Exploration of marine lichenized fungi as bioindicators of coastal ocean pollution in the Boston Harbor Islands National Park

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Summary

- We examined the distribution of intertidal lichen communities in the Boston Harbor Islands National Park with respect to recorded pollution measurements
- We found significant negative associations among pollution measurements and observations of lichen community health and significant differences in species composition between areas of higher and lower pollution
- Marine lichens are challenging to collect and identify, making them difficult to use broadly as bioindicators
- We recommend further research to understand differential effects of pollution on particular species and to establish practical procedures for quantifying marine lichen community health

Introduction

- Lichens are frequently used as bioindicators of air quality because of the sensitivity of some species to various pollutants (Brodo 1966)
- Freshwater aquatic lichens display sensitivity to pollution such as acidification (Gilbert 2000; Gilbert and Giavarini 1997), eutrophication (Gilbert 2000), siltation (Gilbert 1996), and heavy metal pollution (Bruns et al. 1997)
- The bulk of work on marine lichen response to pollution took place during a lichen die-off in response to emulsifiers employed after the Torrey Canyon oil spill (Fletcher and Crump 2002; Ranwell 1968; Brown 1972; Brown 1973; Gilbert 2001)
  - Other work focuses on algae but suggests heavy metal sensitivity of maritime lichen *Ramalina siliquosa* (Huds.) A.L. Sm.
  - There is no literature on the general use of marine lichens as bioindicators of coastal pollution
- This study focuses on marine lichens in the Verrucariales and Collemopsidiales, especially in the genera *Verrucaria, Wahlenbergiella, Hydropunctaria,* and *Collemopsidium* (Figure 1)
- Boston Harbor has been historically subjected to sewage and industrial discharge, and varied land use histories and exposures to pollution of the Boston Harbor Islands make them an ideal study location for examining lichen response to ocean pollution ("Boston Harbor Islands", Lefebvre et al. 2002; Taylor 2018)
- The Massachusetts Water Resources Authority (MWRA) has been monitoring pollution in the harbor for decades (Taylor 2018)

Figure 1: Intertidal lichen species in the genera *Verrucaria* and *Wahlenbergiella* (Black crusts on rocks)

Figure 2: Map of Boston Harbor Islands National Park (Haelewaters et al. 2015), plot locations marked by gray dots (excluding plot IHP1, taken near the visitor center on Long Wharf). Areas of the map colored black are part of the Boston Harbor Islands National Park.

Methods

- We compared lichen distribution and health with existing pollution sources and measurements
- Pollution measurements included nitrogen, chlorophyll-a, total suspended solids (TSS), turbidity, depositional/erosional sediment, and the heavy metal pollution of the Weir River Area of Critical Environmental Concern (SW corner of harbor) (Lefebvre et al. 2002; Pahlevan et al. 2018; Taylor 2018)
- Lichen health and distribution was examined by observing 33 randomly selected 1 meter wide intertidal transects along the shore of five islands and the inner harbor based on accessibility and distance from historical or current point-sources of pollution.
  - Species richness was measured by identifying samples using Taylor's key (1982), with select verification by DNA sequencing (Dneasy PowerPlant Pro Kit, QIAGEN)
  - Perithecial density was estimated by finding the average number of perithecia within three, 1 cm squares placed on each collected specimen using a dissecting microscope
  - Estimating percent lichen cover and size and number of thalli for each species involved field observation and transect images
- All statistical analyses are non-parametric with $\alpha = 0.05$
- Multivariate analyses use 4 groups of plots determined by turbidity measurements near each plot: Low pollution (7.5-10], Medium-low (10-12.5], Medium-high (12.5-15], High (15-17.5] (all units Spectral Remote Sensing Reflectance (S_{rs}))
  - Spearman's Rho with two-tailed significance test
  - Non-metric Multidimensional Scaling using the species composition of each group of transects
    - ANOSIM and SIMPER to test for significance and patterns in the differences in species composition observed in NMDS

