June 27, 2016

Oakland City Council
c/o Office of the City Clerk
1 Frank Ogawa Plaza
Oakland, CA 94612
(510) 238-3612
cityclerk@oakland.net

Oakland Department of Planning & Building
c/o Heather Klein
250 Frank Ogawa Plaza, Suite 2114
Oakland, CA 94612
(510) 238-3659
OBOT@oaklandnet.com

Re: City Hearing on Ordinance Amending the Oakland Municipal Code to Prohibit the Storage and Handling of Coal and Coke at Bulk Material Facilities Or Terminals Throughout the City of Oakland

To the Oakland City Council and Oakland Department of Planning and Building:

This letter is sent on behalf of Sierra Club, West Oakland Environmental Indicators Project (WOEIP), Asian Pacific Environmental Network (APEN), Communities for a Better Environment (CBE), SEIU 1021, and San Francisco Baykeeper, and in advance of the City Council's Special Meeting on Monday, June 27, 2016 at 5:00 p.m. on the above-mentioned ordinance.

We support the City Council passing an ordinance that prohibits the storage and handling of coal and petroleum coke throughout the City, and adopting a resolution applying the ordinance to the Oakland Army Base development. As set forth in previous comment letters and public testimony by these groups and other allies, coal storage and handling creates impermissible health and safety risks to Oakland's residents. In addition, it is a risky investment for the City because the decline in domestic and international markets for coal would lead to little financial benefit for the City while imposing significant burdens on public health and safety.

This letter provides additional materials in support of these points: (1) additional evidence of the health and safety risks of coal handling and storage; and (2) additional evidence of the continued decline in domestic and worldwide markets for coal. This letter also comments on the City's proposed ordinance and the ESA report underlying the ordinance.

We thank the City Council and Mayor for their strong leadership in protecting City residents, and urge Councilmembers to move forward with passing the aforementioned ordinance and resolution.

1. Additional Evidence of Health and Safety Impacts of Coal Handling and Storage.

This section provides additional information, not previously presented to the City Council, related to the health and safety impacts of coal handling and storage including new studies, major export terminal permit denials and other information.

Citizens throughout the nation have vigorously opposed the development and/or expansion of coal export facilities in their communities, raising similar concerns as Oakland residents about the dangers created by coal handling and storage.

- Recently, a coalition of groups filed comments on deficiencies in the environmental analysis for the proposed Millennium Bulk Terminals Longview coal export project located in Washington State. Among other things, these comments highlight: the potentially serious health impacts of the coal trade on those living near coal terminals, including the adverse air quality impacts caused by coal storage facilities; the health and safety concerns associated with coal dust releases from freight trains and coal transportation; the environmental concerns associated with coal transportation; and the greenhouse gas impacts of coal combustion and the coal trade. We provide a copy of this comment letter and relevant exhibits for your reference.[1]

- In addition, on May 9, 2016, the Army Corps of Engineers denied a Section 404 permit for the proposed Cherry Point coal export facility near Bellingham, Washington because the facility would adversely impact tribal treaty fishing rights for the Lummi Tribe.[2] The Washington Department of Natural Resources also denied a state land lease for Cherry Point based on the project's inability to obtain Army Corps permits.[3]

- Groups have already commented on the problems that coal poses to aquatic species from coal trains and coal export facilities that emit coal dust. A new study published in Nature Scientific Reports outlines the harm to aquatic species posed by coal, including coal being lethal to corals, reducing seagrasses and depressing fish growth rates.[4]

---

[1] Letter from Columbia Riverkeeper, *et. al.* to ICF International (June 13, 2016) and exhibits are submitted in a CD titled "Sierra Club-Exhibits to Comments-06.27.16" accompanying this letter.

[2] Army Corps of Engineers Decision, May 9, 2016, accessed: http://www.nws.usace.army.mil/Portals/27/docs/regulatory/NewsUpdates/160509MFRUADeMinimisDetermination.pdf**.** US Denies Permit for Coal Terminal in Washington State, NY Times, May 9, 2016, accessed: http://www.nytimes.com/2016/05/10/us/washington-state-army-corps-denies-permit-coal-terminal.html?_r=0; Mary Ann Hitt, Huffington Post, "US Government Upholds its Treaty Obligations – Rejects Giant Coal Export Terminal" (May 9, 2016); *available at* http://www.huffingtonpost.com/mary-anne-hitt/us-government-upholds-its_b_9874710.html;

[3] http://www.bellinghamherald.com/news/local/article82228107.html

[4] Berry, et. Al. Simulated coal spill causes mortality and growth inhibition in tropical marine organisms, Nature Scientific Reports, April 22, 2016, accessed: http://www.nature.com/articles/srep25894, attached hereto as **Exh. A.**

- Another study that was accepted for publication before the September 21, 2015 Oakland City Council hearing but had not yet been published is also included for the record.[5] This study, authored by Dr. Daniel A. Jaffe at the University of Washington, discusses coal train pollution and found that coal trains emit airborne coal dust in the respirable form of PM2.5 that would put some homes near rail lines in Washington above the National Ambient Air Quality Standards for fine particulate matter ("PM 2.5"), among other conclusions.

- The Virginia Department of Public Health has also found that in the coal export community of Newport News, health problems associated with coal handing exist. In the southeast community of Newport News, asthma is the number one reason for emergency room visits, and 42% of residents expressed grave concern over coal dust from the coal piers.[6]

- Various groups previously commented on the safety risks associated with coal storage and transportation, largely focusing on rail transportation. Coal transportation on ocean vessels – which would occur if a coal export terminal is built on the Oakland waterfront – also creates dangerous risks to the health of marine environments. It was only a few years ago that the Cosco Busan oil spill caused major damage to the San Francisco Bay. We also provide additional evidence of the risk of shipping accidents associated with marine coal transport.[7]

- A major public health report discussing the impacts of coal transport through Oakland was recently published that provides additional support for the city's proposed ban on coal and petcoke.[8]

In short, as supported by numerous scientific studies, coal and petcoke handling and storage creates impermissible health and safety risks to the communities and environments surrounding the Port, and such activities should not be allowed in Oakland. The City of Oakland's staff recommendation to ban the loading, unloading or transfer of coal and petcoke should be adopted by City Council.

2. **Additional Evidence of Coal as a Risky Investment.**

In addition to creating serious health and safety risks, coal is a risky investment for Oakland, and will not bring the jobs and revenues promised by the developers.

Coal is a dying industry, and does not have any part in the economy of a modern and forward-looking city like Oakland. Since the City held its last public hearing on coal on September 21, 2016, a number of coal

[5] Jaffe et al. Diesel Particulate Matter Emission Factors and Air Quality Implications from In-Service Rail in Washington State, USA, Atmospheric Pollution Research 5 (2014), http://www.atmos.washington.edu/jaffegroup/uploads/Jaffe_2014_trains_final.pdf, attached as **Exh. B.**

[6] Health Needs Assessment, Southeast Community of Newport News, Peninsula Health District, Virginia Department of Public Health, 2005, attached hereto as **Exh. C.**

[7] The Center for Media and Democracy, "Coal Transportation Accidents," *available at* http://www.sourcewatch.org/index.php/Coal_transport_accidents.

[8] An Assessment of the Health and Safety Implications of Coal Transport through Oakland, Public Health, Public Health Advisory Panel on Coal in Oakland, California June 14, 2016, http://www.humanimpact.org/wp-content/uploads/Assessment_Health_Safety_Coal_Oakland.pdf.

companies have declared bankruptcy, including the world's largest coal producer Peabody Energy and other large operations like Arch Coal, Walter Energy Inc., and Alpha Natural Resources, Inc.[9] By some accounts, over a quarter of the companies in the coal industry are in bankruptcy.[10] [11]

The coal company behind the Oakland project, Bowie Resource Partners, recently suffered two credit rating downgrades from Moody's and S&P Global Ratings, "given [a] perceived fundamental shift in the operating environment".[12] Like many other companies in the coal industry, questions have also been raised about whether Bowie Resource Partners might itself also be on the brink of bankruptcy.[13] Several Utah groups, including partners of the undersigned, have noted the dubious legality of the Utah investment scheme in the proposed Oakland coal terminal.[14]

As pointed out by numerous business leaders and concerned citizens throughout the City's public process, the City should foster green and clean businesses and jobs, and the City should not invest its limited resources in propping up a dying industry that contributes to climate change and creates significant local health and safety issues.[15]

3. **Comments Related to Proposed Ordinance.**

The undersigned groups support a strong Oakland ordinance that restricts the ability to handle, store, or transfer coal due to the grave health and safety concerns expressed by our groups, and supported by overwhelming scientific evidence.

---

[9] Charles Riley and Chris Isidore, CNN, "The largest U.S. coal company just filed for bankruptcy" (April 13, 2016); *available at http://money.cnn.com/2016/04/13/news/companies/peabody-coal-bankruptcy/* ; John W. Miller, Wall Street Journal, "Arch Coal Files For Bankruptcy," (Jan. 11, 2016); *available at http://www.wsj.com/articles/arch-coal-files-for-bankruptcy-1452500976*

[10] John W. Miller, Wall Street Journal, "Arch Coal Files For Bankruptcy," (Jan. 11, 2016); *available at http://www.wsj.com/articles/arch-coal-files-for-bankruptcy-1452500976*

[11] Mary Ann Hitt, Huffington Post, "US Government Upholds its Treaty Obligations – Rejects Giant Coal Export Terminal" (May 9, 2016); *available at* http://www.huffingtonpost.com/mary-anne-hitt/us-government-upholds-its_b_9874710.html; *see also* http://www.nws.usace.army.mil/Portals/27/docs/regulatory/NewsUpdates/160509MFRUADeMinimisDetermination.pdf, attached hereto as **Exh. D.**

[12] Moody's Downgrades Bowie to Coa1, Outlook stable, March 2016, https://www.moodys.com/research/Moodys-downgrades-Bowie-to-Caa1-outlook-stable--PR_346665, attached hereto as **Exh. E.** *See also* S&P downgrades coal miner Bowie to CCC+ due to 'unsustainable' commitments, SNL , June 14, 2016, https://www.snl.com/InteractiveX/ArticleAbstract.aspx?id=36819814.

[13] Is Bowie Resource Partners the Next Bankruptcy?, IEEFA, April 13, 2016, http://ieefa.org/bowie-resources-next-bankruptcy%E2%80%A8/, attached hereto as **Exh. F.**

[14] *See* Letter Re: Request To Investigate The Misuse Of $53 Million In Mineral Leasing Act Payments To Utah To Fund A Private Coal Export Terminal In Oakland, June 20, 2016, accessed:.http://earthjustice.org/sites/default/files/files/FINAL%20letter%20to%20investigate%20CIB%20loan_0.pdf, **Exh. G.**

[15] *See, e.g.* E2 letter to Oakland City Council, April 15, 2016 (signed by business leaders from the Bay Area and across California), attached hereto as Exh H.

If exemptions to such an ordinance must be given, as outlined in Section 8.6.040(D) of the proposed ordinance, the process to obtain such an exemption must have stronger notice provisions. As currently written, the procedure to obtain an exemption runs through the office of the City Administrator and there are no notice provisions to alert interested parties about exemption applications and/or decisions. This is of particular concern due to the short time period of 10 days to file an administrative appeal of a decision granting an exemption. As such, we request that all persons living within a quarter-mile from a proposed exemption be given notice of an application for an exemption and/or have the exemption proceeding be run through a city commission that publishes agendas of its meetings, such as the Planning Commission, in order to ensure that the public has adequate notice and the opportunity to participate in any such proceedings.

4. **Comments Related To The City's Staff Report and ESA Study.**

The undersigned groups generally applaud the conclusions reached in the City's Staff Report, the ESA Study, and Dr. Zoe Chafe's study. There are a few minor points of clarification.

The City Staff Report asserts that "The Burlington Northern and Santa Fe (BNSF) Railway requires an 85% reduction in coal dust through the use of a topping agent or surfactant for Wyoming or Montana."[16] BNSF Railway has a tariff that suggests the application of one or a few different types of surfactants, and load profiling. Allegedly, some of the approved surfactants have an efficacy of up to 85%. It is not accurate that an 85% reduction in coal dust is required for coal originating from Wyoming or Montana. As City Staff and ESA correctly point out, the surfactant dust reduction figures are all based on BNSF studies that are not publicly available. In addition, the ESA report makes overly conservative estimates on coal dust emissions because it assumes an 85% control while also pointing out that topping agents are ineffective and covers are unproven.[17] Further, as Dr. Chafe's study supports, coal originating in Utah and shipped on Union Pacific lines has no sort of dust mitigation requirement at all.[18]

The City Staff Report indicates that the action may have a potential fiscal impact.[19] The undersigned groups would like to note that based on their conversations and research, the California Transportation Commission (CTC) has never come after a grantee entity, such as the City, requesting that money be repaid. It is also our understanding that the Oakland portion of the CTC money has already been spent. Finally, the City of Oakland has in the past requested a

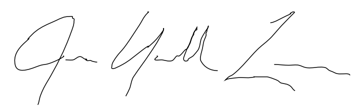
[16] City Staff Report at 11.
[17] *See* Dr. Phyllis Fox, 6-27-16 letter, attached hereto as **Exh I (and its accompanying Exh. 1)** at 2.
[18] Dr. Chafe Report at note 252: "Union Pacific does not require the use of surfactants on coal shipped by rail from Utah, according to a newspaper report from April 2016. A spokesperson for the railroad company said that coal is shipped in open cars, but that Utah coal is considered by the company to be less dusty than coal from Wyoming, which is why surfactant is not required. This raises the question of whether coal arriving in Oakland via Union Pacific would have any dust mitigation measures applied, as well as whether the developers would be permitted to consider using any dust mitigation measures when shipping via Union Pacific. "A spokesman for Union Pacific said it ships coal in uncovered or open cars. Wyoming coal is sprayed with a topping agent to reduce dust. Coal from Utah is not as dusty and is not sprayed, UP officials said." Bizjack, T. (2016). "California, clean fuel leader, weighs oil, coal trains," Sacramento Bee, April 3."
[19] City Staff Report at 21.

restructuring and extension of time on matching funds for this very loan, making it very likely another extension would be given.

Furthermore, the weight of authority provided to the City denotes the great instability posed by a long-term investment in the coal industry given the vast number of coal bankruptcies and long-term market changes. The fiscal impact part of the City Staff Report does not discuss coal industry instability and the long-term impact of building a coal terminal that could well require the City to later bail it out, as was the case in Los Angeles and Portland.[20] Finally, the volume of information discusses the serious public health and safety impacts caused by coal and petcoke, all of which have a fiscal impact to the residents and to the City. As such, the City and its residents will incur a serious negative financial impact if the Council does not adopt an ordinance restricting coal handling, storage and transfer.

In conclusion, we urge the Oakland City Council to adopt the staff recommended ordinance to ban coal and petcoke based on health and safety grounds, and the resolution to apply the ordinance to the former Army Base.

Sincerely,



Jessica Yarnall Loarie
Staff Attorney
Sierra Club Law Program
2101 Webster St, Suite 1300
Oakland, CA 94612
Tel: (415) 977-5636
Jessica.yarnall@sierraclub.org

On behalf of Sierra Club, WOEIP, APEN, CBE, SEIU 1021 and San Francisco Baykeeper.

cc: Honorable Mayor Libby Schaaf

[20] City Staff Report at 17-18 and ESA and 2-20, 2-21 noting demise of the coal terminals at the Port of Los Angeles and Port of Portland costing the cities and taxpayers $19 million and $25 million to build respectively. The City of Los Angeles also had to pay $28 million to settle a lawsuit, and wrote off $94 million in expected revenue.

www.nature.com/scientificreports

SCIENTIFIC REPORTS

OPEN

Simulated coal spill causes mortality and growth inhibition in tropical marine organisms

Received: 16 October 2015
Accepted: 22 April 2016
Published: 13 May 2016

Kathryn L. E. Berry[1,2,3,4], Mia O. Hoogenboom[1,4], Florita Flores[2] & Andrew P. Negri[2]

Coal is a principal fossil fuel driving economic and social development, and increases in global coal shipments have paralleled expansion of the industry. To identify the potential harm associated with chronic marine coal contamination, three taxa abundant in tropical marine ecosystems (the coral *Acropora tenuis*, the reef fish *Acanthochromis polyacanthus* and the seagrass *Halodule uninervis*) were exposed to five concentrations (0–275 mg coal l^{-1}) of suspended coal dust ($<63\,\mu m$) over 28 d. Results demonstrate that chronic coal exposure can cause considerable lethal effects on corals, and reductions in seagrass and fish growth rates. Coral survivorship and seagrass growth rates were inversely related to increasing coal concentrations (≥ 38 mg coal l^{-1}) and effects increased between 14 and 28 d, whereas fish growth rates were similarly depressed at all coal concentrations tested. This investigation provides novel insights into direct coal impacts on key tropical taxa for application in the assessment of risks posed by increasing coal shipments in globally threatened marine ecosystems.

