Biological Synopses For Select British Columbia Intertidal Molluscs In Support Of Marine Emergency Response

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V9T 6N7

2025

Canadian Technical Report of Fisheries and Aquatic Sciences 3647

Fisheries and Oceans Canada | Pêches et Océans Canada

Canada

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and Aquatic Sciences 3647

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by

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Cat. No. Fs97-6/3647E-PDF ISBN 978-0-660-74387-5 ISSN 1488-5379
https://doi.org/10.60825/b665-sj26

Correct citation for this publication:

Gillespie, G.E., M.I. Bigg, S.C. Davies, L.-M. Herborg and G.P. Thomas. 2025. Biological synopses for select British Columbia intertidal molluscs in support of marine emergency response. Can. Tech. Rep. Fish. Aquat. Sci. 3647: ix + 314 p. https://doi.org/10.60825/b665-sj26

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDIX TABLES

ABSTRACT

Gillespie, G.E., M.I. Bigg, S.C. Davies, L.-M. Herborg and G.P. Thomas. 2025. Biological synopses for select British Columbia intertidal molluscs in support of marine emergency response. Can. Tech. Rep. Fish. Aquat. Sci. 3647: ix + 314 p. https://doi.org/10.60825/b665-sj26

Approximately 4,000 emergencies are reported annually in British Columbia coastal waters and majority of them are spills of petroleum hydrocarbon (oils) as per Province of British Columbia. Impacts on the receiving environment and the molluscs described in this document may vary depending on the type of oil, coastal characteristics, the prevalent weather, tidal cycle, response effort, and other variables. The intent of the report is to assess current knowledge for selected intertidal and shallow subtidal mollusc species in Canadian Pacific waters and to inform Environmental Incident Coordinators and other spill response partners to prioritize actions and operations in oil spill events.

Fourteen mollusc species (or species groupings) were selected based on conservation status importance to commercial, recreational or subsistence harvests, or ecological role: northern abalone (*Haliotis kamtschatkana*), Olympia oyster (*Ostrea lurida*), Pacific oyster (*Magallana gigas*), Pacific geoduck (*Panopea abrupta*), Manila clam (*Venerupis philippinarum*), Pacific littleneck clam (*Leukoma staminea*), Washington butter clam (*Saxidomus gigantea*), Pacific razor (*Siliqua patula*), varnish clam (*Nuttallia obscurata*), Nuttall cockle (*Clinocardium nuttallii*), softshell (*Mya arenaria*), sea mussel (*Mytilus californianus*), foolish, blue and Mediterranean mussels (*Mytilus trossulus*, *M. edulis* and *M. galloprovincialis*), and fat and Pacific gapers (*Tresus capax* and *T. nuttallii*). Species summaries include descriptions of significance, vulnerability, biological characteristics, temporal life history, habitat preferences, and physiological tolerances.

Information provided in this report can be used to develop spill response, sampling and monitoring plans and to conduct intertidal habitat assessments and regulatory project reviews as part of oil spills and spill related incidents. Illustrating the linkages between potential impacts of oil releases to the receiving environment and mollusc communities, tools such as Vulnerability Ranking Frameworks and Pathways of Effects (PoE) are discussed within the synopses to further aid in the development of risk assessments, protection planning and preservation of these species. Generalized marine spill scenarios are described and presented with the synopses of biological information for select intertidal molluscs in support of marine emergency response.

RÉSUMÉ

Gillespie, G.E., M.I. Bigg, S.C. Davies, L.-M. Herborg and G.P. Thomas. 2025. Biological synopses for select British Columbia intertidal molluscs in support of marine emergency response. Can. Tech. Rep. Fish. Aquat. Sci. 3647: ix + 314 p. https://doi.org/10.60825/b665-sj26

Environ 4 000 urgences sont signalées chaque année dans les eaux côtières de la Colombie-Britannique et la majorité d'entre elles sont des déversements d'hydrocarbures pétroliers (huiles) selon la province de la Colombie-Britannique. Les répercussions sur le milieu récepteur et les mollusques décrites dans ce document peuvent varier en fonction du type d'hydrocarbures, des caractéristiques côtières, des conditions météorologiques prévalentes, du cycle des marées, de l'effort d'intervention et d'autres variables. Le but du rapport est d'évaluer les connaissances actuelles sur certaines espèces de mollusques se trouvant dans les zones intertidales et infratidales peu profondes des eaux canadiennes du Pacifique, et d'informer les coordonnateurs des incidents environnementaux et les autres partenaires d'intervention en cas de déversement afin qu'ils puissent établir l'ordre de priorité des mesures et des opérations à mettre en œuvre en cas de déversement d'hydrocarbures.

Quatorze espèces (ou groupes d'espèces) de mollusques ont été sélectionnées en fonction de l'importance de leur état de conservation pour la pêche commerciale, récréative ou de subsistance, ou de leur rôle écologique : l'ormeau nordique (*Haliotis kamtschatkana*), l'huître plate du Pacifique (*Ostrea lurida*), l'huître creuse du Pacifique (*Magallana gigas*), la panope du Pacifique (*Panopea abrupta*), la palourde japonaise (*Venerupis philippinarum*), la palourde du Pacifique (*Leukoma staminea*), la palourde jaune (*Saxidomus gigantea*), le couteau du Pacifique (*Siliqua patula*), la palourde lustrée (*Nuttallia obscurata*), la coque de Nuttall (*Clinocardium nuttallii*), la mye (*Mya arenaria*), la moule de Californie (*Mytilus californianus*), la moule bleue de l'ouest, la moule bleue de l'est et la moule de Méditerranée (*Mytilus trossulus*, *M. edulis* et *M. galloprovincialis*), ainsi que la fausse-mactre et la fausse-mactre du Pacifique (*Tresus capax* et *T. nuttallii*). Les résumés comprennent des descriptions de l'importance, de la vulnérabilité, des caractéristiques biologiques, du cycle biologique, des préférences en matière d'habitat et des tolérances physiologiques des espèces.

On peut utiliser les renseignements fournis dans ce rapport pour élaborer des plans d'intervention en cas de déversement, des plans d'échantillonnage et des plans de surveillance, ainsi que pour effectuer des évaluations de l'habitat intertidal et des examens réglementaires de projets en cas de déversements d'hydrocarbures et d'incidents liés à des déversements. Tout en illustrant les liens entre les effets potentiels des rejets d'hydrocarbures sur le milieu récepteur et les communautés de mollusques, nous abordons dans les synopsis différents outils, comme les cadres de classement de la vulnérabilité et les séquences des effets, afin de faciliter l'élaboration des évaluations des risques, la planification de la protection et la préservation de ces espèces. Les scénarios généralisés de déversements en milieu marin sont décrits et présentés avec les synopsis des informations biologiques pour certains mollusques intertidaux à l'appui des interventions d'urgence en mer.

INTRODUCTION

Increases in marine traffic along British Columbia's Pacific coast in recent years due to infrastructure projects, like the expansion of the Trans Mountain pipeline and the Port of Vancouver raise the likelihood of environmental incidents, including spills of petroleum hydrocarbon (oils) or other hazardous substances. On average, over 1,100 spills of varying sizes are reported annually in B.C.'s navigable waters (Herborg, pers. com.). To address these risks, Canada has developed a Marine Oil Spill Preparedness and Response Regime that outlines the roles and responsibilities of different federal agencies (Transport Canada 2019). Within this framework, Transport Canada establishes industry preparedness requirements and certifies response organizations. During a marine environmental incident response, the Canadian Coast Guard is the lead agency and initiates the Incident Command System (ICS), an internationally accepted management system used to coordinate activities within environmental emergency response operations. Environment and Climate Change Canada, Fisheries and Oceans Canada (DFO), impacted First Nations, the Province of BC, and in most cases a polluter representative participate in the Environmental Unit within the ICS and provide scientific and ecological guidance during an incident. Specifically, Environmental Incident Coordinators (EICs) in DFO use existing data holdings to identify resources at risk and environmental sensitivities within the vicinity of a spill, such as known bivalve harvesting locations or distributions of vulnerable mollusc species.

Following a spill, oil can behave in a number of ways; it may form slicks on the water's surface, disperse into the water column, sink to the seabed, or contaminate shoreline environments (DFO 2025). The fate of oil in the marine environment and its ecological impacts vary depending on several factors, including the type of oil and its chemical characteristics, the quantity released, coastal features, weather conditions, tidal cycles, and the effectiveness of the response efforts (ITOPF 2011a). When oil sinks or accumulates in the nearshore environment, it can cause detrimental effects to benthic and intertidal invertebrate species (Environment Canada 1996). Molluscs are particularly vulnerable because they are relatively immobile and can occupy sediments where cleanup methods are both difficult and potentially harmful to the biota. As filter feeders, molluscs are exposed to oil dispersed in the water column, and those occupying intertidal zones are at additional risk of being smothered by oil that washes ashore. In addition to the ecological impacts of a spill, several mollusc species are harvested commercially in B.C. or are significant to First Nations for subsistence or cultural purposes.

The intent of this technical report is to 1) provide an overview of the physical and chemical properties of five types of petroleum hydrocarbons transported in the marine environment, and 2) assess the current knowledge for selected intertidal and shallow subtidal mollusc species in Canadian Pacific waters. Fourteen mollusc species (or species groupings) were selected based on conservation status importance to commercial, recreational or subsistence harvests, or ecological role. Species summaries include descriptions of significance, vulnerability, biological characteristics, temporal life history, habitat preferences, and physiological tolerances. This information will support the identification

of resources at risk and response priorities within an Incident Command System. These synopses will improve the development of opportunistic sampling and monitoring plans, as well as intertidal habitat assessments and incident response reviews. The incorporation of previous developed tools such as Vulnerability Ranking Frameworks (Jeffery *et al.* 2023) and Pathways of Effects (PoE)(Hannah *et al*. 2020) within the synopses further aid this work by illustrating the linkages between potential impacts of oil releases to the receiving environment and mollusc communities.

METHODS

Literature Reviews

Literature reviews were conducted to assess the current knowledge base for species biology, distribution, and vulnerability to oils of concern. Academic databases were used to identify relevant material from a variety of journals. Articles included both peer-reviewed and grey literature (e.g., government publications).

Data Organization

Comprehensive species summaries provided in this report relay ecological significance, vulnerability, biological characteristics, temporal life history, habitat preferences and physiological tolerances. A quick reference guide (Table 1) allows for rapid review and comparison of species of interest. The detailed species descriptions and photographs are provided in species summaries to aid in species identification. Species size ranges follow measurement standards of Sloan and Breen (1988) for abalone (Figure 1), Quayle (1969, 1988) for oysters (Figure 2) and Quayle and Bourne (1972) for clams (Figure 3). Taxonomy follows Coan *et al.* (2000), with recent changes documented in the World Register of Marine Species (WoRMS Editorial Board 2022). Common names were taken from various literature sources, but those deemed official by Turgeon *et al.* (1998) are in bold type in the summary tables.

Oils and their characteristics are summarized in the section below. These five groupings are:

- Group 1 Oils – Gasoline and marine diesel oils;
- Group 2 Oils – Light crude oils containing moderate to high concentrations of hydrocarbons;
- Group 3 Oils – Engine/hydraulic oil, medium crude oil, heavy crude oil, and diluted bitumen oil;
- Group 4 Oils – Bunker C oils;
- Group 5 Oils – Sinking oils.

Within these synopses summaries on oil groupings broadly discuss vulnerability and risk to fresh and weathered oil for species by life stage. Generalized terms are used in these discussions such that larval summaries are inclusive of all life phases within the water

column (spawn, spatting and settling stages) and adult summaries are generalized to include the sessile or low mobility juvenile and mature life stages.

Potential impacts of oil on the listed mollusc species are discussed as simplified pressure-based PoE models for distinct types of oil, species life stage, age of the oil spill and various ocean conditions as set out in the Pathways of Effects National Guidelines (GOC 2012). This document outlines the regulatory contexts in which PoE models are developed, describes the benefits of using such PoE models, outlines the ecological unit considerations of the models, and provides instructions on how to develop PoE models (GOC 2012). Species vulnerability ranking to marine emergencies used the framework of Thornborough *et al.* (2017) and the subgroup taxonomic rankings of Hannah *et al.* (2017). A subsequent literature review by regional biologists and species experts (Jeffery *et al.* 2023) rationalized updated scoring criteria and species rankings for the Pacific, which are presented herein.

Impact Modeling for Oil Spill Response

Effectiveness of response to marine emergencies (e.g., oil spills) depends on available information regarding vulnerability, biology and seasonal distribution of species in the vicinity of the event. Pollutant impacts to an organism are the result of an array of complex, poorly understood or identified processes, often lacking defensible research for the receiving environment, taxonomic group, and uptake capacity of the organism. As such modelling tools are a useful aid in developing a precautionary understanding of these impacts.

As oils will dilute, and constituent properties will change with sea conditions and time, evaluating realistic conditions of exposure from oils spills requires extrapolation from modeling frameworks that account for the multiple interrelated factors. The vulnerability frameworks described and outlined in the species summaries under the heading ‘Vulnerability’ outline the ranking and scoring justifications used to assess species vulnerability to oil spills under the subcategories (Exposure, Sensitivity and Recovery) (Thornborough *et al.* 2017, Hannah *et al.* 2017, Jeffery *et al.* 2023). The model ranked vulnerability of high-level taxonomic groups to ship-sourced oil spills, qualifying species inclusion into the synopses.

For the selected species of interest, these synopses build on the vulnerability framework by focussing on pressure-based conceptual modeling of PoE within each species summary. These tools contribute to developing a knowledge base for detailed risk analysis and timely and informed response to marine emergencies. The mollusc species summaries include vulnerability criteria and scoring outlined in the appendix tables.

As an adaptive management tool, PoE are conceptual models between human based activities and measurable impacts to a specified endpoint within the environment. PoE in this synopses are simplified pressure-based risk probabilities postulated under various exposure scenarios, where ‘pressures’ are oil spill-related changes in the receiving environment that can lead to negative impacts for molluscs. PoE identify likely risk of

effects (quantified as low, moderate and high) on select molluscs caused by spilled oil (human impact). The PoE is used to illustrate the potential for organism exposure by oil type while considering age of the oil spill, species life stage, and various ocean conditions. Whereas the vulnerability frameworks outline and grade the degree a species as a whole is susceptible to harm based on its sensitivity and recovery potential as a function of exposure to any oil type, the PoE identify potential risk probabilities given oil attributes. PoE models serve as a complementary tools to vulnerability frameworks, aiding in preliminary screening to enhance response strategies and planning in the event of an oil spill.

In the event of an oil release into the receiving environment, the tools and information provided within this document should be used alongside a standardized hazard assessment protocol, examining the chemical signature of spill material, measurement of toxicity and spatial estimation of damage to the marine ecosystem, which will aid in the evaluation of predicted species recovery (Martinez-Gomez *et al.* 2010). The magnitude of damage, geographic distribution and long-term impacts of oil spills or remediation efforts, including addition of chemical oil dispersants, shoreline cleaning agents as well as herders (i.e., amphiphilic oil-collecting surfactant) are not addressed herein. Continued research into the species specific PoE, and acute and chronic impacts of oils on marine molluscs within British Columbia will enable the longer-term management of oil spill response with consideration of sensitive ecosystems and socioeconomic and cultural values.

Table 1. Quick reference guide to mollusc summaries.

Species	COSEWIC Status	Geographic Status	Range	Depth (m)[1]	Habitat	Life Span (approx.)	Spawning Season[2]	Food Source	Limiting Factors	Exposure[4]	Substrate[4]	Mobility[4]	Pollutant Sensitivity Risk[5]	Adult Local Pollutant Risk[5]	Adult Vulnerability Ranking Score[6]	Larval Local Pollutant Risk[5]	Larval Vulnerability Ranking Score[6]
Northern abalone																	
Haliotis kamtschatkana	Endangered[3]	Native	Alaska to Baja California	0 - 100	Hard substrate, exposed or semi exposed shoreline, lower intertidal / shallow subtidal, area of high water exchange and kelp forests.	~20 yrs.	April - July	Grazer - on macro drift algae, Coralline algae	Require high salinity and temp. range 2-24°C for survival all life stages	Intertidal/Subtidal Benthic	Sediment Epifauna	Low	Mechanical and Chemical	Patchy populations at Sea Surface and Seafloor	7	Pelagic Larva Aggregations at Sea Surface	6
Olympia oyster																	
Ostrea lurida (formerly *Ostrea conchaphila*)	Special Concern	Native	Alaska to Baja California	0- 50	Lower intertidal and subtidal zones of estuaries.	~10yrs.	April - August	Filter/suspension Feeder	Moderately euryhaline and specific temp. ranges critical to reproduction and larval development	Intertidal/ Subtidal Benthic	Rock and Rubble Dwellers	Sessile	Mechanical and Chemical	Patchy populations at Sea Surface and Seafloor	7	Pelagic Larva Aggregations at Sea Surface	6
Pacific oyster																	
Magallana gigas	Unlisted	Introduced - Primary oyster species cultured in BC	Alaska to California. Native to western Pacific (Russia to Korea)	0 - 1	Dependent on hard substrates for settlement. Upper Intertidal distribution.	~40yrs.	July - August	Filter/suspension Feeder	High tolerance for variable salinity and water temperatures	Intertidal	Rock and Rubble Dwellers	Sessile	Mechanical and Chemical	Patchy populations at Sea Surface and Seafloor	6	Pelagic Larva Aggregations at Sea Surface	5
Pacific geoduck																	
Panopea generosa	Unlisted	Native	(Eastern Pop.) Kodiak Island Alaska to Newport Bay California	0 - 110	Adults inhabit burrows that extend up to 1m into the (soft) substrate	~168 yrs.	March - July	Filter/suspension Feeder	Very sensitive to low Oxygen levels. Require high salinity. Temp. range 6-16°C for larval development.	Intertidal/Subtidal Benthic	Sediment Infauna	Low	Mechanical and Chemical	Patchy populations at Seafloor and Assoc. with unconsolidated substrates	7	Pelagic Larva Aggregations at Sea Surface	5
Venerupis philippinarum	Unlisted	Introduced - Primary clam species cultured in BC	Central BC to Southern California. Native to western Pacific (Russia to Korea)	0 - 1	Dependent on unconsolidated substrates - upper intertidal	~14yrs.	June - October	Filter/suspension Feeder	Euryhaline and specific temp. ranges critical to reproduction and larval development	Intertidal	Sediment Infauna	Low	Mechanical and Chemical	Patchy populations at Sea Surface and Seafloor and Assoc. with unconsolidated substrates	7	Pelagic Larva Aggregations at Sea Surface	5
Pacific littleneck																	
Leukoma staminea	Unlisted	Native	Aleutian Islands to Mexico	0 - 10	Dependent on unconsolidated substrates - mid intertidal	~14yrs.	April - August	Filter/suspension Feeder	Require higher salinity and moderate temp. range for survival / development	Intertidal/Subtidal Benthic	Sediment Infauna	Low	Mechanical and Chemical	Patchy populations at Sea Surface and Seafloor and Assoc. with unconsolidated substrates	7	Pelagic Larva Aggregations at Sea Surface	5

