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# Acronyms

<table>
<thead>
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<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BACI</td>
<td>Before/After Control Impact</td>
</tr>
<tr>
<td>B&amp;S</td>
<td>Biofilm and Shorebirds</td>
</tr>
<tr>
<td>CEAA</td>
<td>Canadian Environmental Assessment Act</td>
</tr>
<tr>
<td>CCIP</td>
<td>Container Capacity Improvement Program</td>
</tr>
<tr>
<td>Compass</td>
<td>Compass Resource Management</td>
</tr>
<tr>
<td>EA</td>
<td>Environmental EPS Assessment</td>
</tr>
<tr>
<td>EPS</td>
<td>Extracellular Polymeric Substance</td>
</tr>
<tr>
<td>FRE</td>
<td>Fraser River Estuary</td>
</tr>
<tr>
<td>HPLC</td>
<td>High-Protein, Low-Carbohydrate</td>
</tr>
<tr>
<td>FRE</td>
<td>Fraser River Estuary</td>
</tr>
<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
</tr>
<tr>
<td>NHC</td>
<td>Northwest Hydraulics Consultants</td>
</tr>
<tr>
<td>POE</td>
<td>Pathways of Effects</td>
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<tr>
<td>PC</td>
<td>Productive Capacity</td>
</tr>
<tr>
<td>PMV</td>
<td>Port Metro Vancouver</td>
</tr>
<tr>
<td>POC</td>
<td>Particulate Organic Carbon</td>
</tr>
<tr>
<td>RB</td>
<td>Roberts Bank</td>
</tr>
<tr>
<td>RBT2</td>
<td>Roberts Bank Terminal 2</td>
</tr>
<tr>
<td>SRKW</td>
<td>Southern Resident Killer Whales</td>
</tr>
<tr>
<td>TAG</td>
<td>Technical Advisory Group</td>
</tr>
<tr>
<td>TEU</td>
<td>Twenty-Foot Equivalent Unit</td>
</tr>
<tr>
<td>TOC</td>
<td>Total Organic Carbon</td>
</tr>
<tr>
<td>TSS</td>
<td>Total Suspended Solids</td>
</tr>
<tr>
<td>USGS</td>
<td>U.S. Geological Survey</td>
</tr>
<tr>
<td>VEC</td>
<td>Valued Ecosystem Component</td>
</tr>
<tr>
<td>WESA</td>
<td>Western Sandpiper</td>
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1 Introduction

1.1 Purpose and Background

The Roberts Bank Terminal 2 (RBT2) project is a proposed new three-berth container terminal in Delta, BC that would expand existing port facilities by 2.4 million twenty-foot equivalent units (TEUs) of container capacity. The project is part of Port Metro Vancouver’s (PMV) Container Capacity Improvement Program (CCIP), a long-term strategy to meet anticipated growth in demand for container capacity. The proposed RBT2 project entails the construction of a new three-berth marine terminal and associated road and rail infrastructure alongside the existing Westshore and Deltaport terminals at Roberts Bank. PMV has a mandate to support the growth of Canadian trade with other countries, and current demand forecasts anticipate container traffic to triple by 2030. Subject to regulatory approvals, the RBT2 project could be operational by the mid-2020s. Further information on the proposed RBT2 project can be found on the project’s website, www.robertsbankterminal.com.

Figure 1.1 Artist's rendering of the proposed RBT2.

The proposed RBT2 project is subject to environmental assessment (EA) under federal and BC provincial laws. EA is a process whereby the potential effects of proposed projects on the environment are examined through a public process. While the scope and nature of the EA for RBT2 has not yet been determined by regulators, PMV expects the EA to be some form of joint review process. The proposed RBT2 project could potentially cause a variety of environmental effects, some of which are reasonably well understood, and some of which are less well understood due to their complexity and based on the current state of scientific knowledge.

PMV has contracted Hemmera, a consulting firm specializing in EA, to conduct the EA studies for the proposed RBT2 project. Some of these studies, such as baseline studies that characterize the environment pre-construction, are currently underway. As part of its pre-EA work, PMV initiated a Technical Advisory Group (TAG) process to gather input from outside experts on four separate topics.

This report is written by Compass on behalf of the Biofilm & Shorebirds TAG and summarizes the proceedings and recommendations of that TAG.
1.2 Overview of the Technical Advisory Group Process

The purpose of the TAG process was to pro-actively gather input from scientific and technical experts prior to the formal initiation of the EA for RBT2 so as to enhance the relevance, quality, and rigour of EA studies for the project (Figure 1.2). Experts were invited from regulatory agencies, academia, First Nations and key non-government organizations based on their ability to contribute to technical discussions pertaining to the EA studies.

Figure 1.2. Role of TAG process in ensuring high-quality EA of the proposed RBT2 project.

The TAG process involved four separate TAGs:

1. Biofilm and Shorebirds;
2. Southern Resident Killer Whales (SRKW);
3. Coastal Geomorphology; and
4. Productive Capacity of Roberts Bank habitat.

The four TAGs each addressed topics that were considered by PMV and its consultants to require additional preliminary scoping in order to satisfy EA requirements.

The initial intention of the Biofilm and Shorebirds TAG was to inform the relationship between biofilm and shorebirds. However, given the importance of infauna as a food source for shorebirds, the TAG decided to include infauna in the discussion. The focus of the Biofilm and Shorebirds TAG therefore gave equal attention to biofilm, infauna, and shorebirds, despite infauna being absent from the title.

Biofilm, shorebirds, and SRKW are likely to be recognized in the forthcoming EA as topics of particular importance to stakeholders and thus of the forthcoming EA process. These topics are discussed in this report, and within a companion report on the SRKW TAG.

Coastal geomorphology—the physical features and processes in the vicinity of the proposed project area at Roberts Bank—was chosen because project-related geomorphic and physical oceanographic changes are expected to be a primary driver for marine biological and ecological changes. RBT2 infrastructure may cause changes to tidal currents and water movement associated with wind-generated waves, which could affect sediment settling and re-suspension, which in turn could cause changes to local marine habitats, such as biofilm and eelgrass beds. This topic is explored in a companion report on the Coastal Geomorphology TAG.
Similarly, the ability of habitat to support species of particular interest to stakeholders is critical to the health of those species. PMV sees merit in entering into technical dialogue on how the productive capacity of habitat is most appropriately defined at Roberts Bank. This topic is explored in a companion report on the Productive Capacity TAG.

Despite the different topics of each of the four TAGs, all four had a similar set of objectives:

- build a common understanding of the potential effects of RBT2 based on the best available information;
- provide input on appropriate methods for assessing potential adverse effects and their significance;
- identify priority information needs and related studies; and
- Identify opportunities for collaboration.

Each TAG met face to face three or four times between November 2012 and May 2013. Meetings were held in Vancouver over full day periods. Each individual TAG was designed and led by Compass, who acted as an external facilitator. In each meeting Compass and PMV consultants led discussions with TAG members. In addition, for all TAGs except Coastal Geomorphology, focus groups were created to investigate particular topics in greater depth with an additional set of experts relevant to each field.

1.3 Participants and Roles in the TAG Process

There were five main parties identified as potential participants in the TAG process: technical experts from government agencies, academia, non-governmental organizations, PMV and PMV consultants, and First Nations. First Nations did not participate in the TAG process, however PMV has committed to share TAG information and obtain input through a separate process.

TAG members were tasked with:

- providing input on current and planned EA studies;
- providing input on potential effects of the project on the environment;
- providing input on impact assessment methods;
- helping prioritize and scope key issues; and
- providing input from their organization.

PMV consultants, Hemmera, were tasked with:

- preparing material for TAG meetings, such as pre-reading packages, presentation slides, and discussion materials;
- managing schedules, scope, and budget for the TAG process;
- explaining current study plans to the TAGs;
- ensuring integration of people and discussions across TAGs where relevant;
- organizing meeting logistics; and
- where relevant, having representatives participate as TAG members in TAG meeting discussions.

PMV was tasked with:

- providing resources and meeting logistics;
- providing communications with TAG participants and the public;
- providing information about the proposed RBT2 project; and
- observing TAG meetings and considering input from each TAG.
The TAG process was advisory in nature, and so PMV sought to gather advice through the process in terms of how best it and its consultants should conduct the EA studies for RBT2.

Compass was tasked with:
- designing the TAG process and advising on implementation;
- facilitating TAG meetings;
- advising on how discussions and outputs of individual TAGs might be used by other TAGs;
- summarizing input, including areas of agreement and disagreement, in meeting notes; and
- producing a record of the process in this summary report.

1.4 About This Report

This report reviews the discussions and outputs of the Biofilm & Shorebirds TAG. This report does not attempt to follow the chronological order in which items were discussed during the meetings, but rather provides a thematically-organized synthesis of discussions that occurred over the course of the TAG meetings.

The next section provides more background information on the Biofilm & Shorebirds TAG in terms of what meetings were held, who was involved, and what specific topics were explored. Sections 3 and 4 examine methods for assessing effects on shorebirds, and on biofilm and benthic macrofaunal and meiofaunal invertebrates (infauna) respectively, and form the bulk of the report. Section 5 examines several related issues that were less prominent in the TAG process. The reader is encouraged to review the reports for the other three TAGs to have a complete understanding of the RBT2 TAG process.

2 Background on Biofilm and Shorebirds TAG

2.1 Introduction

The proposed Roberts Bank Terminal 2 (RBT2) project will introduce changes to the biotic and abiotic environment that may affect shorebirds using the Fraser River Estuary. It will be necessary in the EA context to determine whether the RBT2 project is likely to result in changes to food sources (biofilm and infaunal invertebrates) and to site safety in the Roberts Bank area, thereby causing a significant adverse effect (as defined by the Canadian Environmental Assessment Act - CEAA) on shorebird populations. Of particular interest is the utilization of biofilm as a food source for migrating shorebirds, for which very little is known.

