, but its mean (n = 16) was -0.005769 ± 0.006102 mg¹m⁻²hr⁻¹. September's light chamber measured CH₄ fluxes had a range of 0.3724 mg¹m⁻²hr⁻¹ and a mean (n = 6) of 0.1452 ± 0.1388 mg¹m⁻²hr⁻¹. The largest magnitude light chamber measured CH₄ flux was -1.374 mg¹m⁻²hr⁻¹, measured August 17, in a *S. alterniflorus* zone at the Chéticamp Island saltmarsh. The smallest magnitude light chamber measured CH₄ flux was 0.01401 mg¹m⁻²hr⁻¹, collected July 11, on a dead lower margin at the Captain's Pond Inlet saltmarsh.

Light chamber measured CH₄ fluxes in *S. alterniflorus* zones had the same range as the range of all zones but had a mean (n = 9) of -0.006877 ± 0.7808 mg¹m⁻²hr⁻¹. August's light chamber measured CH₄ fluxes had the same range too but had a mean (n = 6) of -0.07821 ± 0.9706 mg¹m⁻²hr⁻¹. September's light chamber measured CH₄ fluxes had a range of 0.3724 mg¹m⁻²hr⁻¹ and a mean (n = 3) of 0.1358 ± 0.1943 mg¹m⁻²hr⁻¹. The largest magnitude light chamber measured CH₄ flux in a *S. alterniflorus* zone was -1.374 mg¹m⁻²hr⁻¹, taken August 17, at the Chéticamp Mainland saltmarsh. The smallest

magnitude light chamber measured CH₄ flux in a *S. alterniflorus* zone was -0.01841 mg¹m⁻²hr⁻¹, collected September 25, at the Boy Scout Beach saltmarsh.

The light chamber measured CH₄ fluxes in dead zones had a range of 1.1785 mg¹m⁻²hr⁻¹ and a mean (n = 19) of 0.04500 ± 0.2245 mg¹m⁻²hr⁻¹. June and July's ranges and means of light chamber measured CH₄ fluxes in dead zones were the same as across all zones. August's light chamber measured CH₄ fluxes in dead zones had a range of 1.1785 mg¹m⁻²hr⁻¹ and a mean (n = 10) of 0.03769 ± 0.3027 mg¹m⁻²hr⁻¹. September's light chamber measured CH₄ fluxes in dead zones had a range of 0.2012 mg¹m⁻²hr⁻¹ and a mean (n = 3) of 0.1545 ± 0.1007 mg¹m⁻²hr⁻¹. The greatest magnitude light chamber measured CH₄ flux in a dead zone was 844.5 mg¹m⁻²hr⁻¹, measured August 24, on a dead lower margin of the Michael's Landing saltmarsh. The smallest magnitude light chamber measured CH₄ flux in a dead zone was 0.01401 mg¹m⁻²hr⁻¹, measured July 11, on a dead lower margin at the Captain's Pond Inlet saltmarsh.

Dark Chamber Measurements

The dark chamber measured CH₄ fluxes (Table 8) had a range of 1.3735 mg¹m⁻²hr⁻¹ and a mean (n = 29) of 0.009973 ± 0.2602 mg¹m⁻²hr⁻¹. June's dark chamber measured CH₄ fluxes had a range of 0.1004 mg¹m⁻²hr⁻¹ and a mean (n = 2) of 0.09334 ± 0.07101 mg¹m⁻²hr⁻¹. July's dark chamber measured CH₄ fluxes had a range of 0.1513 mg¹m⁻²hr⁻¹ and a mean (n = 5) of 0.06391 ± 0.05705 mg¹m⁻²hr⁻¹. August's dark chamber measured CH₄ fluxes had a range of 0.8090 mg¹m⁻²hr⁻¹ and a mean (n = 16) of 0.02659 ± 0.2009 mg¹m⁻²hr⁻¹. September's dark chamber measured CH₄ fluxes had a range of 1.195 mg¹m⁻²hr⁻¹ and a mean (n = 6) of -0.1071 ± 0.4426 mg¹m⁻²hr⁻¹. The greatest magnitude dark chamber measured CH₄ fluxes was -1.001 mg¹m⁻²hr⁻¹, measured September 24, on

the Captain's Pond Inlet saltmarsh's dead lower margin. The smallest magnitude dark chamber measured CH₄ flux was $-0.01112 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, measured July 27, in a Boy Scout Beach saltmarsh limited salt panne.

The dark chamber measured CH₄ fluxes in *S. alterniflorus* zones had a range of $0.5447 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ and a mean ($n = 9$) of $0.1255 \pm 0.1983 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$. August's range of dark chamber measured CH₄ fluxes in *S. alterniflorus* zones was the same, but its mean ($n = 6$) was $0.1417 \pm 0.2419 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$. September's dark chamber measured CH₄ fluxes had a range of $0.1830 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ and a mean ($n = 3$) of $0.09327 \pm 0.009301 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$. The greatest magnitude dark chamber measured CH₄ flux, in a *S. alterniflorus* zone, was $0.3725 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, measured August 17, at the Chéticamp Island saltmarsh. The smallest magnitude dark chamber measured CH₄ flux in a *S. alterniflorus* zone was $0.01141 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, measured September 25, at the Boy Scout Beach saltmarsh.

The dark chamber measured CH₄ fluxes in dead zones had a range of $1.226 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ and a mean ($n = 20$) of $-0.04203 \pm 0.2721 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$. The ranges and means of dark chamber measured CH₄ fluxes in dead zones for June and July are the same as those across all zones. August's dark chamber measured CH₄ fluxes from dead zones had a range of $0.6616 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ and a mean ($n = 10$) of $-0.04246 \pm 0.2009 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$. September's dark chamber measured CH₄ fluxes in dead zones had a range of $1.047 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ and a mean ($n = 3$) of $-0.3074 \pm 0.6006 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$. The greatest magnitude dark chamber measured CH₄ flux in a dead zone was $-1.001 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, measured September 24, on the Captain's Pond Inlet saltmarsh's dead lower margin. The smallest magnitude dark chamber measured CH₄ flux in a dead zone was $-0.01112 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, measured July 27, in a limited salt panne at the Boy Scout Beach saltmarsh.

Net Fluxes

Adding the light and dark measurements of a measurement set together, corrected by daylight hours on each day, produced net CH₄ fluxes (Table 9) that had a range of 1.5493 mg¹m⁻²hr⁻¹ and a mean (n = 28) of 0.01434 ± 0.2858 mg¹m⁻²hr⁻¹. June's one usable measurement set had net CH₄ flux of 0.0006844 mg¹m⁻²hr⁻¹, from June 29, 2023, on a dead lower margin at the Boy Scout Beach saltmarsh. July's net CH₄ fluxes had a range of 0.07932 mg¹m⁻²hr⁻¹ and a mean (n = 5) of 0.03490 ± 0.03331 mg¹m⁻²hr⁻¹. August's net CH₄ fluxes had an equal range to the entire summer's range, and a mean (n = 16) of 0.006616 ± 0.03234 mg¹m⁻²hr⁻¹. September's net CH₄ fluxes had a range of 0.6953 mg¹m⁻²hr⁻¹ and a mean (n = 6) of 0.02010 ± 0.2350 mg¹m⁻²hr⁻¹. The largest magnitude net CH₄ flux recorded was -0.8365 mg¹m⁻²hr⁻¹, from August 17, in a *S. alterniflorus* zone at the Chéticamp Island saltmarsh. The smallest magnitude net CH₄ flux recorded was June's single calculated net flux of CH₄.

In the *S. alterniflorus* zones, the net CH₄ fluxes had a range of 1.5493 mg¹m⁻²hr⁻¹ and a mean (n = 9) of 0.04641 ± 0.4461 mg¹m⁻²hr⁻¹. August's net CH₄ fluxes in *S. alterniflorus* zones had the same range and a mean (n = 6) of 0.01225 ± 0.5536 mg¹m⁻²hr⁻¹. September's net CH₄ fluxes in *S. alterniflorus* zones had a range of 0.2472 mg¹m⁻²hr⁻¹ and a mean (n = 3) of 0.1147 ± 0.1389 mg¹m⁻²hr⁻¹. The largest magnitude net CH₄ flux in an *S. alterniflorus* zone was -0.8365 mg¹m⁻²hr⁻¹, from August 17, at the Chéticamp Island saltmarsh. The smallest magnitude net CH₄ flux in an *S. alterniflorus* zone was 0.02766 mg¹m⁻²hr⁻¹, collected September 25, from the Boy Scout Beach saltmarsh.

The net CH₄ fluxes measured in dead zones had a range of 0.8335 mg¹m⁻²hr⁻¹ and a mean (n = 19) of 0.0008464 ± 0.1826 mg¹m⁻²hr⁻¹. The June and July ranges and means

of net CH₄ fluxes from dead zones was equal to those across all zones. August's net CH₄ fluxes in dead zones had a range of 0.8335 mg¹m⁻²hr⁻¹ and a mean (n = 10) of 0.003234 ± 0.2078 mg¹m⁻²hr⁻¹. September's net CH₄ fluxes in dead zones had a range of 0.5663 mg¹m⁻²hr⁻¹ and a mean (n = 3) of -0.007453 ± 0.3033 mg¹m⁻²hr⁻¹. The largest magnitude net CH₄ flux in a dead zone was -0.4775 mg¹m⁻²hr⁻¹, collected August 24, on the Michael's Landing saltmarsh's dead lower margin. The smallest magnitude net CH₄ flux in a dead zone June's only useable net CH₄ flux.

Benchmarking

Benchmarking occurred four times throughout the sampling period. Results from benchmarking the SANDI's gas analyzer accuracies and flow rates are in Appendix B.

Tests to Support Assumptions

Testing Accurate Simulation of Night and Day Conditions

Dark Chambers versus Light Chambers

I was able to reject my null hypothesis of no significant difference between the means of the light chamber CO₂ fluxes (n = 28) and dark chamber CO₂ fluxes (n = 29), based on comparison via a Single Factor ANOVA (F_{stat} = 13.26, P-value = 6.005x10⁻⁴). Given their significant difference and that the mean light chamber CO₂ flux rate, -168.7 ± 710.7 mg¹m⁻²hr⁻¹, is more negative than the mean dark chamber CO₂ flux rate, 452.1 ± 535.7 mg¹m⁻²hr⁻¹, I concluded that light chamber and dark chamber accurately simulated daytime and nighttime conditions, respectively better than oppositely.

Based on the Single Factor ANOVAs testing for significant difference between the means of the light chamber CH₄ fluxes (n = 28) and dark chamber CH₄ fluxes (n =

29), I could not reject the null hypothesis of no significant difference ($F_{\text{stat}} = 0.03428$, P-value = 0.8538, $\bar{x} = 3.670 \times 10^{-7} \pm 2.507 \times 10^{-4} \text{ mg}^1 \text{m}^{-2} \text{hr}^{-1}$) between the two means.

Cutting Treatments

I was able to reject my null hypothesis of no significant difference ($F_{\text{stat}} = 5.982$, P-value = 0.004415) amongst mean CO_2 fluxes measured from the uncut light chamber ($n = 6$), cut light chamber ($n = 6$), uncut dark chamber ($n = 6$), and cut dark chamber ($n = 6$), based on comparison via Single Factor ANOVA. The Tukey HSD Test showed that the mean CO_2 flux measured from the uncut light chamber ($\bar{x} = -228.9 \pm 1391 \text{ mg}^1 \text{m}^{-2} \text{hr}^{-1}$) was significantly different from the cut dark ($\bar{x} = 1479 \pm 1214 \text{ mg}^1 \text{m}^{-2} \text{hr}^{-1}$, $q_{\text{crit}} = 3.958$, $q_{\text{stat}} = 4.059$), the uncut dark ($\bar{x} = 1827 \pm 795.7 \text{ mg}^1 \text{m}^{-2} \text{hr}^{-1}$, $q_{\text{crit}} = 3.958$, $q_{\text{stat}} = 4.887$), and the cut light chamber ($\bar{x} = 2029 \pm 453.8 \text{ mg}^1 \text{m}^{-2} \text{hr}^{-1}$, $q_{\text{crit}} = 3.958$, $q_{\text{stat}} = 5.367$).

Based on the Single Factor ANOVA testing for significant differences amongst the mean CO_2 fluxes measured from the cut light chamber ($n = 6$), the uncut dark chamber ($n = 6$), and the dark chamber ($n = 6$), I was unable to reject the null hypothesis of no significant difference ($F_{\text{stat}} = 0.6026$, P-value = 0.5601) amongst the three means. Given that the mean CO_2 flux measured from the uncut light chamber was the most negative and was significantly different from the mean CO_2 fluxes measured from the cut light chamber, the uncut dark chamber, and the cut dark chamber, which were not significantly different from one another ($\bar{x} = 1778 \pm 857.4 \text{ mg}^1 \text{m}^{-2} \text{hr}^{-1}$), I concluded that the dark chamber sufficiently prevented photosynthetic activity.

Testing for Sampling Artifacts

Small Chambers Against Large Chambers

I could not reject the null hypothesis of no significant difference between the mean CO₂ fluxes of the small chamber (n = 21) and large chamber dead zone measurements (n = 18) after comparison via a Single Factor ANOVA ($\bar{x} = 107.8 \pm 269.0$ mg¹m⁻²hr⁻¹, F_{stat} = 0.7961, P-value = 0.3780) between the means of the two groups.

