# RUNNING TIDE TECHNOLOGIES OCEAN CDR: CATALOG OF POTENTIAL ENVIRONMENTAL EXPOSURES

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# PART 1 – PURPOSE & METHODS

## 1.1 LONG TERM CARBON REMOVAL DEVELOPMENT GOAL

Running Tide develops technology focused on making positive interventions for restoring ocean health. Our Ocean Carbon Dioxide Removal (CDR) Platform is meant to operationalize several CDR pathways. The purpose of this document is to provide an overarching review of potential environmental exposures that may arise from our proposed carbon removal methodology. This review will then be used on a project specific basis to perform an environmental impact assessment. Notably, the analysis in this document is tightly coupled to the specific architecture of Running Tide's system.

Mechanistically and operationally, the platform functions via the placement of passive drifting and floating organic material (hereafter, "**carbon buoys**") from an offshore vessel into open ocean currents. The carbon buoys are designed to passively float for a designated period of time at the ocean's surface, continuing to disperse and drift over their floating period, after which they will lose buoyancy and sink rapidly (over a period of hours) to the ocean floor.

### 1.1.1 CARBON BUOY FAQS

**What is a carbon buoy?** A carbon buoy is terrestrial biomass – typically dry wood or other organic biomass – either unbound or bound into an aggregate object that will temporarily float, and which can carry a payload into the ocean. The buoys may range from golf ball to basketball-sized objects in a variety of form factors such as spherical or cylindrical ("puck shaped") objects. Running Tide currently uses woody residues sourced from sawmills and wildfire-suppression-clearing wastes. Carbon buoys are bound and/or coated with a cementitious (alkaline mineral-based) binder or via the growth of a mycelium network which is later sterilized. Macroalgae starting material may then be bound to the carbon buoy exterior.

**How do carbon buoys spread throughout the ocean?** A population of carbon buoys is placed into a region of the ocean, typically far ( ~100s of miles) away from shore. Once floating in the water, the carbon buoys will move completely passively. They will drift in currents, but do not have their own means of propulsion and will not be touched again by human hands or machinery. Placement locations are chosen such that the population of carbon buoys will disperse over large regions (100s of sq km) of ocean basins. When they lose buoyancy and sink, they will similarly come to rest over a large region of the abyssal plain. The goal of this design is to dilute the spatial density of carbon buoys and minimize acute interaction between the carbon buoys and the ocean biochemistry or ecology.

**How do carbon buoys change buoyancy?** Carbon buoys float because of the buoyant property of dry wood, and also because the cementitious binder is formed to enclose air pockets during the curing process (as in so-called "aircrete"). Once in an ocean environment, seawater and turbulent motion causes the erosion of the cementitious binder and exposes the woody material to the intrusion of water. Once a carbon buoy's buoyancy flips from positive to negative, the progressive loss of buoyancy proceeds rapidly and is accelerated with depth by the compressibility of carbon buoy material.

**How many carbon buoys will be deployed at once?** Since carbon buoys will vary in size from golf ball- to basketball-sized objects, Running Tide measures deployment scales by the total mass of carbon buoy materials rather than the number of individual carbon buoys. Carbon buoy size will determine floating duration, and will be chosen to suit the dispersion characteristics of an individual ocean basin. Running Tide's initial deployments will be small in mass (1000s of tons of material) and small in individual size (targeting floating duration of ~ 10-30 days). Nonetheless, one can safely estimate that an individual deployment may contain many millions of individual carbon buoys.

**How will Running Tide monitor, measure, and quantify the motion of carbon buoys and the carbon removal process?** Running Tide develops an integrated program of ocean modeling, laboratory validation, and open ocean in-situ sensing in order to characterize our carbon removal interventions. This quantification program also supports the verification ("MRV") of carbon removal credits. A full exposition of Running Tide's quantification and verification approach is outside the scope of this document.

### 1.1.2 CARBON REMOVAL OBJECTIVES

How does the placement of carbon buoys in the ocean achieve carbon dioxide removal? Carbon Removal is the net movement of carbon from the fast carbon cycle to the slow carbon cycle on a fully accounted supply chain basis. Running Tide's ultimate goal is to provide a platform to amplify several adjacent natural pathways for carbon removal to the deep sea, including:

**Ocean Transport Amplification**: The carbon buoys are synthesized from organic material of natural origin, including carbon-rich forestry and agricultural residue materials. Strategic and targeted removal of this biomass from terrestrial systems amplifies the carbon drawdown of forestry and other land-use projects. Use of this material in our carbon buoys results in the transfer of this material to the deep ocean, amplifying a substantial natural pathway removing carbon from ready flux within the fast carbon cycle.

**Open Ocean Macroalgae Growth**: While floating in the photic zone, the carbon buoys act as a growth substrate for macroalgae. We explore both preparing the flotation with macroalgae starting material as well as allowing the flotation to be passively colonized by macroalgae already in the water. When macroalgae perform photosynthetic carbon fixation, it removes carbon from the surface ocean and perturbs the equilibrium state of the carbonate system in the seawater. This induces carbon dioxide flux into the seawater which later mixes down into the deep ocean. The non-buoyant species of macroalgae sink intact to the sea floor, transporting the carbon fixed into their biomass to durable storage.

**Ocean Alkalinity Enhancement**: The carbon buoys contain an alkaline payload which, when introduced to surface waters, amplifies the transfer of atmospheric carbon dioxide to the durable reservoir of dissolved marine bicarbonate. This procedure is commonly known as ocean alkalinity enhancement (OAE). Ultimately, the contribution of alkalinity enhancement will be smaller than that of the other pathways enabled by our platform, but Running Tide's approach is to find ways to squeeze every ton of carbon out of our system.

See Running Tide's research roadmap and the Framework Protocol for open ocean carbon removal for a more thorough exposition of the topics in this section.

## 1.2 METHODOLOGY OF THIS DOCUMENT

### 1.2.1 METHOD OF CATALOGING EXPOSURES

There exists a multitude of exposures that may impact the physical, chemical, and/or biological characteristics of the ocean system. These exposures are considered for their potentially negative impact on an ecosystem, organism, environment, or service.

Running Tide has compiled this catalog of environmental exposures through a variety of methods. We have participated in formal engagements, such as an advisory and evaluation panel convened by Ocean Visions, and consultancies with individual scientists. We have conducted reviews of published literature, and performed direct analysis within our own scientific teams. We have engaged in additional informal reviews with external researchers.