The international trade of coal is highly dependent on transportation by sea, and coal shipments continue to increase on a global scale[1]. Recent scientific, political and public opinion has raised concerns regarding the increase in coal mining and shipping adjacent to sensitive tropical coastal environments, including World Heritage listed sites such as the Great Barrier Reef (GBR)[2]. To date, major concerns about these activities have pertained to increased dredging to facilitate port access for coal vessels, and the burning of coal increasing greenhouse gas emissions. However, growth in seaborne coal trade has also been accompanied by increased shipping accidents that have potential to cause widespread damage to marine ecosystems. For instance, the groundings of the bulk coal carriers *Castillo de Salas* (Spain, 1986), *Eurobulker IV* (Italy, 2000) and *MV Smart* (South Africa, 2013) released between 17,000 and 100,000 tons of unburnt coal into the marine environment[3,4]. Calm weather conditions helped prevent 68,000 tons of coal on board the grounded *Shen Neng I* from spilling onto the GBR in 2010[5].

Despite the occurrence of these large-scale incidents over a period of several decades, there is currently no scientific consensus on the levels at which unburnt coal becomes a threat to the health of tropical marine organisms. Although seaborne coal trade is highest in tropical regions (Indonesia and Australia)[1], studies of coal impacts on marine environments have generally been conducted in temperate regions where, for example, long-term colliery waste contamination was linked with declines in species richness and diversity[6]. The paucity of knowledge on coal impacts in tropical environments means that we are unable to competently assess the potential threats of accidental release of coal into tropical marine environments.

Other forms of particulate matter contamination in seawater (e.g., sediment) can reduce the growth and survival of tropical marine organisms by reducing light penetration into water and by smothering tissues through direct deposition of particles onto organisms[7,8]. Similarly, direct pathways for organism harm by coal are likely to include suspended particles, increased light attenuation from turbidity, and smothering of sessile benthic organisms, leading to reduced photosynthesis and feeding[9]. In addition, coal may contain contaminants such as polycyclic aromatic hydrocarbons (PAHs) and trace metals, and a fraction of these contaminants can be released from coal dust into the surrounding seawater[9–11]. Metals can be toxic to marine species by disrupting enzyme activity and membrane structure, but the effects of metals are highly dependent on speciation and bioavailability[12]. PAHs

[1]College of Science and Engineering, James Cook University, Townsville, Queensland, Australia. [2]Australian Institute of Marine Science, Townsville, Queensland, Australia. [3]AIMS@JCU, Australian Institute of Marine Science and James Cook University, Townsville, Queensland, Australia. [4]ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, Queensland, Australia. Correspondence and requests for materials should be addressed to K.L.E.B. (email: kathryn.berry@jcu.edu.au)

Treatment	TSC	Light	Light attenuation (%)	Coal deposition (vials)	Coal deposition (pods)	Temperature	Dissolved oxygen	pH
	n = 35–39	n = 12	n = 12	n = 36	n = 22–27	n = 30	n = 27	n = 9
Control	0	177 ± 8.59	–	0	0	26 ± 0.15	8.5 ± 0.02	8.1 ± 0.02
Low	38 ± 6	99 ± 9.39	44	11 ± 1.99	2.3 ± 0.24	26 ± 0.13	8.3 ± 0.03	8.0 ± 0.00
Moderate	73 ± 11	21 ± 3.76	88	38 ± 4.94	11 ± 1.48	26 ± 0.10	8.3 ± 0.02	8.0 ± 0.00
Medium	202 ± 32	1.9 ± 0.70	99	126 ± 24	25 ± 3.16	27 ± 0.09	8.2 ± 0.02	8.0 ± 0.00
High	275 ± 36	1.1 ± 0.32	99	241 ± 37	46 ± 4.25	26 ± 0.10	8.3 ± 0.02	8.0 ± 0.00

Table 1. Summary of water quality parameters. Mean (±s.e.m.) total suspended coal (TSC) (mg l^{-1}), light (PAR, μmol photons $m^{-2}s^{-1}$), light attenuation (% rel. to 0 mg coal l^{-1}), coal deposition rates (mg cm^{-2} day^{-1}) in glass vials and deposition pods, temperature (°C), dissolved oxygen (mg l^{-1}) and pH. Note: Mean deposition of particulate matter in control treatments (7.3 mg l^{-1} for TSC, 5.2 and 0.7 mg cm^{-2} day^{-1} for vials and pods, respectively) was subtracted from all coal treatments to depict only coal suspension and deposition. Variation in TSC and deposition over time are presented in Supplementary Material Fig. S1. n = total replicates per treatment over the experiment duration.

Element	Leach test (μg l^{-1}) from each coal treatment				
	Control (0 mg l^{-1})	Low (38 mg l^{-1})	Moderate (73 mg l^{-1})	Medium (202 mg l^{-1})	High (275 mg l^{-1})
Arsenic (As)	1.2 ± 0.1	1.4 ± 0.1	1.5 ± 0.1*	1.4 ± 0.1	1.4 ± 0.0
Cadmium (Cd)	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.1 ± 0.0
Cobalt (Co)	0.0 ± 0.0	0.1 ± 0.0*	0.1 ± 0.0*	0.2 ± 0.0*	0.1 ± 0.0*
Copper (Cu)	0.3 ± 0.1	0.5 ± 0.1	0.5 ± 0.1	0.5 ± 0.1	0.5 ± 0.3
Lead (Pb)	0.0 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Manganese (Mn)	0.3 ± 0.1	0.3 ± 0.1	0.4 ± 0.1	0.6 ± 0.1	0.6 ± 0.2
Molybdenum (Mo)	11.3 ± 0.2	11.0 ± 0.5	11.4 ± 0.5	12.0 ± 0.2	12.1 ± 0.1
Nickel (Ni)	0.5 ± 0.1	1.1 ± 0.2	1.8 ± 0.4	2.9 ± 0.8*	2.6 ± 0.5
Zinc (Zn)	2.1±0.7	2.9 ± 1.1	3.0 ± 0.9	2.5 ± 0.3	2.9 ± 0.8

Table 2. Elemental analysis (μg l^{-1}) from water samples (n = 3) in each treatment (mean ± s.e.m.). Coal treatments where levels were significantly different from the control treatment (ANOVA, one-way analysis of variance) are depicted with a*.

affect organisms via non-specific narcosis[13] and can be carcinogenic and mutagenic to marine life[14]. Sub-lethal chronic effects may include reduced growth, decreased fecundity and reproductive failure; however, the response to PAHs also varies greatly with bioavailability and the capacity of organisms to detoxify during metabolism[15].

We evaluated lethal and sub-lethal coal concentrations by quantifying the effects of suspended coal dust and coal dust deposition on key demographic rates (growth, mortality) of coral (*A. tenuis*), fish (*A. polyacanthus,* spiny chromis) and seagrass (*H. uninervis*). The potential effects of coal on key representative species from the tropics, measured here for the first time, is critical for the development of appropriate risk assessments and policy development associated with the safe and sustainable shipment of coal through the GBR and other tropical ecosystems of high ecological value.

Results and Discussion

Water Quality in Experimental Treatments. Experimental treatments of suspended and settling coal particles mimicked five broad pulse intensities (ranging from 0–275 mg coal l^{-1}, Table 1) lasting 28 d. Attenuation of light in coal treatments ranged from 44–99%, relative to control values (Table 1). Coal deposition rates ranged from 11–241 mg $cm^{-2}d^{-1}$ in sediment traps and 2–46 mg $cm^{-2}d^{-1}$ on flat surfaces (pods) (Table 1, Supplementary Material Fig. S1). Trace metal analysis of experiment treatment water (filtered leachate) sampled at 28 d showed significantly ($P < 0.05$) higher concentrations of arsenic, cobalt and nickel in certain coal treatments in comparison with control water (Table 2). However, the highest metal concentrations were not always measured in the highest coal treatments. The magnitude of change in dissolved metal concentrations in relation to control seawater was minimal: arsenic varied by 0.3 μg l^{-1}; cadmium 0.1 μg l^{-1}; cobalt 0.2 μg l^{-1}; copper 0.2 μg l^{-1}; lead 0.1 μg l^{-1}; manganese 0.3 μg l^{-1}; molybdenum 0.8 μg l^{-1}; nickel 2.4 μg l^{-1}; zinc 0.9 μg l^{-1}. These findings suggest that metals were not likely contributing to the observed effects.

Although the tanks were moderately turbulent (water flow of 5–10 cm sec^{-1}) due to the presence of pumps, the coal particles attached to many surfaces within the tanks, contributing to lower total suspended coal (TSC) exposures in the latter half of the four week pulse (Supplementary Material Fig. S1). While there is limited evidence documenting the concentrations of suspended coal present in seawater during a spill event, our high coal treatment (275 mg coal l^{-1}) was lower than the concentrations applied to temperate species in other experimental studies (500–13,500 mg coal l^{-1})[16,17]. Moreover, the results of the present experiment may be considered conservative in relation to the broader effects of coal during a spill event as we only investigated the effects of fine

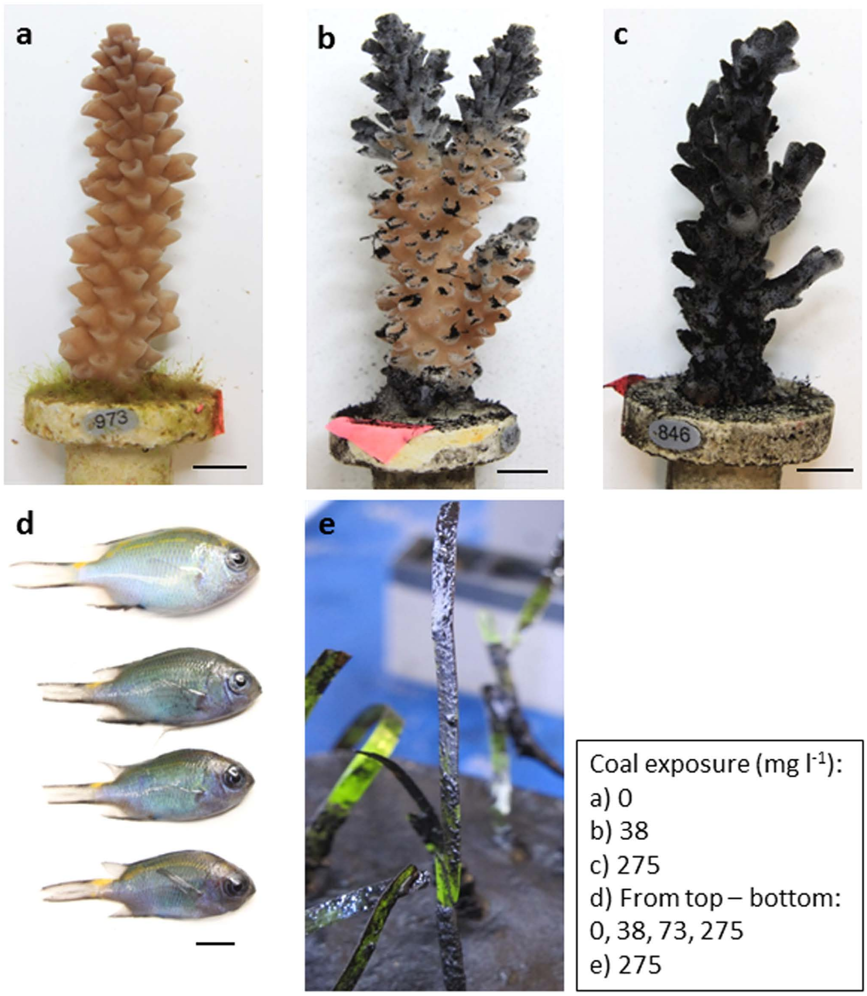


Figure 1. Comparison of three taxa after coal exposure. Stages of coral health degradation after 14 d exposure to 0 mg coal l^{-1} (**a**), 73 mg coal l^{-1} (**b**) and 275 mg coal l^{-1} (**c**). Mucus strands were used to actively remove settled coal (**b**) and coal deposition that exceeded removal efforts resulted in nubbin mortality (**c**). Fish from control vs. coal exposed treatments (0 mg coal l^{-1}–275 mg coal l^{-1}) after 28 d exposure (**d**). Coal settled onto seagrass leaves and substrate (**e**). Note: No fish were present in the 202 mg coal l^{-1} treatment. All scale bars = 5 mm.

coal particles (<63 µm) which are likely to remain in suspension for long periods[3,18]. A large spill scenario at sea would also release larger particles that settle more rapidly[3,18], posing further risks of physical damage, including smothering.

Responses of tropical marine organisms to coal exposure. *Corals.* In all coal treatments, particles settled directly onto coral polyps and connecting tissue (i.e., coenosarc, Fig. 1b,c) and the initial response of corals to coal exposure was the release of fine mucus strands, which trapped coal particles and removed them from the tissue surface, similar to the response of corals exposed to sediments[7,19,20]. Branching corals, such as *A. tenuis,* are often considered among the most resistant morphologies to sedimentation due to their vertical growth[20], yet despite their active mechanisms for coal removal; some coral tissue died and sloughed off the skeleton within 14 d in all treatments ≥38 mg coal l^{-1} (Figs 1b,c and 2a). The extent of tissue mortality on coral branches differed significantly among coal treatments (Permanova, Pseudo-$F_{4,10}$ = 43.6, P = 0.0001), and over time (Permanova, Pseudo-$F_{1,10}$ = 20.5, P = 0.0009) (Fig. 2a, see statistical outputs in Supplementary Material Tables S1 and S2). After 14 d of exposure, control and low (38 mg coal l^{-1}) coal treatments exhibited significantly lower coral mortality than treatments ≥202 mg coal l^{-1} (Student-t post hoc, Monte Carlo simulation, P < 0.05). After 28 d, mortality in all coal treatments ≥38 mg coal l^{-1} was significantly higher than the controls (Student-t post hoc, Monte Carlo simulation, P < 0.05). Corals in the control treatment exhibited less than 3% mortality, while 100% tissue mortality occurred in all branches in the three highest coal exposures (Figs 1c and 2a). Corals in the 38 mg coal l^{-1} treatment exhibited significantly lower mortality than corals in treatments ≥73 mg coal l^{-1} (Student-t post hoc, Monte Carlo simulation, P < 0.05). Pair-wise comparisons between treatments revealed lowest observed effect concentrations (LOEC) of 202 mg coal l^{-1} and 38 mg coal l^{-1} at 14 and 28 d, respectively. Fitting four-parameter

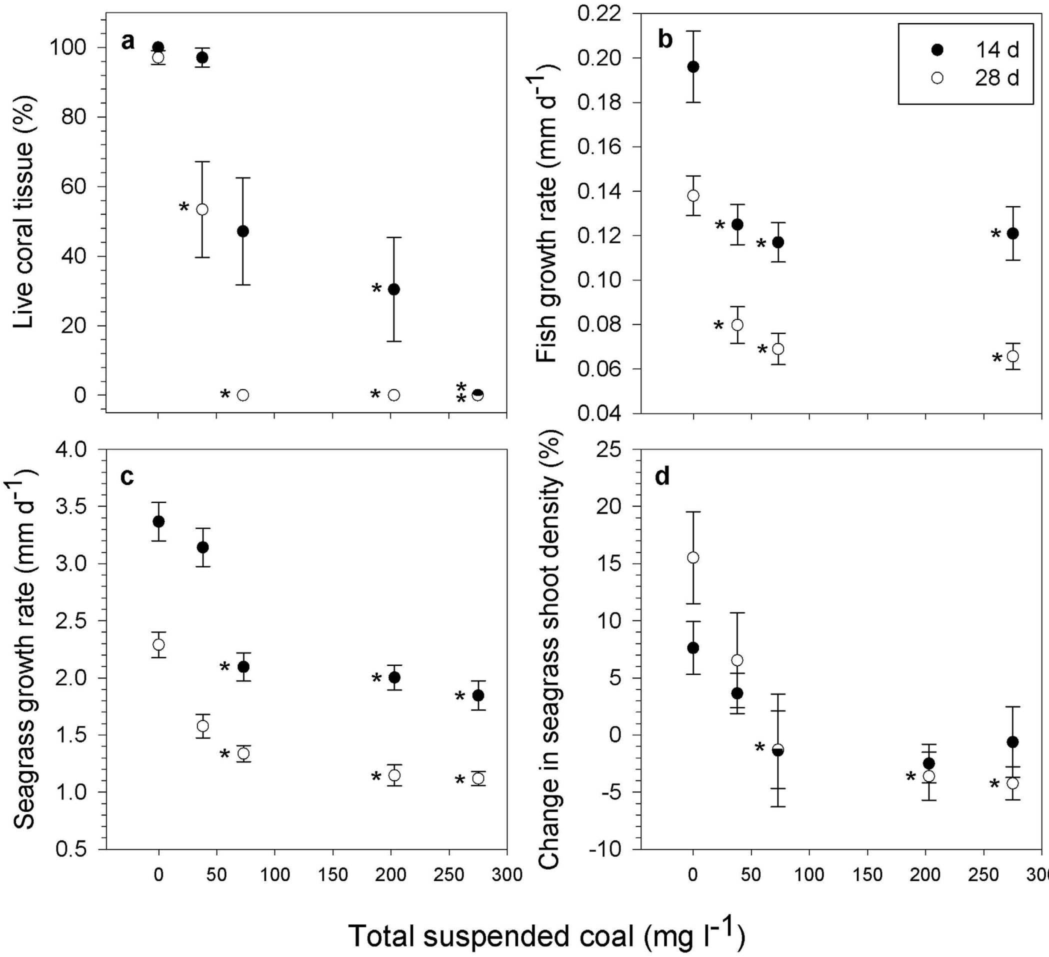


Figure 2. Differences in measures of key demographic rates in relation to coal concentration and exposure duration. Differences in the mean (±s.e.m.) survival of corals (*A. tenuis*) (**a**), growth rates of fish (*A. polyacanthus*) (**b**) and seagrass (*H. uninervis*) (**c**), and percentage change in seagrass shoot density (**d**) at 14 d (*closed circle*) and 28 d (*open circle*) exposure. Asterisks depict a significant difference ($P < 0.05$) between the mean coal treatment and control values. Note: mean change in seagrass shoot density (**d**) is relative to time 0 values at each treatment level in each replicate seagrass pot. Mean values above 0 suggest growth, while values below 0 suggest mortality. No fish were present in the 202 mg coal l^{-1} treatment.

sigmoidal curves to the data revealed lethal concentrations (LC_{10} and LC_{50}) of 29 mg coal l^{-1} and 87 mg coal l^{-1} at 14 d, respectively, and 34 mg coal l^{-1} and 36 mg coal l^{-1} at 28 d, respectively (Supplementary Material Fig. S2a).