I could not reject the null hypothesis that there was no significant difference between the mean CH₄ fluxes of the small chamber (n = 21) and large chamber dead zone measurements (n = 18), after comparison via a Single Factor ANOVA ($\bar{x} = 0.0003670 \pm 0.2507$ mg¹m⁻²hr⁻¹, F_{stat} = 0.4180, P-value = 0.5219) between the means of the two groups. Given that neither the mean CO₂ fluxes nor the mean CH₄ fluxes of the small chamber measurements and large chamber measurements were significantly different from their respective comparators, I concluded that there were no notable differences created by using different sized soil gas chambers.

Test for Artificial Emission

I could not reject the null hypothesis of no significant difference between the mean CO₂ fluxes of the first and second measurements in repeated measurement sets, based on their comparison via a Two-Sample t-Test, assuming equal variance ($\bar{x} = -40.48 \pm 467.1$ mg¹m⁻²hr⁻¹, t_{stat} = 0.4150, P-value = 0.3435).

Nor could I reject the null hypothesis of no significant difference between the mean CH₄ fluxes of the first and the second in repeated measurement sets, based on their comparison via a Two-Sample t-Test, assuming equal variance ($\bar{x} = -0.1192 \pm 0.7226$ mg¹m⁻²hr⁻¹, t_{stat} = 0.7326, P-value = 0.2403). Given that neither the mean CO₂ fluxes nor the mean CH₄ fluxes of the first and the second measurements of the repeated

measurement sets were significantly different from their respective comparators, I concluded that my processing methods sufficiently accounted sampling artifacts.

Measurements Over a Season

Environmental Measurements

The environmental measurements (i.e. soil pore water salinity, soil compressibility, and soil temperature) of each soil gas measurement, along with their CO₂ and CH₄ fluxes, are included in Appendix C.

Seasonality of Fluxes

The CO₂ fluxes and CH₄ fluxes from each measurement set was plotted (in g¹m⁻²hr⁻¹) over the sampling period (June 29, 2023 to September 25, 2023) in Figure 10 and Figure 11, respectively. The exceptions are that cut measurements, small chamber measurements from *S. alterniflorus* zones, and *S. alterniflorus*, *S. pumilus*, and *D. spicata* mixed zones were excluded from both.

Testing for Difference Amongst Zones

All Measurement Sets

CO₂ Tests for Significant Difference

Based on comparison via Single Factor ANOVA, I was unable to reject my null hypothesis of no significant difference ($\bar{x} = -168.7 \pm 710.7 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, $F_{\text{stat}} = 1.474$, $P\text{-value} = 0.2466$) amongst the mean light chamber CO₂ fluxes of the *Sporobolus alterniflorus* zones ($n = 9$, $\bar{x}_i = -547.5 \pm 1152 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), dead lower margins ($n = 8$, $\bar{x}_i = -112.3 \pm 180.1 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), limited salt pannes ($n = 8$, $\bar{x}_i = 119.3 \pm 301.3 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), and extensive salt pannes ($n = 3$, $\bar{x}_i = 48.96 \pm 131.6 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$).

However, comparison via Single Factor ANOVA did allow me to reject my null hypothesis of no significant difference ($F_{\text{stat}} = 7.161$, P-value = 0.001250) amongst the mean dark chamber CO₂ fluxes of the *Sporobolus alterniflorus* zones (n = 9, $\bar{x}_i = 963.3 \pm 626.2 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), dead lower margins (n = 8, $\bar{x}_i = 152.6 \pm 134.4 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), limited salt pannes (n = 9, $\bar{x}_i = 275.3 \pm 353.2 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), and extensive salt pannes (n = 3, $\bar{x}_i = 101.0 \pm 173.2 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$).

A Tukey HSD test, using the Tukey-Kramer procedure, testing for significant difference between each unique pair of the four mean dark chamber CO₂ fluxes, showed that the mean dark chamber CO₂ flux of the *S. alterniflorus* zones was significantly different ($q_{\text{crit}} = 3.89$) from those of the limited salt pannes ($q_{\text{stat}} = 4.96$), dead lower margins ($q_{\text{stat}} = 5.67$), and extensive salt pannes ($q_{\text{stat}} = 4.40$). The mean dark chamber CO₂ flux of the limited salt pannes was not significantly different from those of the dead lower margins ($q_{\text{stat}} = 0.86$) or the extensive salt pannes ($q_{\text{stat}} = 0.89$). The mean dark chamber CO₂ fluxes of the dead lower margins and the extensive salt pannes were also not significantly different ($q_{\text{stat}} = 0.26$).

Using a Single Factor ANOVA, I was unable to reject my null hypothesis of no significant difference ($\bar{x} = 89.03 \pm 382.7 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, $F_{\text{stat}} = 0.3313$, P-value = 0.8028) amongst the mean net CO₂ fluxes of the *Sporobolus alterniflorus* zones (n = 9, $\bar{x}_i = 87.49 \pm 625.6 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), dead lower margins (n = 8, $\bar{x}_i = -4.784 \pm 91.57 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), limited salt pannes (n = 8, $\bar{x}_i = 192.4 \pm 284.4 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), and extensive salt pannes (n = 3, $\bar{x}_i = 68.17 \pm 142.8 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$).

CH₄ Tests for Significant Difference

Based on comparison via a Single Factor ANOVA, I was unable to reject my null hypothesis of no significant difference ($\bar{x} = 0.02832 \pm 0.4635 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, $F_{\text{stat}} = 0.06789$, $P\text{-value} = 0.9765$) amongst the mean light chamber CH_4 fluxes of the *Sporobolus alterniflorus* zones ($n = 9$, $\bar{x}_i = -0.006877 \pm 0.7808 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), dead lower margins ($n = 8$, $\bar{x}_i = 0.01326 \pm 0.2513 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), limited salt pannes ($n = 8$, $\bar{x}_i = 0.09317 \pm 0.2454 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), and extensive salt pannes ($n = 3$, $\bar{x}_i = 0.001178 \pm 0.07542 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$).

Likewise, using a Single Factor ANOVA, I was unable to reject my null hypothesis of no significant difference ($\bar{x} = 0.009973 \pm 0.2602 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, $F_{\text{stat}} = 2.033$, $P\text{-value} = 0.1349$) amongst the mean dark chamber CH_4 fluxes of the *Sporobolus alterniflorus* zones ($n = 9$, $\bar{x}_i = 0.1255 \pm 0.1983 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), dead lower margins ($n = 8$, $\bar{x}_i = -0.1379 \pm 0.3977 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), limited salt pannes ($n = 9$, $\bar{x}_i = 0.06752 \pm 0.08625 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), and extensive salt pannes ($n = 3$, $\bar{x}_i = -0.1151 \pm 0.1461 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$).

Nor was I able to reject my null hypothesis of no significant difference ($\bar{x} = 0.01434 \pm 0.2858 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, $F_{\text{stat}} = 0.4226$, $P\text{-value} = 0.7385$) amongst the mean net CH_4 fluxes of the *Sporobolus alterniflorus* zones ($n = 9$, $\bar{x}_i = 0.04641 \pm 0.4461 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), dead lower margins ($n = 8$, $\bar{x}_i = -0.06727 \pm 0.2411 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), limited salt pannes ($n = 8$, $\bar{x}_i = 0.08252 \pm 0.1167 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), and extensive salt pannes ($n = 3$, $\bar{x}_i = -0.04601 \pm 0.01908 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$) via comparison by Single Factor ANOVA.

August Measurement Sets

CO₂ Tests for Significant Difference

Based on comparison via Single Factor ANOVA, I was unable to reject my null hypothesis of no significant difference ($\bar{x} = -322.0 \pm 913.0 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, $F_{\text{stat}} = 1.777$, $P\text{-value} = 0.2050$) amongst August's mean light chamber CO₂ fluxes of the *Sporobolus*

alterniflorus zones ($n = 6$, $\bar{x}_i = -914.4 \pm 1269 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), dead lower margins ($n = 4$, $\bar{x}_i = -200.2 \pm 224.0 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), limited salt pannes ($n = 3$, $\bar{x}_i = 328.7 \pm 458.5 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), and extensive salt pannes ($n = 3$, $\bar{x}_i = 48.96 \pm 131.6 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$).

However, using Single Factor ANOVA, I was able to reject my null hypothesis of no significant difference ($F_{\text{stat}} = 8.677$, P-value = 0.002471) amongst August's mean dark chamber CO₂ fluxes from the *Sporobolus alterniflorus* zones ($n = 6$, $\bar{x}_i = 1253 \pm 542.7 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), dead lower margins ($n = 4$, $\bar{x}_i = 193.2 \pm 152.0 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), limited salt pannes ($n = 3$, $\bar{x}_i = 401.8 \pm 373.0 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), and extensive salt pannes ($n = 3$, $\bar{x}_i = 101.0 \pm 173.2 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$).

A Tukey HSD test, using the Tukey-Kramer procedure, testing for significant difference between each unique pair of August's four mean dark chamber CO₂ fluxes, showed that August's mean dark chamber CO₂ flux of the *S. alterniflorus* zones was significantly different ($q_{\text{crit}} = 4.08$) from those of the limited salt pannes ($q_{\text{stat}} = 5.82$), dead lower margins ($q_{\text{stat}} = 5.86$), and extensive salt pannes ($q_{\text{stat}} = 4.30$). August's mean dark chamber CO₂ flux of the limited salt pannes was not significantly different from those of the dead lower margins ($q_{\text{stat}} = 1.32$) or extensive salt pannes ($q_{\text{stat}} = 0.976$). The mean dark chamber CO₂ fluxes of the dead lower margins and the extensive salt pannes were also not significantly different ($q_{\text{stat}} = 0.432$).

I was not able to reject my null hypothesis of no significant difference ($\bar{x} = 66.63 \pm 488.6 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, $F_{\text{stat}} = 0.4179$, P-value = 0.7434) amongst August's mean net CO₂ fluxes of the *Sporobolus alterniflorus* zones ($n = 6$, $\bar{x}_i = -11.23 \pm 750.8 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), dead lower margins ($n = 4$, $\bar{x}_i = -37.95 \pm 117.5 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), limited salt pannes ($n = 3$, $\bar{x}_i = 360.2 \pm 417.7 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), and extensive salt pannes ($n = 3$, $\bar{x}_i = 68.17 \pm 142.8 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$).

¹) showed no significant difference ($\bar{x} = 66.63 \pm 488.6 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, $F_{\text{stat}} = 0.4179$, P-value = 0.7434) using comparison via Single Factor ANOVA.

CH₄ Tests for Significant Difference

Using a Single Factor ANOVA did not allow me to reject my null hypothesis of no significant difference ($\bar{x} = -0.005769 \pm 0.6102 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, $F_{\text{stat}} = 0.1302$, P-value = 0.9403) amongst August's mean light chamber CH₄ fluxes of the *Sporobolus alterniflorus* zones (n = 6, $\bar{x}_i = -0.07821 \pm 0.9706 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), dead lower margins (n = 4, $\bar{x}_i = -0.06007 \pm 0.3339 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), limited salt pannes (n = 3, $\bar{x}_i = 0.2046 \pm 0.4202 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), and extensive salt pannes (n = 3, $\bar{x}_i = 0.001178 \pm 0.07542 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$).

Likewise, I was unable to reject my null hypothesis of no significant difference ($\bar{x} = 0.02659 \pm 0.2285 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, $F_{\text{stat}} = 1.4906$, P-value = 0.2669) amongst August's mean dark chamber CH₄ fluxes of the *Sporobolus alterniflorus* zones (n = 6, $\bar{x}_i = 0.1417 \pm 0.2419 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), dead lower margins (n = 4, $\bar{x}_i = -0.09338 \pm 0.2529 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), limited salt pannes (n = 3, $\bar{x}_i = 0.09805 \pm 0.1471 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), and extensive salt pannes (n = 3, $\bar{x}_i = -0.1151 \pm 0.1461 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$) via comparison using a Single Factor ANOVA.

Finally, I was also unable to reject my null hypothesis of no significant difference ($\bar{x} = 0.006616 \pm 0.3579 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, $F_{\text{stat}} = 0.2340$, P-value = 0.8709) amongst August's mean net CH₄ fluxes of the *Sporobolus alterniflorus* zones (n = 6, $\bar{x}_i = 0.01225 \pm 0.5536 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), dead lower margins (n = 4, $\bar{x}_i = -0.07682 \pm 0.2705 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), limited salt pannes (n = 3, $\bar{x}_i = 0.1592 \pm 0.1768 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), and extensive salt pannes (n = 3, $\bar{x}_i = -0.04601 \pm 0.01908 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$) via comparison using a Single Factor ANOVA.

