

Catalog of Potential Environmental Exposures

Ocean CDR: Catalog of Potential Environmental Exposures

Published by Alison Tune, PhD from [Running Tide](#) | Read our [announcement](#)

Version	Published Date	Download Link
v1.0	July 31, 2023	Download PDF 

This catalog consists of two primary documents. The first, our **Catalog of Potential Environmental Exposures**, is a comprehensive list and categorization of the exposures or impacts to marine ecosystems — separated by the pelagic region (the upper open ocean) and to the benthic region (the bottom of the ocean) — that could potentially arise from the deployment of Running Tide’s carbon removal system, as currently designed. We intend for this to be a living document that evolves as our carbon removal technologies and mitigation strategies develop, and as the best available science evolves. This work has also been shared with the Government of Iceland, with whom we are in regular contact related to our ongoing research activities.

The second document is a [review of the aforementioned Catalog of Environmental Exposures, completed by Deloitte](#) in early summer 2023. This summary review was conducted to ensure our consideration of potential exposures was comprehensive, and to provide an independent review of Running Tide’s categorization of these potential impacts (speculative, substantiated, and consensus exposures). This catalog was further reviewed by a number of additional expert groups, including our independent [Scientific Advisory Board](#) (convened by [Ocean Visions](#)), and benefitted from comments provided by several members of the [Deep Ocean Stewardship Initiative \(DOSI\)](#) Climate Change working group.

Looking Ahead

Importantly, these resources are just one step in supporting and demonstrating our responsible ocean stewardship, and we look forward to sharing more of the work associated with this effort in the future. In the meantime, you can find additional

information on Running Tide's monitoring, quantification, and verification methods in our [Framework Protocol for open ocean carbon removal](#), as well as in our [Carbon Removal Research Roadmap](#).

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).

In Part 2, we examine the processes and pathways through which carbon buoy deployment may adversely impact the marine environment, and the effects of these potential exposures.

Part 2 - Exposures & Effects

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 ocean¹. 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 concentrations². 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 levels⁵. 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 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 water⁶. 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 environment⁷, 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

2.1.3 Novel Connectivities

The introduction of floating drifters to the surface ocean may create novel ecological connectivities between regions of the ocean¹. 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 basins⁹, to coastlines, and to the ocean floor as current estimates of floating debris (i.e., plastic) in the ocean amounts to $11 - 21 \times 10^9$ kg¹⁰.

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.

2.1.4 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 species¹¹. 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 POPs¹².

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.
	Foreign substance exposure is mitigated by limiting

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

2.1.6 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 environment¹. Such harm is typically caused by fishing gear which is plastic in origin and of a long vertical form factor¹⁶.

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.

2.1.7 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 feeding¹.

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.

2.1.8 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 macroalgae¹, 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

Substantiated	Nutrient reallocation from phytoplankton is a broadly discussed exposure of open ocean macroalgal 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,

	<p>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.</p>
<p>Mitigation measures</p>	<p>Due to the complexity of nutrient cycling in the surface ocean, direct quantification of nutrient 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</p>

2.1.9 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 water⁶, and therefore may not typically thrive in an offshore environment. These microbes inhabit unique symbiotic niches with macroalgae¹⁹, 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 population².

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).