Coral mortality in response to the suspension of fine coal particles may have a number of causes. The accumulation of coal particles on the vertical tissue could have caused anoxia at the coral-coal interface[21]. Similar surface accumulation of particles was not observed after a month in comparable exposures of *Acropora millepora* branches to fine carbonate sediments[22] and could indicate either greater adhesion by coal or reduced fitness in corals exposed to coal rather than sediments. The energetic costs of removing deposited particles (including mucus production) may be further exacerbated in the presence of coal by the strong attenuation of light over 14 and 28 d, which would reduce primary production rates by the symbiotic dinoflagellates. Although the corals were fed once per week with *Artemia* nauplii, heterotrophic feeding behaviour may have been altered in smothered sections of coral colonies[19].

Fish. The health of coal-exposed fish was compromised in all coal treatments and differences in fish size and colour were observed over the course of the experiment (Fig. 1d). Fish growth rates varied significantly between coal treatments and controls (Permanova, Pseudo-$F_{3,8.1} = 21.7$, $P = 0.01$), and over time (Permanova, Pseudo-$F_{1,8.5} = 141.4$, $P = 0.0002$) (Fig. 2b, see statistical outputs in Supplementary Material Tables S1 and S2). Significant differences in growth occurred within the first 14 d of the experiment, with fish exposed to coal levels ≥38 mg coal l^{-1} showing significantly lower growth rates than control fish, irrespective of coal treatment levels (Student-t post hoc, Monte Carlo simulation, $P < 0.05$, Fig. 2b). Growth inhibition, relative to control fish, at 14 d ranged from 36.1 ± 4.6%–40.2 ± 4.5% and 42.2 ± 6.0%–52.3 ± 4.3% at 28 d (Supplementary Material Fig. S2b). The LOEC on fish growth rates was 38 mg coal l^{-1} at both time points and linear interpolation of the growth data revealed inhibition concentration (IC_{10}) estimates of 11 and 9 mg coal l^{-1} at 14 and 28 d, respectively, and IC_{50} estimates of 73 mg coal l^{-1} at 28 d. IC_{50} estimates were not possible at 14 d because growth inhibition was below 50%.

The negative impact of coal on fish growth is consistent with the response of marine fish to increased suspended sediments which is thought to be caused by visual impairment leading to reduced prey capture success and increased foraging time and energy expenditure[23,24]. A preliminary post mortem investigation on the coal-exposed fish in this experiment revealed coal in the alimentary tracts, which was mistakenly ingested and could have physically blocked normal feeding and digestion contributing to starvation and debilitation. In addition, it is possible that suspended coal affected fish respiration[25,26], an effect that may have been consistent across all coal treatments.

Despite the considerable effects on fish growth, all coal-exposed fish survived except for two individuals that were exposed to the highest coal treatment of 275 mg coal l^{-1}. The lethal effects of suspended sediments on fish are dependent on the particle size, angularity, exposure duration, and are typically observed when concentrations reach ≥hundreds of mg l^{-1} [23,27,28]. The survival of fish in the current study, along with the very high LC_{50} (7000 mg coal l^{-1}) reported for 8 d coal exposures of juvenile coho salmon[17], support the notion that coal spills are not likely to cause direct mortality in fish under most coal spill scenarios. However, suspended sediment can prolong reef fish larvae development[29], negatively influence gill morphology and increase pathogenic bacterial communities on larval gills[30], suggesting further studies are required to investigate the vulnerability of early life stages of fish to suspended coal. Although mortality was low, certain post-settlement processes are size dependent for reef fishes[31], suggesting that lower growth rates *in situ* may have later implications on individual survivorship[23]. Moreover, as fecundity of fish is size dependent[31,32], suppressed growth can lower lifetime reproductive output.

Seagrass. Coal particles were observed to attach to the seagrass leaves less than 24 h after exposure commenced, and many leaves were completely coated in a film of coal throughout the experiment (Fig. 1e). Coal also accumulated onto the sediment surface in seagrass pots where new shoots develop (Fig. 1e). Significant differences were measured for leaf elongation (Permanova, Pseudo-$F_{4,10} = 35.9$, $P = 0.0002$) and shoot density (Permanova, Pseudo-$F_{4,10} = 9.8$, $P = 0.0002$) between experimental treatments. Leaf elongation rates differed significantly over time (Permanova, Pseudo-$F_{1,10} = 67.5$, $P = 0.0001$) (see statistical outputs in Supplementary Material Tables S1 and S2). Leaf elongation was more sensitive than shoot density and was significantly affected (Student-t post hoc, Monte Carlo simulation, $P < 0.05$) in treatments ≥73 mg coal l^{-1} (LOEC) at both 14 d and 28 d (Fig. 2c). The magnitude of the effect of coal exposure on leaf elongation rates was large, with overall growth inhibited by 6.7 ± 5.0%–45.2 ± 3.8% and 31.1 ± 4.5%–49.5 ± 3.1% relative to controls at 14 and 28 d, respectively (Supplementary Material Fig. S2c). The estimated threshold for impact for this parameter (IC_{10}) was 42 mg coal l^{-1} at 14 d and 12 mg coal l^{-1} at 28 d, while the IC_{50} was 275 mg coal l^{-1} at 28 d. IC_{50} estimates were not possible at 14 d because growth inhibition was below 50%. Shoot density continued to increase in control and 38 mg coal l^{-1} treatments throughout the experiment duration, however, was significantly reduced (Student-t post hoc, Monte Carlo simulation, $P < 0.05$) at 28 d in coal treatments ≥73 mg coal l^{-1} (28 d LOEC), with a mean net loss of 1.3 ± 3.4%–4.6 ± 1.4% of shoots at this time point (Fig. 2d).

The coal exposures may have impacted the seagrass in multiple ways. Seagrass requires light to conduct photosynthesis and the light environment was greatly affected by attenuation through the water column (Table 1). Irradiance intensity is a principal factor regulating seagrass growth and shading of surface irradiance to low levels (0.2–4.4 mol $m^{-2} d^{-1}$) has contributed to reduced leaf elongation and shoot loss in the same species[33]. In addition, the direct coating of leaves with a layer of coal particles is likely to further reduce light penetration[34]. Both types of shading and reduced transport of CO_2 into the leaves through the coal barrier will limit photosynthetic carbon fixation, chlorophyll *a* production[34] and inhibit growth[35]. Seagrasses maintain a store of carbohydrates within the root-rhizome complex and this is likely to have enabled slight positive leaf extension over the experimental exposures[36]. Although not directly measured in this experiment, coal exposure can also cause abrasive damage to aquatic plants[16,37].

Conclusions

While there were differences in sensitivity between the taxa tested here, both sessile and mobile organisms were affected by similar concentrations of coal particles. In most cases the impacts increased with suspended coal concentration and exposure duration. Although this study did not specifically investigate the stress-response pathways, it was clear that coal particles affect corals, fish and seagrass in ways that are similar to the effects of other suspended solids, including: light limitation, direct smothering and reduced feeding efficiency. Despite these similarities, coal particles appear to have more severe effects on corals than other suspended solids. For instance, chronic exposure of corals to fine carbonate sediment in a similar experimental setup resulted in only 11% mortality in branching coral *Acropora millepora* after 84 d exposure to 100 mg l^{-1} (83 mg $cm^{-2} d^{-1}$ deposition)[22], while only high levels of acute bottom sand deposition (200 mg $cm^{-2} d^{-1}$) caused mortality in branching coral *Acropora palmata*[38]. These differences may be due to coal particles attenuating light more strongly and adhering to coral to a greater extent than inorganic particles. While several metals were elevated in coal treatments in comparison with controls, the magnitude of this increase due to leaching was minimal and only the relatively low toxicity element cobalt was detected at concentrations greater than ANZECC guidelines[39]. Our results are consistent with previous studies that showed coal generally does not leach toxic levels of trace metals[10,11]. Though not measured in the present study, leaching of PAHs from coal is also generally considered low and to have very low bioavailability[3,9,40], suggesting that the measured adverse effects in the present study were primarily due to physical mechanisms.

As global demand for, and marine transport of, coal continues to increase, specific information is needed to effectively manage risks to areas of high conservation value, such as coral reefs and seagrass meadows, that may be impacted by unburnt coal from terrestrial sources and accidental spills. This first study to examine the effects of fine coal particles on tropical marine organisms demonstrates that moderate to high levels of coal contamination can substantially decrease growth and increase mortality of important reef-building coral species, reef fish and seagrass. Further research is warranted to measure the effects of coal contamination on reproduction and early life histories of corals, fish, invertebrates, as well as the effects of ingestion and smothering on sessile benthic organisms. Considering that hydrocarbon markers for coal have been identified up to 180 m offshore in the World Heritage listed GBR[41], understanding the risks posed by unburnt coal also requires an improved understanding of *in situ* chronic exposures from coastal operations[9] and potential transport into reef and seagrass systems by wind and currents. The experimental scenario applied in the present study is particularly relevant to shipping accidents, where high concentrations of unburnt coal can be present in water adjacent to globally threatened habitats. The effect thresholds of coal to coral, fish and seagrass, such as those identified here, are critically important for marine park managers, regulators, industry and shipping operators as a basis to improve risk assessments and policy development associated with safer and more sustainable shipment of coal.

Materials and Methods

Conceptual basis for experimental design. This experiment was conducted at the indoor facilities of the National Sea Simulator at the Australian Institute of Marine Science (AIMS) in June–July 2014. Thermal coal (sourced from central Queensland, Australia) was crushed, milled and sieved to isolate particles $<63\,\mu m$. Organisms were exposed to five coal treatment levels (0–275 mg coal l^{-1}) in custom 55 l flow-through tanks (n = 3 per treatment) that were designed to maintain particles in suspension, with twice daily turnovers of water. Coal suspension was aided by the sloped tank base that used gravity to draw settled particles towards an external pump that re-circulated/suspended particles, and an air stone within the tank that aided particle movement (see Supplementary Material, Fig. S3). Each treatment tank contained 9 coral (*A. tenuis*) fragments (5 cm length), 10 fish (*A. polyacanthus*, ~11 weeks old) and 3 pots of seagrass (*H. uninervis*, average 33 shoots per pot growing in sediment), with the exception of the 202 mg coal l^{-1} treatments which contained no fish.

Response variables monitored for experimental organisms during coal exposure. Growth and mortality were assessed for the study species in each experimental treatment and at two time points during the experiment (14 and 28 d). For seagrass, leaf elongation was used as a proxy for growth. Between each sampling point 5 leaves per pot (n = 45 per treatment) were haphazardly chosen and pierced 2 times with an insulin needle at the top of the sheath. The distance between the sheath holes and needle scars in the leaf were measured using callipers. New holes were made approximately 1 week prior to each sampling period. Measurements were converted into growth rate per day (mm d^{-1}). For fish, the standard length was measured in each fish 5 d prior to the commencement of the experiment and again after 14 and 28 d of coal exposure. Each fish was tagged with an individual fluorescent marker by subcutaneous injection of an elastomer dye with an insulin needle[23] and fish were measured in seawater-filled zip lock bags with hand held calipers. Seagrass and fish growth inhibition values were calculated relative to the mean control growth rates at 14 and 28 d, respectively.

Coral mortality was measured at each sampling interval. Nine random coral fragments were sacrificed by snap freezing with liquid nitrogen then photographed at 2 different (non-overlapping) angles next to a scale bar. To avoid confounding irregularities at the bases of fragments due to fragmentation and gluing, the bottom 3 mm of each branch was omitted from the measurement. ImageJ software (U.S. NIH, MD, USA http://rsb.info.nih.gov/ij/) was used to analyse the proportion of dead tissue on each coral fragment. Tissue was categorized as 1) alive = presence of pigmented or bleached tissue; 2) dead = sloughed tissue (visible skeletal structure) or coal smothered skeleton. For the seagrass, loss of above ground shoot density was used as a proxy for mortality. Prior to the commencement of the experiment and at each sampling interval individual seagrass shoots were counted in each pot. Change in shoot density was calculated by subtracting the shoot count of each pot at a time point from the initial (time 0) shoot count of the same pot. These values were converted into percentage change in shoot density relative to time 0 for each respective treatment level. Finally, fish mortality was assessed at each sampling interval by counting the number of live fish in each tank. All experimental protocols involving fish were approved by James Cook University and the methods were carried out in accordance with the approved James Cook University animal ethics guidelines.

Water quality parameters. Water quality parameters were measured in each treatment tank throughout the 28 d exposure period. Total suspended solid (TSS) sampling was performed 6–7 times per fortnight on 500 ml aliquots from each tank (n = 1 per tank) during the experimental period. Water was shaken and filtered through pre-weighed filters (0.7 μm glass microfibre) that were then rinsed with deionized water and oven dried (60 °C) until a constant weight was maintained. The gain in weight of each filter was multiplied by 2 to express the TSS in mg l^{-1}. Since other organic materials, such as algae, faecal matter and uneaten fish food, were present in all of the experimental tanks including the control treatment, the mean TSS measured in control tanks was subtracted from coal treatments to derive measurements of total suspended coal (TSC; Supplementary Fig. S1a). Temperature was measured 5 times per fortnight (n = 1 per tank) with a thermometer and light attenuation, expressed as photosynthetically active radiation (PAR) was measured weekly (n = 1 per tank) with a Li-250A light meter (Li-cor, Lincoln NE, USA) at the height of the corals and seagrass in the experimental tanks (approximately 25 cm below the water surface). Dissolved oxygen saturation was measured at the start of the experiment followed by twice per week (n = 1 per tank) using a Hach Probe (HQ 40 d) and pH was measured on 3 occasions (n = 1 per tank) using a potentiometric pH probe (console: OAKTON, USA; pH probe: EUTECH, USA).

Coal deposition rates were measured in each tank using 2 methods (Supplementary Fig. S1b,c). The first involved small sediment traps (n = 3 per tank) (20 ml glass vials, 15 mm opening diameter, 58 mm height) with the top at a height similar to the corals[22]. The second method used flat-surfaced sediment pods (n = 1 per tank), which allow for re-suspension of particles[42]. Both traps (sampled weekly) and pods (sampled 4–5 times per fortnight) were collected 24 h after deployment and contents were filtered through pre-weighed filters (0.7 μm glass microfibre) that were rinsed with deionized water and oven dried (60 °C) until a constant weight was maintained for determination of deposition rate. Similar to TSC measurements, the mean weight of organic material deposited onto control filters was subtracted from the mean coal deposition values in each treatment in order to present a measurement of coal deposition only.

Water samples were taken at 28 d to assess the potential contamination by trace metals (Co, As, Cd, Cu, Pb, Mn, Mo, Ni, Zn). Metal analysis was conducted at Charles Darwin University (Australia) using inductively coupled plasma mass spectrometry (ICP-MS). Water samples (0.45 μm syringe filtered leachate, 150 ml) were taken from each treatment (n = 3; 3 × 50 ml per tank, which was pooled for each treatment replicate). PAHs were not detected or bioavailable in previous coal seawater leaching studies[3,40] and were not analysed here.

Statistical analysis. To evaluate organism responses to coal particles a multifactor analysis of variance between 14 and 28 d was implemented based on permutations using the PERMANOVA routine of PRIMER (Version 6.0). Euclidean Distance was used as the similarity measure (with 9999 permutations) and pair-wise comparisons were made with the Student t-test with Monte Carlo simulations used when unique permutations were <1000. Coral mortality (%) data was arcsine square root transformed prior to analysis. The n for each taxa in the PERMANOVA analysis were as follows: coral (n = 9 per treatment per time point), fish (n = 23–29), and seagrass (growth n = 45 leaves per treatment per time point; change in shoot density n = 9 pots per treatment per time point). The factors analysed were: coal concentration (5 fixed), exposure time (2 fixed), tank (3 random: nested within concentration), with the addition of replicates (e.g., replicated seagrass pots, random: nested within tank) where appropriate (Supplementary Material Table S1). Four-parameter sigmoidal curves were fitted to coral mortality data to estimate lethal concentration (LC_{10} and LC_{50}) values for mortality using GraphPad Prism (Version 6.0). Concentrations resulting in mean inhibition of growth (IC_{10} and IC_{50}) were estimated for fish and seagrass using linear interpolation in SigmaPlot (Version 11.0). Analysis of variance (one-way ANOVA) was used to compare means of trace elements between coal treatments in SigmaPlot (Version 11.0). Elements (Co and Pb) that did not meet the assumptions of normality (based on Shapiro-Wilk normality test) were log-transformed.

