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EDITED BY

João Seródio,
University of Aveiro, Portugal

REVIEWED BY

Allison Coe,
Massachusetts Institute of Technology,
United States
Royston Uning,
Universiti Malaysia Sabah, Malaysia

*CORRESPONDENCE

Kimberly H. Halsey,
✉ kimberly.halsey@oregonstate.edu

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Light-driven growth rate-dependent volatile organic compound production reflects adaptative strategies in *Dunaliella tertiolecta* and *Thalassiosira weissflogii*

Hawra H. Almubarak^{1,2}, Holger H. Buchholz¹ and Kimberly H. Halsey^{1*}

¹Department of Microbiology, Oregon State University, Corvallis, OR, United States, ²Department of Microbiology, College of Science, Jazan University, Jazan, Saudi Arabia

Phytoplankton are important producers of volatile organic compounds (VOCs) involved in atmospheric and ecological processes. VOC production can be sensitive to environmental conditions including light intensity and diel changes in photosynthetic metabolism. Not known is the impact of phytoplankton growth rate on VOC production. This study investigated VOC production in two marine phytoplankton species, *Dunaliella tertiolecta* (green alga) and *Thalassiosira weissflogii* (diatom), during steady state growth controlled by low (10 $\mu\text{mol photons m}^{-2} \text{ s}^{-1}$, LL) or high (180 $\mu\text{mol photons m}^{-2} \text{ s}^{-1}$, HL) light intensity. Oxygen-containing compounds was the most abundant VOC group across both species regardless of light intensity. LL *D. tertiolecta* produced VOCs including acetone, isoprene, and methanethiol, but VOCs were not detected in HL *D. tertiolecta*. *T. weissflogii* produced up to 5.5-fold more VOCs than LL *D. tertiolecta*, and most of the VOCs produced by *T. weissflogii* were detected in both LL and HL treatments. Ethanol production in LL and HL *T. weissflogii* reflected a generalized redox regulatory strategy used in the diatom but not in *D. tertiolecta*. The contrasting patterns of light-driven growth rate-dependent VOC production in the two species are proposed to reflect their adaptation to distinct light environments, with *D. tertiolecta* adapted to relatively stable conditions and *T. weissflogii* adapted to more dynamic light regimes.

KEYWORDS

acetone, diatom, ethanol, green alga, isoprene, light limited growth rate, volatile organic compounds

Introduction

Phytoplankton photosynthetic carbon fixation produces their cell biomass and dissolved organic carbon compounds (DOC) that are used as chemical substrates for heterotrophic bacteria. Volatile organic compounds (VOCs) are estimated to be 30%–40% of the DOC pool (Dachs et al., 2005; Ruiz-Halpern et al., 2010; Hauser et al., 2013) and can be a significant component of gross carbon production (Moore et al., 2022; Padaki et al., 2025b). VOCs are composed of a vast array of chemicals that serve as substrates for bacterial metabolism (Moore et al., 2022; Kieber et al., 2024) and infochemicals that positively or

negatively impact bacterial physiology (Moore et al., 2022; Mutalipassi et al., 2022; Saha and Fink, 2022).

VOCs are metabolic intermediates or end-products in phytoplankton metabolism (Halsey et al., 2024; Padaki et al., 2025a; Padaki et al., 2025b) and are characterized by their low molecular weights and relatively greater hydrophobicities and vapor pressures (Zhao et al., 2023). These properties help facilitate their passive diffusion from phytoplankton cells as dissolved gases. VOCs may also arise from photolysis of DOC (Zhu and Kieber, 2019; 2020). VOCs classified as hydrocarbons, alcohols, aldehydes and ketones, halocarbons, esters, alkyl nitrates and organosulfur compounds have been detected in phytoplankton cultures and in seawater (Sinha et al., 2007; Halsey et al., 2024; Padaki et al., 2025b). Despite their apparent constant production by actively growing phytoplankton, VOCs are maintained at pM-nM concentrations in the surface ocean because they can be rapidly consumed by heterotrophic bacteria (Moore et al., 2020; 2022), chemically react with other dissolved chemicals (Kilgour et al., 2024) or escape into the atmosphere by crossing the air-sea interface (Yang et al., 2014b). VOCs emitted from the ocean have essential roles in atmospheric chemistry and climate because they can participate in secondary organic aerosol formation (O'Dowd et al., 1999; Arnold et al., 2009; Yu and Li, 2021) and reduce the availability of the hydroxyl radical (OH), which is crucial for methane removal and the maintenance of stratospheric ozone (Crutzen, 1988; Lelieveld et al., 2008).