The Biofilm and Shorebirds (B&S) TAG was convened to solicit input on suitable methods that are scientifically defensible, relevant to the regulatory process and relevant to the Roberts Bank area for modelling change to biofilm, infauna and shorebirds, and for assessing and reporting biofilm, infauna and shorebirds response to such change. The B&S TAG discussed how the RBT2 project might affect B&S at Roberts Bank, how PMV and its consultants might assess these effects (using suitable assessment methodologies), and how any effects might be mitigated. This report summarizes the input provided by the B&S TAG and Focus Group in a thematically-organized synthesis of discussions over the course of four TAG meetings.
2.1.1 TAG Meeting Summary

The B&S TAG met four times between November 2012 and March 2013 to discuss a number of topics (Table 2.1).

Table 2.1 Dates and key topics of B&S TAG meetings

<table>
<thead>
<tr>
<th>Meeting Date</th>
<th>Key Topics Covered</th>
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<tbody>
<tr>
<td>November 29, 2012</td>
<td>• TAG process&lt;br&gt;• RBT2 project overview&lt;br&gt;• Overview of biofilm and shorebird issues at Roberts Bank&lt;br&gt;• Pathways of Effects diagram intended for use as an organizing framework to structure B&amp;S TAG discussion about effects, uncertainties, and studies (see Figure 2.1 Pathways of effects on Biofilm, Infauna, and Shorebirds)&lt;br&gt;• Current research: methods, preliminary results and future planned studies&lt;br&gt;• Priorities and work plan for B&amp;S TAG</td>
</tr>
<tr>
<td>January 25, 2013</td>
<td>• Review of anticipated geomorphological changes due to RBT2&lt;br&gt;• Discussion on assessing significance in environmental assessments&lt;br&gt;• Review of preliminary data collected from biofilm, infauna, and shorebird studies across the Fraser River Estuary (FRE)&lt;br&gt;• Review of proposed method for modelling effects on shorebird abundance (based on food availability and site safety)&lt;br&gt;• Decision to convene Focus Group to provide input on possible factors affecting biofilm and infaunal invertebrate distribution, composition, and abundance (i.e., pathways of effects), development of studies&lt;br&gt;• Work plan and next steps</td>
</tr>
<tr>
<td>March 14, 2013</td>
<td>• Review of biofilm and infauna Focus Group results&lt;br&gt;• Review of potential effects of geomorphological changes on biofilm and infauna&lt;br&gt;• Detailed presentation of biofilm and infauna studies, review of assumptions, assessment of potential data gaps or methodological challenges, and identification of additional studies or modifications to existing studies to fill gaps&lt;br&gt;• Assessing effects to infauna and biofilm and identification of potential mitigation options&lt;br&gt;• Review of proposed model for assessing affects to shorebirds</td>
</tr>
<tr>
<td>March 15, 2013</td>
<td>• Continued discussion concerning shorebird model structure&lt;br&gt;• Detailed presentation of shorebird studies and methods&lt;br&gt;• Assessment of potential data gaps or methodological challenges, review of assumptions, and identification of additional studies or modifications to existing studies to fill gaps&lt;br&gt;• Assessing significance of effects&lt;br&gt;• Discussion of mitigation options and post-implementation monitoring&lt;br&gt;• TAG wrap-up and key messages</td>
</tr>
</tbody>
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2.1.2 TAG Participants

In total, twelve TAG members participated in the B&S TAG discussions, and nine observers attended without active participation. Table 2.2 presents participants of the B&S TAG.

Table 2.2 Participants in the Biofilm & Shorebirds TAG

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Role</th>
<th>Participation</th>
</tr>
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<tbody>
<tr>
<td>Juergen Baumann</td>
<td>Baumann Environmental Services Ltd.</td>
<td>TAG member</td>
<td>Meetings 1, 2, 3, 4</td>
</tr>
<tr>
<td>Christian Beaudrie</td>
<td>Compass</td>
<td>Facilitator</td>
<td>Meetings 1, 2</td>
</tr>
<tr>
<td>David Angus</td>
<td>Compass</td>
<td>Support</td>
<td>Meetings 3, 4</td>
</tr>
<tr>
<td>Lee Failing</td>
<td>Compass</td>
<td>Facilitator</td>
<td>Meetings 1, 2, 3, 4</td>
</tr>
<tr>
<td>Andrew Robinson</td>
<td>Environment Canada</td>
<td>Observer</td>
<td>Meetings 2, 3, 4</td>
</tr>
<tr>
<td>Mark Drever</td>
<td>Environment Canada</td>
<td>TAG member</td>
<td>Meetings 2, 3, 4</td>
</tr>
<tr>
<td>Terri Sutherland</td>
<td>Fisheries and Oceans Canada</td>
<td>TAG member</td>
<td></td>
</tr>
<tr>
<td>Ben Wheeler</td>
<td>Hemmera</td>
<td>Observer</td>
<td>Meetings 1, 2, 3, 4</td>
</tr>
<tr>
<td>Carson Keever</td>
<td>Hemmera</td>
<td>TAG member</td>
<td>Meetings 1, 2, 3, 4</td>
</tr>
<tr>
<td>Doug Bright</td>
<td>Hemmera</td>
<td>Observer</td>
<td>Meetings 1</td>
</tr>
<tr>
<td>Eriko Arai</td>
<td>Hemmera</td>
<td>Observer</td>
<td>Meetings 1, 2, 3, 4</td>
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<tr>
<td>Jay Rourke</td>
<td>Hemmera</td>
<td>TAG member</td>
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<tr>
<td>Marina Winterbottom</td>
<td>Hemmera</td>
<td>Observer/Presenter</td>
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<tr>
<td>Tobin Seagel</td>
<td>Hemmera</td>
<td>Presenter</td>
<td>Meeting 2</td>
</tr>
<tr>
<td>Matthew Fields</td>
<td>Montana State University</td>
<td>TAG member</td>
<td>Meetings 1, 2, 3</td>
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<tr>
<td>Derek Ray</td>
<td>Northwest Hydraulic Consultants</td>
<td>Presenter</td>
<td>Meeting 2, 3</td>
</tr>
<tr>
<td>Rob Butler</td>
<td>Pacific Wildlife Foundation</td>
<td>TAG member</td>
<td>Meetings 1, 2, 3, 4</td>
</tr>
<tr>
<td>Tomohiro Kuwae</td>
<td>Port and Airport Research Institute</td>
<td>TAG member</td>
<td>Meetings 2, 3, 4</td>
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<tr>
<td>Jody Addah</td>
<td>Port Metro Vancouver</td>
<td>Observer</td>
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<td>John Parker-Jervis</td>
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<td>Kyle Robertson</td>
<td>Port Metro Vancouver</td>
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<td>Rhona Hunter</td>
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<tr>
<td>David Lank</td>
<td>Simon Fraser University</td>
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<tr>
<td>Ron Ydenberg</td>
<td>Simon Fraser University</td>
<td>TAG member</td>
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<tr>
<td>Maycira Costa</td>
<td>University of Victoria</td>
<td>TAG member</td>
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<tr>
<td>John Takekawa</td>
<td>USGS Western Ecological Research Center</td>
<td>TAG member</td>
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<tr>
<td>Chris Martin</td>
<td>WorleyParsons</td>
<td>Presenter</td>
<td>Meeting 2, 3, 4</td>
</tr>
<tr>
<td>Mary-Lou Lauria</td>
<td>WorleyParsons</td>
<td>TAG member</td>
<td>Meetings 1, 2, 3, 4</td>
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2.1.3 Focus Group Participants

Given the expertise required to inform specific questions raised by the Biofilm & Shorebirds TAG, a Focus Group was convened consisting of individuals with expertise in biofilm and infaunal invertebrates. Focus Group members were engaged through a series of structured interviews to create additional detailed pathway of effects diagrams relating RBT2 to effects on biofilm and infauna. Three experts participated in the Focus Group from government bodies (Environment Canada, Port and Airport Research Institute (Japan)), and one US academic institution (Montana State University).

2.1.4 Initial Selection of TAG Topics

At the onset of the TAG process, PMV consultants identified a number of key areas for guidance, and tasked the TAG members with providing input on several key questions:

- What are the pathways of potential effects linking the proposed RBT2 project to biofilm, infauna, and shorebirds?
• What are the key uncertainties (i.e., knowledge gaps), and how do they affect the ability to assess the effects of the project?

• What are appropriate methods and metrics for assessing the potential effects of the RBT2 project on biofilm, infauna, and shorebirds?

• What should be considered when assessing what would constitute a significant adverse effect on biofilm, infauna, or shorebirds?

• What additional studies are needed to understand how RBT2 may affect biofilm, infauna, and shorebirds?

These topics served to guide the development of agendas for four Biofilm & Shorebirds TAG meetings.

As a starting point, the B&S TAG reviewed potential pathways of effects between the proposed RBT2 project and biofilm, infauna, and shorebirds in the Roberts Bank area (Figure 2.1). This pathway of effects diagram was initially prepared to facilitate discussion, and while revisions proposed by the TAG are incorporated, no attempt was made to seek formal TAG approval. It was not intended for use in quantitative modelling or analysis, but rather as an organizing framework to structure TAG discussion about effects, uncertainties, and studies.

**Figure 2.1 Pathways of effects on Biofilm, Infauna, and Shorebirds**

The possible cause-effect relationships (or hypotheses) summarized in Figure 2.1 were as follows:

1. The proposed RBT2 project footprint may affect physical oceanography (sedimentation, grain size, turbidity, wave/water velocity, salinity, etc.).

2. The presence of terminal construction and operation may affect how shorebirds use the Project area.
3. Infrastructures may affect how predators (raptors) use the Project area which could affect shorebird behaviour and use.