References

1. International Energy Agency (IEA). Coal information (2014 Edition). *Technical Report*, 748 pg. Available for purchase at: http://www.iea.org/publications/.
2. Hughes, T. P., Day, J. C. & Brodie, J. Securing the future of the Great Barrier Reef. *Nat. Clim. Change* **5,** 508–511 (2015).
3. Jaffrennou, C. *et al.* Simulations of accidental coal immersion. *Mar. Pollut. Bull* **54,** 1932–1939 (2007).
4. Department of Environmental Affairs Republic of South Africa. *Department of environmental affairs grants permit for coal from MV Smart to be dumped into the ocean*. *Media release.* (2013). Available at: https://www.environment.gov.za/mediarelease/coalfrom_mvsmart_dumped. (Accessed: 11 September 2014).
5. Australian Transport Safety Bureau (ATSB). Independent investigation into the grounding of the Chinese registered bulk carrier Shen Neng 1 on Douglas Shoal, Queensland 3 April 2010. *Transport Safety Report No. 274* MO-2010-003, 70 (2010).
6. Hyslop, B. T., Davies, M. S., Arthur, W., Gazey, N. J. & Holroyd, S. Effects of colliery waste on littoral communities in north-east England. *Environ. Pollut.* **96,** 383–400 (1997).
7. Rogers, C. S. Responses of coral reefs and reef organisms to sedimentation. *Mar. Ecol. Prog. Ser.* **62,** 185–202 (1990).
8. Fabricius, K. E. Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis. *Mar. Pollut. Bull* **50,** 125–146 (2005).
9. Ahrens, M. J. & Morrisey, D. J. Biological effects of unburnt coal on the marine environment. *Oceanog. Mar. Biol.* **43,** 69–122 (2005).
10. Cabon, J. Y., Burel, L., Jaffrennou, C., Giamarchi, P. & Bautin, F. Study of trace metal leaching from coals into seawater. *Chemosphere* **69,** 1100–1110 (2007).
11. Lucas, S. A. & Planner, J. Grounded or submerged bulk carrier: the potential for leaching of coal trace elements to seawater. *Mar. Pollut. Bull* **64,** 1012–1017 (2012).
12. Bryan, G. W. The effects of heavy metals (other than mercury) on marine and estuarine organisms. *P. Roy. Soc. Lond. B Biol.* **177,** 389–410 (1971).
13. Di Toro, D. M. & McGrath, J. A. Technical basis for narcotic chemicals and polycyclic aromatic hydrocarbon criteria. II. Mixtures and sediments. *Environ. Toxicol. Chem.* **19,** 1971–1982 (2000).
14. Eisler, R. Polycyclic aromatic hydrocarbon hazards to fish, wildlife and invertebrates: a synoptic review. *US fish and wildlife service biological report* 85.1.11, 81 (1987).
15. Kennish, M. J. Pollution Impacts on Marine Biotic Communities. (ed. Kennish, M. J.) 310 (CRC Press, 1998).
16. Lewis, K. The effect of suspended coal particles on the life forms of the aquatic moss *Eurhynchium riparioides* (Hedw.). *Freshwater Biol.* **3,** 251–257 (1973).
17. Pearce, B. C. & McBride, J. A preliminary study on the occurrence of coal dust in Roberts Bank sediments and the effects of coal dust on selected fauna. *Technical Report Series No. PAC/T-77-17, Fisheries and Environment Canada, Water Quality Division* **50** (1977).
18. Johnson, R. & Bustin, R. M. Coal dust dispersal around a marine coal terminal (1977–1999), British Columbia: The fate of coal dust in the marine environment. *Intl. J. Coal Geol.* 68, 57–69 (2006).
19. Peters, E. C. & Pilson, M. E. Q. A comparative study of the effects of sedimentation on symbiotic and asymbiotic colonies of the coral *Astrangiadanae* Milne Edwards and Haime 1849. *J. Exp. Mar. Biol. Ecol.* **92,** 215–230 (1985).
20. Stafford-Smith, M. G. & Ormond, R. F. G. Sediment-rejection mechanisms of 42 species of Australian scleractinian corals. *Mar. Freshwater Res.* **43,** 683–705 (1992).
21. Weber, M. *et al.* Mechanisms of damage to corals exposed to sedimentation. *P. Natl. Acad. Sci. USA* **109,** E1558–1567 (2012).
22. Flores, F. *et al.* Chronic exposure of corals to fine sediments: lethal and sub-lethal impacts. *PloS One* **7,** e37795–37800 (2012).
23. Wenger, A. S., Johansen, J. L. & Jones, G. P. Increasing suspended sediment reduces foraging, growth and condition of a planktivorous damselfish. *J. Exp. Mar. Biol. Ecol.* **428,** 43–48 (2012).
24. Sigler, J. W., Bjornn, T. C. & Everest, F. H. Effects of chronic turbidity on density and growth of steelheads and coho salmon. *T. Am. Fish Soc.* **113,** 142–150 (1984).
25. Hughes, G. M. Coughing in the rainbow trout (*Salmo gairdneri*) and the influence of pollutants. *Rev. Suisse Zool* **82,** 47–64 (1975).
26. Sutherland, A. & Meyer, J. Effects of increased suspended sediment on growth rate and gill condition of two southern Appalachian minnows. *Environ. Biol. Fish.* **80,** 389–403 (2007).
27. Birtwell, I. K. C. The effects of sediment on fish and their habitat. Canadian Stock Assessment Secretariat Research Document. Fisheries and Oceans Canada. *Pacific Science Advice and Review Committee Habitat Subcommittee* 99–139 (1999).
28. Lake, R. G. & Hinch, S. G. Acute effects of suspended sediment angularity on juvenile coho salmon (Oncorhynchus kisutch). *Can. J. Fish Aquat. Sci.* **56,** 862–867 (1999).
29. Wenger, A. S. *et al.* Suspended sediment prolongs larval development in a coral reef fish. *J. Exp. Biol.* **217,** 1122–1128 (2014).

30. Hess, S., Wenger, A. S., Ainsworth, T. D. & Rummer, J. L. Exposure of clownfish larvae to suspended sediment levels found on the Great Barrier Reef: Impacts on gill structure and microbiome. *Scientific Reports* **5,** 10561, doi: 10.1038/srep10561 (2015).
31. Perez, K. O. & Munch, S. B. Extreme selection on size in the early lives of fish. *Evolution* **64,** 2450–2457 (2010).
32. Hislop, J. R. G. The influence of maternal length and age on the size and weight of the eggs and the relative fecundity of the haddock, *Melanogrammus aeglefinus*, in British waters. *J. Fish Biol.* **32,** 923–930 (1988).
33. Collier, C. J., Waycott, M. & Ospina, A. G. Responses of four Indo-West Pacific seagrass species to shading. *Mar. Pollut. Bull* **65,** 342–354 (2012).
34. Naidoo, G. & Chirkoot, D. The effects of coal dust on photosynthetic performance of the mangrove, Avicennia marina in Richards Bay, South Africa. *Environ. Pollut.* **127,** 359–366 (2004).
35. Ralph, P. J., Durako, M. J., Enríquez, S., Collier, C. J. & Doblin, M. A. Impact of light limitation on seagrasses. *J. Exp. Mar. Biol. Ecol.* **350,** 176–193 (2007).
36. Alcoverro, T., Manzanera, M. & Romero, J. Annual metabolic carbon balance of the seagrass *Posidonia oceanica*: the importance of carbohydrate reserves. *Mar. Ecol. Prog. Ser.* **211,** 105–116 (2001).
37. Hyslop, B. T. & Davies, M. S. Evidence for abrasion and enhanced growth of *Ulva lactuca L*. in the presence of colliery waste particles. *Environ. Pollut.* **101,** 117–121 (1998).
38. Rogers, C. S. Sublethal and lethal effects of sediments applied to common Caribbean reef corals in the field. *Mar. Pollut. Bull* **14,** 378–382 (1983).
39. Australian and New Zealand Environment and Conservation Council (ANZECC). *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* **1,** 314 (2000).
40. Bender, M. E., Roberts, Jr., M. H. & deFur, P. O. Unavailability of polynuclear aromatic hydrocarbons from coal particles to the eastern oyster. *Environ. Pollut.* **44,** 243–260 (1987).
41. Burns, K. & Brinkman, D. Organic biomarkers to describe the major carbon inputs and cycling of organic matter in the central Great Barrier Reef region. *Estuar. Coast Shelf S.* **93,** 132–141 (2011).
42. Field, M. E., Chezar, H. & Storlazzi, C. D. SedPods: a low-cost coral proxy for measuring net sedimentation. *Coral Reefs* **32,** 155–159 (2013).

Acknowledgements

This research was conducted with the support of James Cook University, the Australian Institute of Marine Science (AIMS), AIMS@JCU, The Nature Conservancy and Great Barrier Reef Marine Park Authority. We would like to thank Stephen Boyle, CDU and Jeff Tsang (AIMS) for their help with metal analysis, Colette Thomas, Amelia Wenger, MARFU, César Herrera, numerous volunteers, and the National Sea Simulator staff (AIMS) for their expert experimental support. The research was conducted under JCU animal ethics permit number A2038 and GBRMPA permit number G12/35236.1.

Author Contributions

K.B., A.N., M.H. and F.F. designed the study, K.B. and F.F. performed the study, K.B. analysed the data with input from M.H., A.N., F.F. and K.B. A.N. and M.H wrote the manuscript. All authors reviewed the manuscript.

Additional Information

Supplementary information accompanies this paper at http://www.nature.com/srep

Competing financial interests: The authors declare no competing financial interests.

How to cite this article: Berry, K. L. E. *et al.* Simulated coal spill causes mortality and growth inhibition in tropical marine organisms. *Sci. Rep.* **6**, 25894; doi: 10.1038/srep25894 (2016).

Atmospheric Pollution Research 5 (2014) 344-351

Atmospheric Pollution Research

www.atmospolres.com

Diesel particulate matter emission factors and air quality implications from in–service rail in Washington State, USA

Daniel A. Jaffe [1,2], Greg Hof [1], Sofya Malashanka [1,2], Justin Putz [1], Jeffrey Thayer [2], Juliane L. Fry [3], Benjamin Ayres [3], Jeffrey R. Pierce [4]

[1] *University of Washington–Bothell, School of STEM, Bothell, WA USA*
[2] *University of Washington–Seattle, Department of Atmospheric Sciences, Seattle, WA USA*
[3] *Reed College, Department of Chemistry, Reed College, Portland, OR USA*
[4] *Colorado State University, Department of Atmospheric Science, Fort Collins, CO USA*

ABSTRACT

We sought to evaluate the air quality implications of rail traffic at two sites in Washington State. Our goals were to quantify the exposure to diesel particulate matter (DPM) and airborne coal dust from current trains for residents living near the rail lines and to measure the DPM and black carbon emission factors (EFs). We chose two sites in Washington State, one at a residence along the rail lines in the city of Seattle and one near the town of Lyle in the Columbia River Gorge (CRG). At each site, we made measurements of size–segregated particulate matter (PM_1, $PM_{2.5}$ and PM_{10}), CO_2 and meteorology, and used a motion–activated camera to capture video of each train for identification. We measured an average DPM EF of 0.94 g/kg diesel fuel, with an uncertainty of 20%, based on PM_1 and CO_2 measurements from more than 450 diesel trains. We found no significant difference in the average DPM EFs measured at the two sites. Open coal trains have a significantly higher concentration of particles greater than 1 µm diameter, likely coal dust. Measurements of black carbon (BC) at the CRG site show a strong correlation with PM_1 and give an average BC/DPM ratio of 52% from diesel rail emissions. Our measurements of $PM_{2.5}$ show that living close to the rail lines significantly increases $PM_{2.5}$ exposure. For the one month of measurements at the Seattle site, the average $PM_{2.5}$ concentration was 6.8 µg/m^3 higher near the rail lines compared to the average from several background locations. Because the excess $PM_{2.5}$ exposure for residents living near the rail lines is likely to be linearly related to the diesel rail traffic density, a 50% increase in rail traffic may put these residents over the new U.S. National Ambient Air Quality Standards, an annual average of 12 µg/m^3.

Keywords: *Diesel particulate matter, diesel emissions, train emissions, coal dust, DPM*

Corresponding Author:
Daniel A. Jaffe
☎ : *+1-425-352-5357*
🖷 : *+1-425-352-5335*
✉ : *djaffe@u.washington.edu*

Article History:
Received: 03 November 2013
Revised: 27 January 2014
Accepted: 28 January 2014

doi: 10.5094/APR.2014.040

1. Introduction

Rail is an efficient way to move people and freight. However, diesel–powered trains may have a significant impact on air quality. In Washington State, nearly all rail locomotives are powered with diesel fuel and many rail lines are located in busy urban corridors, including Seattle, Tacoma and Spokane, and also pass through the Columbia River Gorge National Scenic Area. At present, there is limited information to evaluate the air quality impacts associated with rail transport for residents living close to the train lines. Recently, there have been proposals to increase rail shipments through Washington and Oregon for transporting coal to west coast ports for export to Asian markets. One proposed facility, the Gateway Pacific Terminal near Bellingham, Washington, could export up to 54 million metric tons of coal per year (WA DOE, 2013). Similar facilities have also been proposed at two other sites in Washington and Oregon.

According to the U.S. Department of Health and Human Services, diesel particulate matter (DPM) is "reasonably anticipated to be a human carcinogen" (U.S.DHHS, 2011); in addition, the World Health Organization classifies it as "carcinogenic to humans" (WHO, 2012). In Seattle and other urban areas, DPM is the most important "air toxic" in the metropolitan area and contributes more than 80% of the risk for cancer from airborne air toxics (Keill and Maykut, 2003; PSCAA, 2005). Monitoring and a chemical mass balance model have found average DPM concentrations to range from 1.4–1.9 µg/m^3 for the Seattle area (Keill and Maykut, 2003; Maykut et al., 2003). These concentrations are about 15–20% by mass of the total $PM_{2.5}$, particulate matter with diameter less than 2.5 µm. Sources of DPM include on–road and off–road diesel trucks, ships and rail locomotives.

The U.S. Environmental Protection Agency (EPA) has developed emissions standards for new and remanufactured locomotives (40 CFR part 1033). The emission standards, in g/bhp–hr, decrease steadily for locomotives manufactured between 1973–2001 (Tier 0), 2002–2004 (Tier 1), 2005–2010 (Tier 2), 2011–2014 (Tier 3) and after 2015 (Tier 4) (U.S. EPA, 2013). For Tier 4, locomotives must meet a PM_{10} emission standard of 0.03 g/bhp–hr, or approximately 0.19 g per kg of fuel burned (U.S. EPA, 2009).

A few studies have examined rail yards as sources of air pollutants and have found that diesel fuel combustion is the primary source of $PM_{2.5}$ at these facilities. Galvis et al. (2013) looked at the influence of DPM emissions on $PM_{2.5}$ concentrations near a rail yard in Atlanta. Based on measurements up–wind/down–wind of the facility, they concluded that the average "neighborhood" contribution to $PM_{2.5}$ was 1.7 µg/m^3. They also derived fuel–based emission factors (EFs) of 0.4–2.3 grams DPM per kg of diesel fuel consumed. These EFs are not based on measurements from individual trains but were calculated using three different methods, each of which requires a different set of assumptions. Two studies on a rail yard in Roseville, CA, also found significant enhancements in $PM_{2.5}$ from the facility. Based on upwind/downwind measurements, Cahill et al. (2011) reported an average enhancement of 4.6 μg/m^3. In another study (Campbell and Fujita, 2006), larger contributions for the same facility were reported (7.2–12.2 μg/m^3). Cahill et al. (2011) also showed that the major component of aerosol mass from diesel rail facilities is from very fine PM, with diameters less than 0.26 μm. Abbasi et al. (2013) provide a review of PM concentrations inside trains and near rail lines. They report substantially elevated $PM_{2.5}$ and PM_{10} concentrations, especially in underground rail stations. Gehrig et al. (2007) examined the influence on PM_{10} concentrations from dust associated with electric trains in Switzerland. A number of previous studies have reported EFs for on–road diesel trucks and buses (Jamriska et al., 2004; Zhu et al., 2005; Cheng et al., 2006; Park et al., 2011; Dallmann et al., 2012), but to our knowledge, similar studies have not been reported for diesel rail.

In addition to DPM emissions, trains carrying coal in uncovered loads may emit coal dust into the atmosphere. This has been a topic of some controversy. Rail transport companies are attempting to mitigate this problem (see BNSF Railway, 2013), but few studies have been reported in the scientific literature. We expect that combustion–related DPM and mechanically generated coal dust are associated with very different particle sizes, so size–segregated PM should be able to distinguish these source types (Seinfeld, 1986).

Black carbon (BC) accounts for a significant fraction (44–60%) of $PM_{2.5}$ mass from diesel engines (Bond et al., 2004; Kirchstetter and Novakov, 2007; Ramanathan and Carmichael, 2008). As the major light–absorbing species in atmospheric aerosol, radiative forcing due to BC is important on a global and regional scale (Jacobson, 2001; Ramanathan and Carmichael, 2008). Furthermore, the surface properties of black carbon allow for adsorption and transport of semi–volatile compounds like polyaromatic hydrocarbons (PAHs) (Dachs and Eisenreich, 2000). BC is under scrutiny by health organizations due to its role in adverse effects caused by $PM_{2.5}$, including cardiopulmonary and respiratory disease (Jansen et al., 2005; Janssen et al., 2011; U.S. EPA, 2012).