Knowledge of the full suite of VOCs emitted from phytoplankton and how their physiology impacts the identities and amounts of VOC produced is limited. VOC production appears to be influenced by taxonomy, cell density, growth phase (i.e., exponential vs. stationary phase, Zhou et al., 2017), day-night cycles (Padaki et al., 2025b), seasonal variation (Davie-Martin et al., 2020; Zhao et al., 2023), and light intensity (Shaw et al., 2003; Halsey et al., 2017). Light is a dominant driver of phytoplankton growth rate (Behrenfeld et al., 2016). For example, in the subarctic North Atlantic Ocean, the phytoplankton community growth rate varied from 0.25 d⁻¹ in November when the median light intensity (I_g) was less than 0.1 mol photons m⁻² hr⁻¹ in the surface mixed layer to 0.95 d⁻¹ in May when I_g was approximately 0.5 photons m⁻² hr⁻¹ in the surface mixed layer (Fox et al., 2020). These light-driven phytoplankton growth rates were associated with net VOC production rates (i.e., VOC production after accounting for heterotrophic VOC uptake) that were higher in May than November (Davie-Martin et al., 2020).

In the laboratory, steady state growth rates can be controlled by culturing techniques that expose phytoplankton to consistent environmental conditions, leading to balanced physiology and population growth rates that are constant over at least ten divisions (Halsey and Jones, 2015). Light-driven growth causes phytoplankton to predictably alter cellular pigment content in response to light availability to balance photosynthetic electron transport with downstream carbon metabolism. Thus, cells acclimated to high light conditions (HL) display low chlorophyll (Chl) to C ratios, whereas cells acclimated to low light (LL) display high Chl:C. These changes in pigment content help optimize light absorption efficiency per unit of cell biomass (Suggett et al., 2004; Rodríguez et al., 2006), which is critical to avoid severe light limitation or high light stress. Light-driven growth rates also cause phytoplankton to shift reliance on different major carbon

metabolic pathways (Fisher and Halsey, 2016). This growth rate-dependent shift in metabolism suggested to us that the amount and composition of VOCs would also vary depending on light-driven growth rate. Alternatively, differences in VOC production may reflect life history strategies for optimizing growth in static vs. dynamic light conditions. For example, diatoms thrive in highly variable light environments, such as coastal waters and deep mixed layers typical of springtime in the ocean (Armbrust, 2009), and some chlorophytes inhabit more stable regions that experience narrow ranges of light availability (Sands et al., 2023). Thus, light-driven adaptations may be reflected in the amounts and types of VOCs produced in different phytoplankton.

In this study, we measured the suite of VOCs produced in two model marine phytoplankton, *Dunaliella tertiolecta* and *Thalassiosira weissflogii*, grown at steady state under LL and HL conditions that resulted in different growth rates. We hypothesized that higher concentrations of VOCs would be produced in HL cells exhibiting fast growth rates compared to LL cells exhibiting slow growth rates and that the composition of VOCs would also differ because the photosynthetic energy allocation through carbon metabolic pathways is growth rate dependent. We next examined whether VOC production is similar between the species and whether any patterns correspond to their taxonomic differences. Our results disproved the hypothesis and instead pointed to adaptive strategies related to light availability as underlying VOC production in phytoplankton.

Materials and methods

Culture conditions

Two model marine phytoplankton, *Dunaliella tertiolecta* CCMP 1320, a green alga, and *Thalassiosira weissflogii* CCMP1336, a diatom, were grown separately and axenically in f/2 + Si medium (Guillard, 1975) to steady state growth rates using semi-continuous culturing. Cultures were passaged into new media three times from late exponential phase to ensure at least ten divisions had occurred (MacIntyre and Cullen, 2005), and growth rates were evaluated through each passaged culture. Invariant growth rates reflected cells that were fully acclimated to their growth conditions (Figure 1). Six axenic cultures of each strain were cultivated in 250 mL sterile, acid washed polycarbonate flasks at 18 °C and grown in either constant (24 h) high light (HL, 180 μmol photons m⁻² s⁻¹) or low light (LL, 10 μmol photons m⁻² s⁻¹). Cool-white, fluorescent tubes were used as the light source, and a quantum meter (Biospherical Instruments QSL-100; San Diego, CA) with 4-pi spherical sensor was used to measure the light intensities. Cells counts were conducted daily using a Multisizer 3 Coulter Counter equipped with a 100-μm aperture (Beckman Coulter; Miami, FL). Light-limited growth rates were determined using the growth rate equation (Guillard, 1973):