4. Changes in seabed morphology may affect changes in eelgrass, and conversely, changes in eelgrass may affect seabed morphology.

5. Changes in physical oceanography may affect eelgrass distribution.

6. Changes in coastal geomorphology can affect abiotic factors related to biofilm growth, e.g. increases in sediment load in water column could lead to smothering of biofilm/biomat through deposition, and changes in water quality characteristics (turbidity) could make it easier or harder for biofilm/biomat to grow.

7. Changes to biofilm may affect seabed morphology (through stabilization in the event of biofilm growth, or through loss of stabilization in the event of biofilm decline).

8. Changes to seabed morphology may affect benthos.

9. Changes in physical oceanography may affect abiotic factors related to infaunal invertebrate growth.

10. Changes in bird behaviour may have bioenergetic costs (e.g. shifting habitat use, reduced foraging efficiency).

11. Changes in predator use may alter the current rate of predation on shorebirds (e.g. an increase in predator use of area may lead to increased predation rate on shorebirds).

12. Changes in biomat may affect biofilm distribution and abundance, and vice versa.

13. Biofilm and eelgrass may interact competitively.

14. Changes in benthos may affect biofilm/biomat as benthos graze on biofilm/biomat Conversely, changes in biofilm/biomat may affect benthos.

15. Changes in bird foraging behaviour could have bioenergetic effects.

16. Changes in predation pressure may lead to changes in alternation in use of habitat.

17. Potential changes in biofilm abundance and distribution at Roberts Banks may potentially affect individual shorebird feeding at Roberts Bank and across the FRE.

18. Potential changes in benthic infauna abundance and distribution at Roberts Banks may potentially affect individual shorebird feeding at Roberts Bank and across the FRE.

19. Changes to individual shorebird bioenergetics may translate into population level effects on shorebirds.

For each pathway, PMV consultants presented the impact hypothesis, the key uncertainties, and the studies currently underway or planned to address them and the preliminary findings to date. They identified where other TAGs or other parts of the consulting team were doing more detailed work (e.g. the pathways related to physical oceanography are addressed by the Coastal Geormorphology TAG). A summary of pathways of effects, hypotheses, uncertainties, available data, and planned studies can be found in Appendix A.
Key messages from the TAG at this stage included:

- The TAG should guard against overemphasizing the study of biofilm at the expense of infauna. The TAG views infauna as an equally important food source that may be affected by many of the same pathways as biofilm but possibly in different ways.

- Biofilm and infauna have special significance as food sources for shorebirds; they are important elements of the ecological community and have broader value than just as food sources for shorebirds. Based on the discussion, the TAG focused in on a simplified set of pathways and key questions, namely the effects of the proposed RBT2 project on the abundance and availability of shorebird food, and site safety, as detailed in Figure 2.2.

Figure 2.2 Simplified Pathways of effects on Biofilm, Infauna, and Shorebirds

This simplified pathway of effects diagram brings into focus four key questions addressed by the TAG (indicated by numbers 1, 2, 3, and 4 in Figure 2.2):

1) How can we model and report the potential effects of RBT2 on biofilm and infauna?

2) a) What is the importance of biofilm as a food source for shorebirds at Roberts Bank?
   b) How substitutable are biofilm and infauna as food sources? At what point and under what conditions do birds switch from one source to another?
   c) How do biofilm and infauna differ as a food source from one location to the next?
   d) What would constitute a biologically meaningful effect on biofilm or infauna?

3) How can we model and report the effect of RBT2 on shorebirds (with respect to food sources, access to food, and site safety in the Roberts Bank area)?

4) a) What is the importance of Roberts Bank relative to other areas in the Fraser River Estuary?
   b) What would constitute a significant adverse effect on shorebird populations?
   c) What kinds of mitigation actions might be suitable, and where might they be located?
These key topics provided a basis for TAG discussion. The TAG began by developing an approach to assessing effects on shorebirds. They then looked at methods for assessing effects on biofilm and infauna. They concluded by reviewing updated list of studies and key assumptions, and provided input to guide the work of the project team.

3 Assessing Effects on Shorebirds

3.1 Assessment Methods

As noted above, the key issues discussed in relation to predicting RBT2 project-related effects on shorebirds included the following:

- How can we model and report the effect of RBT2 on shorebirds (with respect to food sources, access to food, and site safety in the Roberts Bank area)?

- What are good metrics/indicators for effects on shorebirds?

- What is the best way to assess whether projected changes at Roberts Bank cause a significant adverse effect on shorebird populations?

- How do shorebirds use the Roberts Bank area?

- What is the importance of Roberts Bank relative to other areas in the Fraser River Estuary?

- What kinds of mitigation actions might be suitable, and where might they be located?

The TAG discussed various ways of assessing impacts on migratory shorebirds, in consideration of the fact that they use multiple sites and are affected by multiple developments and activities throughout their range. While the TAG appreciated the goal of assessing the effect of the project on the overall fitness and reproductive success of shorebird populations, it was determined to be not feasible and beyond the scope of the assessment.

The TAG therefore recommended the EA focus on assessing the effect of RBT2 on changes to shorebird foraging opportunity at this site, with the goal of avoiding or offsetting any negative effects on shorebirds and ultimately striving for no net loss of opportunity at a) the immediate Roberts Bank site; and / or b) the broader FRE. If it can be demonstrated that there is no net loss of shorebird opportunity at the site / estuary level, then potential effects resulting from the project could be deemed minimal.

In response to the TAG's feedback about the key pathways of effects (Figure 2.2), the project team developed and presented an illustrative ‘shorebird opportunity model’. This model integrates food availability and site safety into an assessment of effects on shorebirds. The conceptual model assumes that shorebirds make a tradeoff between site safety (measured as the distance a location is from cover that predators can use to conceal themselves) and food quality and quantity when choosing whether or not to feed at a site.

---

1 Shorebird opportunity was defined in the TAG as a measure of energy available to a shorebird to feed on at any one location, weighted against site safety, and considering other factors such as tidal exposure.
In overview, the model involves:

- Assigning a food value to each spatial increment of the mudflat (e.g. every 200 m²) across the Project area, based on infaunal invertebrate and biofilm food data collected as part of the proposed RBT2 project EA.

- Assigning site safety scores to the same spatial increment (e.g. every 200 m²).

- Inferring shorebird opportunity at each spatial increment.

- Validating shorebird opportunity inference with shorebird usage data collected as part of the proposed RBT2 project EA.

- Predicting shorebird opportunity post RBT2; predictions are based on data on direct impacts due to the RBT2 footprint and indirect impacts due to changes in waves, currents and water velocity.

- Evaluating change in shorebird opportunity as a result of RBT2.

The resulting index score reflects the “opportunity” for shorebirds, and the change in the score reflects the loss or gain in opportunity for shorebirds at Roberts Bank as a result of RBT2.

The concept of the opportunity model evolved and developed through discussion conducted on days three and four of the TAG. TAG members agreed that the approach is conceptually sound, and provided the following feedback:

- The approach is defensible and the index score will provide useful information. However, it will be critical to validate the predicted index score with post implementation monitoring.

- In combining food quality and site safety into a single metric (shorebird opportunity), TAG members cautioned that there may be a loss of dimensionality.

- Site safety may have a logarithmic relation with distance from cover, whereas food quality may be more linear. It may be reasonable then to scale the axes, and possibly inversely weigh food quality against site safety.

- Safety and food availability are determined temporally by tides giving the birds “windows of opportunity.” If the bulk of the usage occurs where there is not much of a predicted change in abiotic and biotic conditions (due to RBT2), then it stands to reason that effects could be minimal.

- Consider weighting model outcomes according to species (dunlin vs. WESA); however, be mindful that birds will adapt to changing food availability.

- Consider using a balance sheet approach to calculate caloric value of sites combined with a safety rating of the location to create a composite value that would be measured against the foraging area / opportunity time.

- Convert biofilm and infauna into energy units and look at map as an expression of opportunity.

- Complicating factors in modelling may be related to the social behavior between sandpipers and dunlin, whereas western sandpipers may be avoiding areas heavily used by dunlin when dunlin are present.
• Predator densities may also increase from increased perching opportunities.

• Grain size could be used as a surrogate for food suitability as sediment grain size seems to be correlated with infauna.

• Estimated changes in the Roberts Bank area due to climate change should be considered.

• The wintering dunlin population is one of the largest populations on the pacific coast. The FRE is an extremely important site to wintering dunlin. The current dunlin program is not designed to be able to develop an opportunity model that could be used to assess potential effect. This was identified as a gap in the winter program. It was recommended that the winter dunlin program be adjusted to include usage and food data (droppings and infauna), and that a foraging opportunity model (similar to the WESA model) be developed for dunlin.

• Modelling of opportunity changes for Western Sandpiper (WESA) and Dunlin should include the entire Fraser River Estuary (e.g. Roberts Bank, Sturgeon Bank, and Boundary Bay).

• A goal of no net loss in opportunity could be a good metric in assessing project effects on shorebirds.

• TAG members recommended that mitigation and post construction monitoring commitments be written into the terms of commitments.

3.2 Indicators of Effects

The shorebird opportunity model produces an index that can be used to summarize RBT2 effects on shorebirds. TAG members did not reach a conclusion on which metrics would be best for reporting effects on shorebirds, but recommended that the project team consider the following: bird abundance (coarser estimate than others), usage (number of droppings), shorebird usage days (derived from the opportunity model and post-construction droppings transects – similar to the existing program), fattening rate (less intensive than “length of stay” and more repeatable), length of stay (more difficult to measure as it requires radio tagging birds and measuring their length of stay at stopover sites) and flight speed (promising preliminary research indicates this could be an effective (and cost effective) method of measuring site quality).