The City of Seattle has conducted an analysis of potential impacts associated with increasing train traffic. This analysis indicates that the proposed coal export terminal would increase rail traffic by up to 18 additional trains per day if approved (City of Seattle, 2012). Given the lack of information on $PM_{2.5}$ concentrations and human exposure from diesel trains, the controversy over coal dust and the limited information on EFs from diesel trains, we sought to quantify these air quality impacts by addressing the following questions:

(i) What is the exposure to size–segregated PM (e.g., PM_1, $PM_{2.5}$ and PM_{10}) for residents living near the rail lines?

(ii) Can we estimate the potential exposure to size–segregated PM (e.g., PM_1, $PM_{2.5}$ and PM_{10}) for people living near the rail lines if rail traffic increases?

(iii) Do coal trains emit coal dust into the air?

(iv) How do the observed DPM and BC emission factors for locomotives compare with other published EFs?

To address these questions we measured size–segregated PM_1, $PM_{2.5}$, PM_{10}, total suspended particulate (TSP), CO_2 and meteorology at two locations adjacent to rail lines. Because our goal is to quantify the exposure to DPM and coal dust, if present, and the EFs from individual trains, we made 10–second measurements so as to capture the air quality impacts from individual passing trains.

2. Experimental

Measurements on train emissions were made at two sites in Washington State (Figure 1). The first site was located in the residential Blue Ridge (BR) neighborhood (47.70°N, 122.40°W), in the City of Seattle, approximately 10 km north of downtown. The instruments and camera were housed on the patio of a residence, which is approximately 25 meters from two active rail lines. The rail lines are immediately adjacent to the shores of Puget Sound and there are no roads in this direction before the shoreline. A video camera was co–located with the instrumentation and could identify train types both day and night at this site. The second site was located in the Columbia River Gorge (CRG), between the towns of Lyle and Dallesport, Washington (45.67°N, 121.20°W). Here the instruments were housed in a small tent, which was located on a small rock outcropping, approximately 10 meters above and 30 meters north of the rail line. The camera was separate from the other instrumentation and located about 25 meters from the tracks but at a 40–degree angle to it. The lower ambient light levels, the camera angle and distance made it impossible to identify train types at night at this site. The rail lines are along the Columbia River and there were no other roads in that direction before the river. This site was about 100 meters south of Washington Route 14, which is a lightly traveled state highway. The instruments were identical at both the Seattle and CRG sites, except that BC was measured only at the CRG site. The data capture at the Seattle site was greater than 95%, whereas instrument and computer failures at the CRG site gave us lower data capture. At both sites the rail line was essentially flat, with a maximum grade of 1 meter per km in the adjacent few km in either direction.

A third site was used only for comparisons of two different DustTrak instruments with a tapered element oscillating micro-balance (TEOM). This site is one of the regular Seattle air quality monitoring stations operated by the Puget Sound Clean Air Agency (pscleanair.org). The site is located along the Duwamish Waterway in the industrial Duwamish Valley, which has a heavy concentration of diesel trucks, trains and ships, due to its proximity to a major port facility. At this site, a Rupprecht and Patashnick TEOM model 1400AB with Filter Dynamics Measurement Systems (FDMS) 8500 is operated as Federal Equivalent Method (Ray and Vaughn, 2009). An Ecotech M9003 nephelometer was also operated to measure scattering coefficients. The scattering coefficients are converted into $PM_{2.5}$ (μg/m^3) based on a 3–year comparison with a Federal Reference Method. The two DustTrak instruments (described below) were operated at this site in the same way as was done at the train sampling sites. This site was chosen for the DustTrak comparison, as it regularly reports the highest concentrations of $PM_{2.5}$ in the Seattle area, due to the high number of diesel vehicles in the area (Keill and Maykut, 2003).

We measured size–segregated PM measurements using a DustTrak DRX Aerosol Monitor (Model #8533, TSI, Inc., Shoreview, MN). This instrument reports PM mass concentrations in 4 size fractions: PM_1, $PM_{2.5}$, PM_{10} and TSP. Because the DustTrak uses aerosol scattering as the basis for its measurements, the measurements are not identical to a mass–based measurement (Wang et al., 2009). The instrument comes calibrated against standard Arizona road dust (ISO 12103–1), but this will not accurately reflect the scattering efficiency for many aerosol types. This may be especially true for diesel given the small size of particles (Park et al., 2011). Instead, accurate measurements using the DustTrak require a comparison against a mass–based measurement for the aerosol of interest (Moosmuller et al., 2001). A number of previous EF studies have also used the DustTrak to rapidly measure several size fractions of PM and calculate EFs from individual vehicles (e.g., Park et al., 2011; Dallmann et al., 2012), but usually after calibration of the response factor against a mass–based method (Jamriska et al., 2004; Zhu et al., 2005; Cheng et al., 2006). For our study, we calibrated the DustTrak against a mass–

based TEOM measurement (described above). The inlet for the DustTrak was downward–facing stainless steel tubing (5.0 mm i.d.) at a height of approximately 2 meters above ground level. The flow through this inlet was 3.0 liters per minute. Under these conditions, the flow is laminar and we would expect greater than 90% particle transmissions for particles up to 2.5 µm in diameter at wind speeds below 10 m/s (von der Weiden et al., 2009). At higher wind speeds and for larger particle sizes, the sampling efficiency will be reduced. Data were stored as 10–second averages.

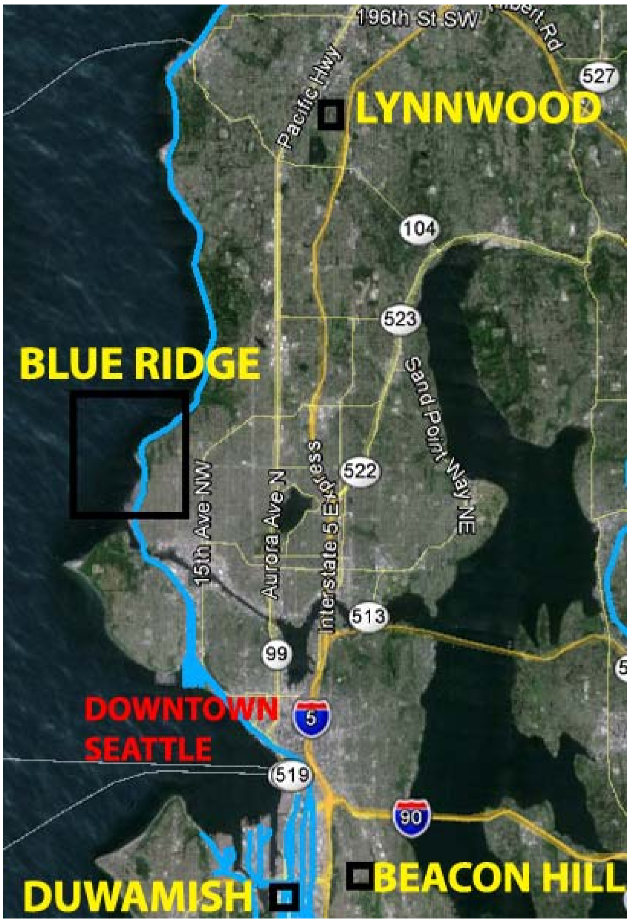


Figure 1. *Map showing air sampling locations in the Seattle area. Major roads and highways are shown by yellow lines and the rail lines are shown in blue. The Duwamish Valley, Lynnwood and Beacon Hill sites are operated by the Puget Sound Clean Air Agency (PSCAA, 2013). At the BR site, PM and CO_2 instrumentation were set up at a residence, approximately 25 meters from the rail lines. The site in the Columbia River Gorge (not shown) is 227 km to the south-southeast of Seattle.*

CO_2 was measured using a Licor–820 (Licor, Inc., Lincoln, NE). Air was pulled through the Licor instrument using a small vacuum pump. The inlet consisted of a 5.0 mm i.d. stainless steel inlet that connected to PFA tubing. The instrument was zeroed by pumping CO_2–free air through it and calibrated with a 395 ppmv standard (Airgas, Inc.). The instrument was calibrated before the Seattle deployment and after the CRG deployment, and the instrument response had drifted by less than 1 ppmv between these times. Data from the DustTrak and the Licor–820 (CO_2, cell temperature and pressure) and the meteorological data were recorded using DAQFactory on a PC. Data were recorded as 10–second averages.

Train types were identified using video taken by a Night Owl camera equipped with infrared night vision (Model CAM–MZ420–425M). The camera was motion activated and controlled using iSpy open source security camera software. At the Seattle site, we were able to classify train types (freight, passenger, etc.) both day and night due to greater ambient light. At the CRG site the camera was able to identify a passing train day or night, but the train type could be identified only in the daytime due to the camera angle, distance and lower ambient light levels.

At the CRG site only, BC measurements were taken using a two–wavelength aethalometer (AE–22, Magee Scientific). BC sampling was performed at 1–minute resolution at 370 nm and 880 nm. Data from the 880 nm infrared absorption signal were used to determine BC loading, as 370 nm is susceptible to absorbance of other organic aerosol from diesel plumes (Wang et al., 2011). The aethalometer measures attenuation (ATN) values (1/m) and determines *BC* concentration (g/m^3) via:

$$BC_0 = ATN/\sigma \tag{1}$$

where, σ is Magee Scientific's calibrated cross–section of $1.4625 \times 10^4/\lambda$ (at 880 nm, σ=16.6 m^2/g). However, since attenuation diminishes as the BC loading on the filter increases, we apply a correction to the BC concentrations following Kirchstetter and Novakov (2007). Transmission (*Tr*) can be calculated from the attenuation values as:

$$Tr = e^{-ATN/100} \tag{2}$$

The corrected BC loading (ng/m^3) can then be calculated following Kirchstetter and Novakov (2007) as:

$$BC_{corr} = BC_0/(0.88 \times Tr + 0.12) \tag{3}$$

Both PM_1 and BC EFs are quantified as emissions per kg of diesel fuel burned. These are calculated for each passing train. The EFs for PM_1 and BC are calculated from:

$$EF\,(PM_1) = \Delta PM_1/\Delta CO_2 \times W_c \tag{4}$$

$$EF\,(BC) = \Delta BC/\Delta CO_2 \times W_c \tag{5}$$

where, $\Delta PM_1/\Delta CO_2$ is calculated from the slopes of the regression lines using the 10–second CO_2 and PM_1 data for each passing train. For BC, the ratio $\Delta BC/\Delta CO_2$ is obtained from the one–minute data by subtracting the background concentrations before and after the train passes:

$$\Delta BC/\Delta CO_2 = \frac{BC_{Corr,train} - BC_{Corr,baseline}}{[CO_2]_{train} - [CO_2]_{baseline}} \tag{6}$$

CO_2 concentrations are converted to g C/m^3 units using the ideal gas law at 1 atm and 25 °C. W_C is the mass fraction of carbon in diesel fuel (0.87 kg C/kg fuel, Lloyd's Register, 1995; Cooper, 2003), giving overall units on the EF of g PM_1/kg fuel consumed or g BC/kg fuel consumed. Yanowitz et al. (2000) show that more than 95% of the diesel fuel carbon is emitted as CO_2. We chose to use PM_1 in these calculations because this is least likely to be influenced from coal dust or dust from other sources. Using the information presented later in our analysis, one could adjust our EFs for other size fractions.

At the BR and CRG sites, measurements of train emissions and PM were conducted from July 23–August 19, 2013, and August 27–September 2, 2013, respectively. At the Duwamish site, the DustTrak–TEOM comparison was carried out from September 23–October 13, 2013.

3. Results

3.1. Calibration of the DustTrak

Figure 2 shows a scatter plot of the hourly $PM_{2.5}$ concentrations measured by the DustTrak and the TEOM at the Duwamish site. There is an excellent correlation between the TEOM and the DustTrak measurements (R^2=0.83), but the slope is far from 1.0. There was also an excellent agreement between the two DustTrak instruments (R^2=0.99), with a slope of 1.00 and essentially no offset between instruments.

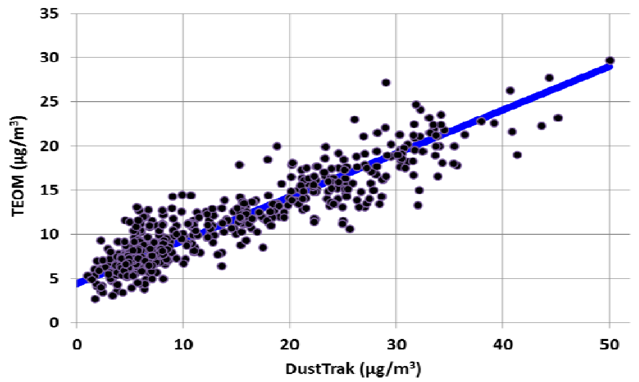


Figure 2. *Comparison of hourly $PM_{2.5}$ concentrations measured by the DustTrak and TEOM-FDMS at the Duwamish site for 9/23/2013 through 10/13/2013. The line shows the RMA regression fit. The regression parameters are m=0.4913, b=4.414 (y=mx+b) and R^2=0.83.*

We determined the regression relationship between the TEOM and DustTrak (serial number 8533131306) using Reduced Major Axis (RMA) regression (Ayers, 2001; Cantrell, 2008):

$$\text{TEOM } PM_{2.5}\ (\mu g/m^3) = \text{DustTrak } PM_{2.5}\ (\mu g/m^3) \times 0.4913 + 4.414 \qquad (7)$$

The 95% confidence interval (CI) for the slope and intercept from the RMA regression are 0.47–0.51 and 4.1–4.7, respectively. Our result agrees remarkably well with a similar comparison on DPM by Jamriska et al. (2004), using both a DustTrak and a TEOM, who reported this relationship:

$$\text{TEOM } PM_{2.5}\ (\mu g/m^3) = \text{DustTrak } PM_{2.5} \times 0.458 + 4.882 \qquad (8)$$

We also compared the DustTrak with the Ecotech nephelometer at the Duwamish site, to obtain the following relationship:

$$\text{Ecotech Nephelometer } PM_{2.5}\ (\mu g/m^3) = \text{DustTrak } PM_{2.5} \times 0.4176 + 2.926 \qquad (9)$$

The R^2 for the DustTrak–nephelometer regression is 0.98, likely due to the fact that both methods are scattering based. However, the intercept using the nephelometer data is smaller (2.9 µg/m^3 vs. 4.4 µg/m^3) compared to the TEOM, suggesting an uncertainty in the intercept of ±2 µg/m^3. The overall uncertainty in our PM measurements made with the DustTrak is due to uncertainty in the slope (10%) and the intercept (±2 µg/m^3). For the remainder of this paper, we will use the corrected DustTrak data, based on our measured relationship to the TEOM data from the Duwamish site. To maintain consistency with different size bins, we correct all PM concentrations (e.g., PM_1, $PM_{2.5}$, etc.) to the TEOM values using Equation (7).

3.2. Observations of PM and CO_2

Figure 3 shows a time series of PM_1 (µg/m^3) and CO_2 (ppmv) concentrations for a 6–hour period at the Seattle site. We define a "train event" as a single spike or enhancement in PM and CO_2 that is confirmed by the video images. During the period shown in Figure 3 we identified 8 train events. Each train event was confirmed and classified (freight, coal, passenger or other) using the videos. Typical train events last from 1 to 5 minutes, depending on the length of the train, the number of locomotives and meteorology. For each train event, we calculated the regression fit for the following relationships: PM_1–CO_2, PM_1–TSP, $PM_{2.5}$–TSP and PM_{10}–TSP. Figure 4 shows an example of the PM_1/CO_2 relationship for one train event. The slope from the linear correlation ($\Delta PM_1/\Delta CO_2$) is used to derive the DPM EF using Equation (4).

Note that not all trains will be detected by the atmospheric data. For example, if the winds are blowing strongly or are from the wrong direction, our sensors will record only small peaks, or no peaks, in PM_1 and CO_2. These smaller events will generally have a lower PM_1–CO_2 correlation coefficient, so we screened out smaller events with an R^2<0.5 or with ΔCO_2<3 ppmv. This results in 456 train events that passed this QC screen, out of a total of 584 for both sites.

Table 1 shows statistics on the $\Delta PM_1/\Delta CO_2$ slope for the 456 trains we identified at both sites. For the Seattle site, these are separated by train type (freight, coal, passenger and other or unidentified). The distributions are slightly skewed, as shown by the higher means compared to median values. The average slopes range from 0.45 µg/m^3/ppmv for coal trains to 0.59 µg/m^3/ppmv for passenger trains. The difference between passenger and freight trains is statistically significant with greater than 95% confidence. The other differences are not statistically significant. For the CRG site, given the very small number of identifiable coal (3) and passenger (8) trains, we do not report statistics separately for different train types.