Test	What groups were being tested for significant difference between or amongst?	Statistical Test Being Performed	Null Hypothesis	Alpha (α)	P-value	Conclusion
1	The mean CO ₂ fluxes of light chamber measurements and dark chamber measurements.	Single Factor Analysis of Variance	No significant difference in the mean CO ₂ fluxes of the light and dark chamber measurements	0.05	0.0006	Reject the null hypothesis
2	The mean CH ₄ fluxes of light chamber measurements and dark chamber measurements.	Single Factor Analysis of Variance	No significant difference in the mean CH ₄ fluxes of the light and dark chamber measurements	0.05	0.8538	Cannot reject the null hypothesis
3	The mean CO ₂ fluxes from uncut light chamber, cut light chamber, uncut dark chamber, and cut dark chamber measurements in cut measurement sets.	Single Factor Analysis of Variance	No mean CO ₂ flux of any vegetation zone would be significantly different from the others	0.05	0.0044	Reject the null hypothesis
3.a	Each pair of mean CO ₂ fluxes from the cut measurement set treatments.	Tukey Test for Honestly Significant Difference	The comparison of each pair of mean dark chamber CO ₂ fluxes would not show significant difference.	0.05	0.0058 0.0123 0.0432	Uncut light measurements were different.
4	The mean CO ₂ fluxes of only cut light chamber, uncut dark chamber, and cut dark chamber measurements from cut measurement sets	Single Factor Analysis of Variance	No mean CO ₂ flux of any vegetation zone would be significantly different from the others	0.50	0.5601	Cannot reject the null hypothesis
5	The mean CO ₂ fluxes of dead zone small and large chamber measurements	Single Factor Analysis of Variance	No significant difference between the mean CO ₂ fluxes of dead zone small and large chamber measurements	0.05	0.3780	Cannot reject the null hypothesis
6	The mean CH ₄ fluxes of dead zone small and large chamber measurements	Single Factor Analysis of Variance	No significant difference between the mean CH ₄ fluxes of dead zone small and large chamber measurements	0.05	0.5219	Cannot reject the null hypothesis
7	The mean CO ₂ fluxes of the first measurement and the second measurement in repeated measurement sets	Two-Sample t-Tests, assuming equal variance	No significant difference between the mean CO ₂ fluxes of the first and second measurements	0.05	0.3435	Cannot reject the null hypothesis
8	The mean CH ₄ fluxes of the first measurement and the second measurement in repeated measurement sets	Two-Sample t-Tests, assuming equal variance	No significant difference between the mean CH ₄ fluxes of the first and second measurements	0.05	0.2403	Cannot reject the null hypothesis

Test	What groups were being tested for significant difference between or amongst?	Statistical Test Being Performed	Null Hypothesis	Alpha (α)	P-value	Conclusion
9	The mean light chamber CO ₂ fluxes of all four vegetation zones <i>S. alterniflorus</i> zones, dead lower margins, limited salt pannes, and extensive salt pannes	Single Factor Analysis of Variance	No vegetation zone would have a significantly different mean light chamber CO ₂ flux from the other vegetation zones	0.05	0.2466	Cannot reject the null hypothesis
10	The mean light chamber CH ₄ fluxes of the <i>S. alterniflorus</i> zones, dead lower margins, limited salt pannes, and extensive salt pannes	Single Factor Analysis of Variance	No vegetation zone would have a significantly different mean light chamber CH ₄ flux from the other vegetation zones	0.05	0.9765	Cannot reject the null hypothesis
11	The mean dark chamber CO ₂ fluxes of the <i>S. alterniflorus</i> zones, dead lower margins, limited salt pannes, and extensive salt pannes	Single Factor Analysis of Variance	No vegetation zone would have a significantly different mean dark chamber CO ₂ flux from the other vegetation zones	0.05	0.0012	Reject the null hypothesis
11.a	Each pair of mean dark chamber CO ₂ fluxes from the <i>S. alterniflorus</i> zones, dead lower margins, limited salt pannes, and extensive salt pannes	Tukey Test for Honestly Significant Difference	The comparison of each pair of mean dark chamber CO ₂ fluxes would not show significant difference.	0.05	0.0025 0.0087 0.0224	Dark <i>S. alterniflorus</i> measurements are different
12.	The mean dark chamber CH ₄ fluxes of the <i>S. alterniflorus</i> zones, dead lower margins, limited salt pannes, and extensive salt pannes	Single Factor Analysis of Variance	No vegetation zone would have a significantly different mean dark chamber CH ₄ flux from the other vegetation zones	0.05	0.1349	Cannot reject the null hypothesis
13	The mean net CO ₂ fluxes of the <i>S. alterniflorus</i> zones, dead lower margins, limited salt pannes, and extensive salt pannes	Single Factor Analysis of Variance	No vegetation zone would have a significantly different mean net CO ₂ flux from the other vegetation zones	0.05	0.8028	Cannot reject the null hypothesis
14	The mean net CH ₄ fluxes of the <i>S. alterniflorus</i> zones, dead lower margins, limited salt pannes, and extensive salt pannes	Single Factor Analysis of Variance	No vegetation zone would have a significantly different mean net CH ₄ flux from the other vegetation zones	0.05	0.7385	Cannot reject the null hypothesis
15	August's mean light chamber CO ₂ fluxes of the <i>S. alterniflorus</i> zones, dead lower margins, limited salt pannes, and extensive salt pannes	Single Factor Analysis of Variance	No vegetation zone would have a significantly different mean light chamber CH ₄ flux from the other vegetation zones in August.	0.05	0.2050	Cannot reject the null hypothesis

Test	What groups were being tested for significant difference between or amongst?	Statistical Test Being Performed	Null Hypothesis	Alpha (α)	P-value	Conclusion
16	August's mean light chamber CH ₄ fluxes of the <i>S. alterniflorus</i> zones, dead lower margins, limited salt pannes, and extensive salt pannes.	Single Factor Analysis of Variance	No vegetation zone would have a significantly different mean light chamber CH ₄ flux from the other vegetation zones in August.	0.05	0.9403	Cannot reject the null hypothesis
17	August's mean dark chamber CO ₂ fluxes of the <i>S. alterniflorus</i> zones, dead lower margins, limited salt pannes, and extensive salt pannes.	Single Factor Analysis of Variance	No vegetation zone would have a significantly different mean dark chamber CO ₂ flux from the other vegetation zones in August.	0.05	0.0025	Reject the null hypothesis
17.a	Each pair of August's mean dark chamber CO ₂ fluxes from the <i>S. alterniflorus</i> zones, dead lower margins, limited salt pannes, and extensive salt pannes	Tukey Test for Honestly Significant Difference	The comparison of each pair of mean dark chamber CO ₂ fluxes, from August, would not show significant difference.	0.05	0.0064 0.0442 0.0068	Dark <i>S. alterniflorus</i> measurements are different
18	August's mean dark chamber CH ₄ fluxes of the <i>S. alterniflorus</i> zones, dead lower margins, limited salt pannes, and extensive salt pannes.	Single Factor Analysis of Variance	No vegetation zone would have a significantly different mean dark chamber CH ₄ flux from the other vegetation zones in August.	0.05	0.2669	Cannot reject the null hypothesis
19	August's mean net CO ₂ fluxes of the <i>S. alterniflorus</i> zones, dead lower margins, limited salt pannes, and extensive salt pannes.	Single Factor Analysis of Variance	No vegetation zone would have a significantly different mean net CO ₂ flux from the other vegetation zones.	0.05	0.7434	Cannot reject the null hypothesis
20	August's mean net CH ₄ fluxes of the <i>S. alterniflorus</i> zones, dead lower margins, limited salt pannes, and extensive salt pannes.	Single Factor Analysis of Variance	No vegetation zone would have a significantly different mean net CH ₄ flux from the other vegetation zones.	0.05	0.8709	Cannot reject the null hypothesis

Table 1. An outline of all statistical tests performed in a 2023 study of CO₂ and CH₄ fluxes from southern Gulf of St. Lawrence saltmarshes. Tests 1 – 8 were performed to verify assumptions about the sampling and processing methods of the study. Tests 9 – 20 were performed to compare the CO₂ and CH₄ fluxes of one living zone, the *S. alterniflorus* zone, and three dead zones, the dead lower margin, the limited salt panne, and the extensive salt panne. Tests with a letter (i.e. 3.a, 11.a, and 17.a) were post-hoc tests of the same numbered test without the letter (i.e. 3, 11, and 17, respectively).

* On August 17, 2023, the size of soil gas chambers used to measure the soil gas flux increased from a small to a large size. This was done because the small soil gas chambers broke the stems of *S. alterniflorus*, compromising measurements. While inconsequential to the use of dead lower margin, limited salt panne, and extensive salt panne soil gas-flux measurements, the soil gas-flux measurements taken with the small chamber in the *S. alterniflorus* zone could not be used in zonal comparison. So, the only small chamber measurements included below from the *S. alterniflorus* zone are the two light chamber cut measurements, and two dark chamber cut measurements taken in July. No other *S. alterniflorus* zone measurements taken with small chambers are included.

Zone	Measurement type	Chamber used	Month				Total
			June	July	August	September	
<i>Sporobolus alterniflorus</i> *	Standard	Dark	0	0	6	3	9
		Light	0	0	6	3	9
	Repeated	Dark	0	0	0	0	0
		Light	0	0	2	0	2
	Cut	Dark	0	2*	4	0	6
		Light	0	2*	4	0	6
Dead Lower Margin	Standard	Dark	1	1	4	2	8
		Light	1	1	4	2	8
	Repeated	Dark	0	0	0	0	0
		Light	0	0	1	0	1
Limited Salt Panne	Standard	Dark	1	4	3	1	9
		Light	0	4	3	1	8
	Repeated	Dark	0	0	1	0	1
		Light	0	0	1	0	1
Extensive Salt Panne	Standard	Dark	0	0	3	0	3
		Light	0	0	3	0	3
	Repeated	Dark	0	0	1	0	1
		Light	0	0	0	0	0
Total			3	14	46	12	75

Table 2. The number of soil gas-flux measurements taken in four saltmarsh vegetation zones under standard, cut, and repeated treatment types from June to September 2023. In total, seventy-five soil gas-flux measurements were taken and usable from the four vegetation zones: thirty-two were taken from the *S. alterniflorus* zone, seventeen were taken in the dead lower margin, nineteen were taken in the limited salt pannes, and seven were taken in extensive salt pannes. Cut treatments were only able to be taken in *S. alterniflorus* zones because there was no vegetation to cut in the other three zones.

* On August 17, 2023, the size of soil gas chambers used to measure the soil gas flux increased from a small to a large size. This was done because the small soil gas chambers broke the stems of *S. alterniflorus*, compromising measurements. While inconsequential to the use of dead lower margin, limited salt panne, and extensive salt panne soil gas-flux measurement sets, the soil gas-flux measurement sets taken with the small chamber in the *S. alterniflorus* zone could not be used in zonal comparison. So, the only small chamber measurement sets included below from the *S. alterniflorus* zone are the two cut measurement sets taken in July. No other *S. alterniflorus* zone measurement sets taken with small chambers are included.

** One repeated measurement set, taken in August, was also a cut measurement set. It is counted in this table twice: once as an *S. alterniflorus*, August repeated measurement set and once as a *S. alterniflorus*, August cut measurement set. In the complete total of thirty-two measurement sets this measurement set is only counted once.

Zone	Measurement type	Month				Total
		June	July	August	September	
<i>Sporobolus alterniflorus</i> *	Standard	0	0	3	3	6
	Repeated	0	0	2**	0	2**
	Cut	0	2	4**	0	6**
Dead Lower Margin	Standard	1	1	3	2	7
	Repeated	0	0	1	0	1
Limited Salt Panne	Standard	0	4	1	1	6
	Repeated	0	0	2	0	2
Extensive Salt Panne	Standard	0	0	2	0	2
	Repeated	0	0	1	0	1
Total		1	7	18	6	32

Table 3. The number of complete soil gas-flux measurement sets taken in four saltmarsh vegetation zones under standard, repeated, and cut treatment types from June to September 2023. In total, thirty-two soil gas-flux measurements were taken and usable from the four vegetation zones: one in June, seven from July, eighteen from August, and six from September. Cut measurement sets were only able to be taken in *S. alterniflorus* zones because there was no vegetation to cut in the other three zones. Standard measurement sets consisted of one light soil-gas chamber measurement and one dark soil-gas chamber measurement. Repeated measurement sets were the same as standard measurement sets, but with either the light or dark soil gas chamber measurements taken a second time. Cut measurement sets added a light and a dark soil gas chamber measurement to a standard measurement set's two measurements, but after vegetation had been removed by garden shears.

Vegetation zone	Flux Rate (in mg/m ² hr) by Month			
	June	July	August	September
<i>Sporobolus alterniflorus</i>	-	-	-2833	485.5
	-	-	-457.5	-43.69
	-	-	-2081	115.6
	-	-	-424.0	-
	-	-	-211.0	-
	-	-	522.5	-
Dead Lower Margin	-102.8	-53.14	-213.8	-1.001
	-	-	-183.2	59.53
	-	-	71.94	-
	-	-	-475.9	-
Limited Salt Panne	-	-24.40	844.5	13.25
	-	45.53	-32.44	-
	-	-31.69	174.1	-
	-	-34.20	-	-
Expansive Salt Panne	-	-	197.8	-
	-	-	-52.03	-
	-	-	1.169	-

Table 4. Soil flux of CO₂ measured across four vegetation zones in Southern Gulf of St. Lawrence saltmarshes over the summer of 2023, using a daytime simulating (light) soil gas chamber. Measurements were taken using a transparent soil gas chamber and a portable, user-made gas concentration analyzer, between June 29 and September 25, 2023. Fluxes were calculated from individual measurements using RStudio (v2023.12.1) and a manual R (v4.3.2, R Core Team, 2023) script. The fluxes of measurements taken in the same location, on the same day, in sequence were organised into measurement sets. Some fluxes shown here are the mean of measurement sets with repeated measurements. Measurements were not taken at any particular point in a tidal cycle.

Vegetation zone	Flux Rate (in mg/m ² hr) by Month			
	June	July	August	September
<i>Sporobolus alterniflorus</i>	-	-	1545	707.3
	-	-	2135	271.1
	-	-	765.2	176.8
	-	-	1294	-
	-	-	1112	-
	-	-	662.2	-
Dead Lower Margin	270.8	-23.51	87.05	91.27
	-	-	65.00	109.8
	-	-	226.4	-
	-	-	394.4	-
Limited Salt Panne	12.55	935.1	777.3	57.48
	-	192.9	31.30	-
	-	33.75	396.7	-
	-	40.64	-	-
Expansive Salt Panne	-	-	290.2	-
	-	-	62.50	-
	-	-	-49.82	-

Table 5. Soil flux of CO₂ measured across four vegetation zones in Southern Gulf of St. Lawrence saltmarshes over the summer of 2023, using a nighttime simulating (dark) soil gas chamber. Measurements were taken using an opaque soil gas chamber and a portable, user-made gas concentration analyzer, between June 29 and September 25, 2023. Fluxes were calculated from individual measurements using RStudio (v2023.12.1) and a manual R (v4.3.2, R Core Team, 2023) script. The fluxes of measurements taken in the same location, on the same day, in sequence were organised into measurement sets. Some fluxes shown here are the average of measurement sets with repeated measurements. Measurements were not taken at any particular point in a tidal cycle.