### 1.2.2 METHOD OF CLASSIFYING EXPOSURES

The intent in classifying these exposures is to create a framework within which specific projects may be assessed for environmental risks on the basis of project details such as site, complexity, and scale. The goal of classification within this document is to assess how a potential exposure may lead to an environmental impact or produce environmental harm, as well as provide guidance on how to determine the risk associated with that impact of harm.

Within the climate mitigation community, the Precautionary Principle is often cited as a foundational tenet against which climate intervention measures might be evaluated. The formulation of this principle in the United Nations' Rio Declaration stipulates "Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation." Ocean-based carbon dioxide removal is both a mitigation measure, as well as a context within which “full scientific certainty” will never be achieved. It is in this spirit that we proceed: in cataloging we endeavor for broad inclusion of potential exposures; in classifying we evaluate for credible empirical evidence of risk.

Exposure classification is primarily the work of Running Tide’s internal scientific teams. Once compiled, this document will be reviewed by our scientific advisory board and external partners. Pending that review, it will be posted on our website for additional transparency.

## 1.3 CLASSIFICATION OF EXPOSURES

Exposure classification is meant to be a foundation from which project-specific impact assessments will be derived. Notably, there are a variety of ways to classify exposures and this represents just one method; however, improved governance mechanisms will be required for consensus within the industry. We classify exposures according to confidence, scale, and risk, as outlined below.

### 1.3.1 EXPOSURE CONFIDENCE

We evaluate exposures on the basis of the underlying knowledge which motivates their consideration.

- **Speculative** exposures are hypothetical in nature and are either proposed as exposures by our own teams or mentioned as a possibility in the literature. Speculative exposures are not supported by substantial rigorous analysis, consensus, or relevant empirical evidence.
- **Substantiated** exposures are either presented with supporting evidence and/or analysis in multiple peer-reviewed publications or identified by governing bodies in governmental publications. Substantiated exposures do not yet have consensus, and there may be some publications and bodies of work that offer alternative hypotheses or results.
- **Consensus** exposures are strongly supported with empirical evidence, rigorous analyses, and widely accepted as an exposure across researchers, governmental agencies, and industry.

### 1.3.2 EXPOSURE RISK DETERMINATION BASIS

We classify exposures on the basis of the consideration or parameter which governs our determination of the risk, significance, or severity of environmental harm.

The risk of environmental harm may depend on **system architecture**, meaning that considerations related to the synthesis of carbon buoys, placement of carbon buoys into the ocean, or selection of the placement region will determine risk assessment regardless of the scale of the proposed activity. This includes architectural choices around size and mass of buoys.

The risk of environmental harm may depend on the **scale** of a proposed project. Given Running Tide's system architecture, there may be different parameterizations of scale relevant to the exposure under consideration. In general, scale magnitude will be evaluated against some set of properties of the project site or region. We identify these parameterizations here:

- **Absolute mass**: the total amount of carbon removal materials placed at the site, the total amount of cultivated macroalgae, or the total amount of material that reaches some defined region of the ocean (e.g. the sea floor).
- **Spatial extent**: exposures may become significant at a certain threshold in space such as mesoscale, basin scale (at either the ocean surface or sea floor), or at either regional or even global extent of projects or a collection of projects.
- **Spatial density**: the ratio of absolute mass to spatial extent, or the likelihood of encountering carbon buoy-associated materials, chemicals, or metabolites per unit area.
- **Temporal persistence**: exposures will likely have different impacts based on the temporal variation in the environmental region of interest (e.g., exposure time from carbon buoys in the surface ocean will be lower than that of sunken material on the seafloor, and lower still in the midwater column). This parameter also considers any lag between forcing and response within the ecological system.
- **Intensity**: The significance of exposures will be determined by the flux concentration of carbon removal materials (**x mass/area/time**).

# PART 2 – EXPOSURES & EFFECTS

In this analysis, we examine the processes and pathways through which carbon buoy deployment may adversely impact the marine environment, and the effects of these potential exposures.

## 2.1 PELAGIC ECOLOGY

Carbon buoys will reside at the surface ocean during the time that they drift and disperse. While generally confined to the upper ~ 1 m of the water column, they may oscillate within the upper ~ 10 m during turbulent conditions. Upon changing buoyancy, the carbon buoys will migrate through the midwater column quickly (within a matter of hours). Perturbations to the midwater region of the ocean will therefore not arise directly from the presence of carbon buoys themselves, but from any biochemical perturbation to the surface waters which propagates down to this region.

In this section we consider exposures to the surface ocean arising from the physical presence of carbon buoys, as well as exposures to the surface and midwater ocean arising from biochemical changes associated with our carbon removal methodology.

### 2.1.1 SHADING OF INCIDENT LIGHT

Floating carbon buoys in the pelagic environment may result in water column shading, leading to obstruction of light for phytoplankton in the surface ocean[1]. Light limitation would lead to a decrease in phytoplankton photosynthesis in near-surface waters as well as a potential shift in the ecological functioning of a region in the water column known as the deep chlorophyll maximum, a niche community set by light availability and nutrient concentrations[2]. A potential decrease in light availability could result in a community shift, allowing low-light tolerant phytoplankton to proliferate and become more prevalent. A change in phytoplankton community composition could alter the biogeochemistry in the surface ocean, thus impacting remineralization rates and carbon export to the benthos. Shifts in the primary producer community could furthermore start a cascade of community composition changes up through the pelagic trophic levels[3,4]. In addition, other non-photosynthetic organisms, such as other plankton and fish, migrate and modify behaviors in response to changes to light levels[5]. Therefore, shading may also impact other ecologically important processes such as diel vertical migrations.

The effects of shading are determined by the fraction and spectrum of incident light that is attenuated, and the duration for which this attenuation persists.

| Running Tide Classification | |
|---|---|
| Consensus | Light availability is an intuitive and broadly understood limitation in all primary producing ecosystems. |
| Risk determined by scale | Risk determination should be made on the basis of the **intensity** of carbon buoy surface |

| Running Tide Classification | |
|---|---|
| | area coverage relative to baseline intensity of Net Primary Production (NPP). |
| Mitigation measures | Shading effects can be largely mitigated by system architecture. The small form factor of carbon buoys and dispersion during floating both minimize the intensity of coverage. Operational considerations may also be used to mitigate shading impacts such as spatially and temporally staggering buoy deployments. |

### 2.1.2 DIRECT INTRODUCTION OF INVASIVE SPECIES

The introduction of living organisms to any ecosystem generally creates a risk for novel colonization (e.g. invasion) of those species to the region. Carbon buoys will introduce any macroalgae with which they have been seeded, along with microorganisms which colonize the macroalgae, to the open ocean environment. To the extent that macroalgae may reach sexual maturity while growing on carbon buoys, the risk of invasion will be based on the potential range through which this reproductive material may spread. This may increase the range of potential colonization beyond the areas that are directly visited by carbon buoys.