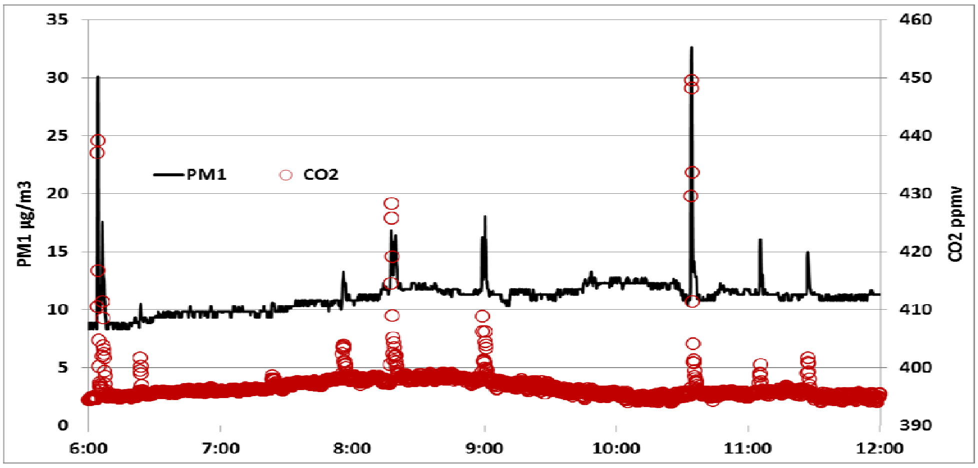


Figure 3. *PM_1 (µg/m^3) and CO_2 (ppmv) data (10-second averages) from the Blue Ridge site for July 25, 2013, between 06:00 and 12:00 local time. During this period, we identified 8 trains from the atmospheric data and confirmed by video images.*

Table 1. *Data on $\Delta PM_1/\Delta CO_2$ slopes (µg/m^3/ppmv) for different train types at the Blue Ridge location and for all trains at the Columbia River Gorge location. To convert to EFs in g/kg, multiply by 1.81*

	Blue Ridge					CRG
	Freight	Coal	Passenger	Other	All trains	All trains
Count	236	36	93	7	372	84
Average	0.52	0.45	0.59	0.77	0.53	0.51
SD	0.28	0.47	0.35	0.73	0.33	0.36
Median	0.47	0.33	0.53	0.44	0.47	0.45

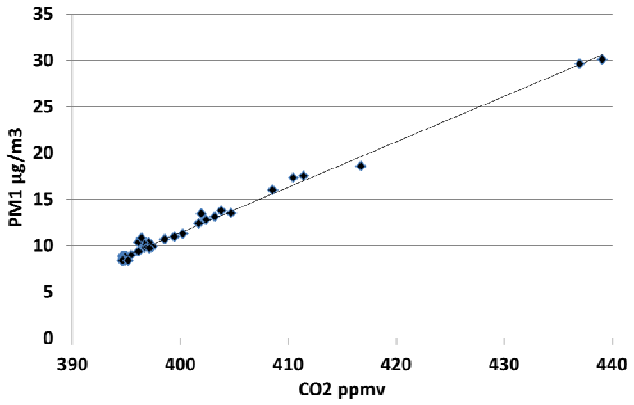


Figure 4. *Linear correlation between PM_1 (µg/m^3) and CO_2 (ppmv) for the train event starting at 06:03 local time on 7/25/2013 (first event shown in Figure 3). The linear regression parameters are m=0.4888, b=-184.11 (y=mx+b) and R^2=0.989.*

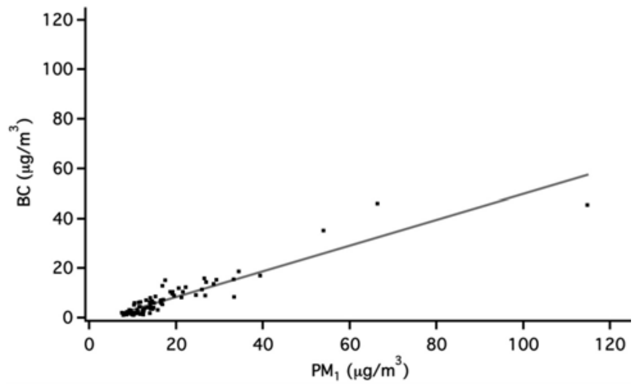


Figure 5. *Correlation of black carbon mass with PM_1 from individual train events. The regression line is y=0.518x-2.009 (R^2=0.85).*

3.3. Emission factors

The average $\Delta PM_1/\Delta CO_2$ slope for all 456 train events was 0.53 µg/m^3/ppmv, with a 95% confidence interval of ±0.03 µg/m^3/ppmv. This converts to a PM_1 EF of 0.94 g/kg diesel fuel consumed, with a 95% confidence interval of 0.06 g/kg. Given the uncertainty in the DustTrak calibration factor (Section 3.1), we assign an overall uncertainty of 20% to our mean EF based on the mean PM_1 enhancement. For comparison, an older study by Kean et al. (2000) reports locomotive emission factors using the EPA "NONROAD" model of between 1.8–2.1 g/kg. A 2009 report (U.S. EPA, 2009) projected future emission factors for the fleet averaged, in–use diesel locomotives. The EPA–estimated average EF for 2013 is 1.2 g/kg. A study by Sierra Research (2004) projected a slower reduction in the diesel locomotive EFs, compared to U.S. EPA (2009), and projected a value of 1.5 g/kg for 2013. A study by Galvis et al. (2013) derived EFs for diesel locomotives of 0.4–2.3 g/kg, depending on the assumptions made. Given the uncertainty in our EF, our average value is consistent with the values given for the 2013 time frame.

At the CRG site, the observed BC and PM_1 measurements on 84 trains reveal that on average, 52% of the PM_1 is BC (Figure 5). This is broadly consistent with previous measurements of black carbon in diesel engine particulate emissions in trucks; Hildemann et al. (1991) report 55% black carbon, and Watson et al. (1994) report 45% in diesel engine particulate emissions, in both cases larger than the fraction observed in gasoline emissions. BC to $PM_{2.5}$ ratios at 47–52% have also been reported for diesel train emissions in Atlanta (Galvis et al., 2013). The average BC EF of 0.66 g_{BC}/kg_{fuel} (see the Supporting Material, SM, Figure S1) suggests that rail BC emissions are similar to those reported from heavy–duty diesel trucks, 0.54 g_{BC}/kg_{fuel} (Dallmann et al., 2012). Because only very few coal trains were identified at the CRG site, there was insufficient data to clearly identify coal dust in the BC time–series data.

3.4. Size distributions

The DustTrak measures PM concentrations in four size ranges. For the majority of trains measured, the mass fraction of the TSP concentration was dominated by particles smaller than 1 µm diameter. To compare the size distributions from different train types, we required that R^2>0.5 for the PM_1–TSP correlation for an event to be included in this analysis. This yielded 449 train events from the Seattle site for this analysis, out of 487 possible events. Data on the PM size distributions are given in Table S1 (see the SM). Note that because we use different QC criteria than for the PM_1/CO_2 slope, the number of train events included in this analysis is different from the number shown in Table 1. For these 449 events, the average PM/TSP mass fraction for all trains was found to be 0.86, 0.89 and 0.97 for PM_1, $PM_{2.5}$ and PM_{10}, respectively.

For some trains, there was evidence for larger particles present. Figure 6 shows the measured PM_1, TSP and CO_2 concentrations for a coal train that passed the Seattle site starting at 9:56 local time on August 13, 2013. For this train event, the first peak, between 9:56 and 9:57, shows an excellent correlation between PM_1 and CO_2 (R^2=0.98) and nearly all aerosol mass is due to particles less than 1 µm diameter (PM_1≈TSP). However, there is a second peak in PM_1 at 9:59 without a corresponding CO_2 peak. For this peak, TSP is now significantly larger than PM_1, indicating the presence of larger particles. It is important to note that our inlet likely excludes a significant fraction of larger particles, so our measured TSP concentrations are likely an underestimate. We examined the data to see if there was a statistically significant difference between the PM fractions by train type. Figure 7 shows the average PM size fraction (PM_1/TSP, $PM_{2.5}$/TSP and PM_{10}/TSP) separated by train types for the Seattle site. On average, the PM fractions show that coal trains emit larger particles into the air. These PM_1/TSP fractions, 0.87, 0.77 and 0.88 for freight, coal and passenger trains, respectively, are significantly different at a *P* value of <0.02. Though we did not collect PM samples for chemical analysis, it seems highly likely that the relative contribution of larger particles due to the total PM mass consist of aerosolized coal dust from the uncovered coal trains.

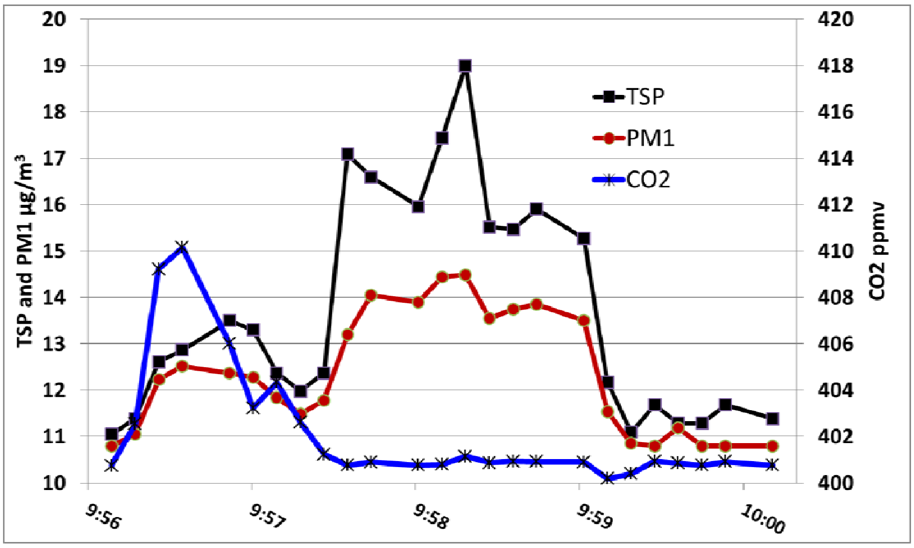


Figure 6. *PM_1 and total suspended particulate (TSP) in µg/m^3 and CO_2 (ppmv) concentrations during passage of a coal train at the Blue Ridge site at 9:56 (PDT) on August 13, 2013.*

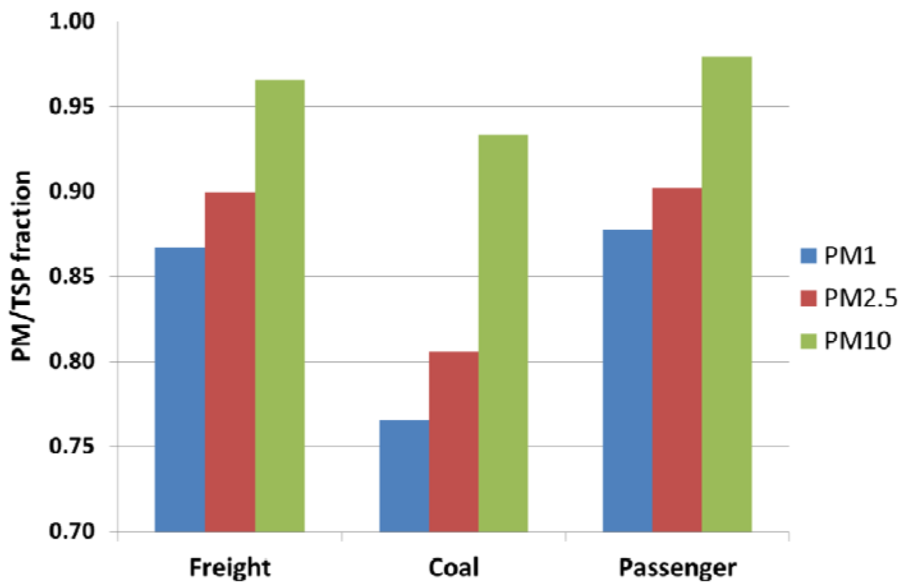


Figure 7. *Fraction of total suspended particulate mass in each size range as measured by the DustTrak at the Blue Ridge site. For this comparison there were 296, 49 and 104 freight, coal and passenger trains, respectively, which had an R^2 for the PM_1-TSP relationship of >0.5. For the PM_1/TSP fraction, the coal trains are significantly lower than freight and passenger trains (p<0.01), indicating that a larger fraction of the total PM mass is greater than 1 µm, compared to the other train types.*

3.5. $PM_{2.5}$ exposure due to trains

We measured average $PM_{2.5}$ concentrations at the Seattle and CRG sites of 11.0 and 7.4 µg/m^3, respectively. The lower concentrations at the CRG site reflect the fact that this region is characterized by higher wind speeds and the fact that our site was on a bluff overlooking the river and railroad tracks. At the Seattle site, the instruments were located only a few meters higher than the tracks and the local topography likely creates a greater barrier to dilution of the train emissions. An additional factor is the cold temperatures of Puget Sound (10–12 °C), which cause a stable layer near the surface of Puget Sound (Mass, 2013).

Figure S2 (see the SM) shows the daily average $PM_{2.5}$ concentrations for the BR site during our measurement period, along with three other sites in the region operated by the Puget Sound Clean Air Agency. The site locations are shown in Figure 1. The daily variations at all sites are well correlated and reflect regional $PM_{2.5}$ source/sink relationships. For example, all sites had lower $PM_{2.5}$ on August 1–2, 2013, when cooler, wetter and windier conditions prevailed across the region. During the 4–week measurement period, the average $PM_{2.5}$ concentrations at the Blue Ridge, Lynnwood, Beacon Hill and Duwamish sites were 11.0, 4.3, 6.6 and 11.1 µg/m^3, respectively. The BR and industrial Duwamish Valley sites show similar concentrations, despite the fact that there are no major roads or industries near the BR site. It is possible that marine vessels could have contributed to the enhanced $PM_{2.5}$ observed at the BR site. To evaluate this possibility, we examined $PM_{2.5}$ concentrations at four marine sites along Puget Sound for the same time period using data from the Puget Sound Clean Air

Agency (PSCAA, 2013). For the sites at Bremerton, Oak Harbor, Port Angeles and Port Townsend, the average $PM_{2.5}$ concentrations during this same time period were 5.0, 3.2, 3.5 and 5.0 μg/m^3, respectively. Thus it appears that marine shipping cannot explain the much higher concentrations observed at the BR site. We attribute the additional $PM_{2.5}$ to the presence of the nearby rail line and trains. The difference between the measured PM at the BR site and the average of the four marine sites (11.0–4.2 μg/m^3) represents the additional $PM_{2.5}$ at the BR site due to diesel trains (6.8 μg/m^3).

The enhancement in $PM_{2.5}$ is not only due to the "spikes" that occur as a train passes, but also the residual that accumulates in the local airshed. The topography in the Puget Sound region may also exacerbate the accumulation of $PM_{2.5}$ from trains. This is because the rail line runs approximately north–south (see Figure 1) in the same direction as the prevailing summer winds, and at the foot of a 50–100 meter–high bluff that further limits mixing. These factors contribute to the $PM_{2.5}$ enhancement due to rail traffic.

We can estimate possible impacts of increasing rail traffic on $PM_{2.5}$ concentrations at the BR site. We assume that the $PM_{2.5}$ enhancement due to trains, 6.8 μg/m^3, is linearly related to the total train traffic. Using this assumption, a 50% increase in diesel train traffic would increase the $PM_{2.5}$ due to trains to 10.2 μg/m^3. When added to the regional background (4.2 μg/m^3), this would bring the $PM_{2.5}$ concentrations at the BR site up to approximately 14 μg/m^3, which is higher than the new U.S. National Ambient Air Quality Standard (NAAQS) of 12.0 μg/m^3 (annual average). It is important to note that compliance with the NAAQS is based on three years of data, and thus our one month of observations cannot indicate compliance. But nonetheless, this calculation suggests that a 50% increase in rail traffic will put some residences, such as our BR home, near or over the NAAQS. This assumes that each train contributes uniformly to the PM exposure. While our diesel emission factors for coal and freight train types were statistically indistinguishable, the train length, number of locomotives and fuel consumption may vary for different train types. Thus a more complete estimate of future impacts on air quality from rail traffic should consider these factors.

4. Summary

We measured the PM_1 emission factors for over 450 trains at two sites in Washington State and the resulting $PM_{2.5}$ exposure (μg/m^3). For 84 of these trains, we also measured the black carbon emission factors. Our measurements demonstrate that rail traffic emits substantial quantities of diesel exhaust and that the $PM_{2.5}$ concentrations are significantly enhanced for residents living close to the rail lines. Future growth in rail traffic will increase the $PM_{2.5}$ exposure and, for some homes, may result in concentrations that exceed the U.S. NAAQS. Our results also show that after passage of coal trains there was a statistically significant enhancement in larger particles, compared to other train types. These larger particles most likely consist of aerosolized coal dust. Our study addresses exposure to residents who live close to the rail lines. Future studies should examine several questions that were not addressed by our study:

(i) How does the concentration of $PM_{2.5}$ vary with proximity to the rail lines?

(ii) What are the total emissions from rail traffic and what is the net contribution to $PM_{2.5}$ across the broader Seattle metropolitan area?

(iii) What are the health effects associated with $PM_{2.5}$ and coal dust from rail traffic?

Acknowledgements

The authors would like to acknowledge the financial contributions of over 270 individuals via microryza.com and a donation by the Sierra Club. These donations were made as gifts to the University of Washington. The authors are also grateful to several anonymous individuals who let us use their home and/or property to conduct these measurements. BA and JLF would like to thank Tony Hansen and Magee Scientific for the generous loan of the AE–22 instrument used to conduct these experiments.

Supporting Material Available

BC emission factors calculated for each train event (Figure S1), Daily average $PM_{2.5}$ for four sites in the Seattle metropolitan region (Figure S2), Fraction of total suspended particulate (TSP) mass in the PM_1 and $PM_{2.5}$ size ranges, for each train type (Table S1). This information is available free of charge via the Internet at http://www.atmospolres.com.