3.3 Significance of Effects

With respect to determining the significance of effects (as per CEAA guidelines), TAG members suggested:

• That the assessment of effects based on the shorebird opportunity model be conducted across the entire FRE, as the estuary functions as a whole to support migrating and overwintering populations;

• That the absolute change and trends in shorebird abundance and diversity be monitored; and
• That the use of historical data on the natural variability of shorebird populations over time be used as a benchmark in determining whether predicted changes are significant.

3.4 Proposed Studies

Shorebird Opportunity Model

TAG members reviewed study needs in support of the proposed shorebird opportunity model and made a number of recommendations, which are captured in the proposed model methodology above, and the current study plan shown in Appendix A. Additional recommendations included:

• That results from the first year of data collection not influence the design of subsequent sampling and that the sampling locations continue to be selected using a randomize procedure;

• That the model include a measure of ‘food availability’; and

• That consideration be made for using a before/after control impact (BACI) design to assess effects.

Food Quality Studies

With respect to defining a unit of food ‘quality’ at a given location, TAG members suggested utilizing a measure of energy density (energy available per unit area) as a metric for food quality at a particular location, calculated as the total caloric content without differentiating between the food source (biofilm versus infauna). TAG members supported this proposed approach with the following suggestions:

• That possible energy density and intake rate measures include: joules per m², food availability, intake rate, and bird fattening rates;

• That further study be conducted to determine the relative quality of these two food sources;

• Biofilm may comprise a high proportion of a migrating shorebird’s diet; however, there is uncertainty concerning the nutritional quality of biofilm compared to infauna; and

• Biomass per unit area (e.g. G/m²), for which data has already been collected, would be an acceptable proxy metric.

The TAG acknowledged that while this approach for assessing food quality is sound, the lab work involved is onerous.

Shorebird Usage Studies

TAG members supported the proposed methodologies, conducting droppings counts, for assessing shorebird usage in the Roberts Bank area (and the FRE), providing valuable feedback
guide the 2013 field program. This feedback has been incorporated into the study program which is summarized in (Appendix A). TAG members suggested the following:

- Avoid bias in sampling by returning to ‘hotspots’; and
- Do not use results from 2012 season to influence sampling design for 2013. Transects and sampling locations should be selected independently from previous results using a random or systematic procedure.

4 Assessing Effects on Biofilm and Infauna

4.1 Assessment Methods

As noted in Section 2.1.4, key issues with respect to biofilm and infauna include:

- How can we model and report the potential effects of RBT2 on biofilm and infauna?
- What is the importance of biofilm as a food source for shorebirds at Roberts Bank?
- How substitutable are biofilm and infauna as food sources? At what point and under what conditions do birds switch from one source to another?
- How do biofilm and infauna differ as food sources from one location to the next?
- How do biofilm and infauna vary in abundance, distribution, and composition both seasonally and annually?
- What would constitute a biologically meaningful effect on biofilm or infauna?

To address these questions, TAG members reviewed preliminary data and discussed the studies planned and currently underway to understand the distribution, abundance, and composition of biofilm and infaunal invertebrates at Roberts Bank. Given the high degree of uncertainty with respect to the factors that affect biofilm and infauna growth, the TAG recommended eliciting input from a broader group of experts to identify:

- Key factors limiting biofilm and infaunal invertebrate growth; and
- Factors likely affected by changes to coastal geomorphology resulting from RBT2.

A small group of external experts was identified and interviewed to provide insight on detailed pathways of effects between RBT2 and biofilm and infauna. Given the findings of these experts, outlined below, the TAG reviewed and discussed proposed approaches for effects assessment and monitoring, and assumptions and uncertainties.

In order to understand anticipated changes to the coastal geomorphology and the ability to predict them as a result of RBT2, TAG members reviewed preliminary results from the Coastal Geomorphology Study being conducted Northwest Hydraulics Consultants (NHC), and which relies on numerical modelling studies as well as interpretive techniques. TAG members discussed:

- The key changes anticipated to coastal geomorphology; and
The capabilities and limitations of the geomorphology study (in particular the numerical modelling component) and any implications for the assessment of effects on biofilm and infauna.

4.2 Biofilm and Infauna Pathways: Focus Group Results

Figure 4.1 is the detailed pathway of effects diagram developed by the Focus Group. It illustrates the main pathways by which RBT2 could affect changes in abiotic (e.g. wave energy, water flow) and biotic (e.g. nutrient) conditions in the Roberts Bank area, thereby affecting the growth of biofilm and infauna. Yellow boxes indicate the key factors identified by Focus Group participants in driving changes to biofilm and infaunal invertebrate growth. White boxes indicate factors that influence biofilm and infauna growth, but are not key factors. For example, the factor ‘sediment grain size’ (in yellow) is considered to be a key factor in affecting biofilm and infauna growth, while ‘nutrient load’ plays a relatively minor role in comparison. Figure 4.1 also shows which pathways are thought to be most critical. Red arrows on the left hand side of the diagram indicate abiotic factors directly affected by RBT2. Blue arrows on the right indicate the pathways which Focus Group participants considered most strongly influence biofilm and infauna growth.

Focus Group findings are summarized in Appendix B, which contains a summary table of key uncertainties and data available for key pathways, and planned studies to evaluate effects, along with a summary of more general input. Some of the key messages from the focus group work are listed below:

- The same abiotic and biotic factors drive growth for infauna and biofilm. Similarly, the key factors that drive growth are the same for both biofilm and infauna. The only exception is that intensity of available sunlight is a key factor for biofilm only. This creates some synergies for data collection and effects modelling.

- From Figure 4.1, the TAG noted that in particular, the ability to reliably predict depth and duration of inundation and sediment grain size is critical to being able to reliably predict changes in biofilm and infaunal communities (especially the composition of infaunal invertebrates).

While the pathways in Figure 4.1 can be readily identified, there are important uncertainties on some of the pathways, particularly for biofilm. One focus group member felt that there is a need to convene a major science panel, consisting of neutral international experts to study biofilm.
Figure 4.1 Key Pathways of Effects for Biofilm and Infauna
Given the results of the Focus Group, TAG members discussed what must be known about potential changes to the coastal geomorphology in the Roberts Bank area in order to predict changes to infauna and biofilm. Preliminary results from the Coastal Geomorphology Study (in particular results of preliminary hydrodynamic, morphodynamic, and wave modelling) performed by Northwest Hydraulics Consultants (NHC) were presented. TAG members reviewed these results and discussed several challenges for assessing changes to biofilm and infauna using the pathway of effects methodology, including the following:

- Based on the information presented by NHC, there are limits to the ability of numerical models to predict future change. While modelling of waves and ocean currents are thought to be quite robust, modelling of sediment transport (morphodynamics) is less certain. In particular, model predictions of fine, cohesive sediment transport is highly uncertain. NHC has adopted an approach to increase certainty in these areas by relying on interpretive and empirical techniques. This topic is explored in a companion report on the Coastal Geomorphology TAG. The residual uncertainty may have implications for assessments of biofilm and infauna. TAG members encourage close linkage between the ongoing geomorphological study efforts and the assessment of infauna/biofilm.

- The TAG noted that there is no clear precedent on which indicators are best for characterizing the effect of RBT2 on biofilm and infauna.

Despite these challenges, the TAG provided comment on studies that need to be in place to clearly understand key (limiting) factors and key pathways of effects by which RBT2 may affect biofilm and infauna. A summary of the key pathways of effects, available data, and drivers can be found in Appendix B.

### 4.3 Biofilm Studies

TAG members discussed key issues related to biofilm, and provided feedback on assessment methods, planned studies, assumptions, metrics, and uncertainties. Key messages included:

- TAG members concurred that biofilm is important both as a food source for shorebirds and for its role in the overall ecology in the region.

- Although the TAG did not recommend specific indicators for assessing changes to biofilm, they did propose that the indicators encompass biomass, diversity, distribution, and possibly fat and carbohydrate content. TAG members suggested including total organic carbon (TOC) and particulate organic carbon (POC).

- TAG members established that shorebird energy requirements are met through the consumption of both biofilm and infauna. The amount of biofilm consumed by shorebirds varies by species, season, and site.

- TAG members agreed that the selection and substitutability of biofilm versus infauna as food sources requires further study.

- TAG members suggested that there are two main ways to characterize the biofilm: from an energy perspective and from a diversity perspective.

- TAG members recommended that studies focus on how biofilm differs at two separate locations where biofilm is found: the area near Canoe Pass, and the known biofilm polygon from the work of Catherine Berris Associates Inc. It was discussed that the biological characteristics (e.g. species composition, biomass, etc.) of the
biofilm documented near Canoe Pass may differ from those of the existing biofilm polygon.

- TAG members recommended changes to sampling techniques: keep samples shallow (1-2mm), keep sampling randomized, and maximize spatial coverage, to minimize extrapolation of results from one area to another. Mapping of interpolated spatial data was suggested, though no specific interpolation radius was agreed to.

- TAG members debated the appropriateness of extrapolating results from one sampled area to an area which has evidence of biofilm presence and similar substrate qualities. No consensus was reached.

- TAG members endorsed the proposed methodology for assessing impacts on biofilm as sound, though suggested that the assumption of spatial homogeneity of results be tested (e.g. it may not be valid to assume that biofilm at locations other than the studied locations have the same characteristics).

TAG members supported the proposed studies, and in addition to the feedback and recommendations above, they recommended two additional studies:

- An investigation into the role of fatty acids in diet and the palatability of biofilm to understand shorebird preference for different biofilm types.

- Consideration of hyperspectral surveys or substitutes, remote sensing, unmanned drones or satellites for mapping of biofilm across the FRE. This would enable a comparison between biofilm in the project area and the surrounding FRE.

4.4 Infaunal Invertebrate Studies

TAG members discussed a number of key questions related to infaunal invertebrates, and provided feedback on study methods, metrics, and uncertainties. Key messages included:

- TAG members concurred that infauna is important both as a food source for shorebirds and for its role in the overall ecology in the region. Infauna also plays a role in aerating and modifying substrate, among other functions.