California mussel																
Mytilus californianus	Unlisted	Native	Cook Inlet Alaska to Punta Rompiente Baja California	0 - 100	Dependent on hard substrate and each other to form dense beds - Exposed coastlines upper intertidal to subtidal	~50 - 100yrs.	April - May and Sept - Dec	Filter/suspension Feeder	Require higher salinities and moderate temperatures for survival.	Intertidal/Subtidal Benthic	Rock and Rubble Dwellers	Sessile	Mechanical and Chemical	Patchy populations at Sea Surface and Seafloor	6	Pelagic Larva Aggregations at Sea Surface	5
Bay mussels (Foolish mussel, Mediterranean mussel and Blue mussel)																
Mytilus trossulus, M. edulis and *M. galloprovincialis*	Unlisted	Native, Introduced and Hybrid	Multiple species cannot be ID on external morphology. Transglobal	0 - 100	Dependent on hard substrate and each other to form dense beds also occur on unconsolidated substrates - sheltered intertidal to subtidal	~20yrs.	June and August - Oct	Filter/suspension Feeder	Tolerant of a broad range of salinities. Temperature tolerance varies with species	Intertidal/Subtidal Benthic	Rock and Rubble Dwellers	Sessile	Mechanical and Chemical	Patchy populations at Sea Surface and Seafloor	6	Pelagic Larva Aggregations at Sea Surface	5
Gaper (Fat gaper and Pacific gaperl)																
Tresus capax and *T. nuttallii*	Unlisted	Native	Alaska to Baja California	0 - 80	Dependent on unconsolidated substrates - Protected mid-intertidal to the shallow subtidal seagrass beds. Fat gapers found in 25-50 cm burrows; Pacific gapers burrow deeper (60-90 cm)	~18 - 24yrs.	March - July	Filter/suspension Feeder	Require moderate to higher salinities and temperatures for survival.	Intertidal/Subtidal Benthic	Sediment Infauna	Low	Mechanical and Chemical	Patchy populations at Sea Surface and Seafloor and Assoc. with unconsolidated substrates	7	Pelagic Larva Aggregations at Sea Surface	5

Note: This is a generalized summary table to quickly assess and compare species of interest. Refer to species summary sections noted by page number for greater detail and source citations.
1: Depth listed is a typical range, organisms may be observed beyond these limits.
2: Spawning Season may vary significantly with latitude
3: IUCN Red List of Threatened Species in 2020 - Critically Endangered
4: Subgroup Classifications for vulnerability (Thornborough *et al.* 2017, Hannah *et al.* 2017)
5: Vulnerability Ranking Qualification Exposure (Jeffery *et al.* 2023)
6: Vulnerability Ranking Score (Thornborough *et al.* 2017, Hannah *et al.* 2017, Jeffery *et al.* 2023)

OIL AND THE ENVIRONMENT

Oils of Concern in Emergency Response

Liquid petroleum (oil) is a mixture of thousands of compounds including various hydrocarbons (saturated, unsaturated aromatic and polar compounds). Constituents such as metals, nitrogenous and sulfurous compounds may be present in varying proportions depending on the specific oil's source material and processing. The chemical and physical properties of the oil will determine its impacts to the receiving environment and how the constituents, particularly polycyclic aromatic hydrocarbons (PAHs), and monocyclic aromatic hydrocarbons (benzene, toluene, phenols) contaminate and affect an organisms. PAHs having with higher molecular weight, specifically those with more than three aromatic rings are less water soluble and tend to bind to material in the environment such as algae compared to PAHs less than three aromatic rings. (Martínez-Gómez 2010). Specific environmental conditions, including climate, prevailing winds, water temperature, salinity and shoreline characterization will influence oil behaviour and persistence in the environment (Bejarano and Michel 2016).

Oils are categorized into five groups based on their API gravity (ºAPI) as assigned by the American Petroleum Institute (ITOPF 2011a). The ºAPI is a measure of oil weight, based on the following formula, where specific gravity is (ITOPF 2011a):

ºAPI = (141.5/Specific Gravity at 15.6 °C) – 131.5

Oils with an ºAPI >10 are lighter than distilled water at 15.6 °C and will float, oils with an ºAPI <10 are heavier than distilled water at 15.6 °C and sink. Additionally, specific gravity of sea water is 1.025. Group 1 contains gasoline and marine diesel oils (MDO), which are split into two (2) subcategories due to fate and behavioral differences, given MDO is a heavier blend of oils than gasoline. Group 2 is light crude oils (LCOs). Group 3 contains diluted bitumen oil, engine/hydraulic oil, heavy crude oil, and medium crude oil. Group 4 contains Bunker C oil. Group 5 contains sinking oils. Table 2 outlines the five oil groups of concern, based on oil behaviour.

Group 1: Gasoline and Marine Diesel Oils

Group 1A: Gasoline

Gasoline is a commonly used fuel product which gets commonly spilled as well. Gasoline's specific gravity is <0.8 (or ºAPI >45) indicating it is buoyant in marine water and forms a surface layer 1-2 mm thick (ITOPF 2011a). It is highly volatile distillate and can completely evaporate within 24 hours. Gasoline has a low viscosity causing it to rapidly spread and disperse. It easily forms emulsions with water, but these are typically unstable and can be quickly disrupted by environmental factors such as turbulence, temperature fluctuations, tidal streams, currents, sunlight, and other abiotic elements. The combination of these factors can accelerate the process of emulsion breakdown.

Gasoline has high aquatic toxicity due to high concentrations of aromatic hydrocarbons; however, due to its volatile nature and rapid evaporation, the timeframe for toxic interactions is relatively short (ITOPF 2011b). Chronic toxic effects are limited unless there is an ongoing spill or it penetrates deeper into the sediment (ITOPF 2011b, Lee *et al.* 2015). Possible acute toxic effects on aquatic organisms include mortality or, at lower concentrations, impaired feeding and reproduction (ITOPF 2011b).

Group 1B: Marine Diesel Oils

Marine diesel oil (MDO) is a commonly used fuel for marine vessels and is a mix of middle distillates and heavy fuel oils. MDO specific gravity ranges from 0.839 to 0.903 depending on the ratio of distillates to heavy fuel oils (Environment Canada 1999). MDOs are volatile, but less so than gasoline and will partially evaporate (up to 50%) or disperse within five days (Environment Canada 1999). In high-energy situations, MDOs will create unstable emulsifications with water which are easily broken apart through changes in turbulence, temperature and sunlight.

MDOs have a high aquatic toxicity due to a high percentage of light aromatic hydrocarbons (Environment Canada 1999). Aquatic toxicity will decrease as the light hydrocarbons evaporate. Possible acute toxic effects include mortality or impaired feeding and reproduction at low concentrations (ITOPF 2011b). Additionally, MDOs can coat and smother aquatic organisms and have a tendency to penetrate porous substrates, preventing breakdown and increasing persistence in the environment (Martinez-Gomez *et al.* 2010).

Group 2: Light Crude Oil

LCOs are globally used conventional oils. Examples of light crude include Arabian Light, West Texas Intermediate, and Canadian Norman Wells (Lee *et al.* 2015). The specific gravity of LCOs ranges from 0.80 to 0.85, making them buoyant in water (ITOPF 2011a). LCOs have a higher viscosity than Group 1 oils, indicating they will disperse and emulsify more slowly in water. When emulsifications form, they are more stable than Group 1 oils. Stable emulsions increase volume and surface area of oil spills and raise their specific gravity, possibly resulting in them sinking.

LCOs are moderately toxic to aquatic organisms when freshly spilled. As the oil weathers and toxic hydrocarbons evaporate and disperse, aquatic toxicity decreases (ITOPF 2011b). Acute toxic effects can include mortality or at lower concentrations impaired feeding and reproduction. LCOs can cause acute toxic impacts through dissolution, mixing, and sorption onto suspended sediments, increasing exposure to aquatic organisms (Lee *et al.* 2015). They can also penetrate deeper into porous substrates, slowing breakdown and thereby persisting in the environment (Martinez-Gomez *et al.* 2010).

Group 3: Heavy and Persistent Oils

Group 3 includes heavy and persistent oils such as engine/hydraulic oil, medium crude oil, heavy crude oil, and diluted bitumen oil. Examples of Group 3 oils include Alaska North Slope and Norwegian South Sea oils (Lee *et al.* 2015). Group 3 oils have a specific gravity range of 0.85 to 0.95, meaning in the event of a spill the oil will float on the in water (ITOPF 2011a). Group 3 oils can contain around 30% volatile condensate, depending on the blend, which will readily evaporate (Fingas 2015). Group 3 oils have high viscosities meaning dispersion and emulsification is limited (ITOPF 2011a). When emulsifications are formed, they are stable and form a "mousse," resulting in increased volume, surface area and specific gravity (Lee *et al.* 2015). Stable emulsifications may cause oil to sink in the water column, creating difficulty for physical recovery (Lee *et al.* 2015). If washed ashore, Group 3 oils have the potential to form asphalt pavements which are naturally forming mixes of highly weathered oil and pebbles (ITOPF 2011a).

Group 3 oils generally have fewer volatile compounds; therefore, when freshly spilled they are less likely to make the aquatic environment toxic. However, as weathering occurs, toxic compounds evaporate, further decreasing aquatic toxicity (ITOPF 2011b). Group 3 oils can negatively impact aquatic organisms through coating, smothering and ingestion. Asphalt pavements may also be formed if washed ashore, modifying shoreline habitat, smothering organisms and reducing food sources.

Group 4: Bunker C Oil

Bunker C oil is a heavy, highly persistent residual fuel not mixed with any distillates (Environment Canada 1999). It is typically blended with lighter oils to create a fuel or used to make asphalt (Lee *et al.* 2015). Bunker C has a specific gravity range of 0.95 to 1.03, usually resulting in buoyancy in marine water; however, there is potential for sedimentation to cause sinking (ITOPF 2011a, NOAA 2019). Bunker C oils have very high viscosities and remain semi-solid in cold temperatures (ITOPF 2011a). High viscosity can cause very slow weathering to occur, limiting dispersion and emulsification. Asphalt pavements can be formed if Bunker C oils are washed ashore.

Bunker C oil generally has low aquatic toxicity and low quantities of water-soluble compounds (if not blended with lighter oils); therefore, it will not readily emulsify and interact with aquatic organisms (Environment Canada 1999). Negative environmental effects include coating, smothering, and ingestion by organisms, and the persistence of Bunker C may cause it to be more damaging than lighter oils (ITOPF 2011b). Sedimentation-caused sinking poses a smothering risk to aquatic organisms lower in the water column or on the sea floor. Asphalt pavements, if formed, can cause habitat alteration, coating, smothering and ingestion in aquatic and terrestrial organisms.

Group 5: Sinking Oils

Sinking oils are heavy, highly persistent oils (sometimes referred to as low API oils) with a specific gravity >1 and readily sink in water in their unweathered state. Sinking oils have

very high viscosities and usually exist in a semi-solid form (ITOPF 2011a). There is limited effect of weathering on sinking oils.

Sinking oil has low aquatic toxicity due to a lack of light aromatic hydrocarbons. However, sinking oils can cause smothering and chronic issues due to their highly persistent qualities (ITOPF 2011b). Due to the density of sinking oils, they can cause coating, smothering, and ingestion to aquatic organisms on the sea floor. The persistence and difficult cleanup of sinking oils can cause long-lasting environmental effects including contamination of intertidal areas which can impact waterfowl and furbearing mammals. Sinking oils can also penetrate sediments, directly impacting benthic organisms (Lee *et al.* 2015).

Receiving Environment

Oils of concern can influence, and be influenced by, the chemical and physical properties of the receiving environment, resulting in toxicity to molluscs and degradation of their habitat. Oils may cause compaction and reduced permeability of substrates, potentially decreasing oxygen exchange and increasing hypoxia for infauna (Bejarano and Michel 2016), or change thermal properties and water quality, inhibit and/or alter temperature-dependent life processes such as spawning and larval development.

Heavily oiled sediments may form tar mats or asphalt pavements either on the surface or subsurface causing long term oil persistence and habitat modification (Owens *et al.* 2008). These hardened surfaces can prevent filter feeding and respiration in molluscs or impede burrowing by infaunal species (Bejarano and Michel 2016). Weathered oil within sediment can contain high enough PAH levels to cause adverse effects to aquatic life. Heavy wave action, winds and tidal events also influence the distribution, emulsification, dilution and weathering of oils and therefore directly influence the PoE to resident organisms. After nearshore oil spills, onshore winds and falling tides can cover the intertidal zone with oil. Oil spilled in the intertidal zone can eventually be washed back into the ocean, settling in the subtidal zone, and increasing oil concentrations within subtidal sediment (Boehm *et al.* 1985). Risk of oil exposure to species within the subtidal zone increases with time.

Substrate characteristics also effect oil spill behaviour thus the PoE. Some compounds in oil can dissolve in the water; therefore, coarse rocky and gravelly substrates easily coated and infiltrated by oil, whereas fine grained sediments such as mud are more resistant to oil infiltration (Little 2023). Fine-grained sand and mud penetration is generally restricted to lighter oils and depths of ~15 cm, whereas coarser sand can be penetrated to depths of up to 25 cm (Bejarano and Michel 2016). Lighter oil may penetrate the substrate until fine grained sediment or bedrock is reached (Owens *et al.* 2008), persisting in the matrices with slowed breakdown and evaporation and prolonging chronic exposure of infaunal species to hydrocarbons (Martinez-Gomez *et al.* 2010). Deeply penetrated oil can be brought back to the surface through erosion and bioturbation, re-exposing aquatic organisms (Bejarano and Michel 2016).

The co-influence of increased temperature and decreased pH has been observed to increase oil toxicity. Projected temperature and pH fluctuations under continuing climate change

would increase oil toxicity by 1.3-fold on average (Nordborg *et al.* 2020). Decrease in surrounding pH can lead to acidification which can result in thinner shells for molluscs (Fitzer *et al.* 2018). Ultraviolet radiation (UVR) can increase the toxicity of petroleum hydrocarbons from oil spills by 3.2-fold (Nordborg *et al.* 2020). UVR increased toxicity is a threat for aquatic organisms found <10 meters from the water surface (Nordborg *et al.* 2020), therefore potentially affecting larval and spawning molluscs, along with juveniles and adults in some cases. Temperature and pH are directly related to salinity: decrease in temperatures can lead to decreased salinity which can result in decrease in pH. PAH solubility increases as salinity decreases (Whitehead 2013). Increased solubility increases the likelihood of ingestion of PAHs by filter-feeding molluscs or directly absorption from the marine environment.

Intertidal Mollusc Community

Intertidal mollusc community structure in British Columbia is determined by many factors. Substrate is a major determinant of community structure, as bedrock and boulder substrates are utilized primarily by epifauna while unconsolidated substrates (cobble, gravel, shell, sand, mud, silt) can also support infauna. Degree of exposure (termed wave shock by Ricketts and Calvin (1968)) affects the composition of unconsolidated substrates; shorelines exposed to open ocean or in high fetch or current areas generally do not accumulate finer substrate and tend to be rocky with only some interstitial spaces offering habitat for infauna. Exceptions include the wave-swept sand beaches of Haida Gwaii and the west coasts of Calvert and Vancouver Island, which support populations of Pacific razors, and the interstitial habitat that develops in mature beds of California mussels (Quayle and Bourne 1972, Seed 1976, Seed and Suchanek 1992).

Infaunal species have different tolerances for exposure at low tide, resulting in species dominance at different tidal heights. In the Salish Sea varnish clams are found at the highest tidal elevations, both Manila and varnish clams are present at moderately high elevations, Manila clams overlap with Pacific littlenecks in moderately low tidal levels, and littlenecks and butter clams dominate in the lower intertidal and shallow subtidal (Quayle and Bourne 1972, Gillespie *et al.* 1999). In the absence of competitors (i.e., Manila and varnish clams), littlenecks are found at higher elevations in Alaska (Nickerson 1977).

Salinity gradients also contribute to intertidal community structure. Varnish clams extend into lower salinity areas than Manila or littleneck clams. California mussels require full salinity seawater, while bay mussels tolerate a much wider range of salinity (Suchanek 1978, Gillespie *et al.* 1999, Heibert *et al.* 2016).

Seasonal timing of spawning and presence of pelagic larvae can inform decisions on timing of potential salvage operations, increased vulnerability (e.g., movements of abalone into shallower water during spawning), or potential for a species to recover from impacts or re-populate an affected site. Note that for all mollusc species examined in this review, pelagic larval phases, as per the subgroup vulnerability scores listed in Jeffery *et al.* (2023), are separate from the epifaunal and infaunal adult phases on the vulnerability rankings table to reflect scaling separated for each significant life phase of these animals. Generalized PoE

risk scenarios of contaminant oils for these species are further discussed within the individual species summaries.

Identified knowledge gaps for the species of interest, as well as insufficient data on the fate and behaviour of different oils in water and sediment under various conditions limit the capacity to use non-adaptive spill response, wherein spills naturally dissipate without human intervention - natural attenuation. Distribution data are generally not available at the resolution required (i.e., hundreds of meters) for response for much of the British Columbia coast; however, habitat preferences can provide guidance as to which species are likely to be present. This information is also useful to guide sampling effort to confirm presence or select species to consistently monitor impacts.

Table 2. Behaviour of different oil types during a marine spill.