$$\mu = 3.322 \cdot \log(N_2/N_1) / \Delta t,$$

where μ (d⁻¹) is specific growth rate, N_2 and N_1 are the cell densities at day t_2 and t_1 , respectively, Δt is $t_2 - t_1$.

Chlorophyll *a* content (Chl) was determined using 4 mL of culture filtered through a 25 mm glass fiber filter (Whatman GF/F).

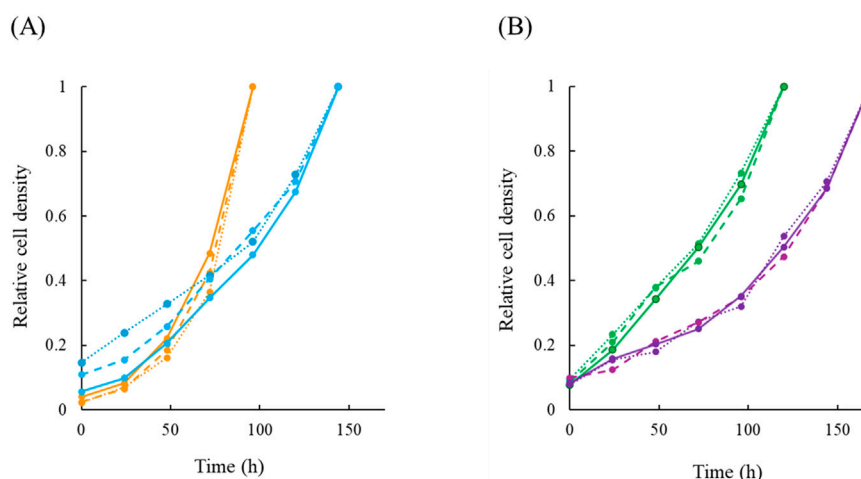


FIGURE 1

Steady state growth of (A) *Dunaliella tertiolecta* and (B) *Thalassiosira weissflogii* under high light (180 μE) and low light (10 μE) using semi-continuous culturing. *Dunaliella tertiolecta* growth in high (orange) and low (blue) light. *Thalassiosira weissflogii* growth in high (green) and low (purple) light. Three consecutive culture passages (P) are shown for each treatment (P1, dotted; P2, dashed; P3, solid). VOC measurements and cell properties were made using P3 cultures at the last point shown for each species and light level. Because of slight differences in the starting concentrations of each passage, data are shown normalized to the maximum cell density in each treatment.

Two mL of 90% acetone was added to the filter and Chl extracted at -20°C for 24 h. Absorbance at 630, 647, 664, and 750 nm was measured using a UV-Vis spectrophotometer (Shimadzu, Kyoto, Japan). Chl was calculated using equations specific to each taxa according to (Ritchie, 2006).

Proton-transfer reaction time-of-flight mass spectrometry

VOCs in the cultures and in the $f/2 + \text{Si}$ medium (used to measure background VOC concentrations that accumulate from exchange with laboratory air) were measured by proton-transfer reaction time-of-flight mass spectrometry (PTR-MS) (Ionicon Analytik; Innsbruck, Austria). Cultures or media (100 mL) were transferred to a dynamic stripping chamber (DSC, Davie-Martin et al., 2020), and VOC-free air was bubbled through the samples at 50 mL min^{-1} for 5 min (Padaki et al., 2025b). Each culture and media control was measured separately using the same DSC to minimize variability caused by differences in chamber design or bubble formation. The gas in the headspace of the DSC was directed into the PTR-MS for ionization and detection. VOCs with higher proton affinities than water are protonated by hydronium ions (H_3O^+) and detected at their molar mass +1 (m/z). A mass spectrum ranging from 30 to 240 a.m.u was acquired every 5 s. The final 2.5 min, containing VOCs released from the culture medium, were included in the analysis because the initial 2.5 min of the measurement were dedicated to flushing out the chamber headspace. All raw data h5 files were mass calibrated by referencing three known peaks within each mass spectrum (m/z 29.998, 203.943, and 330.848). A total of six samples were collected for each species and light condition (totaling 24). Peak signal integrations were normalized to the H_3O^+ reagent ion concentration, the concentrations (ppbv) were estimated without calibration, applying the simple reaction kinetics approach with an accuracy