Here we consider the risk of persistent colonization of novel organisms (e.g. which continues after the carbon buoy life cycle has expired). This is because the presence of the directly introduced species (macroalgae and their microbiome) in the pelagic zone during the carbon buoy lifecycle is the deliberate intention of Running Tide's carbon removal program.

Non-buoyant species of macroalgae have no known mechanism to independently colonize the pelagic zone of the open ocean. Running Tide thereby sustains their growth through the provision of floating substrates (carbon buoys) which are designed to eventually become waterlogged and sink.

The macroalgal microbiome is understood to be distinct from that of surrounding ambient water[6]. This microbiome has also been observed to be more similar on conspecific algae from different geographic origins than to other algal species from the same environment[7], in keeping with the precept of microbiology that "everything is everywhere and the environment selects.[8]"

| Running Tide Classification | |
|---|---|
| Speculative (macroalgae, open ocean) | Non-buoyant species of macroalgae are not likely to persist beyond the deliberate lifecycle governed by the presence of carbon buoys. |
| Consensus (macroalgae, regional coasts) | Beaching events and the spread of reproductive material could bring macroalgae in contact with novel coastal habitats. |
| Speculative (microbiome, open ocean) | Carbon buoy associated microbes are distinct from the ambient water and not likely to independently colonize pelagic surface waters. |
| Speculative (microbiome, regional coasts) | Since microbiome composition is governed by phylogeny instead of location, it is not likely that the mechanical introduction of microbes to a region where they are not already abundant will cause novel colonization. |
| Risk determined by architecture | Risk of invasion is scale independent, as invasive species' populations will continue to grow once introduced. |
| Mitigation measures | Invasion risks can be mitigated by architectural choices including the following: operating sufficiently far offshore to minimize beaching events or to limit the range of spore transport to coastlines, selecting species of macroalgae that are broadly endemic to the coastlines surrounding the project region, using carbon buoy floating duration that is too short for macroalgae seedlings to reach sexual maturity, and using sterile macroalgae or macroalgae lifecycle interventions that suppress the generation of reproductive material. |

## 2.1.2 NOVEL CONNECTIVITIES

The introduction of floating drifters to the surface ocean may create novel ecological connectivities between regions of the ocean[1]. It is possible that the drifting carbon buoys could become vectors for organisms to spread beyond their native range. Some transported species may find an opportunity to become invasive to a novel region of the ocean or coastline. A number of carbon buoys, macroalgal fronds, or verification instruments may reach coastlines or carry organisms with them either to a different ocean region or to the ocean floor. Floating debris regularly transports organisms across ocean basins[9], to coastlines, and to the ocean floor as current estimates of floating debris (i.e., plastic) in the ocean amounts to 11 – 21 x $10^9$ kg[10].

| Running Tide Classification | |
|---|---|
| Consensus | There is a broadly understood history of engineered transport leading to novel interactions between previously isolated ecologies. |
| Risk determined by scale | Risk determination should be on the basis of the **spatial extent** of carbon buoy spread at the ocean surface, relative to both the existing connectivity (arising from vessel traffic, for example) and the spatial variation of ecological composition and interactions in the project region. |
| Mitigation measures | Connectivity impacts can be evaluated through pre-deployment surface transport modeling and by deploying ocean observing platforms. Similar to the mitigation of invasion impacts, deployments will take place sufficiently far offshore to minimize beaching. |

## 2.1.3 PHYSICAL EXPOSURE TO FOREIGN SUBSTANCES

Carbon buoy materials, such as organic matter of terrestrial origin and calcium carbonate, are selected to be non-exogenous to the ocean environment. However their form factor, particularly if they degrade into particulates, may introduce a pathway of bioavailability of this material to pelagic organisms which is novel in its concentration or duration. The same consideration arises for metals and plastics that enter the ocean environment in verification buoys and are not retrieved at the end of observation; these materials may be an additional exposure to fin fish during and after carbon buoy deployment.

Bioaccumulation of microplastics has been shown to occur in many marine species[11]. Microplastics often contain chemical additives (e.g., plasticizers, flame retardants, and biocides). Due to their hydrophobic nature, microplastics tend to absorb persistent organic pollutants (i.e., toxic chemicals that adversely affect environmental health) in seawater. Once ingested, marine organisms are not only exposed to microplastic polymers, but are also exposed to a wider variety of chemical additives, heavy metals, and persistent organic pollutants (POPs) that are known to elicit toxicological effects. Microplastic exposure can trigger a wide variety of toxicological effects in marine organisms, such as abrasion of digestive tracts, feeding disruption, nutrient deficiencies, disturbances in reproduction (i.e., endocrine disruption), alterations in energy metabolism, growth inhibition, alterations in photosynthetic rate, and synergistic or antagonistic action with other POPs[12].

| Running Tide Classification | |
|---|---|
| Speculative (non-plastic) | Given that Running Tide's system architecture avoids the use of extended form factors which have been known to harm pelagic fauna (i.e. in the case of ghost gear[13] such as lines), this exposure is *speculative* for non-plastic materials. |
| Consensus (plastic) | For plastic materials, there is *consensus* understanding that their introduction to the marine environment creates ecological exposure in any form factor, due to their tendency to degrade into microplastics[14]. |
| Risk determined by scale | Governed by the **intensity** of these material introductions relative to the baseline of the project region. |

| Running Tide Classification | |
|---|---|
| Mitigation measures | Foreign substance exposure is mitigated by limiting plastic in our ocean observing platform design and iteratively dematerializing where possible. |

### 2.1.4 CHEMICAL EXPOSURE TO FOREIGN SUBSTANCES

Organisms may be exposed to foreign chemical compounds introduced in carbon and verification buoy input materials. For example, if pesticides were used to cultivate carbon buoy input materials they may still be present at the time of release and may interact metabolically with pelagic fauna or pelagic larvae of marine fauna. Similarly, any chemical compounds in battery materials that enter the ocean environment in verification buoys and are not retrieved at the end of observation may be an additional exposure to pelagic or benthic organisms during and after deployment through enclosure degradation.