Group 1
Group 1A - Gasoline • Non-persistent • Number of carbon range 4 to 12 • High volatility - loss to evaporation up to 100% within 24 hours • Low viscosity - rapid spreading; readily disperses; readily emulsifies with stable emulsions • Specific gravity less than 0.80; buoyant on water • High aquatic toxicity when fresh; high concentrations of low molecular weight aromatic hydrocarbons • Toxicity decreases with weathering; low molecular weight aromatic hydrocarbons evaporate
Group 1B – Marine Diesel • Persistent • Number of carbon range 7 to 24 • Less volatile components - loss due to evaporation; 50% in 5 days • Low viscosity - higher than gasoline; rapid spreading; emulsifies with stable emulsions in high energy situations • Specific gravity range 0.839-0.903; buoyant on water • High aquatic toxicity when fresh • Toxicity decreases with weathering; low molecular weight aromatic hydrocarbons evaporate
Group 2
Light Crude Oil • Slightly persistent • Less volatile components - less loss due to evaporation • Higher viscosity - spreading is slowed; dispersion is limited; emulsions are stable • Specific gravity range 0.80 - 0.85; buoyant on water • Moderate aquatic toxicity when fresh • Toxicity decreases with weathering; low molecular weight aromatic hydrocarbons evaporate
Engine / Hydraulic Oil - Medium Crude Oil - Heavy Crude Oil – Diluted Bitumen • Persistent • Fewer volatile components – generally less evaporation • High viscosity – spreading, dispersion and formation of emulsions is limited; emulsions are stable once formed • Specific gravity range 0.85 – 0.95; buoyant on water; potential for sinking if sedimentation occurs • Potential of formation of asphalt pavements if washed ashore • Moderate aquatic toxicity when fresh

- Toxicity decreases with weathering; low molecular weight aromatic hydrocarbons evaporate

Group 4

Bunker C Oil

- Highly persistent
- Number of carbon range 9 to 26
- Evaporation effect is negligible
- Very high viscosity; potential to remain in semi-solid form in cold temperatures; weathering occurs very slowly
- Specific gravity greater than 0.95; buoyant on water; potential for sinking if sedimentation occurs; potential for over washing in turbulent seas Potential of formation of asphalt pavements
- Generally, very low aquatic toxicity thus very low number of aromatic hydrocarbons
- Toxicity decreases with weathering; low molecular weight aromatic hydrocarbons evaporate

Group 5

Sinking Oil*

- Highly persistent
- Very high viscosity - most likely in semi-solid form; virtually zero weathering effects
- Specific gravity greater than 1.0
- Sinking residues can also occur from weathered oil or through sedimentation
- Very low aquatic toxicity; very low amount of low molecular weight aromatic hydrocarbons; weathering does not change toxicity

Notes

Specific Gravity of sea water - 1.025; Persistence - level relative to other groups; level and speed of degradation of oils can vary greatly depending on many external factors including: sea state, wind velocity, sun exposure, air temperature and water temperature.

The qualitative traits of the groups are generally accurate, though there may be exceptions depending on the composition of the mixture.

*Sinking Oils are uncommon and often composed of heavy fuels or residual slurry oils (ITOPF 2011a).

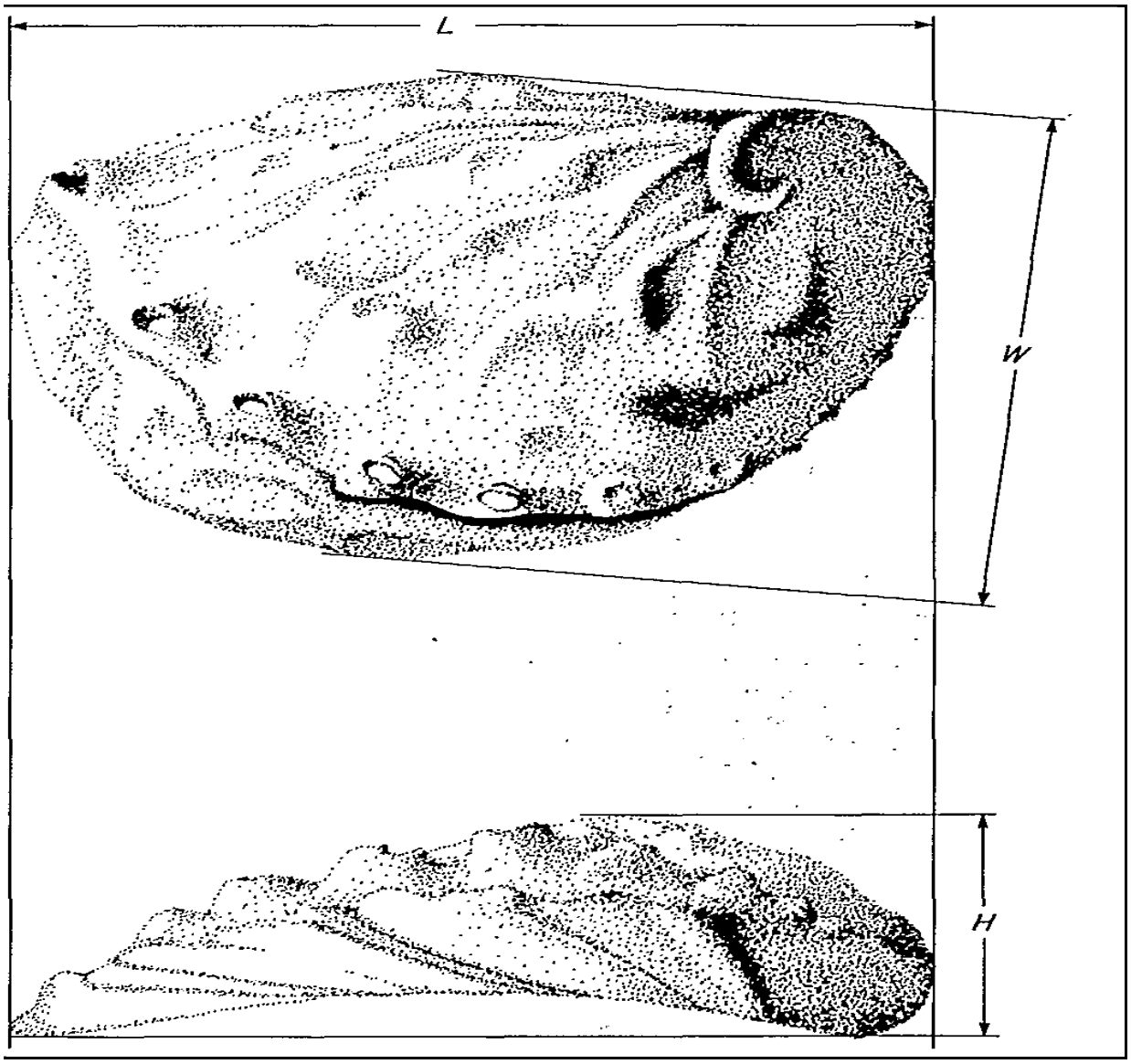

Figure 1. Standard linear measurements of height (H), length (L) and width (W) of abalone (Sloan and Breen 1988).

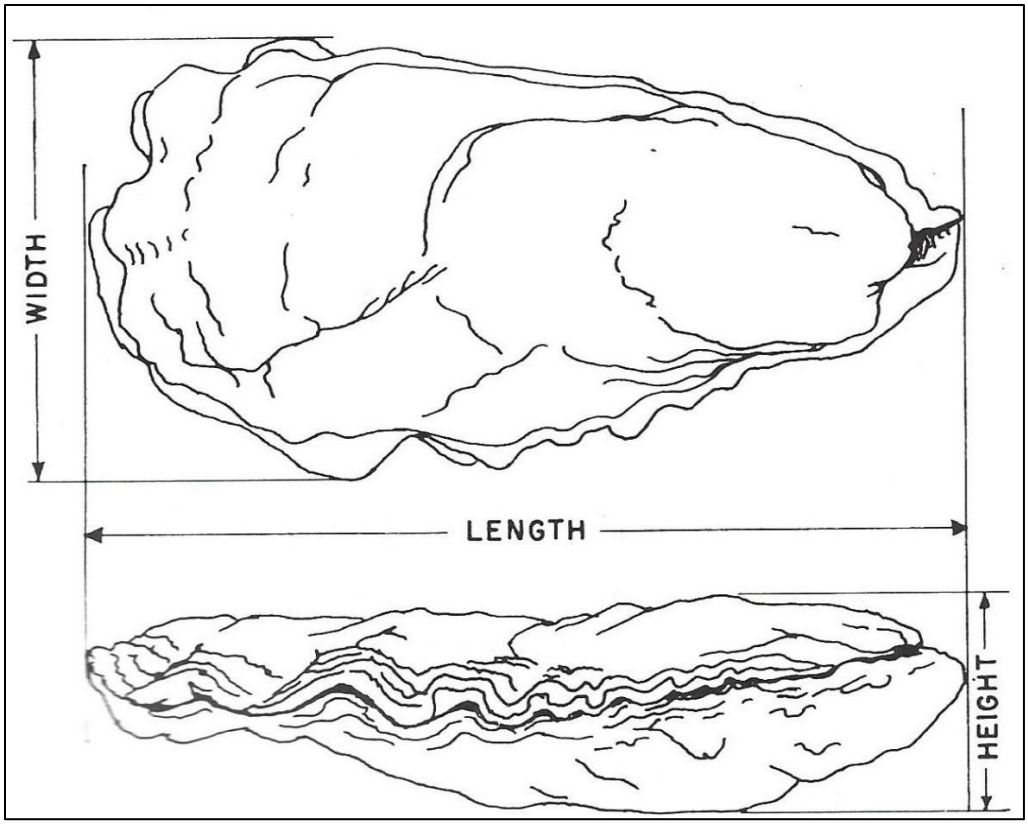

Figure 2. Standard linear measurements of height, length and width of oysters (Quayle 1969, 1988).

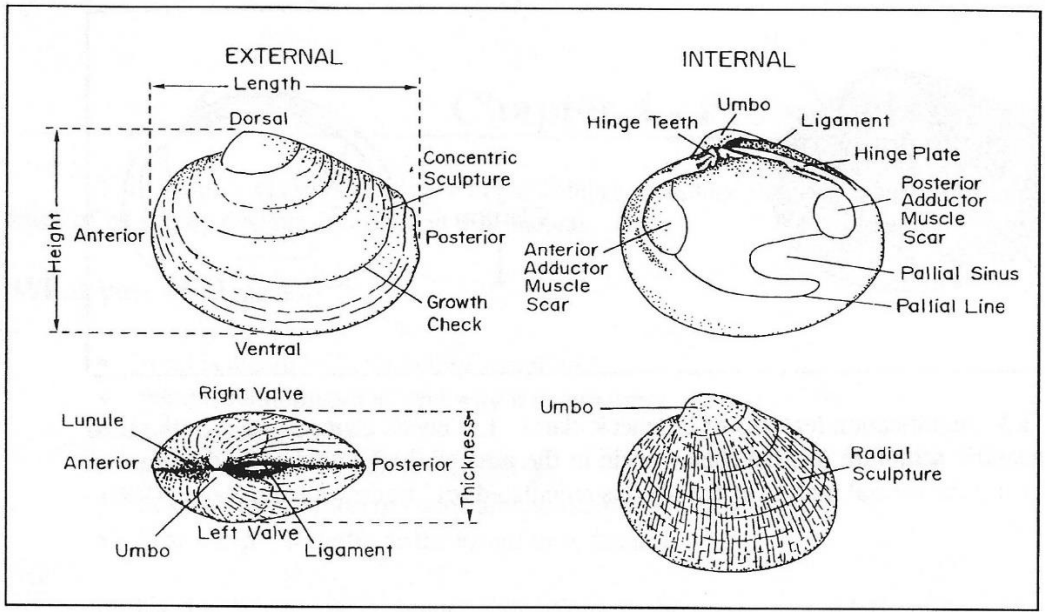

Figure 3. Anatomical features of clams and standard linear measurement of height, length and width (redrawn from Quayle and Bourne (1972)).

SPECIES SUMMARIES AND PATHWAYS OF EFFECTS

Studies on the PoE and toxicity of oils to resident mollusc species on the coast of British Columbia are limited, however inferences to the acute and chronic effects from exposure to oils and their constituents can be made from the extensive studies on surrogate bivalve molluscs from other regions of the world. Effects of oil exposure to resident species are likely to be both lethal and sublethal interfering with the bioenergetic, biosynthetic and morphogenic processes (McDowell *et al.* 1999). Impacts may include damaging feeding structures, reduced feeding and food absorption, tissue damage, inhibited reproduction, reduced carbon flux, respiration, immune and developmental effects, as well as death and damage to species population resilience (Martínez-Gómez 2010, Bejarano and Michel 2016). In the event of oil exposure, an organism may modify behaviour, alter spawning patterns or relocate in an attempt to avoid the contaminant. Oils on sediment may permeate burrows, stressing fossorial species to move to the surface, exposing them to greater contamination and predation (Pavia 1982). Sessile species and egg or larval phases cannot actively avoid oil spills. Mollusc egg and larval phases do not have the same detoxification mechanisms as adults, leaving them more vulnerable to the toxic effects of oils (Irwin 1997). The research on the molluscs' ability to metabolize or accumulate hydrocarbons is limited for most of the species discussed in this document; however, there have been studies where metabolism and accumulation have been noted (Li *et al.* 2020, Gan *et al.* 2021).

Northern Abalone (Haliotis kamtschatkana)

Significance

Northern abalone are the only species of abalone commonly present in British Columbia; they have the northernmost distribution of all species of abalone (COSEWIC 2009). There are at least seven BC records of live red abalone, *H. rufescens* Swainson, 1822 and unverified reports of flat abalone, *H. walallensis* Stearns, 1899 (Campbell *et al.* 2010, Sloan *et al.* 2010, Obradovich *et al.* 2021).

Northern abalone were traditionally harvested by First Nations and also have spiritual and cultural significance. Artisanal and commercial fisheries were initiated in the early 1900s and closed due to conservation concerns in 1990 (Bourne 1997, Harbo 1997, Obradovich *et al.* 2021). Some fisheries in adjacent jurisdictions have been closed (Washington State in 1994, Alaska in 1995 and California in 2000) but there are still illegal harvests and populations continue to decline (Lessard and Campbell 2007, Rothaus *et al.* 2008, Rogers-Bennett *et al.* 2011, Neuman *et al.* 2018).

Northern abalone were designated Threatened by COSEWIC in April 1999, status re-examined and confirmed in May 2000. The status was re-examined and designated Endangered in April 2009 (COSEWIC 2009, Obradovich *et al.* 2021). Northern abalone were legally listed as Threatened in June of 2003; the listing was changed to Endangered in 2011 (GOC 2011, Obradovich *et al.* 2021).

Vulnerability

Subgroup classification

Northern abalone were included in the following subgroups: 1 – Subtidal Benthic/Intertidal location for exposure; 2 - Sediment Epifauna substrate; 3 - Low mobility; and taxonomy to inform feeding types and reproductive strategies - Mollusca (Thornborough *et al.* 2017, Hannah *et al.* 2017, Jeffery *et al.* 2023).

Exposure

As with many epifaunal molluscs, aggregated distributions of abalone are a result of habitat preferences, physiological tolerances and ecological interactions and are beneficial for spawning synchrony and fertilization success (Hannah *et al.* 2017).

Northern abalone have limited mobility; limited dispersal is through short pelagic larval stages; adults are largely sessile and confined to the immediate area where they settled; Quayle (1971b) found that tagged abalone moved less than 50 yards (45.7 m) from their tagging site in one year. They are primarily shallow subtidal in distribution with a small portion of the population found in the deep intertidal, thus populations have a low level of interaction with the sea surface. As epifaunal organisms they have intimate contact with the consolidated sediments they inhabit.

Sensitivity

Adult abalone do not regularly interact with the water surface, although a small proportion of the population are occasionally found in the intertidal (Sloan and Breen 1988, Obradovich *et al.* 2021). During the brief pelagic larval period, phototactic larvae can approach the surface and may be exposed to petroleum by-products or dispersants and suffer developmental issues or mortality (e.g., Singer *et al.* 1990,1998, Bejarano *et al.* 2014).

Recovery

Status is actively monitored for index populations in British Columbia (Hansen *et al.* 2020, Obradovich *et al.* 2021). Abalone have low fecundity and low reproductive capacity relative to other intertidal molluscs, and significant recruitment can be sporadic. They are distributed in suitable habitat throughout British Columbia and beyond. They are dependent on hard substrate which is less affected as the pollutants that have adhered to the substrate can be removed easily.

Taxonomy

The accepted scientific name is *Haliotis kamtschatkana* Jonas, 1845 (Turgeon et al. 1998). The accepted vernacular name is northern abalone. Pinto abalone is also commonly used in California maintaining a tradition of naming abalone species based on their colour (Sloan and Breen 1988; Table 3). The name Japanese abalone (e.g., Harbo 1997) is used in error as abalone in the northwest Pacific were determined to be a distinct subspecies, *Haliotis discus hannai* Ino, 1953. Sloan and Breen (1988) reported two subspecies in the northeast Pacific: *H. k. kamtschatkana* Jonas, 1845 in the northern part of the distribution (Alaska to Point Conception) and *H. k. assimilis* Dall, 1878, locally called threaded abalone (Wolotira *et al.* 1989), in the south (central California to Baja California).

Description

The shell is large with nacreous interior. Apical whorls are low and wide, final whorl very broad and shell form is limpet-like (McLean 2007, Figure 4). A series of 3-6 oval, raised openings along left side of shell, are formed at the aperture and overgrown in later stages of growth. Sloan and Breen (1988) suggested that the first two openings function as incurrent apertures along with the shell margins, while others describe all openings as excurrent apertures. A shallow, broad channel parallel to shell edge is less obvious in BC and Alaskan populations (Sloan and Breen 1988). The outer surface is green-brown to red-brown, mottled with scattered blue and white areas. No muscle scar apparent on the inner surface, colour pearly white with iridescence of pink and green. The mantle cavity is shortened and displaced to the left side. The right shell muscle is expanded to form a large clamping foot. Maximum length reported as 90 mm (McLean 2007) to 195 mm (Harbo 1997), maximum size for British Columbia reported as 165 mm (Obradovich *et al.* 2021).

Distribution

Northern abalone range from Salisbury Sound, Alaska to Bahia Tortugas, Baja California (Sloan and Breen 1988, Neuman *et al.* 2018, Obradovich *et al.* 2021). They have the most

northern distribution of any abalone. Northern populations are found from the lower intertidal to 100 m (most found <10 m), southern populations are subtidal with most individuals found between 10-20m.

Habitat Preferences

Northern abalone prefer shallow rocky subtidal habitats with low to medium exposure, some boulders and kelp canopy (Tomascik and Holmes 2003, Lessard and Campbell 2007, Rogers-Bennett *et al.* 2011; Figure 5). They are primarily sublittoral but occasionally found in the intertidal. Northern abalone preferentially inhabited kelp (*Nereocystis luetkeana*) beds with abundant coralline algae cover and were less common in sea urchin (*Strongylocentrotus franciscanus*) barrens or kelp beds with abundant sea urchins and little coralline algae cover (Rogers-Bennet *et al.* 2011). Predation influences microhabitat utilization with abalone found more commonly in cryptic than exposed habitats in the presence of sea otters (Watson 2000, Obradovich *et al.* 2021).