of approximately 30% for E/N values $> 100 \text{ Td}$ (E/N in this study = 126 Td) (Holzinger et al., 2019).

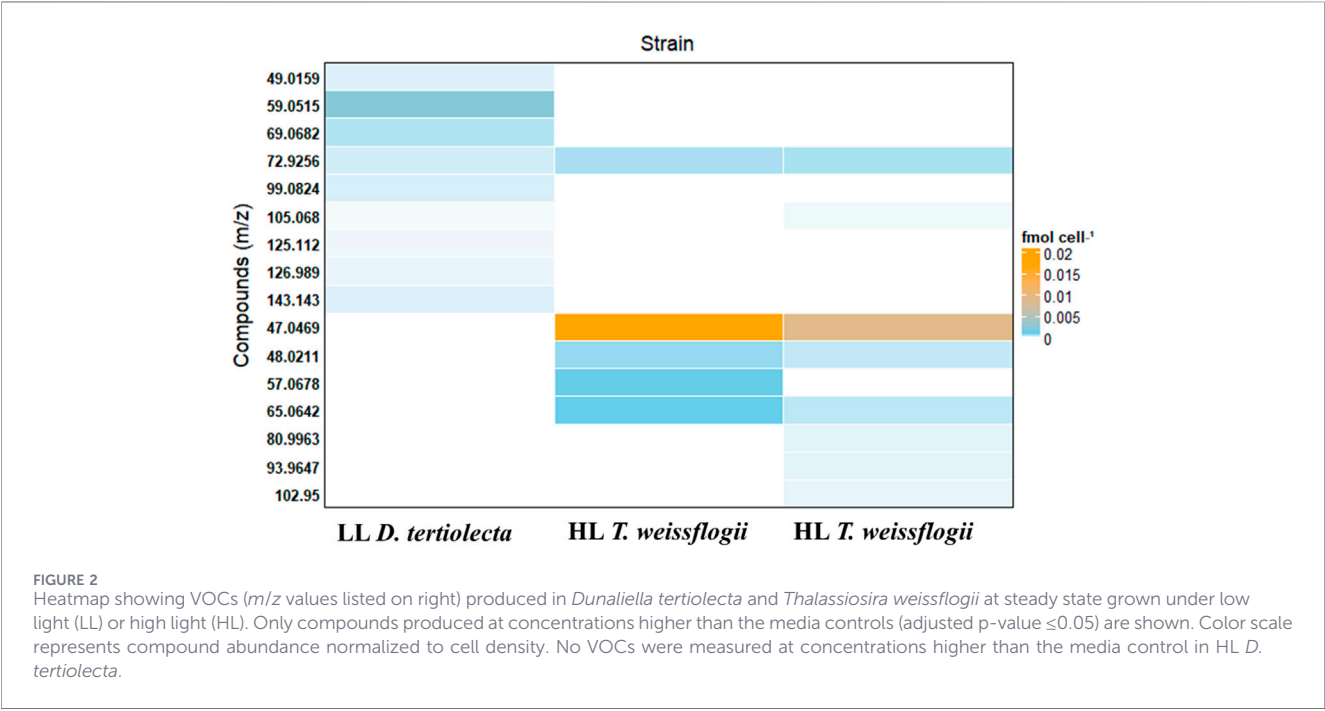
The PTR-MS data were analyzed using PTRwid and PTR-Viewer software (version 3.4.4) provided by Ionicon Analytik. PTRwid is a high-speed data analysis tool designed for processing data from PTR-MS. It automatically performs mass scale calibration and generates a “unified mass list” of all peaks detected across multiple samples (Holzinger, 2015). PTR-Viewer software was used to quantify and identify m/z signals by editing each peak manually. R studio v. 4.3.1, with ggplot2 and Complex heatmap packages were used for visualization and statistical analyses. The Wald statistical test ($p \leq 0.05$) was applied to identify compounds in treatment samples with concentrations significantly different from those in media controls. m/z signals present in significantly higher concentrations compared to the media control were then subjected to Benjamini–Hochberg correction to control the false discovery rate. Finally, m/z signals were classified using the GLOVOCS compound assignment database guide for PTR-MS users (Yáñez-Serrano et al., 2021). GLOVOCS helps match m/z signals to possible candidates for chemical formulas and VOC identities and indicates the VOCs biogenic or anthropogenic origins and arranges them using the ClassyFire chemotaxonomic system. m/z signals corresponding to more than one possible isomer in different functional groups were classified as mixed. All water clusters or fragments of larger parent molecules were manually removed from the final dataset.