Vegetation zone	Flux Rate (in mg/m ² hr) by Month			
	June	July	August	September
<i>Sporobolus alterniflorus</i>	-	-	-1030	595.5
	-	-	610	113.3
	-	-	-901.2	146.1
	-	-	312	-
	-	-	358	-
	-	-	582.6	-
Dead Lower Margin	26.8	-42.58	-98.7	44.75
	-	-	-88.2	84.5
	-	-	138.1	-
	-	-	-103.0	-
Limited Salt Panne	-	335.4	815.7	35.31
	-	100.8	-4.99	-
	-	-7.01	269.9	-
	-	-5.98	-	-
Expansive Salt Panne	-	-	232.9	-
	-	-	-8.44	-
	-	-	-19.97	-

Table 6. Net soil flux rate of CO₂ measured across four vegetation zones in Southern Gulf of St. Lawrence saltmarshes over the summer of 2023. Measurements were taken using a transparent and an opaque soil gas chamber and a portable, user-made gas concentration analyzer, between June 29 and September 25, 2023. Fluxes were calculated from individual measurements using RStudio (v2023.12.1) and a manual R (v4.3.2, R Core Team, 2023) script. The fluxes of measurements taken in the same location, on the same day, in sequence were organised into measurement sets. The fluxes of CO₂ from the transparent and opaque soil gas chambers were combined proportionally to the number of daylight hours on the day of each measurement set. Some fluxes shown here are the average of measurement sets with repeated measurements. Measurements were not taken at any particular point in a tidal cycle.

Vegetation zone	Flux Rate (in mg/m ² hr) by Month			
	June	July	August	September
<i>Sporobolus alterniflorus</i>	-	-	-1.375	0.3540
	-	-	-0.9606	-0.01841
	-	-	1.339	0.07178
	-	-	0.3498	-
	-	-	0.1411	-
	-	-	0.03468	-
Dead Lower Margin	-0.07531	0.01401	-0.04331	0.1505
	-	-	0.01372	0.2571
	-	-	-0.5083	-
	-	-	0.2976	-
Limited Salt Panne	-	0.01651	0.6702	0.05592
	-	0.07026	-0.1462	-
	-	-0.04952	0.08967	-
	-	0.03849	-	-
Expansive Salt Panne	-	-	0.04969	-
	-	-	-0.08572	-
	-	-	0.03956	-

Table 7. Soil flux rate of CH₄ measured across four vegetation zones in Southern Gulf of St. Lawrence saltmarshes over the summer of 2023, using a daytime simulating (light) soil gas chamber. Measurements were taken using a transparent soil gas chamber and a portable, user-made gas concentration analyzer, between June 29 and September 25, 2023. Flux rates were calculated from individual measurements using RStudio (v2023.12.1) and a manual R (v4.3.2, R Core Team, 2023) script. The fluxes of measurements taken in the same location, on the same day, in sequence were organised into measurement sets. Some fluxes shown here are the average of measurement sets with repeated measurements. Measurements were not taken at any particular time in a tidal cycle.

Vegetation zone	Flux Rate (in mg/m ² hr) by Month			
	June	July	August	September
<i>Sporobolus alterniflorus</i>	-	-	-0.06940	0.1944
	-	-	0.3725	0.07399
	-	-	-0.1722	0.01141
	-	-	0.3324	-
	-	-	0.02828	-
	-	-	0.3585	-
Dead Lower Margin	0.1436	0.09499	0.1351	-1.001
	-	-	0.05148	0.03283
	-	-	-0.4365	-
	-	-	-0.1236	-
Limited Salt Panne	0.04313	0.1402	-0.06321	0.04579
	-	0.05393	0.2251	-
	-	0.04154	0.1322	-
	-	-0.01112	-	-
Expansive Salt Panne	-	-	-0.1773	-
	-	-	0.05181	-
	-	-	-0.2198	-

Table 8. Soil flux rate of CH₄ measured across four vegetation zones in Southern Gulf of St. Lawrence saltmarshes over the summer of 2023, using a nighttime simulating (dark) soil gas chamber. Measurements were taken using an opaque soil gas chamber and a portable, user-made gas concentration analyzer, between June 29 and September 25, 2023. Fluxes were calculated from individual measurements using RStudio (v2023.12.1) and a manual R (v4.3.2, R Core Team, 2023) script. The fluxes of measurements taken in the same location, on the same day, in sequence were organised into measurement sets. Some fluxes shown here are the average of measurement sets with repeated measurements. Measurements were not taken at any particular time in a tidal cycle.

Vegetation zone	Flux Rate (in mg/m ² hr) by Month			
	June	July	August	September
<i>Sporobolus alterniflorus</i>	-	-	-0.8365	0.2749
	-	-	-0.4117	0.02766
	-	-	0.7128	0.04168
	-	-	0.3423	-
	-	-	0.09250	-
	-	-	0.1741	-
Dead Lower Margin	0.0006844	0.04286	0.02497	-0.4204
	-	-	0.02817	0.1459
	-	-	-0.4775	-
	-	-	0.1171	-
Limited Salt Panne	-	0.06290	0.3560	0.05087
	-	0.06414	0.01366	-
	-	-0.01518	0.1080	-
	-	0.01978	-	-
Expansive Salt Panne	-	-	-0.03669	-
	-	-	-0.03338	-
	-	-	-0.06795	-

Table 9. Net soil flux rate of CH₄ measured across four vegetation zones in Southern Gulf of St. Lawrence saltmarshes over the summer of 2023. Measurements were taken using a transparent and an opaque soil gas chamber and a portable, user-made gas concentration analyzer, between June 29 and September 25, 2023. Flux rates were calculated from individual measurements using RStudio (v2023.12.1) and a manual R (v4.3.2, R Core Team, 2023) script. The fluxes of measurements taken in the same location, on the same day, in sequence were organised into measurement sets. The fluxes of CH₄ from the transparent and opaque soil gas chambers were combined proportionally to the number of daylight hours on the day of each measurement set. Some fluxes shown here are the average of measurement sets with repeated measurements. Measurements were not taken at any particular time in a tidal cycle.



Figure 11. CO₂ fluxes (in g·m⁻²·day⁻¹) of different soil gas chamber measurement groups plotted against the date they were measured. Measurements of CO₂ flux were taken using opaque (dark) and transparent (light) soil gas chambers, simulating nighttime and daytime conditions respectively, across four different vegetation zones in saltmarshes of the Southern Gulf of St. Lawrence: *Sporobolus alterniflorus* zones (Sa), dead lower margins (DLM), limited salt pannes (LSP), and extensive salt pannes (ESP). Dark and light chamber CO₂ fluxes followed the rough shapes of normal curves mirrored about the axis of the independent variable. Magnitudes of both dark and light chamber measurements were relatively small in June and increased to their respective maximums in the middle of August before decreasing again as the measurements approached the end of September. Dark chamber CO₂ flux measurements tended to be positive while light chamber CO₂ flux measurements tended to be negative. Although, light chamber measurements did sometimes record positive CO₂ fluxes, notably at the end of September. Smaller soil gas chambers were replaced with larger soil gas chambers on August 17, 2023. Measurements were taken between June 29 and September 25, 2023.



Figure 12. CH₄ fluxes of different soil gas chamber measurement groups plotted against the date they were measured. Measurements of CH₄ flux were taken using opaque (dark) and transparent (light) soil gas chambers, simulating nighttime and daytime conditions respectively, across four different vegetation zones in southern Gulf of St. Lawrence saltmarshes: *Sporobolus alterniflorus* zones (Sa), dead lower margins (DLM), limited salt pannes (LSP), and extensive salt pannes (ESP). The magnitudes of both dark and light chamber CH₄ fluxes followed the rough shapes of normal curves. Magnitudes of both dark and light chamber CH₄ fluxes were relatively small in June and increased to their respective maximums in the middle of August before decreasing again as the measurements approached the end of September. Neither dark nor light chamber measurements recorded any trend toward positive or negative fluxes of CH₄. Light chamber measurements did often have a larger magnitude than light chamber measurements of CH₄. Smaller soil gas chambers were replaced with larger soil gas chambers on August 17, 2023. Measurements were taken between June 29 and September 25, 2023.

Discussion

The results of the verification tests supported my assumptions. Based on Test 1, the light and dark chambers were the better simulations of daytime and nighttime conditions, respectively. Test 3, Test 3.a, and Test 4 demonstrated that the light chamber allowed photosynthesis, while the dark chamber did not. Test 5 and Test 6 showed that there was no significant artifacts caused by changing from small to large chambers on August 17. Finally, Test 7 and Test 8 showed that my processing methods did not leave any significant artifacts from my measurement methods. Although, the P-values of Test 7 and Test 8 were low, 0.3435 and 0.2403 respectively, and I will address that later in this discussion. Interestingly Test 2 clearly showed that there was no significant difference (P-value = 0.8538) between the CH₄ fluxes of light and dark chamber measurements, which would suggest that CH₄ fluxes in saltmarshes are perhaps unaffected by sunlight.

While analysis of the soil's pore water salinity, temperature, and compressibility could not be explored as potential drivers of CO₂ and CH₄ fluxes in *S. alterniflorus* and dead zones, the data in Appendix C is available to anyone for said analyses.

Plotting the CO₂ and CH₄ fluxes from all measurement sets (Figure 10 and Figure 11, respectively) suggested seasonal controls on both CO₂ and CH₄ fluxes.

The tests comparing the CO₂ and CH₄ fluxes of the *S. alterniflorus* zones, dead lower margins, limited salt pannes, and extensive salt pannes only found a significant difference between the dark chamber measured fluxes of CO₂ of the *S. alterniflorus* zone and the three dead zones. Test 11, Test 11.a, Test 17, and Test 17.a showed that dark chamber CO₂ fluxes, and therefore that respiration rates, were significantly greater in *S. alterniflorus* zones than in dead zones. While Test 9 (P-value = 0.2466), Test 12 (P-value

= 0.1349), Test 15 (P-value = 0.2050), and Test 19 (P-value = 0.2669) all had relatively low P-values, I was unable to reject their null hypotheses that there were no significant differences amongst the respective means they compared.

Study Constraints

To further interpret my results, I should first elaborate on factors that constrained the quality of my results (constraining factors) and the resulting constraints.

Constraining Factors

The first constraining factor was simply that the bulk of my preparation and sampling work was restricted to May through August 2023. Although I did have two days of sampling in September, the 24 and 25 of that month, those two days were one month after the previous sampling day. I did not have the capacity to sample after this.

The second constraining factor is that instrument preparation further delayed my field season. Instruments and equipment needed to be programmed, repaired, replaced, and manufactured. This prevented the first field test from happening until June 8, 2023.

The third constraining factor was that the small soil gas chambers compromised *S. alterniflorus* zone measurements. The damage to *S. alterniflorus* stalks was most obvious in August and late July, but I had no objective way of determining which small chamber *S. alterniflorus* zone measurements were unaffected. I therefore excluded all small chamber *S. alterniflorus* zone measurements from zonal comparisons, assuming that they were all compromised.

The fourth constraining factor was that the air temperature and pressure in my light chamber measurements likely increased by some unknown amount from the beginning to the end of each measurement. While the soil gas chambers were relatively

closed to the exchange of air above the soil surface, light chambers allowed light to enter, likely increasing air temperature inside would by some unknown amount. According to the Ideal Gas Law, $PV = nRT$, if air temperature increased in a constant volume soil gas chamber, the air pressure would rise too.

The fifth constraining factor was that photosynthetic rate may have decreased during each light chamber measurement. Because the concentration of CO₂ would decrease over the course of a light chamber measurement, the rate of photosynthesis would also decrease, given that reactant concentrations are a control on rate of reaction.

The sixth constraining factor was that measurements were not evenly taken amongst saltmarshes, over the sampling period, or amongst zones. For instance, only two days were spent taking measurements at the Michael's Landing saltmarsh, August 24 and 25, whereas five days were spent sampling at the Boy Scout Beach saltmarsh, June 29, July 11, 12, and 27, and September 25. There were three notable gaps in measurements over the summer. Between July 12 and 24, August 3 and 16, and August 25 and September 24, no measurements were taken. Finally, only three measurement sets were taken in extensive salt pannes where either eight or nine usable measurement sets were taken in each of the other zones

Resulting Constraints

The resulting constraints of these factors are notably that less seasonal variation was able to be recorded and observed, less representative mean CO₂ and CH₄ fluxes, less statistical power to my tests comparing the CO₂ and CH₄ of different zones, and likely a positive directing bias for fluxes under my light chamber measurements.

With my sampling period running from June 16 to September 25, 2023, I unfortunately did not capture much of the CO₂ and CH₄ fluxes of the ‘shoulder seasons,’ or rather late April to the end of May and the end of August to the middle of October. While having measurements from late April till early October was not and is not completely necessary to make comparisons of mean CO₂ and CH₄ fluxes between zones, having had measurements from the shoulder seasons in addition to the summer would have provided a more complete picture of the seasonal variability and mean CO₂ and CH₄ fluxes more representative of a growing season.