- TAG members suggested several metrics for characterizing effects on infauna, including measures of species richness, abundance, biomass, and diversity. TAG members cautioned however, that indexing these measures can be deceiving, and as a result there was no consensus on which metrics to use.

- TAG members were concerned about how changes due to RBT2 might affect infauna, and reiterated the importance of infauna in relation to biofilm.

- TAG members supported the use of a stratified sampling design of 60% of sampling occurring within 1 km from shore, or the causeway, and 40% occurring between 1-3 km. This was justified based on known WESA foraging distributions.

- TAG members cautioned that it would be difficult to differentiate between natural variation and project effects.

TAG members supported the studies proposed, and no new studies were recommended.
5  Summary of Approach

In summary, TAG members provided input on various aspects of study design and sampling, and recommended additional studies. Based on this input, the current approach for biofilm, shorebirds and infauna is to proceed with a spatial opportunity model that integrates food availability and site safety.

Food availability is assumed to be the energy available from biofilm and infauna, and will be calculated per unit area (e.g. joules/m² or joules/hectare). With some minor study design modifications, the TAG endorsed the infaunal field program, which seeks to derive (i) abundance, biomass, distribution and taxonomic data from sediment cores and (ii) abiotic co-variates through co-located sediment sampling. The TAG also endorsed the biofilm field program with some minor study design recommendations. This program includes studies of (i) the distribution of biofilm at Roberts Bank from hyperspectral mapping, (ii) taxonomic composition through HPLC (High-Protein, Low-Carbohydrate) analysis of sediment cores, (iii) abiotic co-variates through co-located sediment sampling, and (iv) the carbohydrate or “EPS” (extracellular polymeric substance) composition through spectrophotometry. Taken together, these studies will lay the foundation for quantifying the amount of food available for foraging shorebirds. Details of these field programs can be found in Table 5.1.

In addition to food availability, an estimate of “opportunity” will also consider site safety, as the perception of danger affects the timing, duration, and location of shorebird foraging. It is assumed that less potential energy is available to shorebirds at sites with nearby predators, as they would decide it was too dangerous to feed at a specific location thereby reducing their foraging “opportunity”. Site safety scores will be assigned through a field assessment conducted in summer 2013. Opportunity will also consider other factors such as tidal exposure (e.g. the amount of time an area of mudflat is exposed and therefore available to a foraging shorebird).

These weighted opportunity values across the FRE would then be summed to estimate the total shorebird foraging opportunity (in joules). Opportunity would be modeled against actual droppings counted on mudflats to help build and validate the overall model. The model could be rerun with the RBT2 project footprint and proposed mitigation and/or offsetting to see if the opportunity changed. The goal set by the TAG was no net change in opportunity across the FRE (and preferably at RB).

### Table 5.1 TAG Endorsed Biofilm and Infauna Field Program Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Methodology</th>
<th>Endorsed (Yes/NO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyperspectral Mapping</td>
<td>Aerial surveys using a hyperspectral sensor and concurrent in situ sampling with handheld spectrophotometer &amp; sediment cores</td>
<td>Yes</td>
</tr>
<tr>
<td>Biofilm Taxonomic Analysis</td>
<td>Field sampling of sediment cores for taxonomic validation using HPLC analysis (17 pigments) and microscopic taxonomic ID</td>
<td>Yes</td>
</tr>
<tr>
<td>Biofilm EPS Study</td>
<td>Laboratory carbohydrate measurements</td>
<td>Yes</td>
</tr>
<tr>
<td>Biofilm Abiotic Parameters</td>
<td>Multivariate analysis of abiotic covariates of biofilm</td>
<td>Yes</td>
</tr>
<tr>
<td>Benthic Infaunal Invertebrate Sampling</td>
<td>Sediment core sampling; lab analysis for abundance, biomass and taxonomic composition.</td>
<td>Yes</td>
</tr>
<tr>
<td>Benthic Infaunal Abiotic Parameters</td>
<td>Multivariate analysis of abiotic covariates of benthic infauna</td>
<td>Yes</td>
</tr>
</tbody>
</table>
6 Other Considerations

6.1 Mitigation Options

While specific mitigation measures were not the focus of discussion given the early stage of the pre-environmental assessment work, the project team proposed a high level approach to mitigation and post implementation monitoring for discussion with the TAG. TAG members provided input on the approach and on specific issues that merit further examination.

Potential mitigation options were presented and discussed for the abiotic environment (sediment, water flow and wave height, and beach elevation), biofilm and infauna (shorebird food enhancement), and shorebirds (site safety). TAG members suggested that the project follow a hierarchy of enhancements, and suggested a number of non-food related habitat enhancements, including upland food enhancements, and reducing impact from invasive species (e.g. spartina).

TAG members suggested a number of additional mitigation options for consideration. The options are highly conceptual in nature; therefore further investigation into each option is warranted:

- Consider engineered mitigations to slow water velocity in order to establish conditions suitable for biofilm growth.
- Seek like-for-like enhancements (habitat creation) at other sites, such as at the mouth of the Fraser River (however, some TAG members cautioned that the creation of artificial mudflats has proven difficult in certain cases).
- Enhance habitat for shorebirds by determining how to best manage the water output of pumping stations.
- Enhance shorebird safety by removing or altering structures that can be utilized by predators for hunting.

6.2 Other disturbances

TAG members discussed the potential effects from a number of other disturbances, and suggested the consideration of effects from new invasive species, effects on existing invasives, effects due to potential lubricant or hydrocarbon leaks from ships and potential effects related to climate change.

6.3 Linkages to Other EA Work

The modelling work proposed for assessing effects of RBT2 on biofilm, infauna, and shorebirds, is highly dependent on the results from the Geomorphology Study.

7 Conclusion and Future Opportunities

The Biofilm & Shorebirds TAG met four times over 2012 and 2013 to provide PMV and its consultants with feedback on appropriate methods to assess the potential effects of the proposed RBT2 project on biofilm, infauna, and shorebird populations at Roberts Bank. This report catalogues this TAG process and the key findings and outputs of the process. At this point, PMV and its consultants are continuing their pre-EA studies with this additional
guidance in mind. Looking forward, PMV and its consultants will complete their EA studies, engage the provincial and federal governments in the formal EA process, and continue to consult with stakeholders and First Nations.
### Appendix A – Pathways of Effects Studies Planned

#### Table A1. Pathways of Effects and Planned Studies

This table summarizes key Pathways of Effects (POE) linkages, hypotheses, uncertainties, data available, and studies planned for each linkage in the pathway of effects diagram in Figure 2.1.