Results

Light-limited semi-continuous cultures of *D. tertiolecta* grown at $10 \mu\text{mol photons m}^{-2} \text{ s}^{-1}$ (LL) and $180 \mu\text{mol photons m}^{-2} \text{ s}^{-1}$ (HL) resulted in steady state growth rates of 0.6 and 1.2 d^{-1} , respectively (Figure 1; Table 1). *T. weissflogii*, grown under LL and HL conditions, achieved growth rates of 0.4 and 0.7 d^{-1} , respectively

TABLE1 Summary of parameters for *Dunaliella tertiolecta* and *Thalassiosira weissflogii* grown to steady-state growth under high and low light intensities. Data are given $\pm$ SD of six independent replicate cultures. P1-3, refer to the first, second, and third passaged semicontinuous cultures (Figure 1). Cell properties and VOC production were measured during P3.

Phytoplankton species	Light intensity (μ E)	Specific growth rate (d^{-1})	Chla content (pg cell $^{-1}$)	Cell density ($\times 10^5$ per mL)
<i>D. tertiolecta</i>	180	1.2 $\pm$ 0.1 (P3) 1.2 $\pm$ 0.1 (P2) 1.2 $\pm$ 0.1 (P1)	0.49 $\pm$ 0.1	2.41 $\pm$ 0.6
<i>D. tertiolecta</i>	10	0.6 $\pm$ 0.2 (P3) 0.5 $\pm$ 0.1 (P2) 0.5 $\pm$ 0.1 (P1)	3.64 $\pm$ 0.5	1.74 $\pm$ 0.3
<i>T. weissflogii</i>	180	0.7 $\pm$ 0.1 (P3) 0.6 $\pm$ 0.1 (P2) 0.7 $\pm$ 0.1 (P1)	3.02 $\pm$ 0.1	1.07 $\pm$ 0.1
<i>T. weissflogii</i>	10	0.4 $\pm$ 0.1 (P3) 0.4 $\pm$ 0.1 (P2) 0.4 $\pm$ 0.1 (P1)	8.05 $\pm$ 1.8	1.10 $\pm$ 0.2



(Figure 1; Table 1). Consistent with photoacclimation, Chla in *D. tertiolecta* was 7.1-fold higher in LL than HL. In *T. weissflogii*, Chla was 2.7-fold higher in LL than HL (Table 1).

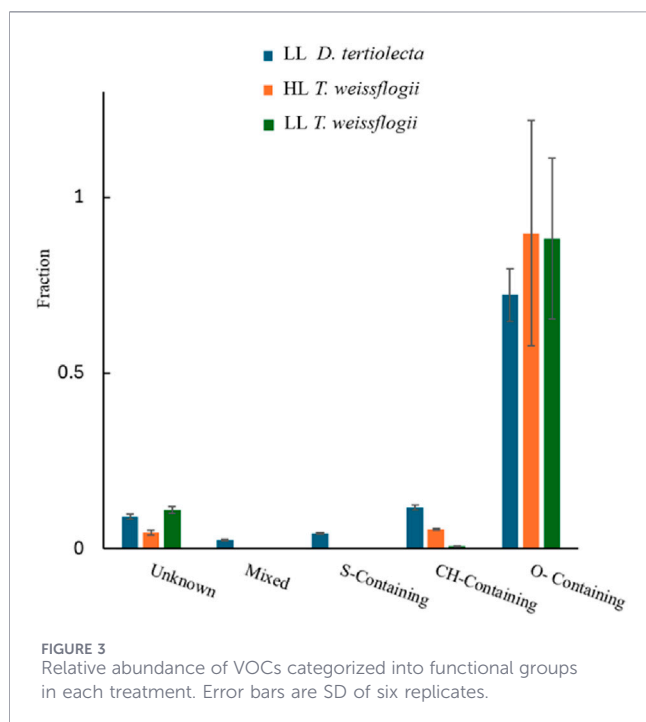
Comparison of VOCs produced in *Dunaliella tertiolecta* vs. *Thalassiosira weissflogii*