Further, with only my large chamber *S. alterniflorus* measurements – taken between August 17 and September 25 – being usable I have only a slim view of seasonal variation and a sample size of fifteen fewer measurement sets in that zone. My *S. alterniflorus* zone measurements likely only captured the very end of the *S. alterniflorus* maturation phase and the beginning and middle of their senescence phase (Hill et al. 2021; Garbary per com. 2024). My CO₂ and CH₄ mean fluxes in the *S. alterniflorus* zone therefore represent a period of the year where *S. alterniflorus* was performing little to no photosynthesis to build biomass. My mean CO₂ fluxes from *S. alterniflorus* zones were therefore much lower than what an entire growing season’s mean CO₂ fluxes likely would have been. Finally, with a smaller sample size, the standard deviations of the mean CO₂ and CH₄ fluxes are greater. These two effects reduced the statistical power of my comparisons between the mean CO₂ and CH₄ fluxes of *S. alterniflorus* and dead zones.

Statistical power was also reduced by the inequivalent distribution of measurements across zones, at different saltmarshes, throughout the sampling period. Unequal sample sizes decrease statistical power, but statistical power is also decreased by

other factors. It is documented that CO₂ and CH₄ fluxes can vary between saltmarshes (Chmura et al. 2016), throughout tidal periods (Abdul-Aziz et al. 2018), and throughout growing seasons (Bartlett et al. 1987; Hill et al. 2021). If measurements in different zones are not taken equivalently at all saltmarshes, throughout tidal periods, and throughout a sampling period, biases can be introduced. For instance, taking all my extensive salt panne measurements at a single saltmarsh and only in August means that my extensive salt panne measurements were subjected to a narrower set of environmental conditions than other zones. While it is difficult to control environmental conditions in field work, one should strive for equivalent conditions amongst treatments. That is, I should have better designed my field work so that measurements in different zones were taken as equivalently as possible across saltmarshes, throughout the tidal period, and throughout the sampling period. My consequence of not equivalently distributing measurements, is that I now have unknown biases in my mean CO₂ and CH₄ fluxes of each of my zones.

Finally, the likely combination of increasing air pressure and the decreasing photosynthetic rate over the course of each light chamber measurement would have biased each light chamber CO₂ and, to a lesser extent, CH₄ flux, toward a more positive value than the true CO₂ and CH₄ fluxes. My gas concentration analyzers were calibrated to around 1 atm (101.325 kPa) of pressure. At higher pressures, with more movement of gas particles, the analyzers would have estimated greater concentrations of CO₂ and CH₄. Combining that higher concentration reading with the slowing of photosynthesis and the CO₂ fluxes of my light chamber measurements would likely have trended more positive by a noticeable margin. In a natural saltmarsh setting, where air mixing prevents the depletion of CO₂, and therefore the slowing of photosynthesis by CO₂ depletion.

Nonetheless, even though the precision and accuracy of my results is limited, I will discuss the notable trends and insights that have still arisen from my data analysis.

Significance of Statistical Test Results

Results from Tests Verifying Assumptions

Comparison of Light and Dark Chamber Measurements

The results of the ANOVA testing for significant difference between the mean CO₂ fluxes of the light and dark chamber measurements was expected, but the relative values of the mean CO₂ fluxes were not. When comparing the mean CO₂ fluxes of light chamber measurements ($\bar{x} = -168.7 \pm 710.7 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$) against that of the dark chamber measurements ($\bar{x} = 452.1 \pm 535.7 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), one might expect their magnitudes to be near equal in a “stable ecosystem.” In a wetland, where anoxic soil conditions reduce the rate of aerobic decomposition, one would expect the magnitude of the mean CO₂ flux from light chamber measurements to be greater than from dark chamber measurements. In my case, the magnitude of my mean CO₂ flux rate from dark chamber measurements is 2.680 times greater than that of my light chamber measurements.

The relatively larger magnitude of the dark chamber measured mean CO₂ flux could be explained by some combination of the positive bias of my light chamber measurements, random variation in CO₂ fluxes under light and dark chambers, the time of year of my measurements, and perhaps the zones in which I surveyed. I have already mentioned that photosynthetic rate likely slowed, and air pressure likely increased in my light chambers during measurements, which would have biased my light chamber CO₂ fluxes more positively, therefore producing a smaller magnitude light chamber measured mean CO₂ flux. The standard deviations of my light and dark chamber measured mean

CO₂ fluxes produce ranges of between -879.4 and 542.0 mg¹m⁻²hr⁻¹ and between -83.6 and 987.8 mg¹m⁻²hr⁻¹ for the true means, respectively. With measurements from the *S. alterniflorus* zone being taken as the cordgrass enter their senescence phase (Hill et al. 2021), their photosynthetic rate could have simply been lesser than the rate of aerobic respiration from all organisms under the soil gas chamber. Finally, it is also possible that dead zones are simply net sources of CO₂ and that by taking most of my useable measurements in dead zones, my mean light chamber measured CO₂ flux was lowered.

With respect to the ANOVA testing for significant difference between the mean CH₄ fluxes of light and dark chamber measurements, it is interesting that there was no significant difference ($F_{\text{stat}} = 0.03428$, P-value = 0.8538) between the two means, 0.02832 ± 0.4635 mg¹m⁻²hr⁻¹ and 0.009972 ± 0.2602 mg¹m⁻²hr⁻¹, respectively. Moseman-Valtierra et al. (2016) was also unable find a significant difference between their mean light and dark chamber CH₄ fluxes in the low marsh (P-value = 0.44). This suggests that CH₄ flux is not or only weakly affected by the presence of light.

The results of the ANOVAs comparing the mean CO₂ fluxes of uncut light chamber, cut light chamber, uncut dark chamber, and cut dark chamber measurements were expected. Interestingly, the mean cut light chamber measured CO₂ flux of ($\bar{x} = 2029 \pm 453.8$ mg¹m⁻²hr⁻¹) was greater than that of the uncut dark chamber measurements ($\bar{x} = 1827 \pm 795.7$ mg¹m⁻²hr⁻¹), but random chance and the bias of my light chamber likely explain this. Ideally, I would have taken more cut measurement sets and weighed cuttings to discern photosynthetic rate by above-ground biomass-weight throughout the summer.

Tests for Artifacts of Sampling Methods

While the mean CO₂ and CH₄ fluxes between the first and second measurements in repeated measurement sets were not significantly different ($t_{\text{stat}} = 0.4150$, P-value = 0.3435; $t_{\text{stat}} = 0.7326$, P-value = 0.2403, respectively), per their t-tests, their respective P-values are still relatively low. Although a high degree of variation is not unusual that soil gas flux measurements (e.g. Chmura et al. 2011), one would expect successive measurements to be more similar. Soil gas flux studies often employ the use of soil gas chamber collars (e.g. Abdul-Aziz et al. 2018; Chmura et al. 2011; and Emery and Fulweiler, 2014). Collars reduce the soil disturbance caused by placing soil gas chambers atop the peat. Collars must be installed well before sampling, requiring better planning, but, as evidenced by the relatively low P-values of my comparisons of mean CO₂ and CH₄ fluxes, soil gas chamber collars are likely better practice for soil gas flux sampling.

Zonal Comparisons

CO₂

It is unsurprising that the *S. alterniflorus* zones ($\bar{x} = 963.3 \pm 626.2 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$) had a significantly different mean dark chamber measured CO₂ flux from that of the dead zones ($\bar{x} = 200.1 \pm 259.9 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$). *S. alterniflorus* zones have above- and below-ground plant tissue respiration under dark condition, in addition to the animal and microbial aerobic respiration that dead zones have. Additionally, while organic matter is certainly present in the soil of dead zones, those that I sampled had comparatively little aboveground primary producing biomass without any live vascular plants.

I am more surprised by my inability to reject my null hypothesis that there would be no significant difference amongst the four zones' mean light chamber measured CO₂ fluxes. I would have expected – given that the *S. alterniflorus* shoots seem to be creating

much more biomass throughout the growing season than dead zone primary producers – that the mean light chamber measured CO₂ flux of the *S. alterniflorus* zones would have been significantly different from those of the dead zones. The P-values of the Single Factor ANOVAs comparing the mean light chamber measured CO₂ fluxes of light chamber over the whole sampling period (P-value = 0.2466) and just in August (P-value = 0.2050) were not significant, but not very large either.

I am also surprised that I was unable to reject my null hypothesis that there would be no significant difference amongst the mean CO₂ net fluxes from the four zones. I had originally wondered, when starting this work, if even though dead zones were to have smaller magnitude light and dark chamber measured CO₂ fluxes than *S. alterniflorus* zones, would their net CO₂ fluxes balance out to be the same? At least in August, this appears to be true, according to my Single Factor ANOVA comparing August's mean net CO₂ fluxes (P-value = 0.8709). Although the Single Factor ANOVA comparing the mean net CO₂ fluxes from the entire sampling period also did not allow me to reject my null hypothesis (P-value = 0.8028), the lack of *S. alterniflorus* zone measurements before August 17 likely played a strong role in this.

My inability to show significant difference amongst my light chamber measured mean CO₂ fluxes and amongst my net CO₂ fluxes is striking to me. The sampling period's mean light chamber measured CO₂ flux from the *S. alterniflorus* zones ($\bar{x} = -547.5 \pm 1152 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$) was more negative than from the dead zones ($\bar{x} = -112.3 \pm 249.1 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), albeit with a much greater standard deviation as well. The sampling period's mean net CO₂ flux from the *S. alterniflorus* zone ($\bar{x} = 87.49 \pm 625.6 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$) was quite like that of the dead zone ($\bar{x} = 89.76 \pm 213.8 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$), again the standard

deviation of the *S. alterniflorus* zone was greater though. I believe that my mean light chamber measured and mean net CO₂ fluxes from the *S. alterniflorus* zones are much lower than they would have been over an entire growing season. Abdul-Aziz et al. (2018) found a daily mean net ecosystem CO₂ flux of $-473 \pm 927 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ from four low marsh dominant saltmarshes near Waquoit Bay, Massachusetts, between May and October 2013. Hill et al. (2021) reported a daily mean net CO₂ flux of -84 ± 250 and $-71 \pm 317 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ from a *S. alterniflorus* dominated saltmarsh in the Delaware Bay, for the entire years of 2017 and 2018, respectively. More, my smallest magnitude light chamber measured, dark chamber measured, and net CO₂ fluxes were all from dead zones, $-1.001 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, $12.55 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, and $-4.993 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, respectively. Whereas my largest light chamber measured, dark chamber measured, and net CO₂ fluxes were all from the *S. alterniflorus* zone, $-2833 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, $2135 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, and $-1030 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, respectively. Given that my *S. alterniflorus* zone measurements were all taken at the end of the maturation phase and into the senescence phase of the cordgrass, I believe a study in the southern Gulf of St. Lawrence that was more equivalently spread across zones and throughout the growing season would have had found that dead zone have significantly smaller magnitude daytime and daily net fluxes of CO₂.

CH₄

For CH₄ fluxes, my work showed no significant difference amongst the mean light chamber measured, mean dark chamber measured, and mean net CH₄ fluxes of the four zones, when comparing all measurement sets and just August. Although the P-values of the six different Single-Factor ANOVAs comparing the mean CH₄ fluxes of the four zones did vary. The Single Factor ANOVAs comparing the mean light chamber

measured and mean net CH₄ fluxes all had P-values greater than 0.70. The comparison of the mean dark chamber measured CH₄ fluxes produced comparatively lesser P-values; 0.1349 from comparing all measurement sets and 0.2669 from just August. Given that I so strongly found no significant difference between the mean CH₄ fluxes of light and dark chamber measurements, it is interesting that the mean dark chamber measured CH₄ fluxes might vary more amongst zones than mean light chamber measured CH₄ fluxes.

Previous studies have found that CH₄ sometimes varies with zone. Comer-Warner et al. (2022), a study performed on the south shore of the St. Lawrence River, using dark chambers only, previously reported that *S. alterniflorus* zones had significantly higher fluxes than mudflats, *S. pumilus* zone, and *Phragmites australis* zone. Comer-Warner et al. (2022) found no significant difference amongst the mean CH₄ fluxes of their mudflats, *S. pumilus* zone, and *P. australis* zone. Moseman-Valtierra et al. (2016), a study performed at a saltmarsh on the southern shore of Cape Cod, reported a significant difference between the mean CH₄ fluxes of their invasive *P. australis* zone and their native low marsh zone, native high marsh zone, and unvegetated ponds. Moseman-Valtierra et al. (2016) also found no significant difference amongst the mean CH₄ fluxes of their native low marsh zone, native high marsh zone, and unvegetated ponds. My dead lower margins have a notably. It is possible that variation of mean CH₄ fluxes amongst zones is driven by environmental conditions that do not change simply between zones.

Seasonal Variation

CO₂

Figure 11, showing the CO₂ fluxes from light and dark chamber measurements from all measurement sets over the sampling period, shows two shapes of CO₂ fluxes

similar to normal curves. Figure 11 essentially shows the rate of aerobic respiration and photosynthesis in the *S. alterniflorus* and dead zones. Both respiration and photosynthesis increase and decrease together, although not perfectly equal at any time. Hill et al. (2021) plotted the net ecosystem production (NEP) for the St. Jones Reserve saltmarsh complex in Delaware Bay, Delaware, and found similar normal curve shapes, with NEP peaking around the 225th day of 2017 and 165th day in 2018 (mid-August and mid-June, respectively). My greatest photosynthetic rates were also recorded in mid-August. I unfortunately do not have usable *S. alterniflorus* measurements from the entire growing season to see this trend more clearly. But Figure 11 would still show that photosynthesis and decomposition would have appeared to have reached their respective maximum rates in these southern Gulf of St. Lawrence saltmarshes by or before the middle of August.