Role in the Ecosystem

Trophic Ecology

Juvenile northern abalone graze on encrusting coralline algae and the epibionts found in that habitat (Sloan and Breen 1988). As they grow, grazing on attached algae becomes less important and northern abalone shift to entrapment of drift algae. Brown algae are particularly important; *Macrocystis*/*Nereocystis* were preferred, *Laminaria*/*Pterygophora* also utilized but *Agarum* was rejected. Additional foods accepted in laboratory studies included diatoms and red and green algae (Paul *et al.* 1977, Pearce *et al*. 2003).

Ecological Interactions

Northern abalone abundance is greatly reduced in areas of high abundance of red sea urchins (*Strongylocentrotus franciscanus*) (Obradovich *et al.* 2021).

Northern abalone are preyed upon by sea stars (e.g., *Pycnopodia helianthoides*), octopus (e.g., *Enteroctopus dofleini*), crabs (e.g., *Cancer productus*), fish (e.g., *Scorpaenichthys marmoratus*, *Anarrhyichthys ocellatus*) and sea otters (*Enhydra lutris*) (Sloan and Breen 1988, Watson 2000, Obradovich *et al.* 2021).

Physical Tolerances

In the laboratory, northern abalone perished when held at 0.5°C and 26.5°C but showed no signs of stress at temperatures between 2-24°C (Paul and Paul 1998). Northern abalone require high salinity water and their reduced abundance and distribution in inside waters (e.g., Strait of Georgia) may be related to reduced salinities (COSEWIC 2009, Obradovich *et al.* 2021).

Reproductive Biology

Sexes are separate, fertilization is external and fertilized eggs sink (Sloan and Breen 1988). Hatching occurs within days and early larvae are free-swimming and phototactic and rise into the water column. Larvae are planktonic for 5-6 days, thus the potential for larval distribution is limited; there may be some larval exchange between subpopulations on a small geographic scale (hundreds of meters to several kilometers; Campbell 2000).

Northern abalone spawn primarily in the spring to summer (April-July) in British Columbia although some may spawn throughout the year (Sloan and Breen 1988, Campbell *et al.* 2003) (Figure 6). Northern abalone aggregate in the highest subtidal to release gametes and have been observed to form stacked aggregations at the top of large algal stipes (Breen and Adkins 1980, Sloan and Breen 1988, Stekoll and Shirley 1993). Quayle (1971b) reported spawning in the laboratory to occur at the water surface. Shallow aggregations are more vulnerable to predation and harvest (Campbell 2000).

Quayle (1971b) estimated size at maturity at 50 mm shell length and age at ~3 years. Campbell *et al.* (2003) recorded lower size at maturity in "surf" habitats (44 mm shell length) than in more protected and productive habitats (50 mm shell length) in Barkley Sound. Obradovich *et al.* (2021; citing Quayle 1971b and Campbell et al. 1992, 2003) estimated 50% maturity at 50 mm shell length and 100% maturity at 70 mm shell length. Fecundity was estimated at 91,000 to 11.6 million eggs per female; fecundity increased with increasing size and age (Sloan and Breen 1988, Campbell *et al.* 2003, Obradovich *et al.* 2021). There may be multiple spawning events in a given year, with individuals releasing a portion of their gametes (30,000 to 2.3 million eggs) per event (Neuman *et al.* 2018, Carson and Ulrich 2019, Obradovich *et al.* 2021).

Early Life History

Settlement success and recruitment are low to sporadic and may be influenced by unfavourable environmental conditions, spawner density (Allee effect), asynchronous spawning and/or high predation rates (Campbell 2000, Obradovich *et al.* 2021).

Settled juvenile abalone are difficult to locate (Quayle 1971b, Sloan and Breen 1988). They are believed to settle deeper than adults (5-15 m) on smooth bedrock and on or under boulders. Juveniles are associated with crustose red algae rather than foliose algae; the presence of crustose coralline algae may be a cue for settlement (Obradovich *et al.* 2021). Small juveniles prefer exposed habitats but shift to cryptic habitats as they grow; adults again move to more exposed habitats (Sloan and Breen 1988). These shifts may be influenced by shifts in diet and predation pressures.

Growth Rates and Life Span

Growth is initially rapid and decreases with age (Shepherd *et al.* 2000, Obradovich *et al.* 2021). Quayle (1971b) estimated size to be ~20 mm total length (TL) in 1 year, 35 mm TL in 2 years, 50-60 mm TL in 3 years, and 90 mm TL in 6 years. Sloan and Breen (1988)

suggested that a length of 50 mm could be achieved in 2-5 years and 100 mm in 6-9 years. Growth rate and size are decreased in high wave energy environments and increased in areas of high-quality food resources (e.g., giant kelp, *Macrocystis pyrifera*, or bull kelp, *Nereocystis luetkeana*); temperature also affects growth rates (Paul and Paul 1981, Sloan and Breen 1988, Lessard and Campbell 2007, Obradovich *et al.* 2021). "Surf" abalone in high energy environments may not reach 100 mm TL (Campbell 2000).

Direct age determination of individual abalone is not common (e.g., Shepherd *et al.* 2000); estimates of maximum age are approximately 15-20 years, less in the presence of significant predators such as sea otters (Quayle 1971b, Obradovich *et al.* 2021). In laboratory settings, northern abalone have been observed to live at least 20 years (Paul and Paul 2000).

Pathways of Effects (PoE): Oil Exposure

A Pathways of Effects oil exposure model can aid oil spill emergency response by identifying low to high-risk scenarios for species exposure. This section describes PoE for northern abalone through exposure paths of specific species life stages and the potential dispersion and fates of five oil groups (Table 2). The specific environmental conditions and chemical signature of the oil spill should be taken into consideration as they may cause differences in the outcomes described in this document. A summary table for this section is available in Appendix Table 1.

Habitat utilization and temporal distribution of spawning, larval and adult presence and vulnerability ranks of northern abalone are illustrated in Figure 5 and Figure 6 with vulnerability ranking scores for northern abalone generalized for all oil groupings as 6 for the larval life stage and 7 for adult life stages (Jeffery *et al.* 2023).

Group 1 Oils

Group 1 contains gasoline and marine diesel oil. Both gasoline and MDO are light, volatile, and acutely toxic oils (ITOPF 2011a). The two oils are split into subcategories due to differences in fate and behaviour, causing different potential PoE on northern abalone.

Gasoline

Gasoline has high concentrations of LMW hydrocarbons (C4 to C12) which may cause both acute and chronic toxic effects on aquatic organisms (ITOPF 2011b). Possible toxic effects include mortality (Keesing *et al.* 2018), decreased locomotive ability and other physiological functioning (MacFarlane *et al.* 2004, Adzigbli and Yeuwen 2018).

Fresh Gasoline Oil Spill

Due to gasoline remaining on the top of the water, risk of larval exposure is low during low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion throughout the water column within the intertidal and subtidal zones. This increased dispersion increases the potential of exposure to northern abalone throughout all its life stages.

The diet of juvenile northern abalone is dominated by algae species, notably crustose coralline algae and attached bacteria (Sloan and Breen 1988). These crustose coralline algae are known to be sensitive to oil, causing bleaching in some instances (O'Brien and Dixon 1978). Impacts to this food source may cause mortalities in juvenile northern abalone.

Mature northern abalone are most commonly observed between 0-10 m depths on the sea floor or rock substrates (Sloan and Breen 1988). Spawning northern abalone move to high points in the intertidal zone such as the tops of boulders, kelp stipes, or piling on top of each other (Sloan and Breen 1988). Spawning occurs between April and July and is dependent on environmental factors such as temperature (Sloan and Breen 1988). Given the location of mature and spawning northern abalone, gasoline spills pose a high risk in the intertidal and shallow subtidal zones. Oil spills in intertidal zones have historically caused high mortality in gastropod molluscs such as northern abalone (Keesing *et al.* 2018).

Weathered Gasoline Oil Spill

Gasoline is highly volatile and can completely evaporate within 24 hours; as such, as gasoline weathers the risk to northern abalone decreases. Weathered gasoline is unlikely to pose any risks to northern abalone as it evaporates and disperses quickly, however, northern abalone exposed to spills originating in or quickly deposited in the intertidal will still lead to increased risk.

Marine Diesel Oils (MDO)

Fresh MDO Oil Spill

Fresh MDO has high aquatic toxicity due to high concentrations of LMW hydrocarbons (Environment Canada 1999). In the case of marine diesel fuel oil #2 distillate, the hydrocarbon range typically spans from C12 to C20. This distinguishes it from heavier fuel oils, which are composed of a blend of both light and heavy oil products. Fresh MDO has similar potential PoE for northern abalone as gasoline.

As with gasoline, MDOs have a potential to interact with larvae at the water surface; however, the risk of this occurring in low energy ocean conditions is low, but it is there. Whereas, medium and high energy ocean conditions can cause increased dispersion and dissolution. The increase in dispersion and dissolution can cause MDOs to spread throughout the upper water column, increasing the risk of exposure to larval northern abalone. In high energy ocean conditions, the risk of this occurring is high.

Mature northern abalone stay on the substrate generally within the shallow subtidal zone, although they are occasionally found in the intertidal, with little potential for interaction with an MDO spill at the water surface in low energy ocean conditions (COSEWIC 2009). High energy ocean conditions can cause increased dispersion and dissolution causing MDOs to spread throughout the water column, leading to the potential exposure of mature northern abalone.

Northern abalone spawn between April and July, moving to high points in the intertidal zone to release their gametes (Sloan and Breen 1988). Moving for spawning leaves

northern abalone vulnerable to oil spills within the intertidal zone, even where oil remains on the water surface. Possible effects may include coating, smothering, ingestion, and habitat modification, which may inhibit spawning. Intertidal zone oil spills have historically caused high mortalities in molluscs (Keesing *et al*. 2018).

Weathered MDO Oil Spill

As MDOs weather, aquatic toxicity decreases as the light molecular weight hydrocarbons evaporate. MDO's can evaporate between 10% and 40% within 48 hours, and up to 50% after five days dependent on the amounts of light molecular weight hydrocarbons (Environment Canada 1999) and environmental conditions, since evaporation may be reduced in colder climates. MDO still poses potential risks to northern abalone through coating, smothering and ingestion (ITOPF 2011b). The persistence of MDO causes it to pose many of the same potential effects on northern abalone after weathering. Northern abalone larvae still have the potential to interact with the oil spill on the surface of the water with potential effects including coating and smothering, likely without acute toxic effects. However, the risk of this potential interaction remains low.

MDO is persistent and possesses the capability to interact and adhere to drifting particles including sediments, phytoplankton, snow, and/or microplastics especially in the environment with higher energy ocean conditions (ITOPF 2011a). As mature northern abalone mainly feed on these drift particles (Sloan and Breen 1988), there is the potential for ingestion of MDO. The risk of this occurring is moderate. Ingestion of MDOs in gastropods can lead to mortality and effects such as impaired physiological function, including damage to feeding apparatuses (Adzigbli and Yeuwen 2018).

Given the persistence of MDO, weathered MDOs still pose a risk to spawning northern abalone. Effects include coating, smothering, and habitat modification. Intertidal zone oils spills can cause high mortality in molluscs (Keesing *et al.* 2018).

Group 2 Oils

Light Crude Oils (LCOs)

Group 2 oils are LCOs containing moderate to high concentrations of aromatic hydrocarbons and can cause acute and chronic toxic effects in aquatic organisms (Adzigbli and Yeuwen 2018). LCOs can cause additional negative effects through coating and smothering aquatic organisms (Tarr *et al.* 2016). There are similar PoE between Group 2 and Group 1 oils (Appendix Table 1).

Fresh LCO Oil Spill

As with Group 1 oils, LCOs have potential impacts on larval and juvenile northern abalone, either directly or indirectly. LCOs have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring in low energy ocean conditions. High energy ocean conditions can increase dispersion and dissolution causing a higher risk due

to increased likelihood of larval exposure at depth. LCO spills have the potential to cause algal bleaching which would eliminate or reduce the abundance of food sources for juvenile northern abalone (O'Brien and Dixon 1978).

Fresh LCO spills have little to no potential to directly impact mature subtidal northern abalone. Mature northern abalone reside on the substrate in the shallow subtidal zone, with little potential for interaction with an oil spill at the water's surface in low energy ocean conditions. High energy ocean conditions may cause increased dispersion and dissolution; however, if these ocean conditions do cause oil to reach the substrate, Group 2 oils are unlikely to become incorporated into the hard substrates that northern abalone inhabit (Keesing *et al.* 2018). High energy ocean conditions could cause increased dissolution through the water column, contaminating drift algae and causing ingestion in mature northern abalone. There is a higher risk of LCO spills interacting directly with mature northern abalone in the intertidal zone, especially during low tides.

Spawning northern abalone move to high points in the intertidal to release their gametes between April and July, depending on environmental conditions (Sloan and Breen 1988). As with MDO, spawning northern abalone are therefore vulnerable to LCO spills. The risk of exposure during spawning is high as the spawning northern abalone could be fully exposed as the tide recedes.

Weathered LCO Oil Spill

As LCOs weather, their acute toxicity decreases as the light molecular weight aromatic hydrocarbons evaporate. The majority of evaporation, dispersion and spreading are likely to occur within the initial few days of an oil spill – the number of days will depend on ambient abiotic conditions – with additional weathering processes such as emulsification, photo-oxidation, and sedimentation occurring for months or years (ITOPF 2011a). Light crude oils persist and can form stable emulsions, leading to increased volume and specific gravity of the spill (ITOPF 2011a). The PoE for weathered LCOs are the same as those of fresh LCOs for larval, juvenile, and spawning northern abalone; however, the risk of these effects is decreased as many toxic hydrocarbons evaporate as weathering occurs (Wang and Fingas 1995). Acute toxicity becomes less of a concern as weathering occurs, decreasing the risk of effects to northern abalone.

Light crude oils persist as they weather (ITOPF 2011a). High energy ocean conditions can cause the potential interaction with drift particles throughout the water column potentially adsorbing to drift algae, a common food source for mature northern abalone (Sloan and Breen 1988). The interaction between light crude oils and drift algae leads to the potential for ingestion, causing toxic and potentially fatal effects (MacFarlane *et al.* 2004, Adzigbli and Yuewen 2018). Under high energy ocean conditions there is a moderate risk of this occurring.

Group 3 Oils

Heavy and Persistent Oils

Group 3 contains engine/hydraulic oil, medium crude oil, heavy crude oil, and dilbit oil. Group 3 oils are heavy and persistent, while not being as toxic as Group 1 and 2 oils (ITOPF 2011a, 2011b). There are many similar PoE between Group 3 and Group 1 oils (Appendix Table 1).

Fresh Heavy and Persistent Oil Spill

As with Group 1 oils, Group 3 oils have potential to interact with larval and juvenile northern abalone, either directly of indirectly. Group 3 oils can impact larval northern abalone at the water surface; however, there is low risk of this occurring in low energy ocean conditions. As with previous oil groups, high energy ocean conditions can cause increased dispersion and dissolution causing the potential for interaction with larval northern abalone throughout the water column. Group 3 oils have the potential to cause bleaching in coralline algae (O'Brien and Dixon 1978), decreasing juvenile northern abalone's food sources.

Fresh Group 3 oil spills have very low potential to impact mature subtidal northern abalone under low energy conditions. Mature northern abalone stay on the substrate in the shallow subtidal zone (Lessard 2009), with little potential for interaction with an oil spill at the water's surface. High energy ocean conditions can cause oil to be dispersed throughout the water column causing potential exposure to mature subtidal northern abalone; however, the exposure would be brief as oils have low residency times on the hard substrates northern abalone inhabit (Keesing *et al.* 2018). Therefore, the risk of this effect is low. There is a moderate risk of mature northern abalone within the intertidal zone being exposed to fresh Group 3 oil spills.

Northern abalone spawn between April and July, dependent on environmental conditions, and move to high points in the intertidal to release their gametes (Sloan and Breen 1988). As with previously discussed oils, Group 3 oil spills in the intertidal zone may coat and smother spawning northern abalone.

Weathered Heavy and Persistent Oil Spill

As Group 3 oils weather, evaporation may occurs depending on the type of oil, but it is likely to be low. Group 3 oils can sink depending on ocean conditions (ITOPF 2011a). As with Group 2 oils, the majority of evaporation, dissolution and dispersion will occur within the first ten days of a spill, with additional weathering effects such as photo-oxidation, sedimentation and emulsification occurring for months to years. Heavy oils are predicted to sink when there is low surface salinity; however, this only occurs in areas such as river mouths or fjords and not in areas that northern abalone inhabit (Johannessen *et al.* 2020). Due to the persistence of Group 3 oils, the PoE and risks of effects remain the same for larval, juvenile, and spawning northern abalone (Appendix Table 1).

There is little potential for direct interaction with mature subtidal northern abalone as sinking is unlikely to occur in areas that northern abalone inhabit (Johannessen *et al.* 2020). As with fresh Group 3 oil spills there is potential for interaction with drift algae in high energy ocean conditions causing ingestion by mature northern abalone. There is also a moderate to high risk of direct interaction with mature northern abalone in the intertidal zone during low tides.

Group 4 Oils

Bunker C Oils

Group 4 oils are Bunker C oils. Bunker C oils are heavy and highly persistent oils (Environment Canada 1999). Bunker C oils contain few toxic light molecular weight hydrocarbons meaning they will likely have little to no acute toxic effects on aquatic organisms depending on the specific type of oil. Bunker C oils still pose risk through coating and smothering as well as chronic effects due to heavier toxic hydrocarbons (Adzigbli and Yuewen 2018).

Fresh Bunker C Oil Spill

As with Group 1 oils, Bunker C oils have a potential to interact with larval and juvenile northern abalone, directly or indirectly. Bunker C oils could interact with larvae at the water surface; however, there is a low risk of this occurring. As with previous oil groups, high energy ocean conditions can cause increased dispersion and dissolution causing the potential for interaction with larval northern abalone throughout the water column. Negative effects that this interaction may have differ from previous oils given lower concentrations of LMW hydrocarbons, causing less acute toxic effects. Crustose coralline algae could be contaminated by Bunker C oil spills, especially in intertidal zones, decreasing the available food for juvenile northern abalone and potentially through ingestion. Ingestion of oils can cause decreased physiological function and mortality (MacFarlane *et al.* 2004, Adzigbli and Yuewen 2018).