The types and amounts of VOCs produced were strikingly different between the two species. Of the 16 VOCs detected across all treatments, only two VOCs were produced by both species (Figure 2). One VOC, $m/z = 72.926$, was produced at about the same amount (1.0 ± 0.1 amol cell⁻¹) in three treatments, LL *D. tertiolecta*, and HL and LL *T. weissflogii*. One

other VOC, $m/z = 105.068$, was produced in both LL *D. tertiolecta* and LL *T. weissflogii*. Seven VOCs were uniquely produced in *D. tertiolecta* and seven VOCs were uniquely produced in *T. weissflogii*. The total VOC pool in LL *T. weissflogii* was 2.8-fold larger than in LL *D. tertiolecta*. Because no VOCs were detected in HL *D. tertiolecta*, we report only the comparison that the VOC pool in HL *T. weissflogii* was 5.5-fold larger than in LL *D. tertiolecta*.

VOCs produced in *Dunaliella tertiolecta* cultures

VOCs produced at levels greater than media-only controls were observed in LL *D. tertiolecta* but not detected in HL *D. tertiolecta*.



Nine m/z signals were detected at levels higher than the media control in LL. These m/z signals corresponded to oxygen-containing compounds, organosulfur compounds, hydrocarbons, mixed compounds (m/z signals that could not be assigned to a single category), and unknown compounds (Figures 2, 3). Oxygen-containing compounds were the most abundant VOCs in the LL treatment and made up 72% of the total VOC pool. Acetone ($m/z = 59.051$) was the most abundantly produced compound in LL. Hydrocarbons, including isoprene ($m/z = 69.068$), were 12% of the total LL VOC pool, and organosulfur compounds including methanethiol ($m/z = 49.015$) were 4% of the LL VOC pool. Unknown compounds (9%) and mixed compounds (3%) made up the rest of the LL VOC pool (Figures 2, 3).

VOCs produced in *Thalassiosira weissflogii* cultures

The diversity of VOCs was very similar in HL and LL *T. weissflogii*; however, the total VOC pools in *T. weissflogii* were two-fold higher in HL (0.05 ± 0.03 fmol cell⁻¹) than in LL (0.02 ± 0.01 fmol cell⁻¹) treatments (Figure 2). Again, oxygen-containing compounds were the most abundantly produced VOC category in HL and LL, with ethanol (m/z 47.046) and m/z 65.064, making up 88%–90% of the VOC pool steady state *T. weissflogii*. CH-containing m/z 57.068 corresponding to (C₄H₈)H⁺, unknown, and mixed compounds made up the rest of the VOC pool (Figures 2, 3).

Discussion

Predicting VOC fluxes, either positive (from the ocean into the atmosphere) or negative (from the atmosphere into the ocean) is challenging because of limited knowledge about the biological

processes involved in VOC production and consumption. A fundamental question is, how do light-driven phytoplankton growth rates regulate VOC production? To isolate the effect of growth rate on VOC production, we used semicontinuous culturing to ensure the phytoplankton were fully acclimated to their constant light environments. Thus, VOC production could be attributed to non-stress conditions and nonfluctuating photosynthetic energy flow under LL vs. HL. Variations in photosynthetic electron transport can be caused by dynamic changes in light [i.e., sinusoidal light phases that mimic diel light periods (Schuback and Tortell, 2019) or pulses of light which may simulate changes in cloud cover or mixing events (Bonnafant et al., 2019)]. In contrast, under steady state growth conditions light absorption is balanced with downstream carbon metabolism and other adaptive growth strategies (MacIntyre and Cullen, 2005), and any VOCs produced can be attributed to metabolism that is tuned for that species and light intensity. In our experiments *D. tertiolecta* and *T. weissflogii* exhibited steady state growth rates and Chl consistent with balanced growth in their high and low light conditions (Table 1; Figure 1; Geider, 1987; Fisher and Halsey, 2016).