An interesting note is that by August 24th and 25th, photosynthesis in *S. alterniflorus* and dead zones slowed considerably from the peak on August 17th and was often outpaced by respiration during light chamber measurements on September 24th and 25th. This would align with *S. alterniflorus* moving into its senescence phase by the end of August (Garbary per com. 2024). By this time, *S. alterniflorus* would no longer be producing more biomass. Instead, *S. alterniflorus* would be allocating resources for future generations and the next growing season. At this same time, so long as temperatures allow respiration by decomposers and other organisms continues.

CH₄

CH₄ fluxes followed a somewhat different trend than CO₂ fluxes over the sampling period. The magnitudes of CH₄ fluxes remained relatively stable from July 16th till August 2nd. All but one of the seven largest mCH₄ fluxes were recorded on August

17th and 18th. The fluxes of CH₄ decreased in magnitude after August 18th, but not to the magnitudes of before August 17th. The third largest magnitude flux of CH₄ was taken on September 24th, in a dead lower margin, where it was an outlier amongst the other measurements that day. Previous studies in Chesapeake Bay reported seasonal peaks in CH₄ flux between July and November and varied from saltmarsh to saltmarsh, even in the same estuary (Bartlett et al. 1985; Bartlett et al. 1987). Those same studies also found that a single saltmarsh site could have multiple peaks in CH₄ flux in a single growing season.

CH₄ flux in saltmarshes has previously been found to be correlated with several environmental variables, including tidal height, soil temperature, soil pore water salinity, and photosynthetically available radiation (Abdul-Aziz et al. 2018; Bartlett et al. 1985; Bartlett et al. 1987). It is possible that the variation in CH₄ flux is not easily predictable over a growing season. Rather, CH₄ flux over a growing season might more strongly be affected by intersecting factors that can produce somewhat chaotic seasonal patterns.

In the Context of Climate Change

Both CO₂ and CH₄ fluxes are correlated to soil temperature (Abdul-Aziz et al. 2018) and saltmarsh soil temperature is controlled by water and air temperatures. The metabolisms of organisms – namely primary producers and decomposers – are controlled by the temperature of their environments. As I've noted, it appears that in late August and into September daytime decomposition outpaces photosynthetic rate in the *S. alterniflorus* and dead zones southern Gulf of Saint Lawrence saltmarshes. This means that the low marsh is a net source of CO₂ during both that days and nights of autumn. This happens because *S. alterniflorus* performs little to no photosynthesis as they enter their senescence phase, but decomposition is allowed to continue by the still warm

autumn temperatures. As Nova Scotian autumns warm quickly from their 1960 to 1990 climate average and there are fewer frost free days in the autumn (Garbary and Hill, 2021), this period where saltmarshes are net sources of CO₂ will lengthen

In the Context of the Literature

Study Design

Light and Dark Chamber Measurements

Previous studies of saltmarsh greenhouse gas flux have often only used dark chamber measurements (Poffenbarger et al. 2011). While both my findings and those of Moseman Valtierra et al. (2016) found no significant difference between CH₄ flux under light and dark chambers, suggesting light is inconsequential to CH₄ flux, the same is evidently not true for the flux of CO₂. Without both light and dark chamber measurements of CO₂ flux, the net ecosystem exchange (NEE) of CO₂ in saltmarshes cannot be discerned. Much work using only dark chambers has previously been done on the North American East Coast to discern the drivers of CH₄ flux in saltmarshes (e.g. Bartlett et al. 1985; Bartlett et al. 1987; Comer-Warner et al. 2022; Chmura et al. 2011; and Chmura et al. 2016), which has improved our understanding of CH₄ flux in saltmarshes and therefore our estimation ability in grander pictures.

However, to make accurate estimations of CO₂ flux in saltmarshes, studies using only dark chamber measurements and biomass collections have fall short. Carbon removed from the atmosphere does not necessarily remain in saltmarshes. Herbivory (Roberts and Robertson, 1986) and tidal exchange (Chalmers et al. 1985) can remove stored carbon from saltmarshes, making it undetectable by biomass sampling at the end of a growing season. Although, to make accurate NEE estimations of CO₂, the seasonal

variation should also be captured (Hill et al. 2021). Else, my findings would suggest that both *S. alterniflorus* and dead zones in the Southern Gulf of St. Lawrence are losing carbon much faster than they can acquire it.

The Timing of Studies

My sampling period was relatively constricted compared to other studies on the North American East Coast. Studies have previously often been performed over an extended growing season (e.g. Abdul-Aziz et al. 2018) or even entire years (e.g. Capooci & Vargas, 2022) and would have noted the major CO₂ and CH₄ fluxes of a year. My dead zone measurements would have captured a relatively shorter period of the growing season, and my *S. alterniflorus* zone measurements would have solely capture the end of the growing season and into the *S. alterniflorus* zones' senescence (Hill et al. 2021).

Comparisons Amongst Zones

While there are few studies comparing the CO₂ and CH₄ fluxes between live and dead zones, mine joins a few that have been conducted in recent years. Comer-Warner et al. (2022) for example, surveyed the CO₂ and CH₄ fluxes of mudflats below the low marsh and the low marsh *S. alterniflorus* zone of a St. Lawrence River saltmarsh in late August using a dark chamber. In one of two surveys conducted in a saltmarsh on the southern coast of Cape Cod, Mosemann-Valtierra et al. (2016) investigated the CO₂ and CH₄ fluxes of unvegetated ponds, in addition to native high marsh zones and invasive *P. australis* zones. However, there have been little to no studies comparing the CO₂ and CH₄ fluxes from dead lower margins, limited salt pannes, and expansive salt pannes to other, vegetated, areas of the marsh.

Fluxes

CO₂

My mean light chamber measured CO₂ flux ($-168.7 \pm 710.7 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$) was smaller in magnitude than other studies using light chamber measurements have reported. Abdul-Aziz et al. (2018) reported a mean light chamber measured CO₂ flux of $-1140 \pm 797 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ from low marsh dominated southwestern Cape Cod saltmarshes, between May and October 2013. Moseman-Valtierra et al. (2016) reported a mean light chamber measured CO₂ flux of $-870 \pm 100 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ from *S. alterniflorus* zones of a southern Cape Cod saltmarsh, from July 10, 2013. My smaller mean light chamber measured CO₂ flux may be a result of decreasing productivity with increasing latitude (McLeod et al, 2011). My slant toward later season measurements likely also have reduced my mean CO₂ light chamber measurements. Eighteen of my twenty-nine (62%) of my usable measurement sets were taken after August 17, 2023. I believe that my inability to exclude dead zone measurements from the mean CO₂ flux for light chamber measurements also explains the lesser magnitude of my mean compared to others. Where my mean CO₂ flux from light chamber measurements was $-547.5 \pm 1152 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ from all usable *S. alterniflorus* measurement sets, it was $10.69 \pm 249.1 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ from dead zones.

In contrast, my mean dark chamber measured CO₂ flux in *S. alterniflorus* zones ($963.3 \pm 626.2 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$) is one of the larger magnitude mean fluxes measured from vegetated areas in eastern North America. Comer-Warner et al. (2022) reported a mean CO₂ flux of $333.9 \pm 67.7 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ from *S. alterniflorus* zones, $156.7 \pm 48.3 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ from *S. pumilus* zones, and $279.2 \pm 100.7 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ from invasive *P. australis* zones on August 23, 2020. Chmura et al. (2011) reported mean dark chamber measured CO₂ fluxes of $398 \pm 201 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ and $485 \pm 253 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ at the end of August and beginning of

September 2006, from *S. pumilus* zones in southern Gulf of St. Lawrence and Bay of Fundy saltmarshes, respectively. Capooci and Vargas (2022) reported their greatest mean dark chamber measured CO₂ flux of $528 \pm 24 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ between May 31 and June 3, 2021, from *S. alterniflorus* zones in Delaware Bay saltmarshes. This greater magnitude mean CO₂ flux rate is unlikely to be strictly a result of latitude and the timing of measurements. It is possible that my sampling methods produced artificially greater CO₂ fluxes. Alternatively, rates of respiration may be relatively greater in southern Gulf of St. Lawrence saltmarshes than previous years. The closest reported mean dark chamber measured CO₂ fluxes I have found were 840, 920, and 1200 $\text{mg}^1\text{m}^{-2}\text{hr}^{-1}$ from fertilized southern Gulf of St. Lawrence and Bay of Fundy saltmarshes, measured from July 4, 2011, to July 2, 2012 (Chmura et al. 2016).

My mean dark chamber measured CO₂ flux in dead zones ($200.1 \pm 259.9 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$) is not overly unlike other unvegetated marsh zones. Comer-Warner et al. (2022) reported a mean dark chamber measured CO₂ flux of $59.7 \pm 49.4 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ from the mudflats below the *S. alterniflorus* zone on August 23, 2020. Moseman-Valtierra et al. (2016) reported mean CO₂ fluxes between $120 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ and $-150 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ from light chamber measurements in unvegetated ponds taken between June and August in 2013 and between May and August in 2014. It is possible that CO₂ flux from unvegetated ponds is greater in dark conditions, as photosynthetic microbes would likely absorb some CO₂ in light conditions. Overall, it seems unvegetated saltmarsh zones tend to emit somewhat less CO₂ under dark conditions than *S. alterniflorus* zones in the same saltmarshes (Comer-Warner et al. 2022; Moseman-Valtierra et al. 2016).

Unfortunately, there are also few studies that I can compare my mean daily net CO₂ flux ($89.03 \pm 382.7 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$). Hill et al. (2021) however, using eddy covariance, reported mean daily net CO₂ fluxes of $-84 \pm 250 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ and $-71 \pm 317 \text{ mg}^1\text{m}^{-2}\text{s}^{-1}$ for the entire years of 2017 and 2018, respectively, from a low marsh dominated Delaware Bay saltmarsh. Abdul-Aziz et al. (2018) also provide a net flux rate in its supporting documentation, $-454 \pm 927 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$, from between May and October, 2013. My mean daily net CO₂ flux is a similar magnitude and has a significant standard deviation as those reported by Hill et al. (2021) but is smaller in magnitude to that reported by Abdul-Aziz et al. (2018). I believe it is likely that my net emission of CO₂ can be attributed to late growing season sampling *S. alterniflorus* zones and the dead zone measurements.

CH₄

My mean light and dark chamber measured CH₄ flux in *S. alterniflorus* and dead zones ($0.01899 \pm 0.3709 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$) is quite like those previously reported from *S. alterniflorus* zones. Bartlett et al. (1985) reported mean CH₄ fluxes of 0.15 and 0.14 $\text{mg}^1\text{m}^{-2}\text{hr}^{-1}$ over a two year period in short and tall *S. alterniflorus* stands, respectively. Magenheimer et al. (1996) reported a mean CH₄ flux of $0.067 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ from measurements between mid-July to early September in 1993. Abdul-Aziz et al. (2018) reported a mean CH₄ flux of $0.0664 \pm 0.0416 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ between May and October in 2013. Comer-Warner et al. (2022) reported mean CH₄ fluxes of $17.7 \pm 9.7 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ and $0.1 \pm 0.2 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$ on August 23, 2020, from *S. alterniflorus* and intertidal mudflats, respectively. A range of several order of magnitude is not unusual for CH₄ fluxes (Bartlett et al. 1987; Emery and Fulweiler, 2017). With a high mean salinity of 23.3 ± 5.3 ppt, my lower mean CH₄ flux seems reasonable.

Future Work in the Saltmarshes of the Southern Gulf of St. Lawrence

Repetition and Expansion of Gas Flux Studies

A goal of my study was to contribute to understanding how southern Gulf of St. Lawrence saltmarshes will change with respect to their effect on global warming potential (GWP) in the context of climate change. In setting out to do this, I have become aware of at least some of what needs to be done to accomplish this goal.

First, dead zones should be better characterized for their GHG fluxes. My measurements likely captured some of the higher magnitude CO₂ fluxes in dead zones, but I was unable to measure them well in the spring and autumn. Having a longer sampling period could also aid in better understanding seasonal variation in dead zone CH₄ fluxes. There is also little to no information on N₂O fluxes in dead zones. My impression is that dead zones simply generate smaller magnitude CO₂ fluxes and comparable CH₄ and N₂O fluxes, compared to *S. alterniflorus* zones, but this impression lacks robust data.

Second, the GHG fluxes of other saltmarsh zones should be measured. The low marsh receives a large portion of GHG flux attention in northeastern North American saltmarshes. As higher marsh zones are threatened by coastal squeeze, information on their net GHG fluxes will be needed to understand how the GHG fluxes of entire saltmarshes will change. This information may even demonstrate the value conserving entire saltmarshes.

Finally, community structure changes should also be studied. As dead zones are increasing in cover and high marsh zones are subjected to coastal squeeze, it is likely that

the each zone's relative cover will change in the coming years come. If GHG fluxes vary by zone, then how zones change will be needed to predict how GHG fluxes will change.

Erosion and Accretion of Saltmarsh

Aside from their effects on GWP, the erosion and accretion of saltmarshes in the southern Gulf of St. Lawrence should also be monitored. At Captain's Pond Inlet, I observed no *S. alterniflorus* zone between the saltmarsh's lower margin and its *S. pumilus* zone, in some areas. I observed the same in some areas of the Michael's Landing saltmarsh complex. Researchers at the Gulf Aquarium and Marine Station (2023) had told me that both the Chéticamp Mainland and Chéticamp Island saltmarshes have drastically decreased the amount of coastline in recent decades. By these accounts, it would suggest that my saltmarshes are overall in danger of being lost. Afterall, the effects on GWP of saltmarshes will be irrelevant if they are altogether lost.