The risk of a fresh Bunker C oil spill to cause harm to mature subtidal northern abalone is low. Mature northern abalone stay on the substrate within the shallow subtidal zone, with little potential for interaction with an oil spill at the water's surface. There is a high risk of Bunker C oil spills interacting and causing harm to mature northern abalone in the intertidal zone through coating and smothering (Adzigbli and Yuewen 2018).

Northern abalone spawn between April and July, dependent on environmental conditions, and move to high points in the intertidal to release their gametes (Sloan and Breen 1988). Bunker C oil spills in the intertidal zone have potential to cause high northern abalone mortalities during the spawning season, through coating and smothering (Adzigbli and Yuewen 2018).

Weathered Bunker C Oil Spill

There are few weathering effects on Bunker C oil given a low concentration of volatile LMW hydrocarbons and high persistence (ITOPF 2011a). Evaporation of volatile hydrocarbons will occur within the first hours of a spill (NOAA 2019). The PoE are similar between weathered and fresh Bunker C oils; however, Bunker C oils are susceptible to creation of stable emulsions, causing increased volume and specific gravity and potential for sinking and sedimentation-caused sinking. However, this is only likely to occur in areas with high amounts of sediments such as beaches (ITOPF 2011a, NOAA 2019). PoE and vulnerability effects that weathered Bunker C oil may have on northern abalone are similar between fresh and weathered oils.

Should sinking occur through emulsion or sedimentation, mature subtidal northern abalone are at risk of oil exposure. Sinking oils could coat and smother northern abalone on substrates in the shallow subtidal zone causing locomotion and feeding issues or potentially mortality (Adzigbli and Yuewen 2018). The Nestucca oil spill of 1988 provides an example of conditions that can cause sinking of Bunker C oils (ESL Environmental Sciences Limited 1989). Rough seas caused Bunker C oils to interact with and chemically adsorb to suspended organic and inorganic materials in the water column causing increased specific gravity and sinking once conditions calmed. This occurred in surf and nearshore zones where there were high concentrations of suspended sediments.

Group 5 Oils

Sinking Oils

Group 5 oils are extremely heavy and persistent oils known as sinking oils. Sinking oils have a specific gravity >1, causing them to readily sink in water (ITOPF 2011a). Due to high specific gravity, sinking oils have a high potential to negatively impact northern abalone at all life stages.

Fresh Sinking Oil Spill

Sinking oils have a high risk of interacting with northern abalone larvae given the potential of oil being present throughout the water column or interacting with larvae while sinking. Sinking oils have a high risk of contaminating crustose coralline algae, causing a decrease in available food for juvenile northern abalone, along with increased potential for ingestion.

Sinking oils have a high risk of oil interacting with drift particles and being ingested by mature northern abalone. Ingestion of oils can cause physiological issues along with potential mortality in molluscs (MacFarlane *et al.* 2004, Adzigbli and Yuewen 2018). Sinking oils may also smother mature northern abalone causing mortality in both the subtidal and intertidal zones.

Northern abalone spawn between April and July, dependent on environmental conditions, and move to high intertidal areas to release gametes (Sloan and Breen 1988). Sinking oil spills in the intertidal zone have a high risk of interacting with spawning northern abalone through coating and smothering, potentially causing mortality (Adzigbli and Yuewen 2018).

Weathered Sinking Oil Spill

Sinking oils have little to no weathering effects; therefore, the PoE on northern abalone are the same for fresh and weathered sinking oils.

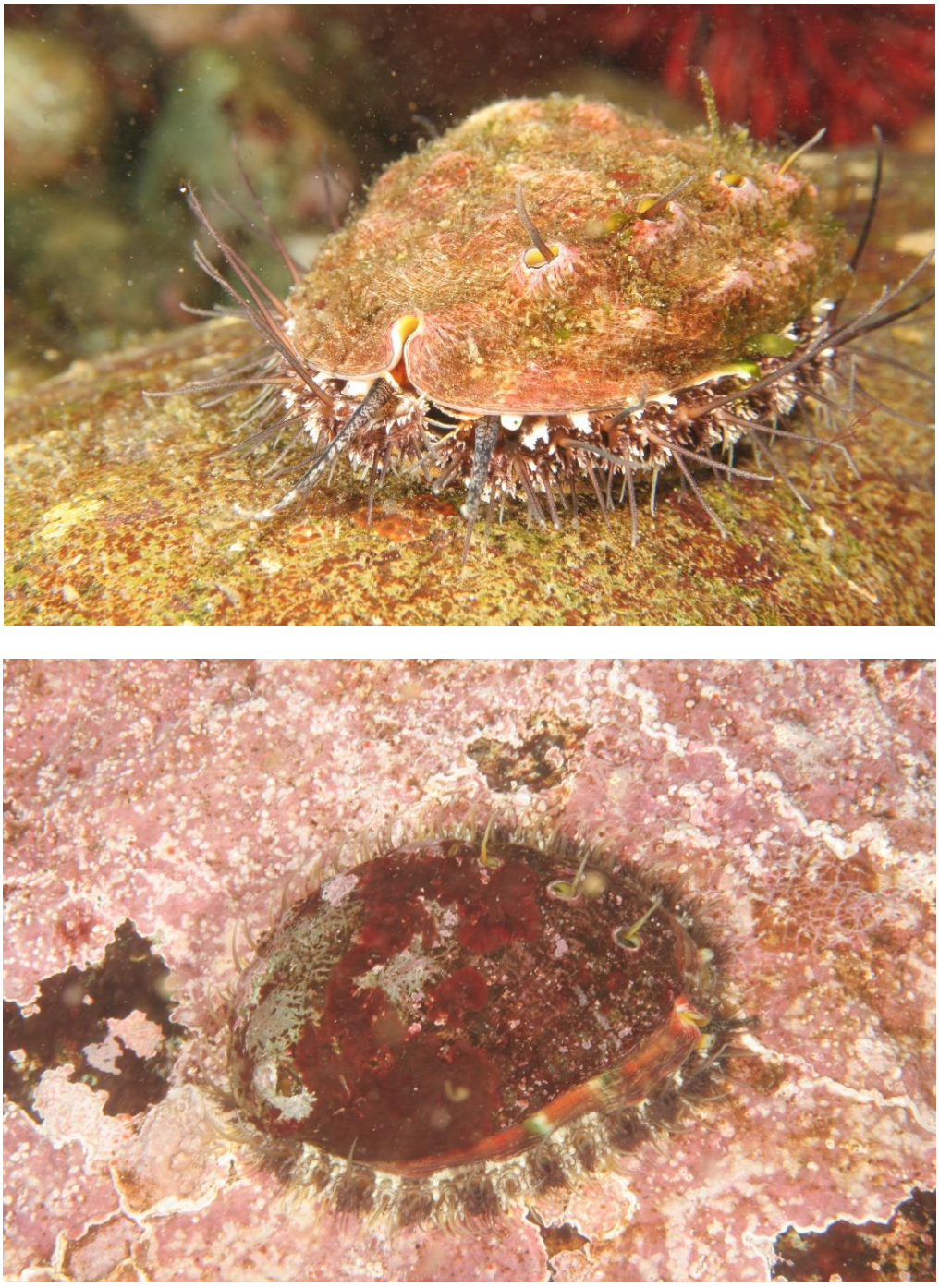

Figure 4. Northern abalone, *Haliots kamtschatkana*.

Images © Dominique Bureau

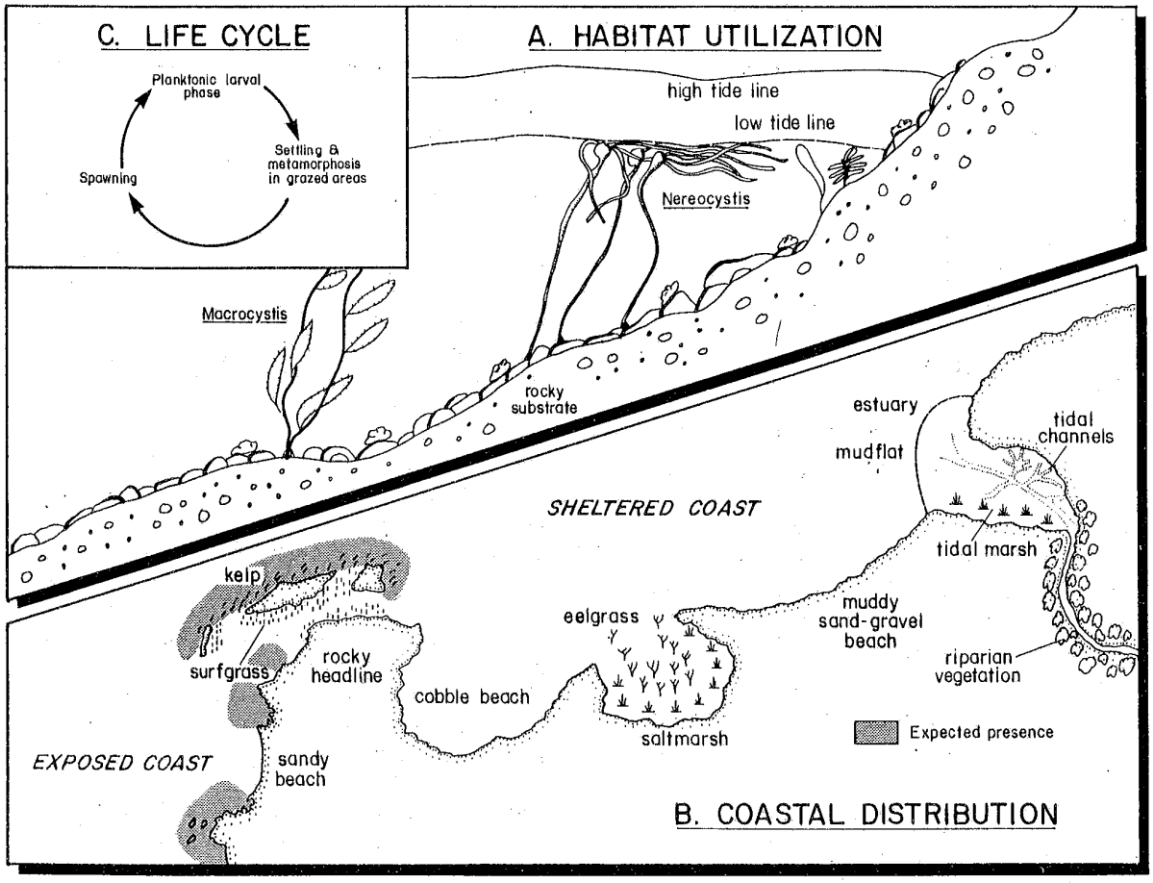

Figure 5. Habitat utilization (A), coastal distribution (B, gray polygons indicate expected presence) and life cycle (C) of northern abalone, *Haliotis kamschatkana* (Williams 1989).

J	F	M	A	M	J	J	A	S	O	N	D
1	1	1	3	3	3	3	1	1	1	1	1
			---Spawning---								
1	1	1	3	3	3	3	1	1	1	1	1
			---Larval Presence---								
2	2	2	3	3	3	3	2	2	2	2	2
---Adult Presence---											

Figure 6. Temporal distribution of spawning, larval and adult presence and vulnerability ranks of northern abalone, *Haliotis kamschatkana*.

Legend: 1 (green) = low/negligible vulnerability; 2 (yellow) = moderate vulnerability; 3 (red) = high vulnerability.

Table 3. Summary of information required to inform marine emergency response for northern abalone, *Haliotis kamtchatkana*.

Taxonomy
Scientific Name:
Haliotis kamtschatkana Jonas, 1845

Common Name(s):
Northern abalone, Japanese abalone, pinto abalone, threaded abalone

Higher Taxonomy:
Mollusca; Gastropoda; Lepitellida; Haliotidae

Description

Apical whorls low and wide, final whorl very broad, Shell form limpet-like, apical whorls low and wide, final whorl very broad. Series of 3-6 oval, raised openings along left side of shell. Shallow, broad channel parallel to shell edge. Outer surface green-brown to red-brown, mottled with scattered blue and white areas. No muscle scar on nacreous inner surface, colour pearly white with iridescence of pink and green. Mantle cavity shortened and displaced to the left side. Right shell muscle expanded to form a large clamping foot. Maximum size at least 195 mm TL, 165 mm TL for British Columbia.

Distribution

Salisbury Sound, Alaska to Bahia Tortugas, Baja California. Northern populations from lower intertidal to 100 m (most found <10 m), southern populations subtidal with most between 10-20m.

Habitat Preferences

Shallow rocky subtidal with low-medium exposure, boulders and kelp canopy. Primarily sublittoral but occasionally intertidal. Preferentially inhabited kelp beds with coralline algae cover, less common in sea urchin barrens or kelp beds with abundant sea urchins and little coralline algae cover. More cryptic in presence of sea otters.

Physical Tolerances

Salinity
Require high salinity water, reduced abundance and distribution in inside waters may be related to reduced salinities.

Temperature

Adults perished when held at 0.5°C and 26.5°C but showed no signs of stress at temperatures between 2-24°C.

Table 3. continued.

Reproductive Biology Sexes separate, fertilization external and fertilized eggs sink. Hatching occurs within days, early larvae free-swimming and phototactic and rise into the water column. Larvae planktonic for 5-6 days, potential for larval distribution is limited. May be some larval exchange between subpopulations on a small geographic scale (hundreds of meters to several kilometers). Spawn primarily in summer (April-July) in British Columbia, some may spawn throughout the year. Aggregate in highest subtidal to release gametes, have been observed to form stacked aggregations at the top of large algal stipes. Spawning in the laboratory reported to occur at the water surface. Shallow aggregations are more vulnerable to predation and harvest. Estimated size at maturity 50 mm TL, age at ~3 years. Lower size at maturity in "surf" habitats (44 mm shell length). Estimated 50% maturity at 50 mm TL, 100% maturity at 70 mm TL. Fecundity estimated at 91,000 to 11.6 million eggs per female, increased with increasing size and age. May be multiple spawning events in a given year, with individual abalone releasing only a portion of their gametes (30,000 to 2.3 million eggs) per event.
Growth Rate and Lifespan Growth initially rapid, decreases with age. Estimated growth ~20 mm TL in 1 year, 35 mm TL in 2 years, 50-60 mm TL in 3 years, and 90 mm TL in 6 years. Growth rate and size decreased in high wave energy environments, increased in areas of high-quality food resources. Temperature also affects growth rates. "Surf" abalone may not reach 100 mm TL. Direct age determination of individual abalone is not common. Estimated maximum age approximately 15-20 years, less in the presence of significant predators such as sea otters.
Migratory Behaviour Dispersal between subpopulations is through the short pelagic larval stage, perhaps on the scale of hundreds of meters to a few kilometers. Adults are essentially sessile but form local aggregations for spawning.
Role in the Ecosystem Juvenile abalone graze on encrusting coralline algae and other epibionts, adults shift to entrapment of drift algae. Brown algae are preferred. Northern abalone are preyed on by sea stars, octopus, crabs, fish and sea otters. Abalone abundance is reduced in urchin barrens.

Table 3. continued.

Significance Traditionally harvested by First Nations, have spiritual and cultural significance. Artisanal and commercial fisheries closed due to conservation concerns in 1990. Designated Threatened by COSEWIC in April 1999, status confirmed May 2000. Designated Endangered in April 2009. Listed under SARA as Threatened in June of 2003, changed to Endangered in 2010.
Vulnerability **Subgroup Classification**: Subtidal Benthic/Intertidal; Rock and Rubble Dwellers; Low Mobility; Mollusca. **Adult Exposure Criteria**: Aggregate in shallow water for spawning; Low Mobility; Primarily subtidal (limited interaction with sea surface); Epifaunal (high interaction with sea floor). Score: 4. **Adult Sensitivity Criteria**: Adults graze epifaunal and drift algae, feeding appendages that can become clogged by oil; Chemical sensitivity assumed to be high. Score: 2. **Adult Recovery Criteria**: Endangered (COSEWIC and SARA listed); Relatively low reproductive capacity; Broadly distributed in suitable habitats; Low degree of interaction with unconsolidated substrates. Score: 1. Adult Cumulative Total Score: 7. **Larval Exposure Criteria**: Aggregate or Patchiness where large number of larvae affected; Low Mobility; Interaction with sea surface. Score: 3. **Larval Sensitivity Criteria**: Larvae lecithotrophic, later phase larval stage feeding appendages that can become clogged by oil; Chemical sensitivity assumed to be high. Score: 2. **Larval Recovery Criteria**: Endangered (COSEWIC and SARA listed); Relatively low reproductive capacity; Broadly distributed in suitable habitats; Low degree of interaction with unconsolidated substrates. Score: 1. Larval Cumulative Total Score: 6.

Olympia Oyster (Ostrea lurida)

Significance

Olympia oysters (*Ostrea lurida*, formerly, *Ostrea conchaphila*), were designated as a species of Special Concern by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2000 and 2010 and listed under the Species at Risk Act (SARA) in 2003 (DFO 2009, COSEWIC 2011).

Vulnerability

Subgroup classification

Olympia oysters were included in the following subgroups: 1 - Intertidal/Subtidal Benthic location for exposure; 2 - Rock and Rubble Dwellers substrate; 3 - Sessile; and taxonomy to inform feeding types and reproductive strategies - Mollusca (Thornborough *et al.* 2017, Hannah *et al.* 2017, Jeffery *et al.* 2023).

Exposure

As with many epifaunal bivalve molluscs, aggregated distributions of Olympia oysters are a result of habitat preferences, physiological tolerances and are beneficial for spawning synchrony and fertilization success (Hannah *et al.* 2017).

Olympia oysters have low mobility; dispersal is through relatively short pelagic larval stages, adults are sessile, either attached to hard substrate or loose on the substrate surface (COSEWIC 2011). They are primarily intertidal in distribution; thus, their populations have a high level of interaction with the sea surface. As epifaunal organisms, they have intimate contact with the consolidated and unconsolidated sediments they inhabit.

Sensitivity

As filter/suspension feeders, Olympia oysters are very sensitive to pollutants that may clog or damage their feeding apparatus. Chemical effects of pollutants on bivalve physiology, reproduction and larval survival have been documented (COSEWIC 2011).