<table>
<thead>
<tr>
<th>Pathway</th>
<th>Linkage</th>
<th>Hypothesis</th>
<th>Specific Uncertainties</th>
<th>Data Available</th>
<th>Planned Studies (Details in Table A2)</th>
</tr>
</thead>
</table>
| 1       | RBT2 - coastal geomorphology | The proposed RBT2 Project will potentially affect physical oceanography (sedimentation, grain size, turbidity, wave, water velocity salinity). | - Changes in ebb and flow tidal currents  
- Changes in salinity  
- Changes in turbidity  
- Changes in temperature  
- Changes in light penetration  
- Changes in sediment grain size  
- Changes in wave climate | - 2004 Coastal Geomorphology Study for DP3  
- Existing scientific literature  
- Existing consultants and government reports  
- Historical and recent measurements of tides/waves/winds/current  
- Historical and recent bathymetric surveys, air photos, sediment data, etc. | Coastal geomorphology studies (NHC): 35, 38, 39, 40, 42  
Abiotic parameters studies: 29, 44 |
| 2       | RBT2 - bird behaviour | Presence of terminal construction and operation may affect how shorebirds use the RBT2 area. | - Spatial distribution of shorebird use across the FRE  
- Intensity of shorebird use across the FRE | - Shorebird dropping counts across the FRE (2012-2013)  
- Shorebird abundance counts across the FRE (2012-2013) | Shorebird habitat use surveys: 31  
- |
| 3       | RBT2 - predator habitat | Infrastructures may affect how raptors use the RBT2 area which could affect shorebird behaviour and use. | - Whether new RBT2 infrastructure will affect raptor use/hunting within Roberts Bank | - Data to become available through planned site safety assessment | Shorebird site safety assessment: 33 |
| 4       | phys oceanography - eelgrass | Changes in physical oceanography and seabed morphology may affect eelgrass AND vice versa. | - Eelgrass/biofilm interactions  
- Eelgrass/infauna interactions | - Scientific literature | Coastal geomorphology studies (NHC): 40, 42 |
<p>| 5       | | | | | |</p>
<table>
<thead>
<tr>
<th>Pathway</th>
<th>Linkage</th>
<th>Hypothesis</th>
<th>Specific Uncertainties</th>
<th>Data Available</th>
<th>Planned Studies (Details in Table A2)</th>
</tr>
</thead>
</table>
| 6       | phys oceanography - biofilm/biomat | Changes in coastal geomorphology can change abiotic factors related to biofilm growth, e.g. increases in sediment load in water column could lead to smothering of biofilm/biomat through deposition, and changes in water quality characteristics (turbidity) could make it easier/harder for biofilm/biomat to grow. | - Physical oceanographic correlates of biofilm and/or biomat growth and distribution  
- How changes in these processes may potentially affect biofilm and/or biomat at Roberts Bank  
- Biotic and abiotic sources of nutrients for biofilm and their origins | - NHC field data  
- Sediment grain size and chemistry data for FRE (2012-2013)  
- Biofilm isotope data | Coastal geomorphology studies (NHC): 35, 38, 40  
Biofilm abiotic parameters study: 27, 29 |
| 7       | phys oceanography - biofilm/biomat | Changes to biofilm may affect seabed morphology (through stabilization in the event of biofilm growth or through loss of stabilization in the event of biofilm decline). | - Critical shear stress tolerance of biofilm  
- Cohesion and chemical composition of polysaccharides associated with the biofilm community  
- Methods to measure sediment stabilization | - Scientific literature  
- Biofilm EPS data  
- Biofilm shear stress levels  
- NHC hydrodynamic model | Coastal geomorphology studies (NHC): 38, 40  
Biofilm critical shear stress study: 30  
Biofilm recolonization study: 28  
- |
| 8       | phys oceanography - benthic infauna | Changes in physical oceanography can change abiotic factors related to infaunal invertebrate growth. | - Physical oceanographic correlates of benthic infaunal growth and distribution  
- How changes in these processes may potentially affect benthic infaunal communities | - Sediment grain size and chemistry data for FRE (2012-2013)  
- NHC hydrodynamic model | Coastal geomorphology studies (NHC): 39, 40  
Abiotic parameters of infauna study: 44 |
| 9       | bird behaviour - foraging efficiency | Changes in bird behaviour may have bioenergetic costs (e.g. shifting habitat use, reduced foraging efficiency). | - Shorebird food (infauna and biofilm) may be affected by changes in abiotic processes resulting from construction of RBT2, which could affect food availability, quality, and use by shorebirds | - Shorebird dropping counts across the FRE for northward and southward migration 2012-2013  
- Distribution and biomass of biofilm and infauna for northward and southward migration 2012-2013 | Shorebird habitat use study: 31  
Biofilm studies: 24, 25, 26, 28, 29, 30  
Benthic |
<table>
<thead>
<tr>
<th>Pathway</th>
<th>Linkage</th>
<th>Hypothesis</th>
<th>Specific Uncertainties</th>
<th>Data Available</th>
<th>Planned Studies (Details in Table A2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>predator habitat - predation rate</td>
<td>Construction of RBT2 may increase the availability of structures used by predators for concealment and increase the predation rate on shorebirds.</td>
<td>- If and how changes in raptor use might affect shorebird use</td>
<td>Assessment of changes in site safety to shorebirds resulting from RBT2 construction (summer 2013)</td>
<td>Shorebird site safety assessment: 33</td>
</tr>
<tr>
<td>11</td>
<td>relationship between biofilm and biomat</td>
<td>These studies will further characterize shorebird biofilm at Roberts Bank and the FRE.</td>
<td>- Composition of biofilm and/or biomat that is important to shorebirds at Roberts Bank - Difference between biofilm and biomat - Whether biomat promotes the growth of biofilm or the reciprocal - Whether shorebirds require both biofilm and biomat - Current velocities (and associated shear) withstood by biofilm and/or biomat - Recolonization potential of biofilm and/or biomat after a disturbance (removal from substrate via abiotic processes or grazing pressure)</td>
<td>- Scientific literature - Biofilm/biomat distribution at Roberts Bank - Taxonomic composition of biofilm - Shear stress thresholds of biofilm - Recolonization rates of biofilm</td>
<td>Biofilm studies: 24, 25, 26, 27, 28, 29, 30</td>
</tr>
<tr>
<td>12</td>
<td>relationship between biofilm/biomat and eelgrass</td>
<td>Biofilm and eelgrass may interact competitively.</td>
<td>- Eelgrass/biofilm interactions - If eelgrass limits biofilm are the two species always found in different parts of the mudflat? - If they are found in different parts of the mudflat, how do these areas relate to abiotic parameters? - How does the distribution of eelgrass and biofilm relate to shorebird use?</td>
<td>- Scientific literature - Biofilm and eelgrass distributions at Roberts Bank - Sediment grain size and chemistry data for FRE (2012-2013)</td>
<td>Coastal geomorphology studies (NHC): 35, 40 Biofilm studies: 24, 25, 29 Shorebird habitat use study: 31</td>
</tr>
<tr>
<td>13</td>
<td>relationship between biofilm/biomat and benthic infauna</td>
<td>Changes in benthos may affect biofilm/biomat as benthos graze on biofilm/biomat OR changes in biofilm/ biomat may affect benthos.</td>
<td>- Do infaunal invertebrates also graze on biofilm? - Is there a geospatial relationship between the infaunal invertebrate and biofilm communities?</td>
<td>- Distribution and taxonomic composition of biofilm and infaunal communities</td>
<td>Biofilm studies 24, 25, 29 Benthic infauna studies: 43, 44</td>
</tr>
<tr>
<td>14</td>
<td>foraging efficiency - shorebird</td>
<td>Changes in bird foraging behaviour could have bioenergetic effects.</td>
<td>- How and whether potential changes to food abundance, quality, and distribution will affect fattening rates, length of stay and - Scientific literature on site quality, site safety, rating rates, and usage of</td>
<td>-</td>
<td>Shorebird opportunity model</td>
</tr>
<tr>
<td>Pathway</td>
<td>Linkage</td>
<td>Hypothesis</td>
<td>Specific Uncertainties</td>
<td>Data Available</td>
<td>Planned Studies (Details in Table A2)</td>
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<tr>
<td>energetic</td>
<td>other metrics associated with shorebird site quality</td>
<td>shorebird sites.</td>
<td></td>
<td></td>
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<tr>
<td>15</td>
<td>predation rate - shorebird energetics</td>
<td>Changes in predation pressure may lead to changes in use of habitat.</td>
<td>Changes in raptor usage and resulting shorebird behaviour may affect shorebirds use of particular foraging areas</td>
<td>Scientific literature</td>
<td>Shorebird site safety assessment: 33, Shorebird opportunity model</td>
</tr>
<tr>
<td>16</td>
<td>biofilm/biomat - shorebird energetics</td>
<td>Potential changes in biofilm abundance and distribution at Roberts Banks may potentially affect individual shorebird feeding across the FRE.</td>
<td>Biofilm abundance and distribution across the estuary and its relative abundance at Roberts Bank, Are there different kinds of biofilm, and if so, which kinds of biofilm are important for shorebirds?, How much is bird feeding rates on biofilm affected by benthos availability?, What’s the relative contribution of biofilm and biomat to shorebird diet?, What’s the relative contribution of biofilm at Roberts Bank to other food sources across the FRE?</td>
<td>Distribution and taxonomic composition of biofilm and infaunal communities, Shorebird isotope data, Shorebird droppings data</td>
<td>Biofilm studies: 24, 25, 26, Benthic infauna studies: 43, Shorebird studies: 31, 32, Shorebird opportunity model</td>
</tr>
<tr>
<td>17</td>
<td>benthic infauna - shorebird energetics</td>
<td>Potential changes in benthic infauna abundance and distribution at Roberts Banks may potentially affect individual shorebird feeding across the FRE.</td>
<td>Infaunal distribution and abundance at Roberts Bank relative to the entire FRE, What is the relative importance of infaunal invertebrates (vs. biofilm) in the shorebirds annual cycle?, How does infaunal invertebrate distribution correlate with shorebird use?</td>
<td>Distribution and taxonomic composition of infaunal communities, Shorebird isotope data, Shorebird droppings data</td>
<td>Benthic infauna studies: 43, Shorebird studies: 31, 32, Shorebird opportunity model</td>
</tr>
<tr>
<td>18</td>
<td>shorebird energetics - shorebird populations</td>
<td>Changes to individual shorebird bioenergetics may translate into population level effects on shorebirds.</td>
<td>How does individual shorebird bioenergetics translate to successful migration and breeding?, How do shorebirds use the Fraser River Estuary (FRE)?, How do shorebirds use Roberts Bank in the context of the entire FRE?</td>
<td>Shorebird droppings counts, Shorebird abundance counts</td>
<td>None – determined not to be feasible to assess and beyond the scope of the EA</td>
</tr>
<tr>
<td>Study ID</td>
<td>Related to Pathway # (Details in Table A1)</td>
<td>Field Study Full Title</td>
<td>Study Objectives</td>
<td>Methods/Approach</td>
<td></td>
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<tr>
<td>24</td>
<td>12, 13, 14, 17</td>
<td>Biofilm Hyperspectral Mapping</td>
<td>Delineate and map the extent of biofilm &amp; identify main taxonomic groups which comprise biofilm community at Roberts Bank</td>
<td>Aerial surveys using a hyperspectral sensor and concurrent in situ sampling with handheld spectrophotometer &amp; sediment cores</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>12, 13, 14, 17</td>
<td>Biofilm Taxonomic Analysis</td>
<td>Identify the main taxonomic groups which comprise the biofilm community, ground truthing of hyperspectral</td>
<td>Field sampling of sediment cores for taxonomic validation; HPLC analysis (17 pigments); microscopic taxonomic ID</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>12, 17</td>
<td>Biofilm EPS Study</td>
<td>Quantify carbohydrate composition of biofilm to determine nutritional value</td>
<td>Spectrophotometry to measure colloidal and non-colloidal carbohydrate content</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>7, 12</td>
<td>Biofilm Recolonization Study</td>
<td>Determine recolonization/growth rates of biofilm to assess its ability to rebound from disturbance</td>
<td>Laboratory and field experiments</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>1, 6, 7, 9, 12, 13</td>
<td>Biofilm Abiotic Parameters Study</td>
<td>Identify and quantify abiotic co-variates of biofilm</td>
<td>Multivariate correlational analysis between taxonomic and abiotic data</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>6, 7, 12</td>
<td>Biofilm Critical Shear Stress Study</td>
<td>Determine the critical shear stress of biofilm to better elucidate a) its role in sediment stabilization b) its tolerance to changes in flow</td>
<td>Laboratory and field experiments</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>13, 17, 19</td>
<td>Shorebird/WESA/Dunlin Habitat Use Study</td>
<td>Develop a usage map of the Fraser River Estuary (FRE) by shorebirds during north and southward migrations; determine the number and broad distribution of shorebirds across the FRE during north/south migratory periods; model usage data against other biotic and abiotic data collected to determine locations of greatest shorebird use, food availability and habitat quality</td>
<td>Counting dropping (fecal) densities at sampling stations along transects. Shorebird relative abundance counts across the FRE.</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>17, 19</td>
<td>WESA/Dunlin Stable Isotope Analysis</td>
<td>Determine the contribution of biofilm to WESA diet at Sturgeon Bank, Boundary Bay, and Roberts Bank during northward migration</td>
<td>Stable isotope analysis of bird droppings or blood</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>3, 11, 14</td>
<td>Site Safety Assessment</td>
<td>Assess to what extent RBT2 infrastructure may influence the predation danger for shorebirds from raptors at Roberts Bank</td>
<td>Desktop evaluation of design drawings; field visits</td>
<td></td>
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<tr>
<td>35</td>
<td>1</td>
<td>Study of Vertical, Lateral and Tidal Variations in Salinity &amp; Turbidity</td>
<td>Understand the spatial and temporal distribution of the salt wedge and fresh water lens within Canoe Passage and the Fraser River plume over the Roberts Bank tidal flats</td>
<td>Sound used to collect depth profiles of the water column (turbidity, salinity, conductivity &amp; depth measured at 1 s intervals); collection of water samples at sub-set of sites using handheld sampler; generate</td>
<td></td>
</tr>
<tr>
<td>Study ID</td>
<td>Related to Pathway # (Details in Table A1)</td>
<td>Field Study Full Title</td>
<td>Study Objectives</td>
<td>Methods/Approach</td>
<td></td>
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<tr>
<td>38</td>
<td>1</td>
<td>Roberts Bank Sediment &amp; Erosion Monitoring</td>
<td>Gain an understanding of the existing disturbance regime at Roberts Bank</td>
<td>Installation of 30 DoD rods on tidal flats in groups of 10 to monitor three distinct regions (lower flats; biofilm; biomat) over 2 months; measurements of temporal variation in erosion &amp; deposition (distance from top of rod to sediment surface and washer)</td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>1</td>
<td>Roberts Bank Wave Heights &amp; Periodicity Study</td>
<td>Collect wave height and period data to validate numerical models and help interpret erosion pin observations</td>
<td>Three wave recorders installed along a transect stretching from deep to shallower water (allowing for characterization of changing wave environment through transition of delta slope to mid intertidal; tidal measurements every 15 minutes as well as burst samples (4096 samples at 6 Hz)</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>1</td>
<td>Hydrodynamic Modelling</td>
<td>Define interaction of currents and waves near project site; define magnitude and spatial extent of hydrodynamic effects</td>
<td>Hydrodynamic model runs to determine if project effects can be minimized by optimizing its orientation; run model using adopted boundary input conditions; hydraulic information will also be used to carry out analytical calculations to estimate local scour and deposition patterns near the terminal</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>1</td>
<td>Biofilm Investigations</td>
<td>Predict potential changes to the physical environment and the wave and tidal current climate</td>
<td>Inputs from biofilm studies used to assess results from the model in order to predict potential changes in biofilm; models used to identify other biofilm regions as well as regions that may be engineered to foster biofilm growth</td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>9, 14, 18</td>
<td>Benthic Infauna Sampling</td>
<td>Quantify the abundance, biomass, taxonomic composition, and distribution of infaunal invertebrates at Roberts Bank relative to the entire FRE</td>
<td>Sediment core sampling and microscopic identification</td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>9, 14, 18</td>
<td>Benthic Infauna Abiotic Parameters Study</td>
<td>Identify and quantify abiotic co-variates of benthic infauna</td>
<td>Multivariate correlational analysis between taxonomic and abiotic data</td>
<td></td>
</tr>
</tbody>
</table>
Appendix B – Biofilm and Infauna Pathways of Effects Focus Group Results
Biofilm & Infauna Focus Group Summary