Restoration or Conservation

Further, saltmarshes loss is not only a local anecdote, but a global trend (Bridgham et al. 2006; Duarte et al. 2008). In the southern Gulf of St. Lawrence, where many rural communities live and work around the coast, the ecosystem services provided by saltmarshes, particularly to fisheries and coastal protection, is especially valuable. Along with their carbon sequestration potential, saltmarshes are valuable ecosystems in the southern Gulf of St. Lawrence, even if they are not recognized by its human inhabitants.

People in the southern Gulf of St. Lawrence are to continue to benefit from saltmarshes, they must be conserved and restored. Direct remediation, removal of human infrastructure, and mitigation of human activities on or near saltmarshes are all options. If

conservation and restoration efforts are not made, studies investigating how saltmarshes are changing is simply a catalogue of ecosystem collapse.

Conclusions

I performed exploratory CO₂ and CH₄ flux measurements on the recently prevailing dead zones of southern Gulf of St. Lawrence saltmarshes. My dead zones, that is dead lower margins, limited salt pannes, and extensive salt pannes, had not previously been investigated for their GHG fluxes. I measured their CO₂ and CH₄ fluxes throughout most of the growing season at five different saltmarshes in the southern Gulf of St. Lawrence. I found that the mean light and dark chamber measured CO₂ fluxes of dead zones were generally smaller in magnitude when compared to those of the late summer *S. alterniflorus* zone. Although only the mean dark chamber measured CO₂ flux of the dead zones were significantly different from that of the *S. alterniflorus* zones. I was unable to show any differences amongst the mean light chamber measured, dark chamber measured, or net daily CO₂ fluxes of the dead lower margin, the limited salt panne, and the extensive salt panne. I also found that CH₄ flux is similar between my dead zones and *S. alterniflorus* zones.

I found my mean CH₄ fluxes were not insignificant to the GWP of *S. alterniflorus* zones and dead zones. The CO₂e of my mean CH₄ flux ($0.01899 \pm 0.3709 \text{ mg}^1\text{m}^{-2}\text{hr}^{-1}$) would be between 24 to 30 mg of CO₂e¹m⁻²hr⁻¹ over a 100 year period and between 81 and 96 mg of CO₂e¹m⁻²hr⁻¹ over a 20 year period.

I also identified that *S. alterniflorus* zones in southern Gulf of St. Lawrence saltmarshes transition into a state of net CO₂ efflux in late summer and early autumn. In fact, the net daily CO₂ flux from my late summer and early autumn *S. alterniflorus* zones

was very similar to my dead zones, which were never measured with standing vegetation. This is concerning in the context of warmer autumns in northern Nova Scotia (Garbary and Hill, 2021).

Further studies of GHG fluxes from southern Gulf of St. Lawrence saltmarshes should be done, to challenge, verify, and add to my findings here.

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Appendices

Appendix A – Field-Book Observational Notes

July 12, 2023 – Boy Scout Beach

- Before sampling, the Axetris was reading unusual CH₄ concentrations (i.e. -6ppm... - 0.547ppm, 7.643ppm, etc.). After disconnecting the inlet tube just before the sensor & running it for a few minutes, readings returned to acceptable values (1.76 to 1.85 ppm).
 - o After consideration, I think the Axetris probably needed to warm up.
- Zones are not wholly one species. In a *Juncus spp. (gerardii?)* zone, *Argentina spp. (egedei?)* is present. In *Sporobolus pumilus* zones, *Sporobolus alterniflorus* is present, and vice versa. There are also transitional areas where the cover of *S. alterniflorus* and *S. pumilus* are roughly the same (between 40% to 60% cover from each species).
- Near the lower margin of the marsh, a band of black, brown, & sometimes green “seagrass” lays during low tide.
- Fog had burned by 15:23, but cloud cover was then around 90%.
- Most dead zones in this marsh are not simply like mudflats, but often have pools of water, sometimes shallow, sometimes a few feet deep.
- *S. alterniflorus* is easily broken by stepping on it, I’m going to try to step in the same spots or use other methods to avoid unnecessary harm to the plants.
- The marsh edge seems to be almost fracturing in some areas.
- Stepping on the brown mud dead zones seems to surface a black sediment from below.
- David viewed the Captain’s Pond Inlet saltmarsh as ‘less healthy’ than the Boy Scout Beach saltmarsh, which has more complex zone shapes & less dead zone, proportionally.
- This marsh is on the shore side of Boy Scout Beach dune system.
- The literature mentions tall & short *S. alterniflorus*. I have not noticed group differences in zones, but only individual shoots being much taller than those around them.
- Channels are present, although shallower than those in the Chéticamp saltmarshes.
- Here, *S. alterniflorus* shoots are near 60cm tall now, some taller though, near 90 cm.
- It is 17:07 and the tide doesn’t seem much higher than when I got here at 14:27. David mentioned wind was a significant factor in the tides here.
- The margin here, and at all the marshes I have visited, has had a relatively steep slope compared to the gradual slope of the low- and middle-marsh.

July 26, 2023 – Captain’s Pond Inlet

- I’m noticing many more cordgrass shoots that are signifying taller than the others.
- In this saltmarsh, dead zones are mostly near the lower margin and the slope is seemingly more uniform. If dead zone formation relates to elevation, this make sense.
- Limited salt pannes are extensively used by flies & other insects.
- The erosion of dead zones makes a structurally non-uniform form. See photos. This increases erosional potential as it enables entire mats to break off.
- The *S. pumilus* zone is thin here, *S. alterniflorus* and *Juncus* zones dominate.
- It is now 15:44 & I have seen the tide is now again at a similar height to when I arrived.

July 27, 2023 – Boy Scout Beach

- *S. alterniflorus* zones here have shoots 1m tall. Why are they taller here than at Captain’s Pond Inlet? Are these the tall form *S. alterniflorus*? There are shorter ones here too.

- That pink bacterium David mentioned is evident in limited salt pannes and pools.
- The dead zones here are different than those at Captain's Pond Inlet. First, these dead zones are not mostly near the lower margin, they are relatively internal to the marsh. Second, the algae mats in this dead zone are different and thicker.

July 28, 2023 – Captain's Pond Inlet

- Between the 1st and 2nd measures the CH₄ concentration readings were implausible. After some time the CH₄ returned to an acceptable level, but still high for normal.
- 1 hour past Antigonish Harbour's low tide, the tide was just past the dead lower margin.
- The path of saltmarsh vegetation I've used doesn't seem to tolerate repeated trampling.
- Clipping with these clippers was a little difficult, use different ones.
- Is the mean high of dead zone/sparse zone cordgrass shorter than dense zone?
- Near the lower margin, the *S. alterniflorus* shoots are more punctuated. Is this due to colonization speed, erosion, stress?
- Walking in here there is a flattened patch, perhaps by an ATV, a bear, or deer.

August 1, 2023 – Chéticamp Mainland

- The extensive salt panne here is quite large. Between the lower margin and the extensive salt panne is a dense *S. alterniflorus* zone; 5.3m, 8.1m, 7.7m in some places.
- This marsh also a steep drop off into the water at the lower margin
- A purple flower (*Limonium carolinianum*) is all over the marsh here as well as at CPI.
- This extensive salt panne is punctuated with small patches of *S. pumilus*, sometimes on raised peat mats and dotted with *L. carolinianum*.
- This marsh has some deep and wide draining channels.
- The dead lower margin appears to be fracturing often here.
- The extensive salt pannes was 30.0m, 28.3m, 26.0m, and 28.0m wide in some places.
- I saw what appeared to be a dark, eel-like fish in the water below the lower margin.
- In other parts of this marsh, limited salt pannes punctuate the *S. pumilus* meadow.
- The pink bacterium is in the extensive salt panne, limited salt panes, and pools here.
- A lot of peat mats seem to have washed up here and have been colonized by plants.
- The marsh drains in stream systems, like watersheds.
- Increased drainage concentration may increase erosional power by concentrating volume and increasing velocity of water as it drains at low tide, carrying sediment out.
- There is a white bacterium on much of the organic matter in the draining streams.
- Mats of algae can be found around the marsh, very obviously in the dead zones.
- At this marsh's northern edge, *S. alterniflorus* is much shorter at the margin.
- The dead lower margin fractures more near the north edge, until a rocky corner is met.

August 2, 2023 – Chéticamp site 1

- This marsh's shape seems more complex than the Antigonish Harbour saltmarshes.
- Dead zones are prevalent here between *S. alterniflorus* *S. pumilus* zones.
- The dead zone here is not bare, *L. carolinianum* and *Salicornia virginica* are here, and have greater density in dead zones than in vegetated zones.
- Rocks are in groups or piles here. Perhaps birds, storms or people are responsible.
- The dead zones don't have a uniform colour here like at others. Blacks, dark and light browns form a mosaic on the soil surface.

- This lower margin's drop-off into the water more gradually than at other saltmarshes.
- A culvert at the upper margin feeds a relatively deep stream, cutting through the peat:
 - o I measured 10ppt, 8ppt, and 6ppt salinity from the mouth of the stream to the culvert. 23ppt was the salinity where it met the north pool.
- Many eroded portions of this marsh have subsurface streams.
- The sediment in streams is very compressible. Stepping in, I sank halfway up my boot.
- A stringy green alga is very prevalent at this marsh.
- A tree's root networks were evident in the low marsh, perhaps uncovered by erosion.
- A more northern culvert feeds another stream surrounded by an unidentified grass.
- An extensive salt panne here host dense of *L. carolinianum* and *Salicornia virginica*.
- This marsh has a sort of small bay that it drains into, this was likely mostly marsh less than a few decades ago according to Gretchen.
- The southern edge of the marsh ends by changing into a rocky shore, Gretchen says this area used to be marsh too, but it has died and eroded away. It is now a mussel bed.
- A different grass is all over the high marsh, and it is not *Sporobolus michauxianus*.

August 3, 2023 – Chéticamp site 2

- Some of the extensive salt panne here resembles the extensive salt panne at the Chéticamp Island saltmarsh more than other parts of itself. Have these different looking areas of extensive salt panne been a part of the extensive salt panne for different amounts of time?
 - o David mentioned that after extensive salt pannes are created by disturbance, like freezing and lifting, they will begin to progress through succession. It begins mostly bare, then it is colonized by *Salicornia virginica*, an annual, and *L. carolinianum*, a perennial. Then, based on the tidal zone a grass will move in, be it *S. alterniflorus*, *S. pumilus*, or *D. spicata*. David says though that that is under normal circumstances.
 - o From what Haley has told me, the growth of extensive salt pannes has increased on in the last couple of years. David's guess as to why the mudflats are increasing so rapidly is that the grasses that would occupy these areas are being drowned because they are spending longer periods underwater. This relates to climate change, by rapid sea level rise. This would explain why the slightly elevated band of *S. alterniflorus* at this saltmarsh's lower margin survives and is even relatively dense. David says that it is important for us to have data on the elevation gradient of the marsh to support this.
- The watershed of a saltmarsh appears much like that of a typical river system. Small streams meet, join, and grow on their way to emptying into a basin.
- Subsurface flow can take the form of streams which carve tunnels under the surface.
- Holes inside the marsh become pools, which may be inhabited by crabs and fish, even when isolated by low tide. Algae will often grow here as well as that pink bacterium.
- *S. alterniflorus* is as tall as 80cm in some places here but is shorter near the lower margin around 50cm.

Appendix B – Benchmarking Record

Date (yyyy-mm-dd)	Benchmarking Method	Inflow Rate (L/min)	Outflow Rate (L/min)	CO ₂ Offset (in ppm)	CH ₄ Offset (in ppm)
2023-07-24	Tedlar Bags	2.0	2.0	0.5801	-142.9
2023-08-01	Tedlar Bags	2.2	2.2	0.08609	37.76
2023-08-16	Tedlar Bags	2.3	2.3	0.2781	40.30
2023-08-23	Tedlar Bags	2.2	2.3	0.2441	-12.36

Appendix B Table. A table showing the results of four benchmarking tests carried out on a user-made, portable gas concentration analyzer, the Soil Air Nature Description Instrument (SANDI), during a 2023 summer field season. The SANDI was benchmarked on four occasions. Benchmarking involved checking the inflow and outflow rates and the offset of the gas analyzers. I checked the inflow and outflow rates using an Aalborg GFM mass flow meter (2022) on the inlet and outlet tubes, respectively. Over time, laser-based gas analysers, such as the Vaisala CARBOCAP® Carbon Dioxide Probe GMP343 and Axetris Laser Gas Detection (LGD) Compact-A CH₄ sensors I used, change in accuracy. The difference between the sensor accuracy and the true concentration on the gas it is sensing for, is called the offset. The offset was calculated by finding the mean CO₂ and CH₄ concentrations of approximately 4L of a gas s