| Running Tide Classification | |
|---|---|
| Consensus | Evidence is broadly understood to suggest that the threshold theory of pollution is inappropriate for application to substances that impact endocrine or other metabolic pathways[15]. |
| Risk determined by architecture **at any scale** | The specific relevant architectural considerations include the extent and confidence with which carbon buoy materials are sourced and tested to control for foreign chemicals, and the properties of the enclosures in which verification batteries are housed. |
| Mitigation measures | Foreign chemical exposure is mitigated through a layered testing process of carbon buoy materials including laboratory-based screening |

| Running Tide Classification | |
|---|---|
| | for compounds of interest and field experiments as appropriate. Chemicals contained within ocean observation platforms are quantified, but ideally these systems will be recovered. |

## 2.1.5 PHYSICAL HARM TO MARINE MAMMALS

Entanglement or scarring of whales and other marine mammals is known to arise from the introduction of engineered objects into the surface ocean environment[1]. Such harm is typically caused by fishing gear which is plastic in origin and of a long vertical form factor[16].

| Running Tide Classification | |
|---|---|
| Consensus | Interactions between marine mammals and engineered marine structures is broadly known and has been incorporated into, for example, aquaculture regulation[17]. Given the fragility of many cetacean populations, risk should be assessed on the basis of system architecture at any scale. |
| Risk determined by architecture **at any scale** | Extended vertical and horizontal components in system architecture are a hazard to marine mammals. |
| Mitigation measures | Mitigation of physical harm to marine mammals through architecture has already been achieved. Running Tide consulted with the Marine Mammal Commission and the Anderson Cabot Center, and have consequently removed any long vertical or horizontal components from the design of our carbon buoys and verification instruments. |

## 2.1.6 ECOLOGICAL TRAPPING OF FIN FISH

Fish are known to associate with free floating objects, a phenomenon which is exploited by commercial fisheries through their use of fish aggregating devices (FADs). If fish aggregate around and follow a drifting population of carbon buoys, this induced unnatural migration may impact biological processes that require fish to be in certain locations at specific times, such as spawning or feeding[1].

| Running Tide Classification | |
|---|---|
| Substantiated | Given the known efficacy of FADs, it is reasonable to expect that fish may aggregate around carbon buoys. |
| Risk determined by scale | Risk determination should be made on the basis of project **spatial extent** relative to the baseline habitat and migration patterns of pelagic fish in the project region. Furthermore, **temporal persistence** of the carbon buoys in the pelagic zone should be taken into account. |
| Mitigation measures | While not consensus, potential ecological trapping risks could be evaluated on the basis of deployment site, trajectories, and temporal persistence of carbon buoys in relation to migration pathways as well as spawning and feeding locations of pelagic fish populations. |

## 2.1.7 NUTRIENT REALLOCATION AND DRAWDOWN

In much of the open ocean, phytoplankton are in intense competition for nutrients, specifically nitrate and phosphate, and the micronutrient iron. For diatom-rich regions (e.g., spring in the subpolar North Atlantic or the Southern Ocean), silicate is a limiting nutrient as well. In the surface ocean, nutrients are recycled through remineralization and new supply of nutrients occurs via upwelling or nitrogen fixation by phytoplankton capable of this unique metabolic strategy. The addition of macroalgae cultivation in the open ocean where nutrient concentrations are already limiting has the potential to decrease phytoplankton NPP and change overall phytoplankton community composition through nutrient reallocation from phytoplankton to macroalgae[1], leading to cascading effects in the food chain.

Also, to the extent that the introduction of terrestrial biomass or the cultivation of marine biomass perturbs the quality and form of particulate organic carbon (POC) in the surface ocean, it is expected to similarly alter the allocation of nutrient availability between the surface and mid-water column. This is because slowly sinking POC generated in the photic (surface) zone is grazed upon by mid-water organisms and scavenged for nutrients as well as calories.

If ocean cultivated macroalgae is sunk at a rate which draws down pelagic nutrients faster than the baseline sinking of such nutrients associated with the biological pump, then the reservoir of these nutrients will be depleted. This would likely reduce the phytoplankton NPP associated with this nutrient reservoir thereafter, even if macroalgae cultivation ceased, at least until the nutrient reservoir was replenished with novel nutrient inflows.

| Running Tide Classification | |
|---|---|
| Consensus | Nutrient reallocation from phytoplankton is a broadly discussed exposure of open ocean macroalgae afforestation[18]. |
| Risk determined by scale | Risk assessment entails analyzing the project's macroalgal growth rate (i.e., **intensity** of macroalgae primary production) under current residual nutrient levels relative to phytoplankton NPP. Additionally, risk determination should be made on the basis of **absolute mass** of nutrient sinking relative to the size of the pelagic nutrient reservoir in the project region, and the rate of novel nutrient flux into that region. |
| Mitigation measures | Due to the complexity of nutrient cycling in the surface ocean, direct quantification of nutrient |

| Running Tide Classification | |
|---|---|
| | reallocation from phytoplankton to macroalgae is challenging. At the scale of Running Tide's current research operations (e.g., sinking terrestrial biomass), nutrient reallocation concerns are expected to be negligible. Nutrient drawdown impacts may be mitigated by aiming for macroalgae genera that have C:N ratios less similar to those of phytoplankton C:N to reduce the potential for nutrient reallocation.[17] |

### 2.1.8 INTRODUCTION OF NOVEL METABOLITES

Living organisms are metabolically active, and produce various specialized biochemical compounds throughout their lifecycle. Furthermore, mature macroalgae are typically colonized by an associated microbiome that is understood to be distinct from that of surrounding ambient water[6], and therefore may not typically thrive in an offshore environment. These microbes inhabit unique symbiotic niches with macroalgae[19], e.g., nitrogen provision or chemical signaling for morphological development. It has been suggested that "physicochemical and biological gradients" resulting from the metabolic activity of these microbes may perturb the ecology of the endemic microbial population[2].

The risk that biochemical metabolites may perturb endemic microbial populations is equally true of the metabolism of the macroalgae itself. This is especially true given that many macroalgal species produce secondary metabolites and chemical defense molecules to prevent fouling and pathogenic microorganisms which could be a strong selective factor for epiphytic microbial colonizers[20–22].