This document summarizes the findings of the Biofilm & Infauna Focus Group, which involved structured expert interviews to explore potential effects from the proposed Port Metro Vancouver Roberts Bank Terminal 2 (RBT2) project on biofilm and infaunal invertebrates.

Overview

The Biofilm & Infauna Focus Group involved the iterative development of a ‘pathways of effects’ (POE) diagram, a review of key factors and pathways by which biofilm and infauna may be affected by the RBT2 project, and an assessment of key uncertainties. Three experts participated in the Focus Group from government bodies (Environment Canada, Port and Airport Research Institute (Japan)), and a US academic institution.

Overall, this process involved four main steps:

1. Develop a pathway of effects diagram relating biotic and abiotic factors with biofilm and infaunal invertebrates
2. Identify most significant pathways of effects (i.e. which key factors, if changed by RBT2, would result in changes to biofilm and/or infauna)
3. Identify key areas of uncertainty with respect to infauna/biofilm growth, and studies or models that can address these uncertainties
4. Identify which of these factors are expected to change as a result of RBT2

This Focus Group process was run in parallel with a Biofilm & Shorebirds Technical Advisory Group (TAG) process. The results from the Focus Group study were fed back to the Biofilm & Shorebirds TAG for further review and discussion, and to identify additional questions for the Focus Group members. The resulting findings will serve as a guide for the development of studies and approaches to assess potential effects from RBT2 on biofilm, infauna, and shorebirds, and for identifying mitigation strategies to minimize potential effects.

1) Pathways of Effects Diagram

An initial POE diagram was developed by Compass and Hemmera consultants based on a questionnaire to TAG members and in-house expertise. This diagram served as a basis for initial discussion with Focus Group experts, and was revised significantly over the course of the Focus Group interviews and TAG review. Figure 1 illustrates the detailed pathway of effects diagram developed by the Focus Group. It summarizes the main pathways by which RBT2 could affect changes in abiotic (e.g. wave energy, water flow) and biotic (e.g. nutrient) conditions in the Roberts Bank area, thereby affecting the growth of biofilm and infauna. Focus Group members suggested that the same abiotic and biotic factors drive growth for infauna and biofilm, hence one diagram can be utilized to relate RBT2 to both infauna and biofilm. Further, it was recommended that ‘epifauna’ be included in the study in addition to ‘infauna’.
2) Key pathways of effects

Focus Group members were then asked the question: “Given the pathway of effects diagram for infauna and biofilm, what do you think are the most significant pathways?” In summary, the key factors that drive infauna, epifauna, and biofilm quantity, quality, and distribution were deemed to be:

- sediment moisture content
- sediment ‘habitat’ – including the presence, stability (considering resuspension, adsorption of sediment), and quality of habitat
- light intensity and wavelengths that penetrate water (for photosynthetic biofilm only)
- direct habitat loss

These factors are directly influenced by:

- duration of inundation - the frequency with which sediment is covered in water will determine how moist the sediment is
- seabed/beach elevation and water depth – this factor will influence moisture content, the amount of sediment that is available as ‘habitat’, and the light that can penetrate the water
• sediment grain size – *this will affect the sediment moisture content, and the suitability of sediment ‘habitat’ for different organisms*
• direct habitat loss – *biofilm habitat will be directly affected by the placement of the RBT2 terminal and causeway footprint, as well as potential associated habitat loss such as scour and channel formation*
• water flow (pattern and velocity) and wave energy – *these geomorphic processes will influence seabed elevation, duration of inundation, and sediment grain size*

Other concerns raised by Focus Group members include:

• Indirect habitat loss
  - *Caused by river inflow changes, water flow patterns and velocity as a result of the RBT2 project*
  - *Caused by a system change from ‘mud’ to sea grass-type habitat as the result of changes to flow patterns, velocity, and sediment grain size*
• Shallow sub-surface water – *this will also play a role in the wetting of sediments (in addition to surface waters)*
• The ‘availability’ of food sources (primarily infauna) should be considered in modeling – migration occurs vertically in sediments to and from the surface, and so may or may not be available as food

Figure 2 illustrates they key pathways by which Focus Group members believe potential hydrological and geomorphological changes due to RBT2 may affect biofilm and infaunal and epifaunal invertebrates. Yellow boxes indicate the key factors identified by Focus Group participants in driving changes to biofilm and infaunal invertebrate growth. White boxes indicate factors that influence biofilm and infauna growth, but are not key factors. For example, ‘duration of inundation’ and ‘moisture content’ (in yellow) are considered to be key factors affecting biofilm and infauna growth, while ‘nutrient load’ plays a relatively minor role by comparison. This figure also shows which pathways are thought to be most critical. Red arrows on the left hand side of the diagram indicate critical abiotic factors directly affected by RBT2. The hydrological and geomorphological processes that determine sedimentation patterns and sediment grain size (for example) were discussed in detail in the Coastal Geomorphology TAG and were not reviewed in detail by Focus Group members. Blue arrows on the right indicate the pathways which Focus Group participants considered most strongly influence biofilm and infauna/epifauna growth. The key factors that drive growth are the same for both biofilm and infauna. The only exception is that intensity of available sunlight is a key factor for biofilm only.
3) Key Uncertainties

Key Uncertainties raised by Focus Group members for further examination include:

- What is the specific composition of bacteria, extracellular polysaccharides (EPS), diatoms that compose the biofilm present in Roberts Bank? How does this differ spatially across the area?

- What biofilm compositions are preferred by shorebirds (i.e. which composition is considered a ‘high quality’ food source)? How might changes to biofilm composition affect the palatability? How might changes to biofilm composition affect shorebird energetics?

- What factors/processes support the development of this ‘high quality’ biofilm versus lower quality biofilm?

- What factors are involved in shorebirds’ selection of whether to eat biofilm or infauna? When would they switch from one food source to another? Is biofilm a necessary component of their diet?
Does biofilm serve as more than just a food source? Does it contain biochemical components that are necessary for functions such as assisting in breeding, testosterone, providing beta carotene for plumage?