Recovery

Population status is monitored at index locations in British Columbia (Stanton *et al.* 2011, Finney *et al.* 2012, Norgard *et al.* 2018, Herder *et al*. 2022). Olympia oysters have moderate fecundity and reproductive capacity but inconsistent recruitment. They are distributed as patchy aggregations in suitable habitat in southern British Columbia (Strait of Georgia, west coast of Vancouver Island and mainland inlets). They are dependent on hard substrates for settlement but also occur on gravel substrates, which can be affected for extended periods due to difficulties removing pollutants that have seeped into the substrate (COSEWIC 2011).

Taxonomy

Until recently, the Olympia oyster was included in the species *Ostrea conchaphila* (Carpenter 1857). Harry (1985) synonymized *lurida* with *Ostreola conchaphila* (Carpenter 1857). Coan *et al.* (1997) felt that *Ostreola* was not sufficiently different from *Ostrea* to warrant separating the two genera and Turgeon *et al.* (1998) supported this arrangement. Polson *et al.* (2009) provided molecular evidence for separating *lurida* from *conchaphila*. Phenotypic plasticity, varied habitats where specimens were collected, and the taxonomic tendencies of early naturalists have led to a moderate list of synonyms (Coan *et al.* 2000).

The various English common names reflect either preferred habitats (e.g., rock oyster, shell-loving oyster), geographic locations (e.g., Olympia oyster, California oyster, Yaquina oyster, Shoalwater oyster (Shoalwater Bay was an early name for Willapa Bay, Washington), etc.), or distinguish *O. lurida* from introduced species (e.g., native oyster)(Table 4). The French common name for the species is huître plate du Pacifique. The name officially recognized by the American Fisheries Society is Olympia oyster (Turgeon *et al.* 1998). The term "native oyster" is commonly used to refer to *O. lurida* in areas other than Puget Sound (Gillespie 2009).

Description

Olympia oysters are small, irregularly-shaped oysters, tending to be more or less elliptical or circular (Gillespie 2009)(Figure 7). The valves are thin, not chalky as in *Crassostrea*, are unequal, with the lower (left) valve shallowly cupped and the upper (right) valve generally flat, fitting into the raised margin of the left valve. The lower valve is often attached to a hard substrate, but individuals may be found lying freely on soft substrate as singles or clusters. Free-living individuals often exhibit small scars on the left valve indicating the original point of attachment. The outer surface of the valves may be gray, gray blotched with purple, white, brown, yellow or purplish black; the inner surface grades from white to iridescent green to dark purple. The adductor muscle scar is not much different in color from the rest of the inner surface, unlike the darker scars present in Atlantic or Pacific oysters. The triangular ligament is internal. The shells exhibit a series of 2-12 pits in the lower valve on either side of the hinge, with associated denticles in the upper valve (described as ostreine chomata by Harry (1985)). Both left and right pryomyal chambers are closed (as opposed to *Magallana* (= *Crassostrea*), in which the right pryomyal chamber is open). Juveniles may have a thin yellow periostracum, which is lacking in adults. After settlement, oysters lack a foot typical of clams and byssus typical of mussels (Harry 1985, Quayle 1988, Couch and Hassler 1989, Baker 1995, Kozloff 1996, Harbo 1997).

Maximum size is approximately 90 mm diameter (Harbo 1997), but individuals in British Columbia generally are 60 mm in diameter or less (Gillespie 2009, Norgard *et al.* 2018), and other populations (Puget Sound, WA, Humbolt and San Francisco Bays, CA) are generally of a smaller size (Baker 1995). Newly settled oyster spat are difficult to identify to species, often leading to uncertainty whether they are Pacific or Olympia oysters (e.g., Norgard *et al.* 2018).

Distribution

Olympia oysters are found only on the west coast of North America from Sitka, Alaska (approximately 57°N) to Baja California (approximately 30°N) (Polson and Zacherl 2009). The northern limit, based on a record by Dall (1914), is suspect; reports from Southeast Alaska do not describe dense aggregations or document specific locations and their occurrence there has not been substantiated despite investigation (Foster 1991, Polson and Zacherl 2009). The currently documented northern limit is in the Bardswell Group on the Central Coast near Bella Bella (approximately 52°N) (Gillespie 2009, COSEWIC 2011). Large populations of Olympia oysters still occur in some habitats in the lower western United States (Baker 1995, Robinson 1997, Shaw 1997). Although generally distributed between these latitudes, specific habitat requirements limit abundant populations to few locations (Galtsoff 1929).

In British Columbia, Olympia oysters have been found on the west coast of Vancouver Island, Straits of Georgia and Juan de Fuca, and the Central Coast (Figure 8)(Gillespie 2009, COSEWIC 2011). Recent surveys indicated continued presence of Olympia oyster populations on the west coast of Vancouver Island and Straits of Georgia and Juan de Fuca and in the Central Coast; none were found on Haida Gwaii (Sloan *et al.* 2001, Gillespie and Bourne 2005a,b; Stanton *et al.* 2011, Finney *et al.* 2012, Norgard *et al.* 2018, Herder *et al*. 2022).

Habitat Preferences

Olympia oysters are primarily found in the lower intertidal and subtidal zones of estuaries and saltwater lagoons but are also found on mud-gravel tidal flats, in splash pools, near freshwater seepage, in tidal channels, bays, and sounds or attached to pilings or the underside of floats (Quayle 1988, Couch and Hassler 1989, Harbo 1997, Gillespie and Bourne 2005b, Figure 9). On the outer coast, they are found only in protected locations. They have been reported as common from the intertidal zone to 10 m, and occasionally to 50 m (Bernard 1983, Coan *et al.* 2000).

Role in the Ecosystem

Trophic Ecology

Olympia oysters are filter feeders with adults relying on suspended organic material and planktonic organisms. Diatoms and dinoflagellates are preferred food items, and other food types include detritus from disintegrating marine plant and animal matter, bacteria, minute flagellates, other protozoa, and gametes of marine algae or invertebrates (Barrett 1963).

Ecological Interactions

Olympia oysters are preyed upon by crabs, gastropods, sea stars and birds. Red rock (*Cancer productus*), Dungeness (*Metacarcinus magister*) and slender crabs (*M. gracilis*) had some minor predatory effects on oysters in British Columbia (Quayle 1988). All three

species were capable of preying on adult Olympia oysters, and the shore crab (*Hemigrapsus oregonensis*) was thought to prey on juveniles. Red rock crabs were specifically mentioned as oyster predators in Oregon (Robinson 1997) and California (Barrett 1963) and European green crabs (*Carcinus maenas*) prey on Olympia oysters (Palacios and Ferraro 2003).

Ochre (*Pisaster ochraceus*), pink (*Pisaster brevispinus*), mottled (*Evasterias troschelii*) and sun stars (*Pycnopodia helianthoides*) were specifically identified as oyster predators (Quayle 1988). Sea stars are not major predators in the upper intertidal zone due to their limited tolerance of desiccation, and they were generally deterred by the lower salinity in oyster dikes (Sherwood 1931).

Predatory gastropods can cause significant mortality in oysters. Elsey (1934) documented predation by the Atlantic or eastern oyster drill, *Urosalpinx cinerea*, which was introduced to Boundary Bay and Ladysmith Harbour with Atlantic oysters (Carl and Guiguet 1957, Quayle 1964) but has since disappeared from these sites (Gillespie 2007). Another introduced oyster drill, *Ocinebrellus* (= *Ceratostoma*) *inornatum*, from Japan is a serious predator of Olympia oysters (Hopkins 1937, Chapman and Banner 1949). This species is present in British Columbia, though their distribution is relatively limited, and dispersal is nearly negligible because of the lack of a pelagic larval stage and patchiness of available habitat (Carl and Guiguet 1957, Quayle 1964, 1988). Early spread of these oyster drill species was also curtailed by regulations prohibiting movement of oysters from areas suffering drill predation to drill-free areas. The native frilled dogwinkle, *Nucella lamellosa*, was observed to prey on both adult Olympia oysters and spat but tended to prefer mussels to oysters (Hopkins 1937). Lewis' moon snail, *Euspira lewisii*, does occasionally prey on adult Olympia oysters, but is not able to penetrate dense oyster beds due to its large soft body and semi-burrowing locomotion (Baker 1995).

White-winged scoters (*Melanitta fusca*), black scoters (*M. nigra*) and greater scaup (*Aythya marila*) have been identified as predators of Olympia oysters (Baker 1995).

Olympia oysters are host to juvenile pinnotherid pea crabs (*Pinnixa littoralis*) (Hart 1982). They are also parasitized by the introduced copepod *Mytilicola orientalis* (Bernard 1969).

Physical Tolerances

Olympia oysters require an ambient water temperature of at least 12.5°C to reproduce (Hopkins 1937), but reproduction occurs more commonly at temperatures of 14-16°C (Strathman 1987). Temperature is a critical element in the timing of reproductive phases; periods of low temperature can interrupt the alteration of sexes, which resumes when temperatures increase (Baker 1995).

Larval development is temperature dependent; Loosanof and Davis (1963) reported spatting after seven days at 24°C, 10-11 days at 21.5°C and 16 days at 18°C. Hopkins (1937) believed that approximately 30-40 days were required from swarming to spatting for Olympia oysters in Puget Sound.

Olympia oysters cannot withstand freezing. Significant mortalities have been attributed to unusually cold weather, including the final depletion to commercially insignificant levels

of oyster populations in Ladysmith Harbour in 1929 and Boundary Bay in approximately 1940 (Quayle 1969). Edmondson (1923) attributed an increase in the price for Yaquina Bay (= Olympia) oysters in 1917 to increased market demand due to decreased production after "partial destruction of the beds of the Puget Sound region by freezing during a previous season (1915)". High summer temperatures can also cause considerable mortality in young-of-the-year oysters. Adults can tolerate 30°C for a few hours (Hopkins 1937).

The vulnerability of Olympia oysters to freezing or high summer temperatures likely explains the limitation of large populations to low tidal levels, lagoons, or other habitats with standing water which serves to insulate the oysters from temperature extremes. Physiological temperature requirements for gonadal development and successful spatting likely explain why there are few large populations of Olympia oysters reported from northern British Columbia.

Olympia oysters are moderately euryhaline with good survival at 15‰ for 49 days, although large populations in Puget Sound are limited to areas with 23-24‰ average in winter months (Baker 1995).

Reproductive Biology

Olympia oysters are larviparous, protandrous, alternating hermaphrodites. They mature first as males and then undergo alternation of sexes between male and female throughout their life (Coe 1932b). During the male phase, hundreds of thousands of sperm balls are released, each containing approximately 2,000 sperm (Coe 1931). Self-fertilization does not occur, partly because sperm is released in packages that require exposure to seawater to dissociate into active spermatozoa (Strathman 1987) and because individuals alternate sexes and cannot be simultaneously mature as both male and female.

There are four major events in the reproductive cycle: gonadal development, spawning, swarming and spatting. Gonadal development commences or continues with increased water temperatures in the spring and summer. Male spawning involves release of sperm balls into the mantle cavity, and their subsequent expulsion through pumping contractions of the shell. Upon contact with seawater, the sperm balls disintegrate, releasing spermatozoa. Female spawning occurs when eggs are extruded into the mantle cavity and fertilized by sperm which have been brought into the mantle cavity in the respiratory current. After approximately two weeks of development in the parental mantle cavity, pelagic larvae are released into the water column, an event called swarming. Once the larvae have grown and are sufficiently developed, they settle and attach themselves to a hard substrate. This process is called spatting, and the newly settled oysters are referred to as spat.

Spawning season varies latitudinally, with spatfall occurring from April to October or November in California (Coe 1932a), mid-June to late July in Puget Sound (Hopkins 1937), and July through September in BC (Stafford 1915, Elsey 1933)(Figure 10). Olympia oyster larvae have been collected from warmer areas such as Pendrell Sound in late May and June (N. Bourne, DFO Pacific Biological Station, pers. comm.). Although oysters may mature in their first year and more than one generation might be produced in a favourable season in southern California (Coe 1932b), cooler temperatures further north may result in only

one or two spawnings in midsummer (Couch and Hassler 1989), later age at maturity, and generally less productive populations.

Age at first reproduction is dependent upon the time of settlement in the summer (Coe 1932b). Given appropriately warm temperatures, the first male phase is complete, ovarian follicles form and the first ova are ready for liberation approximately 22-30 weeks after settlement. The ensuing female stage lasts several weeks, encompassing two periods of ovulation and liberation of eggs. The following male phase occurs 8-12 days later, coincident with the release of developed larvae. Therefore, under appropriate temperature regimes, as many as three sexual phases might occur in the first year of life of individuals that were spawned in early spring (one male and female phase in the fall and a second male phase in the spring). Male and female phases alternate, presumably for the remaining life span of the individual. Because of lower temperatures and later settlement in British Columbia, first male sexual maturity is not usually achieved until the second breeding season, i.e., at nearly one year of age (Elsey 1933).

Stafford (1914) and Coe (1932b) noted retention of larvae in the parental mantle cavity until the larval shell had developed. Coe (1932b) postulated that the pelagic larval period was relatively short, limiting the potential for dispersal. Brooding and pelagic larval stages were estimated to be 14-17 days each in British Columbia (Elsey 1933). Early embryos and larvae are white but become dark grey as the larval shell develops and at the end of gestation appear as a bluish or blackish mass in the mantle chamber (Hopkins 1936). Gravid oysters were referred to as “white sick” or “black sick”, referring to the spent condition and the stage of larval development.

Total fecundity before fertilization has not been documented (Baker 1995), but Hopkins (1937) indicated that brood size for marketable oysters ranges from 250,000 to 300,000 larvae. Egg size is approximately 100-110 µm, and larval shell length is approximately 165-189 µm at swarming and approximately 300 µm at settlement (Loosanof and Davis 1963; Strathman 1987; Baker 1995).

Broods are detectable about mid-May in Puget Sound and mid-May to July in British Columbia (Stafford 1914; Hopkins 1936; Heritage and Bourne 1979). Approximately half of the adult broodstock in Puget Sound produces a second brood in the same season (Hopkins 1936).

Early Life History

Growth of planktonic larvae is relatively rapid (Loosanof and Davis 1963; Strathman 1987). Larvae are released into the water column at shell lengths of approximately 165-189 µm and settle in 2-3 weeks at a length of approximately 300 µm.

Coe (1932a) noted that spat first appeared in southern California in April and a late set usually occurred in October or November, for a spawning season of at least seven months. In Puget Sound, spatting occurred in the summer and fall, usually mid-June to late July (Hopkins 1937). In British Columbia, the spawning season lasts approximately three

months (Stafford 1915), and spatting occurs commonly throughout July, August and September (Elsey 1933). Hopkins (1935) showed that larvae settle preferentially on the undersides of objects.

Growth Rates and Life Span

Post-settlement growth is slow, with 4-5 years required to achieve sizes of approximately 50 mm (Sherwood 1931). Three to four years are required to reach sizes of 35-45 mm in Washington State (Couch and Hassler 1989) and little growth occurs thereafter (Baker 1995).

The maximum age of Olympia oysters is unknown. McKernan *et al.* (1949) recorded approximately 34% annual mortality in adult control groups held for long-term bioassays. Baker (1995) examined fossil Olympia oysters from Coos Bay, Oregon, that exhibited at least 10 major hinge annuli, which may represent age in years. As no information is available regarding either maximum age or age distribution of Canadian populations, generation time (defined as average age of parents in the population) is unknown but may approach 10 years.

Pathways of Effects (PoE): Oil Exposure

A Pathways of Effects oil exposure model can aid oil spill emergency response by identifying low to high-risk scenarios for species exposure. This section describes PoE for Olympia oyster through exposure paths of specific species life stages and the potential dispersion and fates of five oil groups (Table 2). The specific environmental conditions and chemical signature of the oil spill should be taken into consideration as they may cause differences in the outcomes described in this document. A summary table for this section is available in Appendix Table 2.

Habitat utilization and temporal distribution of spawning, larval and adult presence and vulnerability ranks of Olympia oyster are illustrated in Figure 9 and Figure 10, with vulnerability ranking scores for Olympia oyster generalized for all oil groupings as 6 for the larval life stage and 7 for adult life stages (Jeffery *et al.* 2023). Due to low mobility behaviour of Olympia oyster after the larval stage, the PoE and vulnerability levels are grouped together for all post-larval life stages.

Group 1 Oils

Group 1 includes gasoline and marine diesel oil (MDO). Both gasoline and MDO are light, volatile, and acutely toxic oils (ITOPF 2011a). The two oils are split into subcategories due to differences in fate and behaviour, causing different potential PoE on Olympia oysters.

Gasoline

Gasoline has high concentrations of LMW hydrocarbons which may cause both acute and chronic toxic effects on aquatic organisms (ITOPF, 2011b). Possible toxic effects include

mortality (Keesing *et al.* 2018) decreased growth rate, damage to feeding apparatus, and other physiological functioning (Adzigbli and Yeuwen 2018).

Fresh Gasoline Oil Spill

Gasoline is very light, having a specific gravity of <0.80, causing it to float and only be present on the top 1-2 mm of the water column (ITOPF 2011a). Olympia oyster spawning occurs between July and September in British Columbia, depending on environmental conditions (Stafford 1915, Elsey 1933). Larval Olympia oysters are free-swimming and pelagic (Baker 1995); therefore, larvae and/or drift particle food sources may interact with gasoline spills on the water surface. Due to gasoline remaining on the top of the water, risk of larval exposure is low during low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion throughout the water column within the intertidal and subtidal zones. This increased dispersion increases the potential of exposure to epifauna and rock dwellers throughout all life stages; due to low mobility after the larval stage, the PoE and vulnerability levels are grouped together for all post-larval life stages.

Post-larval Olympia oysters are typically found attached to the substrate between the intertidal zone and depths of 10 meters; however, they have been occasionally found at depths up to 50 meters (Bernard 1983, Coan *et al.* 2000). Adult Olympia oysters in the intertidal zone have a high potential to be exposed to gasoline spills due to their high level of interaction with the ocean surface. This direct exposure may cause decreases in physiological functions, along with possible mortality (Keesing *et al.* 2018).

Weathered Gasoline Oil Spill

Gasoline is highly volatile and can completely evaporate within 24 hours; therefore, as gasoline weathers the risk to Olympia oysters decreases. However, shore-based spills or spills during falling tides could impact intertidal populations of Olympia oysters.