In this study, the distinct collections of VOCs observed in the different species showed species-specific VOC production. Nevertheless, oxygen-containing VOCs dominated the VOC pools in both species. Oxygen-containing VOCs are often the most frequently recorded and abundant components of the marine VOC pool, partly because they are also abundant in the atmosphere and exhibit positive and negative air-sea flux depending on season and latitude (Dixon et al., 2013; Yang et al., 2014b; Beale et al., 2015; Mungall et al., 2017; Davie-Martin et al., 2020). Acetaldehyde and methanol are other important and commonly observed oxygen-containing VOCs, but neither were detected in our treatments. Instead, among oxygen-containing VOCs, acetone dominated the VOC profile in LL *D. tertiolecta*, and ethanol dominated the VOC pool in *T. weissflogii*.

In addition to being produced by algal metabolism (Collins and Kalnins, 1966; Sinha et al., 2007; de Bruyn et al., 2011; Kieber et al., 2024), VOCs including acetaldehyde and acetone can be produced through abiotic photodegradation of DOC (de Bruyn et al., 2011; Kieber et al., 2024). In the current study we did not attempt to separate VOCs derived from DOC photodegradation from those produced directly by algal metabolism. Future experiments could collect culture “spent media,” (i.e., remove the algal cells) and expose it to light to derive the VOCs produced via a sequential biological-abiotic process. In this sequential VOC production process, algal released DOC may be acted upon by photochemistry generating VOCs. This sequential process can sometimes account for the majority of acetaldehyde and acetone production (Dixon et al., 2013), whereas other reports do not observe evidence of a photochemical source of VOCs (Yang et al., 2014a).

Dunaliella tertiolecta only produced detectable VOCs, including acetone, isoprene, methanethiol, and other unknown VOCs, during steady state growth in LL. Acetone was previously shown to increase in *D. tertiolecta* with short term (5 min) increases in light exposure (Halsey et al., 2017). Acetone is produced from acetoacetate, a product of fatty acid β -oxidation. Acetone produced via fatty acid recycling in LL *D. tertiolecta* may reflect an auxiliary energy system in addition to photosynthetic electron transport (Becker et al., 2018). The absence of any VOCs detected in HL *D. tertiolecta*

suggested that during faster growth in high light, energy was less limiting, possibly facilitating more efficient retention of high energy molecules. For example, during fast growth volatile metabolites could be maintained in sufficiently small pools that their diffusion into the media was prevented.

The absence of detectable isoprene in HL *D. tertiolecta* may seem surprising considering isoprene's positive correlation with high light stress (Meskhidze et al., 2015) where isoprene has been postulated to quench reactive oxygen species providing a protective response similar to terrestrial plants (Dani and Loreto, 2017). However in our study, neither super-saturating light intensities (i.e., light levels $>200 \mu\text{E}$) nor exposure to short-term pulses of high light were applied to the treatments, such that an isoprene protective response in HL *D. tertiolecta* may not have been needed. In the LL treatment, *D. tertiolecta* produced small amounts of isoprene, in agreement with previous research (Bonsang et al., 2010; Exton et al., 2012). Isoprene is also a precursor for chlorophyll biosynthesis, and Chl increases with decreasing light availability (Geider, 1987; Behrenfeld et al., 2008), thus isoprene production in LL *D. tertiolecta* is likely related to higher Chl compared to HL *D. tertiolecta* (Table 1). Supporting this interpretation, isoprene production was highest in the deep chlorophyll maximum in a freshwater lake (Steinke et al., 2018) and during marine phytoplankton blooms and in coastal regions (Dawson et al., 2021), where light becomes increasingly limited by high biomass. Together these results suggest that light limited growth may be an important and currently unrecognized source of isoprene.