Conclusions

- Compelling evidence that marine lichens could serve as bioindicators of coastal water pollution
- Significant negative association between measurements of pollution and percent cover of intertidal lichens (Table 1)
  - Like trends in terrestrial lichens, where health and extent deteriorate in proximity to sources of air pollution (Brodo 1966)
  - Strongest relationships: cover and chlorophyll-a (ρ = -0.60) and cover and turbidity (ρ = -0.53)
- Lichen desert in littoral zone around Weir River Area of Critical Environmental Concern
  - Zones above the intertidal zone well populated by lichen species, including *Aspicilia* and *Caloplaca* species
  - High heavy metal pollution and sediment runoff
  - In good air quality, lichens still sensitive to water quality
- Significant differences in species composition between areas of lower pollution and higher pollution (Figure 3, Table 2)
  - Low pollution group has high average between-transect similarity, four characteristic species (Table 3)
  - High pollution group has lower average similarity, characterized by two species (Table 3)
    - Differences may have to do with differential distribution within littoral zone, lichens closer to the low-tide line showing higher sensitivity (Taylor 1982)
- Cannot make conclusions about individual lichen species responses to water pollution
- Marine lichens are challenging to use as bioindicators due to hard-to-distinguish morphological characteristics and constant taxonomic revision (Nascimbene 2013)
- We recommend further research on the effect of water vs. air pollution on intertidal lichens, individual species response to pollution, and standard metrics for using marine lichens as bioindicators

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Results

Measure	Statistic	Turbidity	Chlorophyll	TSS
Cover	ρ	-0.53	-0.60	-0.34
	p (2-tailed)	0.0017	0.0002	0.0499

Table 1: Spearman's rho (ρ) and the 2-tailed p-value for ρ for the correlation between percent cover by marine lichens and turbidity, chlorophyll-a, and total suspended solids (TSS). H_0: $\rho = 0$, H_a: $\rho \neq 0$.

Group	High	Med-High	Med-Low	Low
High	-	0.0098	0.0273	0.0010
Med-High	0.0098	-	0.0116	0.0026
Med-Low	0.0273	0.0116	-	0.0007
Low	0.0010	0.0026	0.0007	-

Table 2: ANOSIM (Analysis of Similarities) pairwise p-values for significance of the difference between species composition of each pollution group. H_0: There is no significant difference between the species compositions two pollution groups, H_a: There is a significant difference.

Species	Average Similarity	Contribution %
Low pollution, Average Similarity: 87.23		
Verrucaria ditmarsica Erichsen	19.56	22.42
Collemopsidium halodytes (Nyl.) Grube & B.D. Ryan	18.54	21.25
Verrucaria halizoa Leight.	15.44	17.70
Wahlenbergiella mucosa (Wahlenb.) Gueidan & Thüs	13.94	15.98
Med-Low pollution, Average similarity: 67.61		
Verrucaria ditmarsica	29.73	43.97
Verrucaria erichsenii Zschacke	26.19	38.74
Med-High pollution, Average similarity: 40.67		
Collemopsidium halodytes	19.35	47.57
Verrucaria ditmarsica	14.40	35.41
High Pollution, Average similarity: 40.08		
Verrucaria erichsenii	16.65	41.55
Wahlenbergiella mucosa	13.51	33.71

Table 3: SIMPER (Similarity Percentages) analysis depicting the species contributing most to the between-plot similarity in each group. Species are no longer listed after 75% cumulative contribution.

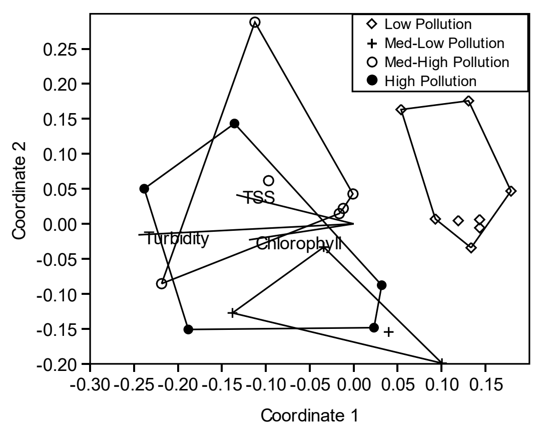

Figure 3: Non-Metric Multidimensional scaling (NMDS) plot depicting the relationship between species composition of transects at different pollution levels, including vectors for pollution measurements.

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