What are the dynamics in terms of seasonal and daily changes? What are expected changes in water flow and current patterns?

One focus group member indicated concern with taking an approach that looks too closely at the details of effects, and suggested taking a ‘big picture’ approach to understanding RBT2 effects on biofilm. This would involve looking at what could be affected if biofilm was degraded or diminished (e.g. shorebirds), how those organisms could be affected, and whether or not it should be a concern. Additionally, they noted that biofilm is not very well understood and it is necessary to understand the composition of biofilm and how it works before it is possible to assess potential effects on it. Further, biofilm at Roberts Bank may be unique (different than in other places of the Fraser River Estuary) since biofilm exists elsewhere but is not fed upon in those other locations. It is also a primary source of food consumed in the Roberts Bank area by some birds. Therefore, the Focus Group member suggested that further study of biofilm is necessary and should be a main focus given that it is not well understood.

4) Potential changes anticipated due to the RBT2 project

Focus Group members indicated a number of factors that must be understood before potential effects on biofilm and infauna can be determined. These factors involve the assessment of:

- Changes to water flow patterns and velocities
- Habitat loss
  - Direct
    - Footprint, scour, channel formation
  - Indirect
    - sediment distribution, elevation
    - sediment grain size
- Sea level changes expected due to climate change

Potential changes to the coastal geomorphology in the Roberts Bank area due to the RBT2 project are currently being investigated, given guidance received from the Coastal Geomorphology Technical Advisory Group. Details can be found in the Coastal Geomorphology TAG Final Report.

Table 1 summarizes the key pathways indicated in Figure 2, along with a summary of specific uncertainties, data available to enable assessment given these uncertainties, and studies planned to better understand the causal linkages. In addition, the table summarizes the Focus Group members’ subjective assessments of the weight of evidence linking the factors, and judgments on the ability to predict changes given available information and models. It summarizes Focus Group member’s judgments and is not a reflection of consensus among members. This table was developed to guide the development of studies to further understand the potential impacts of the RBT2 project on biofilm and infauna in the Roberts Bank area.
Table 1: Summary of pathways of effects, data available, and studies planned

The table below summarizes key POE linkages, hypotheses, uncertainties, data available, and studies planned for each linkage highlighted in the pathway of effects diagram in Figure 2. The table also summarizes Focus Group assessment of evidence available characterizing the linkage, and evaluation of the ability to predict changes within each pathway. These ratings are subjective assessments taking into consideration all potential effects pathways, and information and models available.

<table>
<thead>
<tr>
<th>Linkage</th>
<th>Hypothesis</th>
<th>Weight of evidence linking these factors</th>
<th>Ability to predict effects</th>
<th>Specific Uncertainties</th>
<th>Data available</th>
<th>Studies Planned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terminal 2 effect on geomorphic processes</td>
<td>RBT2 will affect coastal geomorphology (e.g. water flow, wave energy), thereby affecting sedimentation rates and patterns, sediment grain size, and other factors which may affect biofilm and infauna quantity, quality, and distribution in the Roberts Bank area.</td>
<td>N/D</td>
<td>Moderate to High</td>
<td>Details of potential changes are outlined in the Coastal Geomorphology TAG Final report.</td>
<td>YES (Hemmera)</td>
<td>YES (Hemmera Desktop studies 2013)</td>
</tr>
<tr>
<td>RBT2 Footprint effect on direct habitat loss</td>
<td>The RBT2 terminal and causeway footprint will cover portions of the Roberts Bank area, resulting in direct habitat loss</td>
<td>High / certain</td>
<td>High</td>
<td>YES (NHC)</td>
<td>YES (NHC)</td>
<td></td>
</tr>
<tr>
<td>Scouring effect on direct habitat loss</td>
<td>Different erosion rates could alter locations of established, mature biofilm/mats.</td>
<td>N/D</td>
<td>Low</td>
<td>YES (NHC)</td>
<td>YES (NHC)</td>
<td></td>
</tr>
<tr>
<td>Sedimentation rate &amp; deposition pattern effect on seabed/beach elevation, water depth, and duration of inundation</td>
<td></td>
<td>N/D</td>
<td>Low</td>
<td>YES (NHC)</td>
<td>YES (NHC)</td>
<td></td>
</tr>
<tr>
<td>Sediment grain size effect on sediment ‘habitat’</td>
<td>Changes in the distribution of particle sizes and/or particle composition will alter sedimentation rates.</td>
<td>Medium / some scientific evidence</td>
<td>Low</td>
<td>Do biofilms differ dependent upon particle size and/or composition? How does particle size and composition impact sedimentation that in turn affects the localization and distribution of biofilms/mats?</td>
<td>YES (Hemmera field studies 2012)</td>
<td>YES (Hemmera field &amp; Desktop studies 2013)</td>
</tr>
<tr>
<td>Linkage</td>
<td>Hypothesis</td>
<td>Weight of evidence linking these factors</td>
<td>Ability to predict effects</td>
<td>Specific Uncertainties</td>
<td>Data available</td>
<td>Studies Planned</td>
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<tr>
<td>Sediment grain size effect on moisture content</td>
<td>N/D</td>
<td>Low</td>
<td></td>
<td>To what extent is water content/activity of the inhabited sediments dictated by surface- and/or groundwater?</td>
<td>YES (Literature, Hemmera field studies 2012)</td>
<td>YES (Hemmera field &amp; Desktop studies 2013)</td>
</tr>
<tr>
<td>Duration of inundation effect on moisture content</td>
<td>N/D</td>
<td>Low</td>
<td></td>
<td></td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>Seabed/beach elevation, Water depth effect on light intensity and wavelengths</td>
<td>Medium / some scientific evidence</td>
<td>Low</td>
<td></td>
<td>If water depth is deep enough to limit light penetration, then it is most likely that biofilm/mats are not significant or at least for infaunal invertebrates and/or shorebirds.</td>
<td>YES elevation (Lidar Bathymetry data), YES some light intensity, NO water depth/standing water</td>
<td>NO</td>
</tr>
<tr>
<td>Seabed/beach elevation, Water depth on sediment ‘habitat’</td>
<td>Medium / some scientific evidence</td>
<td>Low</td>
<td></td>
<td></td>
<td>YES elevation (Hemmera field studies and Lidar Bathymetry data), NO water depth/standing water</td>
<td>YES (Hemmera Desktop studies 2013)</td>
</tr>
<tr>
<td>Linkage</td>
<td>Hypothesis</td>
<td>Weight of evidence linking these factors</td>
<td>Ability to predict effects</td>
<td>Specific Uncertainties</td>
<td>Data available</td>
<td>Studies Planned</td>
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</tr>
<tr>
<td>Seabed/beach elevation, Water depth on moisture content</td>
<td>There is a preferred water depth (or degree of sediment saturation) for biofilm/mat establishment and maintenance.</td>
<td>Medium / some scientific evidence</td>
<td>Low</td>
<td>Is there a preferred water depth or water saturation in the sediment for biofilm quantity and/or quality?</td>
<td>YES elevation (Hemmera field studies and Lidar Bathymetry data), NO water depth/standing water</td>
<td>YES (Hemmera Desktop studies 2013)</td>
</tr>
<tr>
<td>Moisture content effect on biofilm abundance</td>
<td>For biofilms without significant surface water, moisture saturation will be crucial for &quot;healthy&quot; biofilm establishment and maintenance.</td>
<td>Low / uncertain</td>
<td>Low</td>
<td>Is there a preferred water depth or water saturation in the sediment for biofilm quantity and/or quality?</td>
<td>YES (Literature, Hemmera field studies 2012)</td>
<td>WP (Desktop and Field Studies) Correlation and experimental</td>
</tr>
<tr>
<td>Moisture content effect on infauna and epifauna assemblages and abundance</td>
<td>Moisture content affects composition and abundance of certain infaunal and epifaunal taxa through both passive (hydrodynamic) and active (behavioural) processes</td>
<td>N/D</td>
<td>Low</td>
<td>How does water saturation impact microbial populations and functions?</td>
<td>YES (Hemmera field studies 2012)</td>
<td>YES (Hemmera field &amp; Desktop studies 2013)</td>
</tr>
<tr>
<td>Light Intensity / Wavelengths effect on biofilm abundance</td>
<td></td>
<td>Medium / some scientific evidence</td>
<td>Low</td>
<td>YES (Hemmera field studies 2012)</td>
<td></td>
<td>NO</td>
</tr>
<tr>
<td>Sediment 'habitat' effect on biofilm abundance</td>
<td></td>
<td>Medium / some scientific evidence</td>
<td>Low</td>
<td>YES (Hemmera field studies 2012)</td>
<td>WP (Desktop and Field Studies)</td>
<td>Correlation and experimental</td>
</tr>
<tr>
<td>Sediment 'habitat' effect on infauna and epifauna assemblages and abundance</td>
<td>Small-scale distribution of epifaunal invertebrates in particular, is associated with sediment topography (e.g. ripples, burrows, grass shoots)</td>
<td>N/D</td>
<td>Low</td>
<td>YES (Hemmera field studies 2012)</td>
<td>YES (Hemmera field &amp; Desktop studies 2013)</td>
<td></td>
</tr>
<tr>
<td>Linkage</td>
<td>Hypothesis</td>
<td>Weight of evidence linking these factors</td>
<td>Ability to predict effects</td>
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</tr>
<tr>
<td>Direct habitat loss effect on biofilm abundance</td>
<td>High / certain</td>
<td>High</td>
<td></td>
<td></td>
<td>YES</td>
<td>NO</td>
</tr>
<tr>
<td>Direct habitat loss effect on infauna and epifauna abundance</td>
<td>N/D</td>
<td>Low</td>
<td></td>
<td></td>
<td>NO</td>
<td>NO</td>
</tr>
</tbody>
</table>