Methanethiol in axenic algae is produced through intracellular metabolism of dimethylsulfoniopropionate (DMSP), an abundant osmolyte. In healthy, actively growing cells, DMSP is most likely degraded to methanethiol via demethiolation of methylmercaptopropionate (Kameyama et al., 2011). Methanethiol production was highest in the Subarctic North Atlantic Ocean during November when phytoplankton growth rates were severely light limited compared to May when methanethiol production was low and growth rates were maximal (Davie-Martin et al., 2020; Fox et al., 2020). Similarly, a low level of methanethiol was detected in LL but not HL *D. tertiolecta*. These results are consistent with data showing DMSP content increases with decreasing growth rate in low DMSP producers, such as the species used in our study (Keller et al., 1989; Matrai and Keller, 1994), under balanced growth conditions (McParland et al., 2020). We did not detect methanethiol in steady state LL or HL *T. weissflogii*. The closely related diatom, *Thalassiosira pseudonana* increases DMSP content during imbalanced growth (McParland et al., 2020), and thus, it is possible that such short-term stresses would also increase DMSP and methanethiol production in *T. weissflogii*.

The collection of VOCs produced in *T. weissflogii* were nearly the same across both light treatments. Ethanol, m/z 47.047, was highly produced in HL and LL *T. weissflogii* but was not detected in *D. tertiolecta*. Flux-based analysis indicated that *T. pseudonana* releases ethanol as a fermentation product to balance cellular redox state (NADH/ATP) across a wide range of light-driven growth rates (Van Tol and Armbrust, 2021). *Dunaliella tertiolecta* adopts a different strategy to control redox balance and protect the photosynthetic electron transport chain. For this purpose, *D. tertiolecta* channels excess electrons into glycerol

synthesis (Goyal, 2007; Ng et al., 2014; Demmig-Adams et al., 2017), which may explain the absence of ethanol in steady state *D. tertiolecta*.

We attribute the 2.7 to 5.5-fold greater VOC production in *T. weissflogii* compared to LL *D. tertiolecta*, and similarities/differences in the types of VOCs produced in the different species, to generalized adaptive strategies of the two algal species. The chlorophyte, *D. tertiolecta* is adapted to relatively stable, well-lit waters with moderate nutrient concentrations. In contrast, diatoms can sometimes dominate the community composition of blooms (Platt et al., 2009; Malviya et al., 2016) because of their physiological capacity to achieve fast growth rates and efficient biomass accumulation in deeply mixing, light limited waters (Behrenfeld et al., 2021; Penta et al., 2021). The steady state growth conditions in our experiments likely mimic the adapted niche of *D. tertiolecta* where it balanced metabolism by tightly controlling light harvesting and carbon metabolism, thus limiting metabolic overflow (Halsey and Jones, 2015; Braakman et al., 2017; Zavřel et al., 2019). This appears especially evident in HL *D. tertiolecta*, in which no VOCs were observed. The low levels of VOCs observed in LL *D. tertiolecta* were associated with greater reliance on energy generating pathways (acetone) and increased Chl (isoprene) and DMSP (methanethiol) in low light. It is possible that the highly variable conditions in which diatoms find success require less stringent control on metabolite pools. The consistency of VOC types observed in fast and slow growing *T. weissflogii* was contrary to our hypothesis that VOCs would vary depending on metabolic pathways that dominate depending on growth rate (Halsey and Jones, 2015). Another possibility is that the constitutive production of VOCs in *T. weissflogii* reflects VOC use as grazing deterrents, such as DMS in coccolithophores (Shemi et al., 2021).

If the contrasting VOC production patterns in the species we studied are a result of their adaptive strategies, then exposure of these species to unpredictable pulses of light should reverse the observed patterns, such that *D. tertiolecta* produces a wider array of VOCs in greater quantities, and the patterns observed in *T. weissflogii* are unaffected (i.e., they would be similar to HL and LL *T. weissflogii* in Figure 2). Future studies that evaluate a wider range of phytoplankton taxa and their responses to nutrient limited growth rates may reveal other patterns that are important for understanding VOC accumulation in the surface ocean.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: <https://www.bco-dmo.org/dataset/928006>.

Author contributions

HA: Data curation, Formal Analysis, Investigation, Methodology, Visualization, Writing – original draft. HB: Data curation, Methodology, Visualization, Writing – review and editing. KH: Conceptualization, Formal Analysis, Funding

acquisition, Investigation, Supervision, Writing – review and editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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