Appendix C – Measurements and Environmental Conditions of Measurements

Measurement ID	Date	Site	Zone	Chamber size	Chamber type	Compression (kg/cm2)	Salinity (in ppt)	Air Temp Estimate (in K)	Air Pressure Estimate (in kPa)	Cloud Coverage	Cloudgrass Rough Height	CH ₄ flux (in g/m2hr)	CO ₂ flux (in g/m2hr)	Mean Temp (in C)
20230616_CH2_01	2023-06-16	CH2	LSP	Small	Dark	NA	NA	284.5	100.56	100%	N/A	4.31E-05	1.26E-02	18.31
20230616_CH2_02	2023-06-16	CH2	Sa	Small	Dark	NA	NA	284.5	100.56	100%	very short	8.86E-06	5.38E-01	16.77
20230616_CH2_03	2023-06-16	CH2	Sa	Small	Dark	NA	NA	285.6	100.57	100%	very short	9.59E-05	7.43E-01	17.20
20230616_CH2_04	2023-06-16	CH2	Sa	Small	Light	NA	NA	285.6	100.57	100%	very short	6.26E-05	-1.67E-01	17.34
20230629_BSB_01	2023-06-29	BSB	Sa	Small	Dark	NA	NA	297.1	101.57	25%	short	-1.32E-04	7.64E-01	20.43
20230629_BSB_02	2023-06-29	BSB	Sa	Small	Light	NA	NA	297.0	101.58	25%	short	1.09E-04	-4.27E-01	20.39
20230629_BSB_03	2023-06-29	BSB	DLM	Small	Dark	NA	NA	297.0	101.58	25%	N/A	1.44E-04	2.71E-01	23.09
20230629_BSB_04	2023-06-29	BSB	DLM	Small	Light	NA	NA	295.6	101.59	25%	N/A	-7.53E-05	-1.03E-01	23.19
20230629_BSB_05	2023-06-29	BSB	Sa	Small	Dark	NA	NA	295.6	101.59	25%	short	4.06E-05	1.86E+00	23.96
20230629_BSB_06	2023-06-29	BSB	Sa	Small	Light	NA	NA	294.6	101.57	25%	short	1.38E-04	4.44E-01	20.62
20230711_BSB_01	2023-07-11	BSB	Sa	Small	Dark	0.094	27	289.1	100.63	100%	medium	4.18E-05	5.08E-01	20.64
20230711_BSB_02	2023-07-11	BSB	Sa	Small	Light	0.094	26	289.9	100.61	100%	medium	7.83E-04	-2.18E-01	20.67
20230711_CPI_01	2023-07-11	CPI	Sa	Small	Dark	NA	30	289.0	100.69	100%	short	1.88E-04	6.27E-01	20.03
20230711_CPI_02	2023-07-11	CPI	Sa	Small	Light	NA	30	289.0	100.69	100%	short	-7.97E-05	-3.14E-01	20.12
20230711_CPI_03	2023-07-11	CPI	DLM	Small	Dark	NA	33	289.0	100.69	100%	N/A	9.50E-05	-2.35E-02	21.32
20230711_CPI_04	2023-07-11	CPI	DLM	Small	Light	NA	34	289.0	100.66	100%	N/A	1.40E-05	-5.31E-02	21.34
20230712_BSB_01	2023-07-12	BSB	Sa	Small	Dark	0.063	14	294.6	100.63	40%	medium	6.29E-05	1.12E+00	19.25
20230712_BSB_02	2023-07-12	BSB	Sa	Small	Light	0.063	15	294.6	100.63	65%	medium	5.30E-05	-1.97E-01	19.14
20230712_BSB_03	2023-07-12	BSB	Sa	Small	Dark	0.188	10	296.5	100.59	90%	medium	4.85E-05	1.48E+00	20.71
20230712_BSB_06	2023-07-12	BSB	Sa	Small	Light	0.188	10	296.5	100.59	90%	medium	4.57E-05	-1.64E-01	20.93
20230726_CPI_01	2023-07-26	CPI	Sa	Small	Dark	0.156	20	296.2	100.81	0%	medium	4.95E-03	2.05E+00	25.50
20230726_CPI_02	2023-07-26	CPI	Sa	Small	Light	0.156	17	296.2	100.81	0%	medium	2.24E-04	1.34E+00	25.79
20230726_CPI_03	2023-07-26	CPI	Sa	Small	Dark	0.109	15	296.2	100.81	0%	medium	1.29E-04	2.48E+00	25.50
20230726_CPI_04	2023-07-26	CPI	Sa	Small	Light	0.109	16	296.6	100.76	0%	medium	1.25E-04	1.15E+00	25.79
20230726_CPI_05	2023-07-26	CPI	LSP	Small	Dark	0.078	16	296.6	100.76	0%	N/A	1.40E-04	9.35E-01	26.43
20230726_CPI_06	2023-07-26	CPI	LSP	Small	Light	0.078	15	298.3	100.70	0%	N/A	1.65E-05	-2.44E-02	26.90
20230726_CPI_07	2023-07-26	CPI	LSP	Small	Dark	0.203	14	298.3	100.70	0%	N/A	5.39E-05	1.93E-01	29.03
20230726_CPI_08	2023-07-26	CPI	LSP	Small	Light	0.203	14	299.4	100.68	0%	N/A	7.03E-05	4.55E-02	29.36
20230727_BSB_01	2023-07-27	BSB	LSP	Small	Dark	0.156	20	299.8	100.53	65%	N/A	4.15E-05	3.38E-02	27.42
20230727_BSB_02	2023-07-27	BSB	LSP	Small	Light	0.156	23	299.8	100.53	65%	N/A	-4.95E-05	-3.17E-02	27.42
20230727_BSB_03	2023-07-27	BSB	LSP	Small	Dark	0.203	24	298.7	100.48	65%	N/A	-1.11E-05	4.06E-02	26.61
20230727_BSB_04	2023-07-27	BSB	LSP	Small	Light	0.203	20	298.7	100.48	65%	N/A	3.85E-05	-3.42E-02	26.49
20230728_CPI_01	2023-07-28	CPI	Sa	Small	Dark	0.156	13	295.6	100.31	30%	medium	1.40E-02	1.92E+00	23.04
20230728_CPI_02	2023-07-28	CPI	Sa	Small	Light	0.156	10	295.6	100.31	30%	medium	2.13E-04	3.84E-01	23.04
20230801_CH2_01	2023-08-01	CH2	Sa	Small	Dark	0.094	30	296.0	101.34	30%	medium	1.81E-04	2.14E+00	26.08
20230801_CH2_02	2023-08-01	CH2	Sa	Small	Light	0.094	30	296.0	101.34	30%	medium	1.65E-04	-1.30E-01	26.14
20230801_CH2_03	2023-08-01	CH2	Sa	Small	Dark	0.188	29	294.8	101.35	30%	medium	1.66E-04	1.26E+00	25.14
20230801_CH2_04	2023-08-01	CH2	Sa	Small	Light	0.188	30	294.8	101.35	30%	medium	2.40E-04	-2.48E-01	25.29
20230801_CH2_05	2023-08-01	CH2	ESP	Small	Dark	0.047	30	294.8	101.35	30%	miniscule	-1.77E-04	2.90E-01	25.42
20230801_CH2_06	2023-08-01	CH2	ESP	Small	Light	0.047	30	293.4	101.40	30%	miniscule	4.97E-05	1.98E-01	25.29
20230801_CH2_07	2023-08-01	CH2	ESP	Small	Dark	0.047	30	293.4	101.40	30%	N/A	5.18E-05	6.25E-02	25.10
20230801_CH2_08	2023-08-01	CH2	ESP	Small	Light	0.047	29	292.2	101.44	30%	N/A	-8.57E-05	-5.20E-02	24.92
20230802_CH1_01	2023-08-02	CH1	DLM	Small	Dark	0.219	29	295.3	101.69	20%	N/A	1.35E-04	8.71E-02	24.31
20230802_CH1_02	2023-08-02	CH1	DLM	Small	Light	0.219	29	295.3	101.69	20%	N/A	-4.33E-05	-2.14E-01	24.31
20230802_CH1_03	2023-08-02	CH1	Sa	Small	Dark	0.250	25	295.1	101.68	20%	Small	6.23E-05	1.41E+00	24.31
20230802_CH1_04	2023-08-02	CH1	Sa	Small	Light	0.250	25	295.1	101.68	20%	Small	1.21E-04	-1.49E-01	24.31
20230802_CH1_05	2023-08-02	CH1	DLM	Small	Dark	0.250	28	294.4	101.68	20%	N/A	5.15E-05	6.50E-02	26.00
20230802_CH1_06	2023-08-02	CH1	DLM	Small	Light	0.250	27	294.4	101.68	20%	N/A	1.37E-05	-1.83E-01	25.77
20230802_CH1_07	2023-08-02	CH1	Sa	Small	Dark	0.400	27	294.4	101.68	20%	medium	1.51E-04	9.73E-01	24.31
20230802_CH1_08	2023-08-02	CH1	Sa	Small	Light	0.400	27	293.1	101.72	20%	medium	1.28E-04	-6.69E-02	24.31
20230803_CH2_01	2023-08-03	CH2	Sa	Small	Dark	0.234	27	295.9	101.84	0%	large	8.22E-05	1.91E+00	25.83
20230803_CH2_02	2023-08-03	CH2	Sa	Small	Light	0.234	27	295.9	101.84	0%	large	5.77E-05	9.72E-01	25.94
20230803_CH2_05	2023-08-03	CH2	Sa	Small	Dark	0.266	27	295.3	101.84	0%	Large	1.58E-04	7.80E-01	25.83
20230803_CH2_06	2023-08-03	CH2	Sa	Small	Dark	0.266	26	295.1	101.81	0%	Large	4.58E-04	2.94E+00	25.94
20230817_CH1_01	2023-08-17	CH1	Sa	Large	Dark	0.203	24	293.9	101.85	40%	Large	-6.94E-05	1.55E+00	24.29
20230817_CH1_02	2023-08-17	CH1	Sa	Large	Light	0.203	24	295.5	101.84	40%	Large	-1.37E-03	-2.83E+00	25.77
20230817_CH1_05	2023-08-17	CH1	Sa	Large	Light	0.172	22	294.8	101.80	50%	Large	3.77E-04	1.81E-01	23.42
20230817_CH1_06	2023-08-17	CH1	Sa	Large	Light	0.172	24	293.8	101.80	60%	Large	-2.30E-03	-2.34E-01	21.51
20230817_CH1_07	2023-08-17	CH1	Sa	Large	Dark	0.172	25	293.8	101.80	60%	Large	3.72E-04	2.14E+00	21.15
20230818_CH2_01	2023-08-18	CH2	Sa	Large	Dark	0.156	26	295.8	101.09	100%	Large	-1.72E-04	7.65E-01	20.89
20230818_CH2_02	2023-08-18	CH2	Sa	Large	Light	0.156	26	295.8	101.06	100%	Large	1.34E-03	-2.08E+00	21.01
20230818_CH2_03	2023-08-18	CH2	ESP	Large	Dark	0.094	27	295.8	101.06	100%	N/A	-3.57E-04	-1.25E-01	20.82
20230818_CH2_04	2023-08-18	CH2	ESP	Large	Dark	0.094	27	295.8	101.02	100%	N/A	-8.23E-05	2.52E-02	20.89
20230818_CH2_05	2023-08-18	CH2	ESP	Large	Light	0.094	27	295.8	101.02	100%	N/A	3.96E-05	1.17E-03	20.93
20230824_JQ_01	2023-08-24	JQ	DLM	Large	Dark	0.750	23	292.9	101.11	10%	N/A	-4.37E-04	2.26E-01	20.03
20230824_JQ_02	2023-08-24	JQ	DLM	Large	Light	0.750	26	293.2	101.11	10%	N/A	-5.08E-04	7.19E-02	20.22
20230824_JQ_03	2023-08-24	JQ	DLM	Large	Light	1.500	25	293.2	101.11	10%	short shor	2.71E-04	-4.56E-01	19.40
20230824_JQ_04	2023-08-24	JQ	DLM	Large	Light	1.500	25	293.2	101.11	10%	short shor	3.24E-04	-4.96E-01	19.54
20230824_JQ_05	2023-08-24	JQ	DLM	Large	Dark	1.500	25	293.4	101.12	10%	short shor	-1.24E-04	3.94E-01	19.72
20230824_JQ_06	2023-08-24	JQ	LSP	Large	Dark	0.141	20	293.4	101.12	10%	N/A	-3.02E-04	8.49E-01	19.07
20230824_JQ_07	2023-08-24	JQ	LSP	Large	Dark	0.141	22	293.5	101.13	10%	N/A	1.76E-04	7.05E-01	19.13
20230824_JQ_08	2023-08-24	JQ	LSP	Large	Light	0.141	23	293.5	101.13	10%	N/A	6.70E-04	8.45E-01	19.34
20230824_JQ_09	2023-08-24	JQ	Sa	Large	Light	0.156	24	293.7	101.13	10%	medium	3.50E-04	-4.24E-01	19.90
20230824_JQ_10	2023-08-24	JQ	Sa	Large	Dark	0.156	25	293.7	101.14	10%	medium	3.32E-04	1.29E+00	20.11
20230825_JQ_01	2023-08-25	JQ	LSP	Large	Light	0.078	24	294.2	101.43	20%	N/A	-1.46E-04	-3.24E-02	19.38
20230825_JQ_02	2023-08-25	JQ	LSP	Large	Dark	0.078	23	294.2	101.43	20%	N/A	2.25E-04	3.13E-02	19.07
20230825_JQ_03	2023-08-25	JQ	Sa	Large	Light	0.203	24	294.2	101.43	20%	medium	1.64E-04	-1.41E-01	19.38
20230825_JQ_04	2023-08-25	JQ	Sa	Large	Light	0.203	23	293.6	101.38	20%	medium	1.18E-04	-2.81E-01	19.63
20230825_JQ_05	2023-08-25	JQ	Sa	Large	Dark	0.203	23	293.6	101.38	20%	medium	2.83E-05	1.11E+00	19.85
20230825_JQ_06	2023-08-25	JQ	LSP	Large	Light	0.094	23	293.9	101.37	20%	N/A	6.95E-05	1.60E-01	19.33
20230825_JQ_07	2023-08-25	JQ	LSP	Large	Light	0.094	23	294.2	101.36	20%	N/A	1.10E-04	1.89E-01	19.65
20230825_JQ_08	2023-08-25	JQ	LSP											