<u>Marine Diesel Oils (MDO)</u>

Fresh MDO Oil Spill

Fresh MDO has high aquatic toxicity due to high concentrations of LMW hydrocarbons (Environment Canada 1999). Fresh MDO has similar potential PoE to Olympia oysters as gasoline (Appendix Table 2). Free-swimming larval Olympia oysters are present during the spawning period (July to September; Stafford 1915, Elsey 1933). As with gasoline, MDOs have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring in low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion and dissolution. MDO's spreading through the water column may increase the risk of exposure with larva and drift particle food sources. In high energy ocean conditions, the risk of this occurring is high. Due to low mobility behaviour after the larval stage, the PoE and vulnerability levels are grouped together for all post-larval life stages.

Fresh MDO spills in the intertidal zone have the potential to impact post-larval Olympia oysters. Post-larval Olympia oysters are sessile and settle on the substrate within the intertidal zone, leaving them exposed when the tide recedes. Possible effects may include coating, smothering, ingestion, and habitat modification, which may inhibit spawning. High volume oil spills in the intertidal zone have historically caused high mortalities in molluscs (Keesing *et al.* 2018).

Weathered MDO Oil Spill

As MDOs weather the light molecular weight hydrocarbons evaporate, and aquatic toxicity decreases. However, MDO still poses potential risks to Olympia oysters through coating, smothering and ingestion (ITOPF 2011b). The persistence of MDO causes it to pose many of the same potential effects on Olympia oysters even after weathering. Olympia oyster larvae still have the potential to interact with the oil spill on the surface of the water with potential effects including coating and smothering, though likely without acute toxic effects. The risk of this effect remains low in low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion and dissolution increasing the potential risk.

MDO is persistent and has the potential to interact and adsorb to drift particles within the water column (ITOPF 2011a). Interaction and adsorption to drift particles by MDO causes the potential for Olympia oysters to ingest MDOs. The risk of this occurring is moderate. Ingestion of oil and PAHs can cause decreased cell immunity, DNA destruction, and other physiological effects (Adzigbli and Yeuwen 2018). Given the persistence of MDO, weathered MDOs still pose a risk to post-larval Olympia oyster. Effects include coating, smothering, and habitat modification. Intertidal zone oil spills can cause high mortality in molluscs (Keesing *et al.* 2018).

Group 2 Oils

Light Crude Oils (LCOs)

Group 2 oils are LCOs containing moderate to high concentrations of hydrocarbons which cause acute and chronic toxic effects on aquatic organisms (Adzigbli and Yeuwen 2018). LCOs can cause additional negative effects through coating and smothering aquatic organisms. There are similar PoE between Group 2 and Group 1 oils (Appendix Table 2).

Fresh LCO Oil Spill

As with Group 1 oils, LCOs have a potential to interact with larvae at the water column surface; however, there is a low risk of this occurring in low energy ocean conditions. High energy ocean conditions can increase dispersion and dissolution causing a high risk of larval exposure at depth. Free-swimming larval Olympia oysters are present during the spawning period of July to September in BC (Stafford 1915, Elsey 1933). Due to the low

mobility behaviour after the larval stage, the PoE and vulnerability levels are grouped together for all post-larval life stages.

Fresh LCO spills in the intertidal zone have a high potential to impact post-larval Olympia oysters. Post-larval Olympia oysters most commonly reside on the substrate within the intertidal zone. Due to the high interaction with the ocean surface in the intertidal zone, Olympia oysters are at high risk of being impacted by intertidal zone oil spills.

Weathered LCO Oil Spill

As LCOs weather their acute toxicity decreases as LMW hydrocarbons evaporate; however, the same potential PoE and risks to Olympia oysters remain. LCOs persist and can form stable emulsions, leading to increased volume and specific gravity of the spill (ITOPF 2011a). The PoE for weathered LCO are similar to those of fresh LCO for Olympia oysters, with an increased risk of ingestion.

LCOs persist as they weather causing the potential for them to interact with drift particles throughout the water column potentially adsorbing to floating detritus. Olympia oysters are filter/suspension feeders, putting them at a high risk of ingesting oil sorbed to detritus. The interaction between LCOs and drift algae leads to the potential for ingestion, causing toxic and potentially fatal effects (Adzigbli and Yuewen 2018).

Group 3 Oils

Group 3 contains engine/hydraulic oil, medium crude oil, heavy crude oil, and dilbit oil. Group 3 oils are heavy and persistent, while not being as toxic as Group 1 and 2 oils (ITOPF 2011a, 2011b). There are many similar PoE between Group 3 and Group 1 (Table 2).

Fresh Heavy and Persistent Oil Spill

As with Group 1 oils, Group 3 oils have a potential to interact with larvae at the water column's surface; however, there is low risk of this occurring in low energy ocean conditions. As with previous oil groups, high energy ocean conditions can cause increased dispersion and dissolution causing the potential for interaction with larvae and drift particle food sources throughout the water column. Free-swimming larval Olympia oysters are present during the spawning period of July to September in BC (Stafford 1915, Elsey 1933). The mechanisms and details of PoE are summarized in Appendix Table 2.

Due to the low mobility behaviour after the larval stage, the PoE and vulnerability levels are grouped together for all post-larval life stages.

Fresh Group 3 oil spills have a potential to impact post-larval Olympia oysters in the intertidal zone. Adult Olympia oysters are commonly found in the intertidal zone. Group 3 oil spills in the intertidal zone may coat and smother Olympia oysters causing decreased physiological ability or mortality.

Weathered Heavy and Persistent Oil Spill

As Group 3 oils weather, little to no evaporation occurs; however, sedimentation can occur causing the oils to sink (ITOPF 2011a). Due to Group 3 oils persistence the PoE remain similar for all life stages of Olympia oysters.

Possible sinking due to sedimentation creates a greater risk of exposure for Olympia oysters in the lower intertidal and subtidal zones. Sinking oil may interact directly with oysters on substrates through coating and smothering, affecting individuals found in the lower intertidal zone or those found in the shallow subtidal zone (ITOPF 2011b). The risk of this occurring is high.

Group 4 Oils

Group 4 oils are Bunker C oils. Bunker C oils are heavy and highly persistent oils (Environment Canada 1999). Bunker C oils contain few toxic light molecular weight hydrocarbons meaning they have little to no acute toxic effects on aquatic organisms. Bunker C oils still pose risk through coating and smothering as well as chronic effects due to heavier toxic hydrocarbons (Adzigbli and Yuewen 2018).

Fresh Bunker C Oil Spill

Bunker C oils have a potential to interact with larvae at the water columns surface; however, there is a low risk of this occurring. High energy ocean conditions can cause increased dispersion and dissolution causing the potential for interaction with larvae throughout the water column. Free-swimming larval Olympia oysters are present during the spawning period of July to September in BC (Stafford 1915, Elsey 1933). The negative effects that this interaction could impose on Olympia oysters differ from previous oils given lower concentrations of LMW hydrocarbons, potentially resulting in less acute toxic effects.

Due to the low mobility behaviour after the larval stage, the PoE and vulnerability levels are grouped together for all post-larval life stages.

Fresh Bunker C oil spills pose a threat to Olympia Oysters within the intertidal zone. As the tide recedes oysters in the intertidal zone have the potential to be coated in oil and smothered (Adzigbli and Yuewen 2018). As Olympia Oysters are sessile the risk remains the same for all post-larval life stages.

Weathered Bunker C Oil Spill

There are few weathering effects on Bunker C oil given its low concentrations of volatile LMW hydrocarbons and high persistence (ITOPF 2011a). The PoE are similar between weathered and fresh Bunker C oils; however, Bunker C oils are susceptible to creation of stable emulsions, causing increased volume and specific gravity and potential for sinking and sedimentation-caused sinking.

PoE that weathered Bunker C oil may have on Olympia oysters are similar between fresh and weathered oils. If sinking occurs through emulsions forming or sedimentation, Olympia oysters in the shallow subtidal zone are at risk of oil exposure. Sinking oils could coat and smother Olympia oysters on substrates in shallow subtidal or intertidal zones causing physiological issues or potentially mortality (Adzigbli and Yuewen 2018).

Group 5 Oils

Group 5 oils are extremely heavy and persistent oils known as sinking oils. Sinking oils have a specific gravity >1, causing them to readily sink in water (ITOPF 2011a). Group 5 soils have a high potential to negatively impact Olympia oysters at all life stages and tidal zones.

Fresh Sinking Oil Spill

Free-swimming larval Olympia oysters are present during the spawning period of July to September in BC (Stafford 1915, Elsey 1933). Sinking oils have a high risk of interacting with Olympia oysters' larvae at any potential ocean energy scenario, given the potential of oil being present throughout the water column or interacting with larvae while sinking.

Due to the low mobility behaviour after the larval stage, the PoE and vulnerability levels are grouped together for all post-larval life stages.

Sinking oils have a high risk of oil interacting with drift particles and being ingested by Olympia oysters. Ingestion of oils can cause physiological issues along with potential mortality in molluscs (Adzigbli and Yuewen 2018). Sinking oils may also smother Olympia oysters causing damage to feeding apparatuses and mortality. Sinking oil spills in the intertidal zone have a high risk of interacting with post-larval Olympia oysters through coating and smothering, potentially causing death.

Weathered Sinking Oil Spill

Sinking oils have little to no weathering effects; therefore, the PoE on Olympia oysters are the same for fresh and weathered sinking oils.

Figure 7. Olympia oyster, *Ostrea lurida*.

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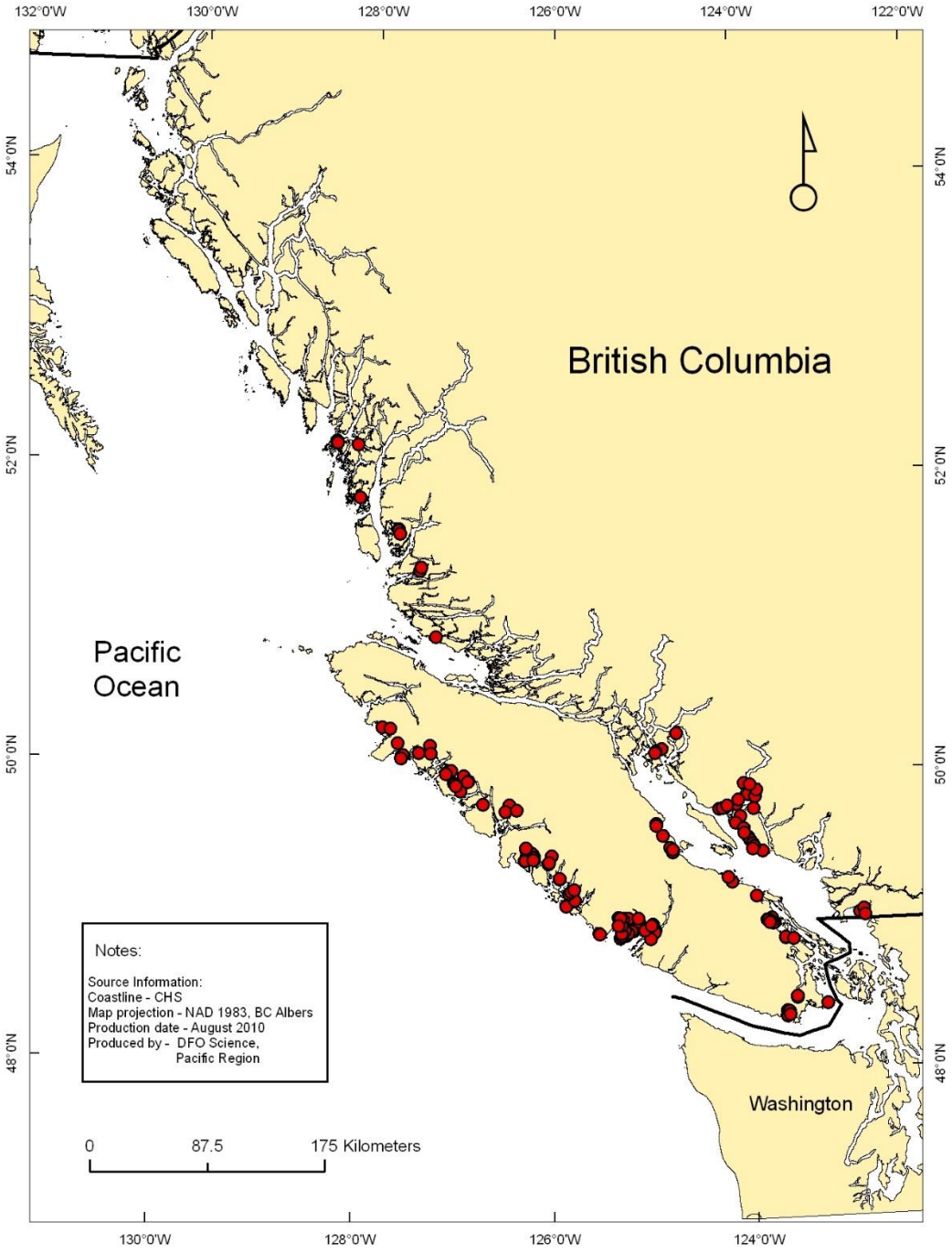

Figure 8. Canadian distribution of Olympia oysters, *Ostrea lurida* (Gillespie 2009, COSEWIC 2011).

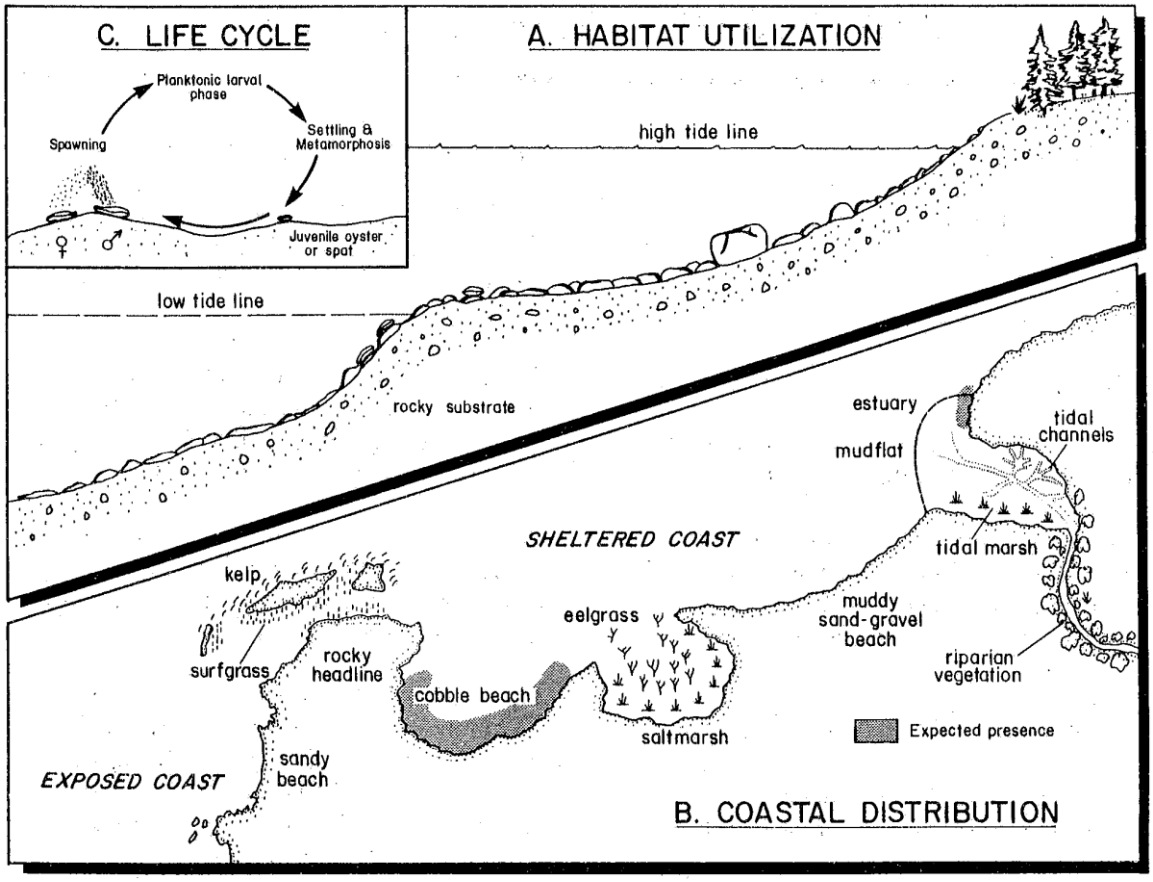

Figure 9. Habitat utilization (A), coastal distribution (B, gray polygons indicate expected presence) and life cycle (C) of Olympia oyster, *Ostrea lurida*. (Williams 1989).

J	F	M	A	M	J	J	A	S	O	N	D
1	1	2	3	3	3	3	3	2	1	1	1
		---Spawning---									
1	1	2	3	3	3	3	3	2	1	1	1
		---Larval Presence---									
3	3	3	3	3	3	3	3	3	3	3	3
---Adult Presence---											

Figure 10. Temporal distribution of spawning, larval and adult presence and vulnerability ranks of Olympia oyster, *Ostrea lurida*.

Legend: 1 (green) = low/negligible vulnerability; 2 (yellow) = moderate vulnerability; 3 (red) = high vulnerability.

Table 4. Summary of information required to inform marine emergency response for Olympia oyster, *Ostrea lurida*.

Taxonomy
Scientific Name:
Ostrea lurida Carpenter, 1864 (formerly *Ostrea conchaphila*)

Common Name(s):
Olympia oyster, native oyster, California oyster, Yaquina oyster, Yaquina Bay oyster, shell-loving oyster, Shoalwater oyster, rock oyster, western oyster, huître plate du Pacifique

Higher Taxonomy:
Mollusca; Bivalvia; Ostreoida; Ostreidae

Description

Small, irregularly-shaped oysters, more or less elliptical or circular. Lower (left) valve shallowly cupped, upper (right) valve generally flat, fitting into the raised margin of the left valve. Lower valve is often attached to a hard substrate, but may be found lying freely on soft substrate as singles or clusters. Valves may be gray, gray blotched with purple, white, brown, yellow or purplish black; inner surface grades from white to iridescent green to dark purple, adductor muscle scar not much different in color. Internal triangular ligament.

Distribution

Central British Columbia to Baja California. Broadly distributed in appropriate habitat on the west coast of Vancouver Island, Straits of Georgia and Juan de Fuca. Few scattered populations in the Central Coast, not reported from Haida Gwaii.

Habitat Preferences

Lower intertidal and subtidal zones of estuaries and saltwater lagoons, also mud-gravel tidal flats, splash pools, near freshwater seepage, tidal channels, bays and sounds or attached to pilings or the underside of floats. Only in protected locations on the outer coast. Common from the intertidal zone to 10 m, occasionally to 50 m.