It is likely that such biochemical metabolites, if generated during the lifecycle of macroalgae and their microbiome, will persist while these organisms are alive. The release of biochemical metabolites is not generally associated with the presence of dead or decaying organisms.

| Running Tide Classification | |
|---|---|
| Speculative | Such novel compounds are not well characterized nor known to be aligned with metabolic receptors in the pelagic ecosystem. The persistence of such compounds in surface waters is similarly under-studied. |
| Risk determined by scale | Risk determination should be made on the basis of the **intensity** of macroalgal metabolic activity (i.e., growth). |

### 2.1.9 STIMULATION OF EPIFAUNA AND CALCIFIERS

The introduction of floating carbon buoys at the ocean surface may provide a novel habitat for substrate-seeking marine organisms, which would not otherwise be able to attach and survive in the open ocean[1]. This alteration to the species diversity in such a region may disrupt the baseline ecology[2]. It has also been suggested that the stimulation of marine calcification will marginally remove alkalinity from the surface ocean and could thereby increase the concentration of atmospheric carbon dioxide.

| Running Tide Classification | |
|---|---|
| Substantiated | Floating objects are known to biofoul or otherwise recruit hitchhikers[9,23]. |
| Risk determined by scale | Risk determination should be made on the basis of both **temporal persistence** and **absolute mass** of carbon buoys at the surface ocean. |

## 2.1.10 ORGANIC CARBON PERTURBATION

The introduction of carbon buoys to the pelagic marine environment may result in additional labile dissolved organic carbon (DOC) or particulate organic carbon (POC) entering the water column. An introduction of an additional food source may perturb the abundance and diversity of endemic species[2].

Similar to the effects of shading, the organic carbon perturbation will be transient and present for the length of time that carbon buoys are floating in the surface ocean. However, the exposure of introduced carbon to the surface ocean and effects on organisms may slightly lag the effects of carbon buoy presence depending on the abiotic- or biotic-mediated degradation of DOC and POC in the surface ocean.

As discussed as it pertains to nutrient reallocation, a perturbation in the organic carbon quantity and composition in the surface water will effect a reallocation of calorie availability between the surface and midwaters. Most relevant to this consideration is any alteration in the quantity of labile DOC and POC produced by surface ecosystems.

| Running Tide Classification | |
|---|---|
| Substantiated | Ecosystems are broadly understood to be calorie limited and will react to novel food subsidies. |
| Risk determined by both architecture and scale | Risk determination should be made on the basis of availability and degradability of the organic carbon placed or cultivated in the ocean, as well as the **intensity** of novel labile organic carbon compared to the baseline intensity of food availability in the project region. |

## 2.1.11 ALKALINITY PERTURBATION

Carbonate dissolution through carbon buoy placement in the surface ocean is an intentional exposure with the intended effect of increasing the alkalinity, dissolved inorganic carbon (DIC), and pH of the surface ocean. Alkalinity is an excess of base that acts to weaken or buffer ocean acidity caused by $CO_2$ emissions. Therefore, this alkalinity perturbation is intended to induce the novel flux of $CO_2$ from the atmosphere into the surface ocean. In the time between carbonate or cation dissolution and $CO_2$ influx, an increase in pH and inorganic carbon in the form of bicarbonate and carbonate may impact the ecology of the surface ocean, especially as it pertains to phytoplankton community composition[24]. Changes in phytoplankton community composition in response to changing inorganic carbon concentrations have been observed on the order of a couple days to two weeks[25,26].

Similar to the exposure and effects of OC introduction, these chemical effects will be present during the time that carbon buoys are floating in the ocean surface, and may persist longer than the floating carbon buoys due to differences in chemical transport times and rebalancing with atmospheric $CO_2$. Carbon buoy mineral dissolution occurs on the same temporal scale as changes to the phytoplankton community, possibly leading to impacts on the pelagic ecosystem from this exposure. At larger scales, the duration and spatial influence of this alkalinity perturbation is expected to have an enhanced impact on the global surface ocean chemistry[24].

| Running Tide Classification | |
|---|---|
| Consensus | Alkalinity enhancement, the resultant increase of ocean DIC, and the impact to phytoplankton communities is an area of active, community-wide research interest. |
| Risk determined by scale | Risk determination should be made on the basis of **spatial density** of alkalinity placed in the ocean compared to the baseline reservoir of alkalinity present in the surface ocean of the project region. |
| Mitigation measures | The intended, positive impacts of alkalinity addition will not be mitigated. The dispersive nature of Running Tide's system architecture is intended to mitigate high local concentrations. Ecological exposures arising from alkalinity |

| Running Tide Classification | |
|---|---|
| | perturbation can be mitigated through changes to the amount of alkaline material included in carbon buoys, the rate of deployment, and the locations where alkalinity enhancement is deployed. |

### 2.1.12 ALLELOPATHY

Adding kelp to an open ocean environment could cause direct interaction between macroalgae and phytoplankton through allelopathy, the release of inhibitory biochemicals, which can drive competition between the added macroalgae and native microalgae[2]. This phenomenon has been documented in offshore environments between natural phytoplankton groups, and kelp-driven allelopathy on phytoplankton has occurred in modified environments such as coastal eutrophic areas[27]. Therefore, it is possible that allelopathy may occur between offshore drifting kelp and natural phytoplankton communities.

| Running Tide Classification | |
|---|---|
| Speculative | The mechanism of allelochemical interaction between micro- and macroalgal species is "putative[2]" in coastal settings and unknown in the open ocean. |
| Risk determined by scale | Risk determination should be made on the basis of the **intensity** of macroalgal metabolic activity (i.e., growth). |

### 2.1.13 ADDITION OF ATMOSPHERIC VOLATILE COMPOUNDS

Some macroalgae metabolically produce volatile organic compounds (VOC) such as dimethyl sulfide (DMS) during growth. Increased growth of macroalgae in the ocean could increase VOC release into the atmosphere and thus alter patterns of cloud formation or lead to ecological trapping of seabirds[2,1].

| Running Tide Classification | |
|---|---|
| Speculative | The lifecycle of VOCs generated by open ocean macroalgae and their resultant accumulation in the atmosphere is unknown. |
| Risk determined by scale | Risk determination should be made on the basis of the **intensity** of macroalgal metabolic activity (i.e., growth) |

## 2.2 PELAGIC ECONOMIC ACTIVITY

### 2.2.1 NAVIGATIONAL HAZARDS

The introduction of engineered objects or macroalgae into the surface ocean creates an exposure to underway vessels via collision or motor entanglement[1].