References

Abbasi, S., Jansson, A., Sellgren, U., Olofsson, U., 2013. Particle emissions from rail traffic: A literature review. *Critical Reviews in Environmental Science and Technology* 43, 2511–2544.

Ayers, G.P., 2001. Comment on regression analysis of air quality data. *Atmospheric Environment* 35, 2423–2425.

BNSF Railway, 2013. BNSF Railway Statement on STB Coal Dust Decision, http://www.bnsf.com/customers/what–can–i–ship/coal/coal–dust.html, accessed in 2013.

Bond, T.C., Streets, D.G., Yarber, K.F., Nelson, S.M., Woo, J.H., Klimont, Z., 2004. A technology–based global inventory of black and organic carbon emissions from combustion. *Journal of Geophysical Research–Atmospheres* 109, art. no. D14203.

Cahill, T.A., Cahill, T.M., Barnes, D.E., Spada, N.J., Miller, R., 2011. Inorganic and organic aerosols downwind of California's Roseville Railyard. *Aerosol Science and Technology* 45, 1049–1059.

Campbell, D.E., Fujita, E.M., 2006. Data Analysis on the Roseville Rail Yard Air Monitoring Project, Year One Interim Report, Desert Research Institute (DRI), http://www.placer.ca.gov/~/media/apc/documents/UP/2006/April/UPRRAMP2005DataAnalysisFinalReport041306.pdf, accessed in November 2013.

Cantrell, C.A., 2008. Technical Note: Review of methods for linear least–squares fitting of data and application to atmospheric chemistry problems. *Atmospheric Chemistry and Physics* 8, 5477–5487.

Cheng, Y., Lee, S.C., Ho, K.F., Louie, P.K.K., 2006. On–road particulate matter ($PM_{2.5}$) and gaseous emissions in the Shing Mun Tunnel, Hong Kong. *Atmospheric Environment* 40, 4235–4245.

City of Seattle, 2012. Coal Train Traffic Impact Study, https://www.seattle.gov/transportation/docs/121105PR–CoalTrainTrafficImpactStudy.pdf, accessed in 2013.

Cooper, D.A., 2003. Exhaust emissions from ships at berth. *Atmospheric Environment* 37, 3817–3830.

Dachs, J., Eisenreich, S.J., 2000. Adsorption onto aerosol soot carbon dominates gas–particle partitioning of polycyclic aromatic hydrocarbons. *Environmental Science & Technology* 34, 3690–3697.

Dallmann, T.R., DeMartini, S.J., Kirchstetter, T.W., Herndon, S.C., Onasch, T.B., Wood, E.C., Harley, R.A., 2012. On–road measurement of gas and particle phase pollutant emission factors for individual heavy–duty diesel trucks. *Environmental Science & Technology* 46, 8511–8518.

Dallmann, T.R., Harley, R.A., Kirchstetter, T.W., 2011. Effects of diesel particle filter retrofits and accelerated fleet turnover on drayage truck emissions at the Port of Oakland. *Environmental Science & Technology* 45, 10773–10779.

Galvis, B., Bergin, M., Russell, A., 2013. Fuel–based fine particulate and black carbon emission factors from a railyard area in Atlanta. *Journal of the Air & Waste Management Association* 63, 648–658.

Gehrig, R., Hill, M., Lienemann, P., Zwicky, C.N., Bukowiecki, N., Weingartner, E., Baltensperger, U., Buchmann, B., 2007. Contribution of railway traffic to local PM_{10} concentrations in Switzerland. *Atmospheric Environment* 41, 923–933.

Hildemann, L.M., Markowski, G.R., Cass, G.R., 1991. Chemical–composition of emissions from urban sources of fine organic aerosol. *Environmental Science & Technology* 25, 744–759.

Jacobson, M.Z., 2001. Strong radiative heating due to the mixing state of black carbon in atmospheric aerosols. *Nature* 409, 695–697.

Jamriska, M., Morawska, L., Thomas, S., He, C., 2004. Diesel bus emissions measured in a tunnel study. *Environmental Science & Technology* 38, 6701–6709.

Jansen, K.L., Larson, T.V., Koenig, J.Q., Mar, T.F., Fields, C., Stewart, J., Lippmann, M., 2005. Associations between health effects and particulate matter and black carbon in subjects with respiratory disease. *Environmental Health Perspectives* 113, 1741–1746.

Janssen, N.A.H., Hoek, G., Simic–Lawson, M., Fischer, P., van Bree, L., ten Brink, H., Keuken, M., Atkinson, R.W., Anderson, H.R., Brunekreef, B., Cassee, F.R., 2011. Black carbon as an additional indicator of the adverse health effects of airborne particles compared with PM_{10} and $PM_{2.5}$. *Environmental Health Perspectives* 119, 1691–1699.

Kean, A.J., Sawyer, R.F., Harley, R.A., 2000. A fuel–based assessment of off–road diesel engine emissions. *Journal of the Air & Waste Management Association* 50, 1929–1939.

Keill, L., Maykut, N., 2003. Final Report: Puget Sound Air Toxics Evaluation, Puget Sound Clean Air Agency, http://www.pscleanair.org/airq/basics/psate_final.pdf, accessed in 2013.

Kirchstetter, T.W., Novakov, T., 2007. Controlled generation of black carbon particles from a diffusion flame and applications in evaluating black carbon measurement methods. *Atmospheric Environment* 41, 1874–1888.

Lloyd's Register, 1995. Marine Exhaust Emissions Research Program, London.

Mass, C., 2013. Personal communication.

Maykut, N.N., Lewtas, J., Kim, E., Larson, T.V., 2003. Source apportionment of $PM_{2.5}$ at an urban improve site in Seattle, Washington. *Environmental Science & Technology* 37, 5135–5142.

Moosmuller, H., Arnott, W.P., Rogers, C.F., Bowen, J.L., Gillies, J.A., Pierson, W.R., Collins, J.F., Durbin, T.D., Norbeck, J.M., 2001. Time resolved characterization of diesel particulate emissions. 1. Instruments for particle mass measurements. *Environmental Science & Technology* 35, 781–787.

Park, S.S., Kozawa, K., Fruin, S., Mara, S., Hsu, Y.K., Jakober, C., Winer, A., Herner, J., 2011. Emission factors for high–emitting vehicles based on on–road measurements of individual vehicle exhaust with a mobile measurement platform. *Journal of the Air & Waste Management Association* 61, 1046–1056.

PSCAA (Puget Sound Clean Air Agency), 2013. Air Quality Data & Reports, http://www.pscleanair.org/airq/reports.aspx, accessed in 2013.

PSCAA (Puget Sound Clean Air Agency), 2005. 2005 National Air Toxics Assessment, http://www.pscleanair.org/airq/basics/3–10–11%202005%20NATA%20info%20sheet.pdf, accessed in 2013.

Ramanathan, V., Carmichael, G., 2008. Global and regional climate changes due to black carbon. *Nature Geoscience* 1, 221–227.

Ray, A., Vaughn, D., 2009. Standard Operating Procedure for the Continuous Measurement of Particulate Matter: Thermo Scientific TEOM® 1405–DF Dichotomous Ambient Particulate Monitor with FDMS® Federal Equivalent Method EQPM–0609–182 for $PM_{2.5}$. http://www.epa.gov/ttnamti1/files/ambient/pm25/sop_project/905505_TEOM_SOP_Draft_Final_Sept09.pdf, accessed in 2013.

Seinfeld, J., 1986. *Atmospheric Chemistry and Physics of Air Pollution*, Wiley, New York.

Sierra Research, 2004. Revised Inventory Guidance for Locomotive Emissions, Report No. SR2004–06–01, http://www.metro4–sesarm.org/pubs/railroad/FinalGuidance.pdf, accessed in 2013.

U.S. DHHS (U.S. Department of Health and Human Services), 2011. Report on Carcinogens, http://ntp.niehs.nih.gov/ntp/roc/twelfth/roc12.pdf, accessed in 2013.

U.S. EPA (U.S. Environmental Protection Agency), 2013. Locomotives, http://www.epa.gov/otaq/locomotives.htm, accessed in 2013.

U.S. EPA (U.S. Environmental Protection Agency), 2012. Report to Congress on Black Carbon, http://www.epa.gov/blackcarbon/2012report/fullreport.pdf, accessed in 2013.

U.S. EPA (U.S. Environmental Protection Agency), 2009. Emission Factors for Locomotives, EPA–420–F–09–025, 9 pages.

von der Weiden, S.L., Drewnick, F., Borrmann, S., 2009. Particle loss calculator – a new software tool for the assessment of the performance of aerosol inlet systems. *Atmospheric Measurement Techniques* 2, 479–494.

WA DOE (Washington Department of Ecology), 2013. Environmental Review: Gateway Pacific Terminal at Cherry Point Proposal, http://www.ecy.wa.gov/geographic/gatewaypacific, accessed in 2013.

F, Y.G., Hopke, P.K., Rattigan, O.V., Xia, X.Y., Chalupa, D.C., Utell, M.J., 2011. Characterization of residential wood combustion particles using the two–wavelength aethalometer. *Environmental Science & Technology* 45, 7387–7393.

Wang, X.L., Chancellor, G., Evenstad, J., Farnsworth, J.E., Hase, A., Olson, G.M., Sreenath, A., Agarwal, J.K., 2009. A novel optical instrument for estimating size segregated aerosol mass concentration in real time. *Aerosol Science and Technology* 43, 939–950.

Watson, J.G., Chow, J.C., Lowenthal, D.H., Pritchett, L.C., Frazier, C.A., Neuroth, G.R., Robbins, R., 1994. Differences in the carbon composition of source profiles for diesel–powered and gasoline–powered vehicles. *Atmospheric Environment* 28, 2493–2505.

WHO (World Health Organization), 2012. IARC: Diesel engine exhaust carcinogenic, Press Release No. 213, http://www.iarc.fr/en/media–centre/pr/2012/pdfs/pr213_E.pdf, accessed in 2013.

Yanowitz, J., McCormick, R.L., Graboski, M.S., 2000. In–use emissions from heavy–duty diesel vehicles. *Environmental Science & Technology* 34, 729–740.

Zhu, J.P., Aikawa, B., Pigeon, R., 2005. Measurement of fine particles in diesel emissions using a real–time aerosol monitor. *Journal of the Air & Waste Management Association* 55, 978–983.

Atmospheric Pollution Research

www.atmospolres.com

SUPPORTING MATERIAL

Diesel particulate matter emission factors and air quality implications from in-service rail in Washington State, USA

Daniel A. Jaffe [1,2], Greg Hof [1], Sofya Malashanka [1,2], Justin Putz [1], Jeffrey Thayer [2], Juliane L. Fry [3], Benjamin Ayres [3] and Jeffrey R. Pierce [4]

[1] *University of Washington-Bothell, School of STEM, Bothell, WA USA*
[2] *University of Washington-Seattle, Department of Atmospheric Sciences, Seattle, WA USA*
[3] *Reed College, Department of Chemistry, Reed College, Portland, OR USA*
[4] *Colorado State University, Department of Atmospheric Science, Fort Collins, CO USA*

Content

Corresponding author: Daniel A. Jaffe, Tel.: 425-352-5357, Fax: 425-352-5335, e-mail: djaffe@u.washington.edu

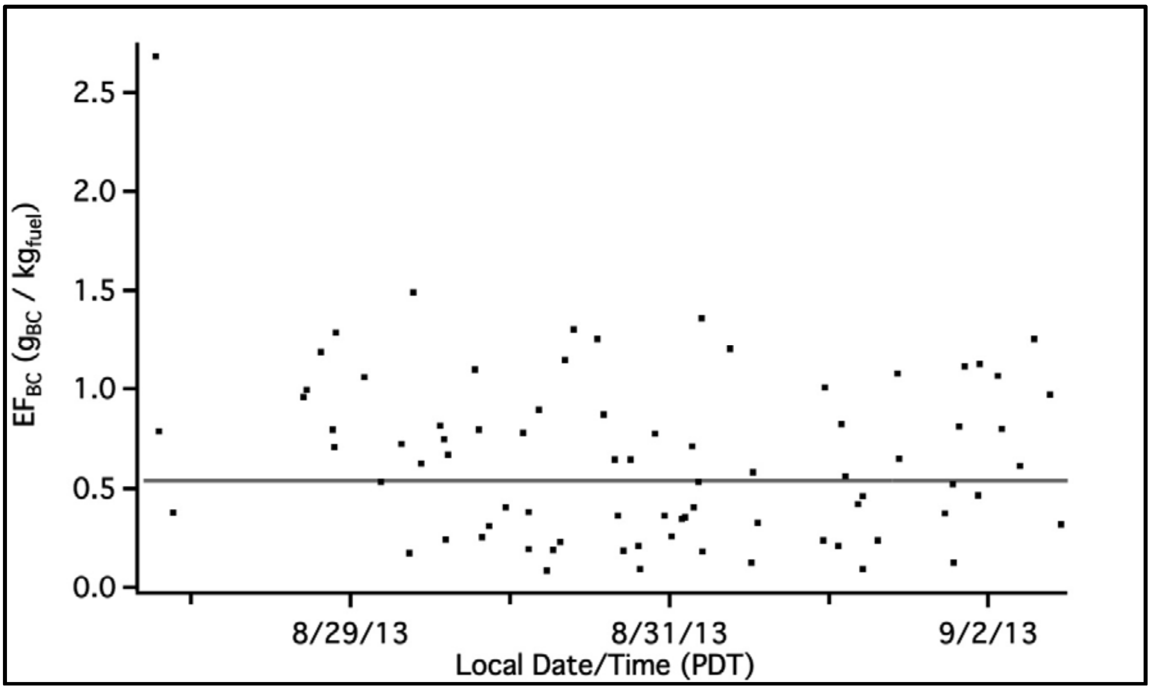


Figure S1. BC emission factors calculated for each train event (dots) show substantial variation, but the mean value of 0.66 g/kg is similar to a recent study on diesel truck engines (0.54 g/kg, horizontal line, Dallmann, et al., 2012).

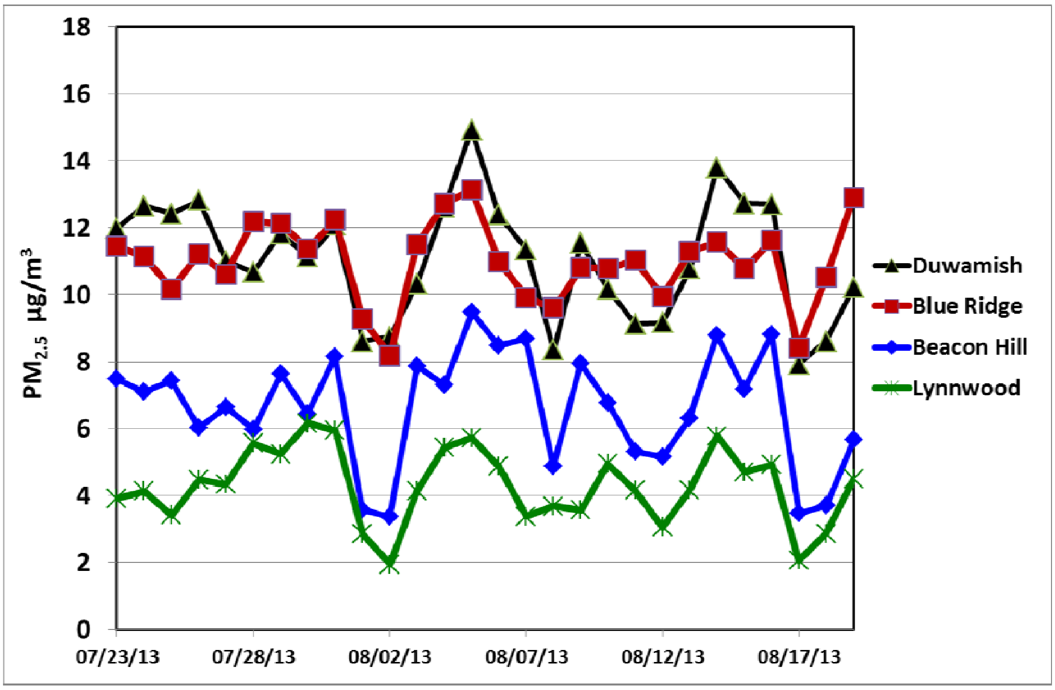


Figure S2. Daily average $PM_{2.5}$ for four sites in the Seattle metropolitan region (see Figure 1 for locations). During this time period the average concentrations for the Duwamish, Blue Ridge, Beacon Hill and Lynnwood sites were 11.1, 11.0, 6.6 and 4.3 µg/m^3, respectively.

Table S1. Fraction of total suspended particulate (TSP) mass in the PM_1 and $PM_{2.5}$ size ranges, for each train type. Data is for the Blue Ridge site only

	Freight	Coal	Passenger
Count	296	49	104
PM1/TSP Average	0.87	0.77	0.88
PM1/TSP Standard Deviation	0.14	0.19	0.12
PM2.5/TSP Average	0.90	0.81	0.90
PM2.5/TSP Standard Deviation	0.13	0.17	0.11

Health Needs Assessment

Southeast Community
City of Newport News

2005

Prepared by:
Peninsula Health District
Virginia Department of Health

Executive Summary

In 2005, Peninsula Health District conducted a community health assessment of the Southeast Community (SEC) of the city of Newport News. Public health professionals perceived and residents reported that the residents of the Southeast Community (zip code areas 23605 and 23607) had significant unmet health needs.