| Running Tide Classification | |
|---|---|
| Speculative | No substantiated evidence of interaction between organic materials such as carbon buoys and commercial vessel traffic. |
| Risk determined by architecture | Most documented ship strikes which cause damage to the striking vessel involve substantially large floating debris, such as derelict vessels[28]. |

### 2.2.2 INTERFERENCE WITH COMMERCIAL FISHING

While at the surface the drifting carbon buoys could be drawn into purse seines. While sinking through the mid water column or at the sea floor, carbon buoys could be drawn into trawl nets. Current sinking rates suggest that exposure in the mid water column is transient and unlikely to extend beyond 1-2 days, while exposure at the surface will last while the carbon buoys are buoyant (from days to months depending on the design).

| Running Tide Classification | |
|---|---|
| Substantiated | Purse seines routinely enclose floating materials such as ocean garbage. |
| Risk determined by scale | Risk determination should be made on the basis of the **intensity** of carbon buoys at the surface ocean compared with cross-section of interaction between surface water and seine fishing in the project region. |
| Mitigation measures | Location of deployments and related information will always be shared with the proper authorities in the project region. These authorities are then responsible for informing ship traffic in the area if needed. As research operations are scaled and the intensity of carbon buoys increases, potential impacts to fishing and trawling can be evaluated. |

## 2.3 BENTHIC ECOLOGY

We consider impacts to the benthic zone, defined here as the lower region of the ocean including surficial ocean sediments and the layer of water immediately above, known as the benthic boundary layer. After carbon buoys lose buoyancy and sink to the floor of the ocean, the benthic zone is where the presence of carbon buoy materials may cause the longest term impacts to benthic ecology and the geochemistry of this ocean region. In this analysis, we examine the impact of sunken carbon buoys on aquatic carbon chemistry, the amount of foreign objects added to the ocean floor, disturbances to benthic communities, and the timescales over which these disturbances may be relevant.

## 2.3.1 ALTERED BENTHIC TOPOGRAPHY

Deposition of carbon buoy materials and macroalgal mass on the seafloor could alter the surface topography or texture/grain size, and therefore hydrodynamics of the deposition region, in a manner which impacts the habitat complexity, ecological patterns of grazing and predation, and ultimately species assemblages[16].

| Running Tide Classification | |
|---|---|
| Substantiated | Habitat complexity[29–31] is considered to be one of the most important factors in the structuring of biotic assemblages, in the abyss[32,33] as well. |
| Risk determined by architecture | Carbon buoys are composed of materials that are largely non-exogenous to the ocean floor, and the carbon buoy form factor is small compared to naturally occurring variations in the surface roughness of abyssal regions. |
| Risk determined by scale | Risk determination should be on the basis of **spatial density** of carbon buoys on the seafloor. Although unlikely, any stacking of carbon buoys on the seafloor due to high spatial density will alter the topography and possibly have secondary impacts on bioturbation and therefore topography. |

## 2.3.2 PHYTODETRITUS PERTURBATION

Any perturbation to the pelagic ecology, especially as it alters net primary production and the sinking export of organic carbon, will have implications for the ecology of the benthos as well. This is because these communities are finely tuned to the magnitude and composition of this food source[34]. For example, reproductive timing, grazing patterns, recruitment, community oxygen consumption, microbial activity and benthic animal recycling could be affected by changes to the seasonal phytodetritus pulses[35].

| Running Tide Classification | |
|---|---|
| Consensus | Most deep sea benthic systems are broadly understood to be calorie limited, with allocthonous organic carbon in marine sediment being a primary food input. |
| Risk determined by scale | Risk should be assessed by the **intensity** of phytoplankton nutrient reallocation and associated effects to the efficiency by which phytodetritus is exported to marine sediment. |
| Mitigation measures | Due to the complexity of the biological pump and its spatial and temporal variability, direct quantification of changes to the delivery of phytodetritus to the benthos is challenging, though done as part of scientific studies[36]. At the scale of Running Tide's current research operations (e.g., sinking terrestrial biomass), alterations to photosynthetically-derived organic carbon delivery to the benthos are expected to be negligible. |

## 2.3.3 BUNDLE DEPOSITION AND PHYSICAL DISTURBANCES

Physical mechanics of bundles of organic carbon striking the seafloor could cause sediment resuspension[37–40], bury and smother benthic fauna, or otherwise physically disrupt the seafloor[34]. Sediment resuspension results in sediment redeposition that can have long-term effects[41] on abyssal benthic communities by entombment of fauna in the vicinity of the deposition site. Deep-sea organisms are particularly sensitive to sedimentation since they have evolved to survive very low sedimentation rates, typically 0.1-2.9 cm kyr[1] on the abyssal plain[42,43]. The community assemblage and functionality of species present needs to be considered as chemoautotrophic communities recover faster than heterotrophic communities in these circumstances[44].

The impact on the benthic community also depends on how much sediment is resuspended, which is inherently linked to the amount of buoy material being deposited on the seafloor. Environmental determinants of sediment resuspension include seafloor composition, currents and natural resuspension patterns at the site in question[45,46].

| Running Tide Classification | |
|---|---|
| Substantiated | Deposition of material on the seafloor results in sediment resuspension. Properties of the seafloor sediment such as grain size and compaction determine the critical values for resuspension. |
| Risk determined by architecture | Risk should be determined by the impact speed at which carbon buoys are expected to strike the seafloor, as well as the size of individual carbon buoys. |
| Risk determined by scale | Risk should be determined by the spatial density of the carbon buoy material upon deposition on the seafloor. |

## 2.3.4 POLLUTION TRANSPORT

Pollution can refer to the introduction of exogenous noxious materials or the creation of an imbalance in the concentration of already present compounds. Here we consider pollutants which are bioaccumulated (e.g., oils and plastics, heavy metals) as opposed to those which are biointegrated (see Section 2.3.2 Phytodetritus Perturbation). Heavy metals such as cadmium, chromium, manganese, and lead may contribute to organism growth in trace quantities but increased concentrations quickly become toxic to aquatic life.

An increase in carbon fixing activity at the surface, and an increase in flux of organic material from the surface to the deep sea, could amplify both the bioaccumulation of surface pollutants as well as their rate of transfer to deep waters and deep ocean sediments. Both microalgae and macroalgae are efficient bioaccumulators of heavy metals, trace elements and other noxious compounds with species and compound-related variance[47,48,49]. Therefore, an increase in biomass of either may lead to enhanced transport of these compounds into the benthic ecosystem beyond baseline conditions[16].

The magnitude of this exposure will be driven by the tendency of macroalgae to bioaccumulate these pollutants compared to the baseline flux of organic material, as well as the overall increase in organic material flux to the deep sea. Also relevant is the lability of macroalgae tissue compared to that baseline organic material, as this will determine how bioavailable these transported pollutants become in the ecological communities of the deep ocean and its sediments.

| Running Tide Classification | |
|---|---|
| Substantiated | To the extent that bioavailable pollution is present and is being transported through the baseline biological pump, it may be amplified by macroalgae cultivation and sinking. |
| Risk determined by scale | Risk should be determined by the total increase in **mass** of organic carbon of marine origin which sinks in the region, compared to the baseline condition, as well as the relative tendency of this novel organic material to both bioaccumulate pollutants and degrade in the deep sea. |

## 2.3.5 ORGANIC CARBON PERTURBATION

Similar to organic carbon introduction in the pelagic environment, the sinking of carbon buoys and their associated macroalgae biomass will result in a novel flux of food to the benthic region[1] which is generally calorie limited. Such a perturbation can be expected to impact the abundance and diversity of species present at the sites of organic carbon deposition[34]. In addition, the chemical character of organic matter and nutrient ratios is expected to influence the degradation rate, timing of ecosystem response, and magnitude of ecosystem response[50].

| Running Tide Classification | |
|---|---|
| Consensus | Species abundance and diversity in benthic communities are broadly understood to be calorie limited. |
| Risk determined by scale | Risk should be determined by **intensity** of the organic carbon flux to the deep sea, relative to the baseline condition. In addition, **spatial density** will likely govern the magnitude of local effects and return to baseline. |
| Risk determined by architecture | The chemical composition and form factor of organic material that composes carbon buoys will influence the degradation rate. Organic matter with higher nutrient ratios is likely to be more rapidly degraded, whereas organic matter with higher carbon content relative to other nutrients is likely to degrade more slowly. |
| Mitigation measures | The overall intentional, positive impact of moving organic carbon from the faster, ocean surface carbon cycle to the slower, benthic carbon cycle is not the subject of mitigation. The dispersive nature of Running Tide's system architecture is intended to mitigate high local organic carbon fluxes. Additionally, composition and form of the carbon buoys and macroalgae will be reviewed with regard to degradation rate. |

### 2.3.6 INCREASED OXYGEN CONSUMPTION

Increased metabolic activity (i.e., remineralization) associated with an increase in sunken biomass may also lead to a decrease in oxygen on the benthos[1], thus potentially leading to new areas of localized hypoxia or expanding benthic oxygen minimum zones[34]. While the feedback between deoxygenation in the benthos and climate change remains an open scientific question, expanding oxygen minimum zones in the benthos is widely viewed as detrimental to biodiversity[51]. In addition to direct oxygen consumption during respiration, additional metabolism byproducts may be generated that will also consume oxygen, such as reduced sulfur compounds (see section 2.3.8 Metabolic Compound Perturbation).

| Running Tide Classification | |
|---|---|
| Consensus | Stimulation of ecological activity via organic matter decay, given a novel increase in food sources, will primarily result in an increase in aerobic respiration in ocean regions which are not already suboxic. |
| Risk determined by scale | The **intensity** of organic carbon flux and the degradation rate of that carbon can be taken together to derive an intensity in oxygen drawdown of the benthic boundary layer and in sediments. This should be compared to the rate of reoxygenation of benthic water and sediments in the project region. |
| Mitigation measures | The dispersive nature of Running Tide's system architecture is intended to mitigate high local organic carbon fluxes, and therefore rates of oxygen drawdown as a result of respiration. |

### 2.3.7 DIC PERTURBATION

By design, carbon buoy sinking will transfer organic carbon to the deep sea. Metabolic remineralization of this organic carbon will likely result in an increase in the DIC content of the benthic boundary layer via carbon dioxide, acidifying this region of water[1]. This could adversely impact the lifecycle of marine organisms, especially benthic calcifiers. In addition, carbon buoys may contain alkaline minerals that did not entirely dissolve while floating in the surface ocean. This will also result in an increase in DIC via carbonate dissolution and will buffer acidity.

| Running Tide Classification | |
|---|---|
| Consensus | The connection between DIC and pH is an established pillar of the oceanographic consensus[52]. We note that the effect of DIC and pH change on midwater and deep benthic organisms is less well known. |
| Risk determined by scale | As with oxygen consumption, the rate of DIC addition to the water will depend on organic carbon deposition and the degradation rate of that carbon. The **spatial density** of DIC added to the benthic boundary layer can be used to determine the expected pH change in this region of the ocean. |
| Risk determined by architecture | The amount of organic carbon in carbon buoys that is remineralized on the seafloor and the amount of alkaline minerals that remain after sinking will affect DIC changes. |
| Mitigation measures | Changes to carbon buoy architecture, such as adding alkaline minerals, can be used to mitigate the generation of acidity during organic carbon degradation. |

### 2.3.8 METABOLIC COMPOUND PERTURBATION

Where regions of the ocean are or become suboxic, the degradation of organic carbon will proceed with alternative electron acceptors, producing methane, sulfide, or nitrous oxide[34], the presence of which will alter sediment biodiversity and species distributions, and may thus be harmful to sediment communities[50]. The intensity and chemical character of organic material, as well as the depth of carbon placement, will affect the magnitude, space scale, and time scale of impact [50,53–56]. For example, one experiment observed macroalgal degradation that occurred rapidly (less than a year) leading to a rapid but transient response in sulfur generation, while slower wood degradation rates resulted in local, reduced macrofaunal density and sulfur generation after multiple years [50].

| Running Tide Classification | |
|---|---|
| Consensus | The degradation of organic carbon resulting in suboxia is well understood. We note the thoroughness of understanding may vary by type of organic matter. |
| Risk determined by scale | As with increased oxygen consumption, the **intensity** of organic carbon deposition will determine the risk of suboxic conditions and the production rate of these metabolites. |
| Mitigation measures | Most existing studies on wood, whale, and other biomass falls focus on placing larger amounts of organic carbon on the seafloor. Perturbations to sediment biodiversity and species distributions may be mitigated by the more dispersive system employed by Running Tide, as well as other design choices in carbon buoy composition affecting the organic carbon flux. |