The community health assessment focused on identifying needs and perceptions on 1) prevention and control of chronic diseases, 2) education of the public about chronic disease prevention and 3) improving access to basic chronic disease medical management and access to affordable medications. These areas were priorities areas in U.S. Healthy People 2010 and by the Virginia Department of Health. Data sources for the health assessment included: publicly available demographic data; mortality data provided by the Virginia Center for Health Statistics; and data for emergency department visits and hospital admissions/ discharges provided by local hospitals. In addition, public health professionals conducted individual interviews with approximately fifty key leaders; held focus groups with six resident/key leader groups; and surveyed 368 residents using a sidewalk survey instrument.

Overall Findings: Of the 180,000 residents of Newport News, 40,000 (22%) live in the SEC. The SEC population is predominately poor and medically uninsured. In the easternmost part of the SEC (zip code area 23607), over 50% of adults are living below the 200% poverty level and at least 20% are medically uninsured: 4,114 persons are uninsured and have an income below the 200% poverty level. The population of the SEC is primarily black, not Hispanic: 90% of 23607 and 50% of 23605 zip codes. Sixty percent is between 18 and 64 years of age; approximately 10% are age 65 or older.

The residents of the SEC are at increased risk for hospitalization and death from chronic diseases. For asthma, diabetes, and hypertension, residents of zip code 23607 experience higher rates of emergency room visits and hospitalization than the residents of the neighboring zip code 23605, the city and the state. For diabetes mellitus, residents of zip code 23607 have a rate of 250 hospitalizations per 100,000 population per year—twice the rate experienced by any other area of the city. The death rates for residents of the SEC exceed the rates for the city overall and for the state for heart disease, malignant neoplasms, cerebrovascular disease, and diabetes.

The survey of 368 residents documented perceptions that diabetes, stroke, and high blood pressure were important problems for the community. Poor eating habits, lack of physical activity or exercise, and tobacco and alcohol use were perceived as important unhealthy behaviors in their community. Respondents were not aware of any coordinated efforts that focused on chronic disease issues among medically uninsured/underserved adults.

The community needs assessment confirmed that residents of the SEC have a great deal of pride in and ownership of their community and its challenges. They will be most interested, supportive and participatory in efforts to improve the overall health of their community. Residents commented: *"I enjoy the diversity to the Southeast Community. However negative, there are many positive things here. There's hope. I like the spirit of making the community a better place to live." "It's important for me as a citizen to support this community."*

Recommendation: We recommend formation of a community task force, including residents of the Southeast Community and stakeholders in local government, health care organizations, and community service agencies, to focus local resources and energy on lifting the burden of chronic diseases from the current and future residents of the Southeast Community.

Introduction

The Peninsula Health District serves as the local health department for the city of Newport News. Although there are sources of medical care in the SEC, members of the community continued to ask for the reestablishment of health department clinics in the SEC. The concern was that public health and clinical service needs in this community remained significant. There was a lack of data to identify and quantify specific needs. Information was incomplete on existing resources and support services to address community public health needs, especially chronic disease related needs among adults. Public health professionals needed to know more about access and barriers to medical care and ancillary services in order to better identify resource and service needs.

The Peninsula Health District decided to conduct a small scale community needs assessment of the SEC using internal public health resources. The initial purpose of the community needs assessment was to use subjective and objective data to determine the overall health of the SEC in preparation for developing an action plan to promote health and prevent disease for the residents of the community.

Methods

A committee of Peninsula Health District public health professionals convened to develop a plan to conduct a community assessment of the SEC. For purposes of the community assessment, the committee defined the SEC as encompassing residents of zip code areas 23605 and 23607.

Steps in the assessment included individual interviews of key community leaders/stakeholders, focus groups of residents and stakeholders, individual resident surveys, observation of the community ("windshield survey") and review of health and health-related statistics.

- **Key leader interviews**: Health department staff interviewed over 45 persons believed to be knowledgeable about this community and interested in improving the overall health of its residents. Leaders were asked their opinions about subjects such as community strengths, weaknesses, health conditions, resources, risk behaviors, priorities and suggestions for improvement.
- **Focus groups:** Health department staff facilitated six focus groups within this community to obtain resident and key stakeholder opinions about the same subjects.
- **Resident opinion surveys:** Health department staff visited multiple sites within the targeted zip codes and obtained 368 individual resident opinion surveys. These provided additional information of residents' perceptions of issues and concerns for their community.
- **Statistics:** Staff reviewed health and demographic data for the Virginia, Newport News and zip codes 23605 and 23607. Comparisons were made to establish issues unique or of higher occurrence for the SEC. Data sources included the Virginia Atlas of Community Health, Sentara Health Foundation's 2004 Hampton Roads Community Assessment, U.S. Census data, Virginia Center for Healthy Communities, de-identified emergency room and hospital admission data from 2005 from local hospitals (Riverside Regional Medical Center, Mary Immaculate Hospital, and Sentara Hospitals), Community Health Solutions Analysis from Demographics Now, and the Virginia Center for Health Statistics.
- **Windshield survey:** Committee members drove through the community to observe the community, its appearance and resources for the residents.

Community Description

Newport News is a culturally and socioeconomically diverse city of over 180,000; 40,000 (22%) live in the SEC. The SEC has a large minority population; 90% of the residents of zip code area 23607 are described as black, not Hispanic. The population of zip code are 23607 has a higher proportion of children, a lower proportion of young adults, and higher proportion of senior adults (age > 65) than the city overall and zip code area 23605. Twenty-five percent (25%) of adults age 25 or older in zip code area 23607 had no high school diploma compared to 18% in zip code area 23605 and 16 % for the city overall.

Many residents are at risk for experiencing health disparities due to low socioeconomic status. In the easternmost section of the SEC (zip code area 23607), over 50% of adults are living below the 200% poverty level—an almost two times higher proportion than in the neighboring zip code area and the city. The SEC has areas that are federally designated as medically underserved. The proportion of the SEC population who are medically uninsured exceeds that of both city of Newport News and the state. In zip code area 23607, at least 20% of the residents are medically uninsured; 16% are medically uninsured and have an income below the 200% poverty level.

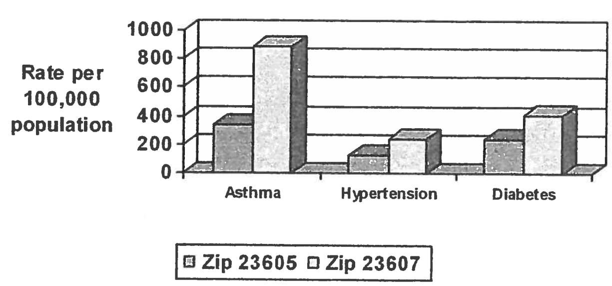
Results

Available data document that residents of the SEC experience higher chronic disease rates and lower quality of life than residents of surrounding areas of the city and the state. The burden of chronic diseases and the need for risk factor reduction were significant concerns voiced by key leaders and residents. The analysis also demonstrated that the SEC is not a homogenous community. Demographics, health statistical data, and resident perceptions varied significantly by zip code area. When feasible, analyses were conducted for zip code areas 23605 and 23607 separately. Because of the increased burden of health issues for residents of zip code area 23607, this report emphasizes the findings and recommendations for that portion of the SEC.

Asthma

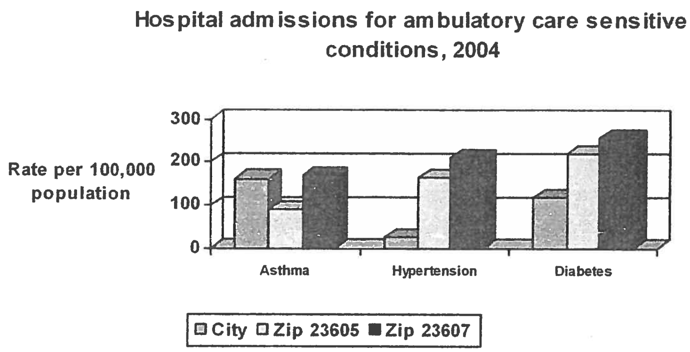
For illnesses characterized as ambulatory care sensitive conditions, **asthma is the number one reason residents of zip code area 23607 visit emergency rooms.** "Ambulatory care sensitive conditions" are illnesses for which there is the potential to minimize visits to the emergency room or hospitalization through an appropriate level of outpatient care and disease self-management. Hospitalization for asthma among residents of 23607 occurs at a rate that is over twice the rate for all city residents and for the state. Concern about air quality in their community and the effect the "coal piers" have on them and their families was voiced frequently by focus group members and by 42 % of survey respondents in 23607. *"The coal dust has always been a problem. It has to have an effect on the health of the people; daily on my mother's porch we wipe off coal dust."*

Emergency department visits for ambulatory care sensitive conditions, 2004



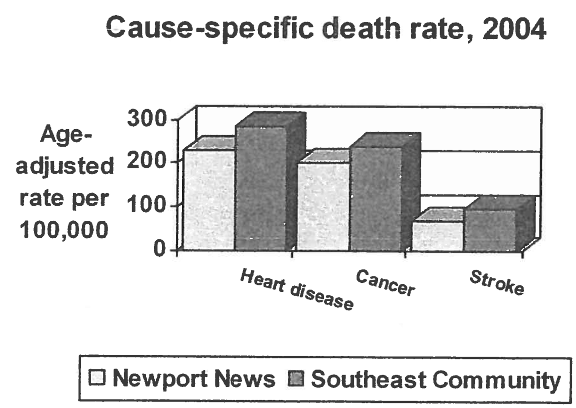
Diabetes

While diabetes mellitus is a growing concern for all adults and children, residents of zip code area 23607 bear a disproportionate burden. Their rate of **hospitalization for diabetes (250 hospitalizations per 100,000 population per year) is twice the rate experienced by any other area of the city** and over twice the state rate. Diabetes is the second most frequent reason for emergency department visits for an ambulatory care sensitive condition by residents of the SEC. Diabetes ranks as the sixth leading cause of death for residents of the SEC, but this standing underplays the role that diabetes plays in mortality since nationwide 75% of persons with diabetes die from heart disease or stroke. From focus groups and the survey, 67% of residents of zip code area 23607 believe that diabetes is a problem for their community.



Hypertension and Heart Disease

Among residents of the SEC, **heart disease is the leading cause of death** and stroke (cerebrovascular disease) is the third leading cause of death. Age-adjusted death rates for heart disease and stroke for residents of the SEC exceed the city and the state rates for these conditions. For residents of 23607, hypertension is the fourth leading reason individuals visit emergency rooms with an ambulatory care sensitive condition reason. Over 50% of the SEC respondents described high blood pressure and stroke as major concerns for the community. For Newport News, 33% of the residents have been told by their doctor they have high blood pressure (Virginia Atlas Adult Behavior Survey, 2004).



Other Causes of Death

Cancer is the second leading cause of death for residents of the SEC. The death rate from cancer exceeds overall city and state rates. The fourth leading cause of death for the SEC was unintentional injuries with the highest rates occurring among those in age groups 20-24 years, 45-54 years and 85 years and above.

Mental Health

Concern with mental health issues was voiced by 59% of the respondents in zip code 23607. **Depression** was a concern for 69%; almost half identified depression as a major concern. At almost 1,000 hospitalizations per 100,000 population per year, **hospitalization for psychoses** among residents of 23607 greatly exceeds the rate in the city and the state.

Access to Health Care

Many residents indicated that **access to health care and health-related services is problematic.** Transportation, especially for the elderly, was identified as a problem by 60% of the respondents of 23607. **Lack of transportation** was recognized as affecting the ability to obtain treatments/therapy and medical testing and to pick-up medications, as well as affecting the ability to obtain food and to apply with social services for assistance with health and income needs. Access to medical care/services requiring **co-pays** present barriers to patient use of service. **Medication access** continues to be a problem for uninsured, indigent patients. One resident stated *"Some older people in the area don't have insurance and don't seek medical care." "Generally there is trust that PICH has does an outstanding job. The biggest problem is transportation."*

There are significant barriers to **access for specialty medical care**. For the uninsured, specialty care services are only through referral to the Medical College of Virginia in Richmond. The added eligibility process, waiting lists for an appointment as long as six to nine months, and the cost of travel and parking impose barriers for many patients. Once a patient sees a specialist, diagnostic tests and follow-up visits require additional trips to Richmond.

Approximately 65 % of the respondents in zip code area 23607 noted a **lack of dental care** as a continuing concern for adults and children. Although the Peninsula Institute for Community Health (PICH) has been providing dental services in the East End Health Facility, one resident stated the *"PICH dental clinic has had to stop taking appointments."*

Other Health-related Concerns

Over 70% of respondents to the survey identified different health behaviors as major problems for the residents of their community: **lack of physical exercise** (75%), **poor eating habits** (71%); **smoking** (80%), **underage smoking** (77%), and **alcohol abuse** (78%).

Sixty-one percent of the respondents in zip code 23607 were concerned about **neglect of older people**. There was a perceived need for more support systems for the elderly.

Focus groups indicated that the residents are often **not aware of services** or activities and, therefore, do not participate or take advantage of them.

The **impact of homelessness** on the community was a concern of most focus and key groups. When persons *"hang around,"* they frighten residents. *"We don't focus enough on health or mental health. Homeless have no services and there is no homeless policy."* Another focus group member observed that the *"homeless bring a sense of trouble with them."* Another resident stated that the *"community's biggest problem is drugs and alcohol. When winter shelter is over, a lot more people will be in the street. And, with four or five people drinking together, there will be a problem. The police run them from corner to corner."*

Teens "hanging around" were a common concern of residents. Seniors verbalized significant fear of the teens. One resident stated *"Young people don't have a lot of places to go. Most recreation centers have a fee in order to go there. Walking trails are not available. There's very little to do in the surrounding area."*

Trash around the neighborhood and the appearance of their community was a major concern for many residents.

Other issues identified as major concerns or problems during the survey of residents of the community were **drinking and driving** (74%), **youth violence** (74%), **youth access to and use of weapons** (75%), **weapons in schools** (66%), and **sexual assault** (65%). Many residents did praise the work of the Newport News police department saying that *"Crime is 100% better; we don't have as much loitering as we had in the past."*

Discussion and Potential Strategies

Residents of the Southeast Community, especially those living in zip code are 23607, shoulder a significant burden of chronic diseases and adverse health behaviors that lead to or complicate common chronic diseases, such as asthma, diabetes, heart disease, and hypertension. Individually and collectively, residents of the SEC face many barriers to improving their health and their health care.

Part of the solution is improved access to health care with more primary medical care and dental care services accessible, affordable, and acceptable to the residents of the SEC, as is improved access to health-related services such as pharmacies and social services. Identifying barriers to access to existing services and planning for the expansion or development of new services are necessary first steps. Residents also need to feel that they live in a safe and cohesive community that facilitates and promotes a healthy lifestyle.

Coordination of existing resources and efforts is a necessary first step. Many groups are providing services which may be more effective if conducted as a combined, collaborative effort. For example, many churches are providing a variety of support services which may reach a broader population if the churches coordinated their efforts. Increased publicity of services and events may increase resident awareness and access to existing resources. The next steps would be collaboration in the development and implementation of new efforts.

The elderly residents of the SEC may benefit from programs, such as "Block Buddies" and "Contact Peninsula," or the services of community police officers and organizations, such as the Peninsula Agency on Aging. For some services, increased awareness may be the key, while for others a service may need to expand or a program will need to be implemented.

Residents may benefit from programs to promote healthy life choices to prevent the occurrence of chronic disease. Those already diagnosed with a chronic disease may benefit from programs to improve their own self-management of their chronic disease and to reduce their disability and improve their quality of life. Community development efforts to improve the environment and provide a greater range of local resources (e.g., new grocery stores) may facilitate residents making healthy choices regarding physical activity and diet.

The impact of asthma in zip code area 23607 strongly suggests the need to examine air quality for asthma triggers and remediation. In addition to community education, it may be helpful to provide asthma patients and their families with nurse case management to assist with better asthma control, reduce emergency department visits and hospital admissions, and decrease school and work absenteeism related to asthma.

Recommendation

This community needs assessment provides a snapshot of the health burdens and health needs of the residents of the Southeast Community. Improving the health and quality of life for residents of the SEC will require a concerted and collaborative approach by the residents, local government departments, local health services providers, community agencies, key community leaders, and other interested persons.

> ***We recommend the formation of a community task force, which includes residents of the Southeast Community and stakeholders in local government, health care organizations, and community service agencies, to focus on lifting the burden of chronic diseases from the current and future residents of the Southeast Community.***

Next Steps

The Peninsula Health District will take the lead in sharing the findings from this community needs assessments with key leaders in the Southeast Community and with leaders in local government. The Health District will initiate and facilitate the formation of the community task force and will make a commitment of staff and time to administrative support of the task force's efforts.

In support of this initiative, the Health District submitted a proposal for a 2-year assignment of a Public Health Prevention Specialist (PHPS) from the Centers for Disease Control and Prevention to the Peninsula Health District. The PHPS's assignment would be dedicated to developing and implementing community-based, community-supported programs to address the chronic disease prevention and disease management needs of the residents of the Southeast Community. The PHPS will focus on building and sustaining community coalitions, initiating and facilitating program development and implementation, and obtaining and sustaining community and stakeholder support and resources for the program activities. The proposal has had favorable reception to date, but a final decision will not be made until late July.