### 2.4.9 ALKALINITY PERTURBATION

Carbon buoy sinking may adjust the alkalinity of water in the benthic boundary layer through dissolution of carbonate minerals, thus increasing pH. While the carbonate in the buoys is designed to dissolve during flotation at the surface, some may remain attached to the buoys either due to rapid buoy sinking or incomplete dissolution. If these carbonate minerals are present during sinking below the lysocline, also known as the calcium carbonate compensation depth, rapid dissolution becomes increasingly likely.

| Running Tide Classification | |
|---|---|
| Consensus | The connection between alkalinity and pH is an established pillar of the oceanographic consensus. |
| Risk determined by scale | As with DIC addition, the **spatial density** of alkalinity added to the benthic boundary layer can be used to determine the expected pH change in this region of the ocean. |
| Risk determined by architecture | Design choices related to alkaline mineral inclusion in carbon buoys will determine the rate and magnitude of dissolution in surface waters and whether alkaline minerals are still present in carbon buoys after sinking to the seafloor. In addition, architecture may determine if alkaline minerals are incorporated into the sediment. |
| Mitigation measures | Alkalinity addition to the seafloor may be mitigated through design choices for the carbon buoys, including the composition and float time, leading to different amounts of dissolution in the surface. |

### 2.3.10 INTRODUCTION OF FOREIGN SUBSTANCES

The eventual end-of-life sinking of verification instruments will create a novel flux of inorganic materials such as metals and plastics to the deep ocean. As in the pelagic zone, chemical compounds from battery materials can be introduced into the benthic environment pending degradation of their enclosure. Additionally, organisms may be exposed to toxic chemical compounds such as pesticides introduced in carbon and verification buoy input materials even if a portion of it will already have leached out into the pelagic zone during the buoy’s floating period.

| Running Tide Classification | |
|---|---|
| Consensus | The migration of man-made materials from the surface of the ocean through the water column to the deep sea is a broadly understood phenomenon. |
| Risk determined by architecture and scale | Risk should be assessed by the **absolute mass** of foreign substances added to the benthic environment compared to the baseline flux and accumulation of these materials in the region. Design and structure of the verification instruments should also be considered. |

## 2.4 BENTHIC ECONOMIC ACTIVITY

### 2.4.1 INTERFERENCE WITH COMMERCIAL FISHING

While at the ocean floor, the deposited carbon buoys could be drawn into fishing trawls.

| Running Tide Classification | |
|---|---|
| Speculative | Trawl nets routinely dredge organic and manufactured materials from the sea floor. There is no evidence to suggest that the addition of carbon buoy materials to the ocean bottom would meaningfully alter this interaction. |
| Risk determined by scale | Risk determination should be made on the basis of the **spatial density** of carbon buoys at the ocean floor with cross section of interaction between the ocean bottom and trawl fishing in the project region. |

### 2.4.2 INTERFERENCE WITH DEEP SEA MINING

Deposition of carbon buoy materials and macroalgae on the sea floor may interfere with future mining operations in this region.

| Running Tide Classification | |
|---|---|
| Speculative | There is no substantially described mechanism through which this interaction may occur. |
| Risk determined by architecture | Carbon buoys are composed of non-exogenous materials to the sea floor, are small in form factor compared to existing variations in surface roughness, and are not expected to measurably impact the topography of the seafloor in the project region. To further address this, available data on deep sea mining operations may be included for consideration during site selection. |

## 2.5 EARTH SYSTEM IMPACTS

### 2.5.1 DIRECT ALBEDO PERTURBATIONS

Floating carbon buoys or macroalgae that detach from their buoy may directly alter the albedo of the surface ocean[18] . According to Seitz[57] the albedo of seawater is 0.05-0.10, which means that it absorbs about 93% of incident solar radiation. However, the albedo of wooden mulch is about 0.20[58] and the albedo of limestone is about 0.26-30 (depending on grain size[59]). The higher albedo of carbon buoy materials (wood chips[58], limestone[59]), macroalgae[60], and colonizing organisms compared to the ocean[57] will cause more short wave radiation to be reflected so that the seawater will absorb less heat. This can ultimately cause negative climate radiative forcing. Floating duration of the buoys, as well as time spent at full buoyancy, need to be taken into account, when estimating the change in albedo at the deployment site, in addition to a number of environmental variables such as wave size and cloud cover.

| Running Tide Classification | |
|---|---|
| Substantiated | The increased albedo of the carbon buoy material compared to the mean albedo of the ocean could cause negative climate radiative forcing. |
| Risk determined by architecture and scale | Risk should be determined by the reflectivity of carbon buoy materials while floating, as well as by the **spatial density** of **temporal persistence** of carbon buoys at the ocean surface. |

### 2.5.2 HALOMETHANE RELEASE

Stimulation of macroalgae growth in the open ocean may lead to increased metabolic production of organic bromine compounds and other halomethanes[34]. These products would then be released to the atmosphere as gasses which contribute to stratospheric ozone loss[61] and contribute to warming.

| Running Tide Classification | |
|---|---|
| Substantiated | Such compounds are known to be metabolic byproducts of macroalgae under certain conditions, and their impact on the atmosphere is broadly understood. |
| Risk determined by scale | Assuming that the stratosphere is well-mixed, risk should be determined by the **total mass** of halomethanes produced during macroalgae metabolic activity (i.e., yield), compared to the total baseline flux of such compounds into the atmosphere, especially including those arising from the total aggregate of global macroalgae forests. |

### 2.6.3 VENTILATION OF METABOLIC GREENHOUSE GASSES

Macroalgal decomposition at the sea floor may lead to methanogenesis, especially if and where the deposition is intense enough for the resulting metabolic activity to result in suboxic conditions. Methane is a potent greenhouse gas, and if methane produced in the deep sea were to escape to the atmosphere, it would contribute to earth system warming[34].

However, for methane to reach the atmosphere from a suboxic region of the benthos, it must first pass through the oxygen rich water column. In deeper waters this means little to no methane is able to reach the surface before being converted to carbon dioxide.

| Running Tide Classification | |
|---|---|
| Speculative | There is not a substantiated mechanism for methane produced in the deep ocean to reach the atmosphere. |
| Risk determined by scale | Risk determination should be made on the basis of **absolute mass** of macroalgae sunk into shallow waters. |

# PART 3 – ACKNOWLEDGEMENTS

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