Table 4. continued.

Physical Tolerances Salinity Moderately euryhaline species, tolerates salinities as low as 15‰ although large populations were in locations with 23-24‰ average salinity in winter. **Temperature** Require ambient water temperature >12.5°C to reproduce, but reproduction occurs more commonly at temperatures of 14-16°C. Larval development is temperature dependent; spatting occurred after seven days at 24°C, 10-11 days at 21.5°C and 16 days at 18°C. Approximately 30-40 days were required from swarming to spatting for Olympia oysters in Puget Sound. Adults and juveniles cannot tolerate exposure to freezing temperatures, juveniles are also vulnerable to dry exposure to high temperatures during summer daylight low tides. Adults can tolerate 30°C for a few hours.
Reproductive Biology Larviparous, protandrous, alternating hermaphrodites; mature first as males and then alternate sexes between male and female throughout their life. Males extrude sperm balls that activate on contact with seawater releasing sperm. Fertilization is internal and females brood larvae in the mantle cavity until they develop larval shells, approximately two weeks. Larvae are extruded and remain pelagic for 2-3 weeks before settling on suitable hard substrates. Gonad development and spawning temperature dependent, may be multiple spawnings per year. Fecundity estimated at 250,000-300,000 per spawning. Broods are present mid-May to July and spatting generally occurs July to September in BC.
Growth Rate and Lifespan Growth rate variable, cannot determine age from shells. Require 3-4 years to reach 35-45 mm and 4-5 years to reach 50 mm. Growth extremely slow thereafter. Lifespan is at least 10 years.
Migratory Behaviour Adults sessile, dispersal through pelagic larval stages.
Role in the Ecosystem Obligate filter feeder, opportunistically utilizing bacteria, protozoans, diatoms, invertebrate larvae and detritus. Preyed on by crabs, sea stars, gastropods and diving ducks.
Significance Designated Special Concern by COSEWIC in 2000 and 2010 and listed as Special Concern under SARA in 2003.

Table 4. continued.

Vulnerability **Subgroup Classification**: Intertidal/Subtidal Benthic; Rock and Rubble Dwellers; Sessile; Mollusca. **Adult Exposure Criteria**: Aggregate in discrete beds, gregarious recruitment; Sessile; Primarily intertidal (high interaction with sea surface); Epifaunal (high interaction with sea floor). Score: 4. **Adult Sensitivity Criteria**: Filter/suspension feeders (feeding apparatus can be clogged or damaged by pollutants); Chemical sensitivity assumed to be high. Score: 2. **Adult Recovery Criteria**: Special Concern (COSEWIC and SARA listed); Relatively high reproductive capacity; Broadly distributed in suitable habitats in southern and central British Columbia; Low degree of interaction with unconsolidated substrates. Score: 1. Cumulative Total Score: 7. **Larval Exposure Criteria**: Aggregate or Patchiness where large number of larvae affected; Low Mobility; Interaction with sea surface. Score: 3. **Larval Sensitivity Criteria**: Larvae feeding appendages that can become clogged by oil; Chemical sensitivity assumed to be high. Score: 2. **Larval Recovery Criteria**: Special Concern (COSEWIC and SARA listed); Relatively high reproductive capacity; Broadly distributed in suitable habitats; Low degree of interaction with unconsolidated substrates. Score: 1. Larval Cumulative Total Score: 6.

Pacific Oyster (Magallana gigas)

Significance

Pacific oysters are the primary oyster species cultured in BC and support First Nations, commercial and recreational fisheries (Bourne 1997).

Vulnerability

Subgroup classification

Pacific oysters were included in the following subgroups: 1 - Intertidal location for exposure; 2 – Rock and Rubble Dwellers substrate; 3 - Sessile; and taxonomy to inform feeding types and reproductive strategies - Mollusca (Thornborough *et al.* 2017, Hannah *et al.* 2017, Jeffery *et al.* 2023).

Exposure

As with many epifaunal bivalve molluscs, aggregated distributions of Pacific oysters are a result of habitat preferences, physiological tolerances and are beneficial for spawning synchrony and fertilization success (Hannah *et al.* 2017).

Pacific oysters have low mobility; dispersal is through pelagic larval stages, adults are sessile, either attached to hard substrate or loose on the substrate surface. They are entirely intertidal in distribution; thus, their populations have a high level of interaction with the sea surface. As epifaunal organisms they have intimate contact with the consolidated and unconsolidated sediments they inhabit.

Sensitivity

As filter/suspension feeders, Pacific oysters are very sensitive to pollutants that may clog or damage their feeding apparatus. Numerous studies document chemical effects of pollutants on bivalve physiology, reproduction and larval survival.

Recovery

Population status is not actively monitored in British Columbia. Pacific oysters have high fecundity and high reproductive capacity, but inconsistent recruitment. They are broadly distributed in suitable habitat in southern British Columbia (Strait of Georgia and west coast of Vancouver Island). They are dependent on hard substrates for settlement but also occur on gravel substrates which can be affected for extended periods due to difficulties removing pollutants that have seeped into the substrate.

Taxonomy

The accepted scientific name is *Magallana gigas* (Thunberg 1793). Based on molecular evidence, Salvi and Mariottini (2017, 2020) erected the genus *Magallana* and placed several former *Crassostrea* species there, despite dissent by Bayne *et al.* (2017). Coan *et al.* (2000) listed three junior synonyms, one of which was divided into three subspecies. Numerous authors have described four regional races or forms of Pacific oysters; Hokkaido, Miyagi, Hiroshima and Kumomoto (e.g., Quayle 1988; Arakawa 1990). Some authors (e.g., Arakawa 1990) believed that the Hiroshima type is a separate species, *C. laperousii*; this species is currently considered a junior synonym of *M. gigas* (Coan *et al.* 2000). The Kumamoto type has been recognized as *M. sikamea*, distinct from *M. gigas*. The Pacific oyster is also known as the Japanese, giant, immigrant or Miyagi oyster; the last a local name related to the race introduced to western North America (Table 5).

Description

The Pacific oyster is a large oyster, occasionally reaching 30 cm in length (Quayle 1969, 1988, Harry 1985, Pauley *et al.* 1988, Arakawa 1990) (Figure 11). The shells are irregular, largely determined by the substrate the oyster is growing on and degree of crowding. The valves may be smooth or possess highly fluted radial lamellae. The lower cupped left valve is larger than the upper flat right valve. The outside of the valves is white, gray or pale yellow with dark pigment (brown or purple), particularly on the lamellae. The inner surface is white with the adductor muscle scars slightly darker (though not as distinctly darkened as in *C. virginica*). Newly settled oyster spat are difficult to identify to species, often leading to uncertainty whether they are Pacific or Olympia oysters (e.g., Norgard *et al.* 2018).

Distribution

Native Distribution

The Pacific oyster is naturally found in the western Pacific from Sakhalin Island to Hokkaido, through Honshu to Kyushu. On the continental shore it ranges from Russia through Korea and China into Southeast Asia and Pakistan (Arakawa 1990, Coan *et al.* 2000). In the south, its range overlaps that of two other oysters; the Suminoe oyster, *Magallana ariakensis*, and the Kumamoto oyster, *M. sikamea*.

Introductions

Pacific oysters were introduced to the west coast of North America beginning in 1902 or 1903 in Puget Sound (Galtsoff 1929, Chew 1979, Shatkin *et al.* 1997, Ruesink *et al.* 2005). Subsequent introductions were made throughout Puget Sound, in Grays Harbour and Willapa Bay in Washington; Alsea, Coos, Netarts, Tillamook and Yaquina Bays and the Umpqua River in Oregon; and Humboldt, Morro, Newport, San Francisco and Tomales Bays, Elkhorn Slough, Bodega and Mugu Lagoons, Anaheim Creek and Drakes Estero in California (Chew 1979, Lindsay and Simons 1997, Robinson 1997, Shaw 1997). Pacific

oysters were recorded from South Central Alaska (Hines and Ruiz 2001) and have been introduced as far west as Kachemak Bay (Foster 1991, 1997), but have not reproduced successfully in Alaska (Foster 2001; Ruesink *et al.* 2005). Oysters were reported to have become established in western Mexico after they were introduced from the western USA and were reported as established in Pearl Harbour, Oahu, Hawaii by Ruesink *et al.* (2005), although Coles *et al.* (1999) did not find them. However, Hunter *et al.* (1995) reported on contaminants found in *Crassostrea gigas* from Kaneohe Bay, Oahu, Hawaii; oysters from five sites in the bay were "pried from the substratum with stainless-steel diving knives" suggesting that they were naturally set rather than spread for culture purposes. Coles *et al.* (2002) indicated that *C. gigas* had been introduced to Kaneohe Bay since 1939 and was still established there.

In British Columbia, Pacific oysters were first introduced to Ladysmith Harbour and Fanny Bay in 1912 or 1913 (Quayle 1969, 1988, Bourne 1997). These small-scale introductions were unregulated; it is likely that government agencies were unaware of the introductions (Bourne 1979). Small-scale introductions likely continued and large-scale importation of seed oysters began in 1925. Evidence of successful reproduction was first seen in Ladysmith Harbour in 1925, 1926 and 1932, followed by successful reproduction and spread of Pacific oysters to areas beyond Ladysmith Harbour in 1936 (Elsey 1932, 1934, Elsey and Quayle 1939, Quayle 1964, 1969, 1988; Bourne 1979). Pacific oysters were transplanted to other growing areas in the Strait of Georgia and widespread reproductive success was reported in 1942, 1958 and 1961 which resulted in establishment of Pacific oyster populations throughout the strait. Pacific oysters were transplanted to Esperanza Inlet and Barkley, Clayoquot and Kyuquot Sounds on the west coast of Vancouver Island in 1937; these resulted in some expansion of populations in Barkley Sound and only limited local reproductive success in the other areas (Bourne 1979). Oysters were transplanted to various areas of the North Coast of BC, including five sites evaluated for raft culture in 1967 and 1968 (Quayle 1971a), without successful reproduction (Bourne 1979). Sloan *et al.* (2001) and Gillespie (2007) reported records of Pacific oysters in Haida Gwaii but found no evidence of successful reproduction. Natural set oysters have since been found in Tasu Sound and Skidegate Inlet in Haida Gwaii (Finney *et al.* 2012, Gillespie *et al.* 2012).

Ruesink *et al.* (2005) collated data on introductions of *C. gigas*, indicating that 69 countries had imported *C. gigas*, 14 had documented established populations, three were judged likely to become established, 16 were unlikely to become established, nine were not established, one indicated some disagreement as to whether establishment had occurred and 26 were unclassified. Pacific oysters are now established on all major coasts in the northern hemisphere with the exception of the Atlantic coast of North America (Shatkin *et al.* 1997). In the southern hemisphere, Pacific oysters were introduced to Australia in the 1940s, 1950s and in 1970 and established populations in New South Wales and Tasmania (Bourne 1979). Pacific oysters have also become established in New Zealand alongside native *S. commercialis*, although the culture industry prefers *C. gigas*. Pacific oysters were introduced to South Africa in 1950 and became established in 2001 (Ruesink *et al.* 2005). They were introduced into Fiji, New Caledonia, New Hebrides, Palau, Tahiti and Tonga, but have not become established (Bourne 1979). In South America they have been introduced to Chile, Peru, Brazil and Argentina (Orensanz *et al.* 2002).

Streftaris *et al.* (2005) indicated that Pacific oysters had been introduced to all the major seas of Europe (Arctic, Atlantic, Baltic, Black, Mediterranean and North), but did not specifically indicate where naturalized populations had become established. *C. gigas* has become established in Belgium, Denmark, France, Germany, Italy, the Netherlands, Portugal and Spain; introductions to the Black Sea and Norway did not result in established populations (Ruesink *et al.* 2005). There is some disagreement as to whether Pacific oysters have become established in the United Kingdom (Walne and Helm 1979, Ruesink *et al.* 2005).

Habitat Preferences

Pacific oyster populations in BC generally occur relatively high in the intertidal zone on hard substrates (Bourne 1979, Ruesink *et al.* 2005)(Figure 12). A preferred settlement substrate is oyster shell and large aggregations form if populations are not disturbed. Under appropriate conditions they can form reefs on gravel banks at the mouth of small streams (e.g., Lucky Creek in Barkley Sound, Figure 11, lower panel). Pacific oysters are more tolerant of exposure during low tides and as such are often found at higher tidal elevations than Olympia oysters (DFO 2023).

Role in the Ecosystem

Trophic Ecology

As sessile, obligate filter feeders, oyster diets are limited to what is carried to them in the water column (Quayle 1969, 1988). Common food items are bacteria, protozoans, diatoms, invertebrate larvae and inanimate organic "detritus". The relative importance of diatoms and organic detritus (with associated bacteria) is uncertain.

Ecological Interactions

Numerous species are associated with oysters by virtue of possessing habitat preferences that match oyster grounds; see Quayle (1969) for a more complete treatment. On the west coast of North America, crabs and sea stars are predators of oysters; the primary species are red rock (*Cancer productus*), Dungeness (*Metacarcinus magister*), and graceful (*Metacarcinus gracilis*) crabs; sunstar (*Pycnopodia helianthoides*), pink (*Pisaster brevispinis*), ochre (*Pisaster ochraceus*) and mottled (*Evasterias troschelli*) stars (Quayle 1969, 1988; Chew 1979, Pauley *et al.* 1988). These predators are all limited by tolerance of desiccation or salinity, therefore Pacific oysters have some refuge at higher tidal elevations.

Greater scaup (*Athya marila*) and black oystercatcher (*Haematopus bachmani*) are predators of Pacific oysters (Butler and Kirbyson 1979, Boune 1989, Verbeek and Butler 1989). Gastropod drills are serious predators of oysters, in particular two introduced species, the Atlantic drill *Urosalpinx cinerea* and the Japanese drill *Ocinebrellus inornatus* (Gillespie *et al.* 2012). The flat worm *Pseudostylochus ostreophagus*, also an invasive

species that arrived with Pacific oyster seed from the western Pacific, can be a serious predator on juvenile oysters (Woelke 1957). Pacific oysters are parasitized by the introduced copepod *Mytilicola orientalis* (Bernard 1968, 1969).

The concept of oysters as ecological engineers has received attention recently (Escapa *et al.* 2004, Ruesink *et al.* 2005). Oyster reefs provide increased habitat complexity, particularly when established in large areas of soft substrate. One potential impact is the negative influence of dense aggregations of Pacific oysters on native eelgrass species, whether through direct replacement or downstream effects (Ruesink *et al.* 2005). Little evidence was found for impacts of oysters on hard substrates, where they may increase surface area for epifauna such as barnacles (Bourne 1979, Ruesink *et al.* 2005).

There is assumed to be little competition between Pacific oysters and native Olympia oysters (*Ostrea lurida*) in BC because Pacific oysters occupy higher tidal elevations (Stafford 1913, Bourne 1979, Gillespie 1999, Ruesink *et al.* 2005). However, introduced oysters often outgrow their native counterparts when their habitat ranges overlap, at least in part because fast-growing species or strains of oyster are specifically chosen for commercial culture (Ruesink *et al.* 2005). Ruesink *et al.* (2005) also proposed that large accumulations of Pacific oyster shell high on the beach represented a recruitment sink for Olympia oyster larvae; in the absence of shell substrate in lower intertidal areas the larvae settle on Pacific oyster shell at elevations not conducive to survival.

Physical Tolerances

Pacific oysters grow at temperatures between 3-35°C (optimal 11-34°C) and salinities of 10-30‰ (optimal 20-30‰) (Mann *et al.* 1991). They can survive air temperatures of -4°C when exposed by the tide (Quayle 1969). Filtration rate, and therefore the amount of food collected, varies with temperature to a maximum at approximately 20°C. Similarly, Pacific oysters respond to changes in salinity by altering the gape of the shells to the point where filtration rate is reduced below approximately 20‰ (Pauley *et al.* 1988). Temperatures of 16-34°C (optimal 20-25°C) and salinities of 10-42‰ (optimal 35‰) are required for spawning.

Oyster larvae require sustained temperatures of 18°C or above and salinities of 19‰ for at least two weeks for successful metamorphosis (Mann *et al.* 1991, Shatkin *et al.* 1997), although some authors describe longer time requirements; e.g., 20°C or greater for at least three weeks (Pauley *et al.* 1988). Lower temperatures may allow complete development but increase the time larvae are vulnerable to predation as plankton. Larvae can survive only for short periods at temperatures below 15°C and above 30°C (Pauley *et al.* 1988).

Reproductive Biology

Pacific oysters are protandric hermaphrodites (Quayle 1969, 1988; Pauley *et al.* 1988). All oysters spawn as males in their first reproductive season but may change sex thereafter; sex change occurs in the winter. Quayle (1988) reported a general belief that environmental conditions affected sex ratios with females changing to males when and where food supply was poor, and males changing to females when food supply is good. He cited cases where

populations in productive areas had a preponderance of females in older age classes, while less productive areas had more males in older age classes.

Sexual maturity is reached in the first year of life (Pauley *et al.* 1988). Gonadal development and spawning are dependent on salinity to some extent, but primarily on temperature. In BC, gonadal development commences as temperatures begin to rise in March. Gonads are fully developed by June and spawning may occur from June to September, most commonly in July and August (Figure 13). Successful spawning at certain sites where temperatures are sufficient (e.g., Pendrell Sound) occurs in most years, with widespread spawning less common. Fecundity has been estimated at 50-100 million eggs per market size (76 mm TL) female (Quayle 1969).

Early Life History

Pacific oysters can only disperse through pelagic larval stages. Once suitable habitat for settlement has been selected, adults are entirely sessile. Elsey (1934) and Quayle (1969, 1988) documented larval dispersal from reproductive events in 1932 and 1936 in Ladysmith Harbour, location of the only oyster stocks in the area that could have produced the larvae. The 1932 spawning produced settled larvae primarily in the harbour with a few individuals found 11 km to the south and 14 km to the east (Elsey 1934). The 1936 spawning resulted in settlement of larvae at False Narrows, approximately 32 km to the north and Saanich Inlet 56 km to the south (Quayle 1969, 1988).

Pacific oyster larvae develop quickly after fertilization and reach the veliger stage in 28 hours (at 22°C) to 72 hours (at 14°C) (Pauley *et al.* 1988). They continue to develop through D-hinge and umbo stages and develop eye spots just prior to settlement. Time to settlement is dependent on temperature, and Quayle (1969, 1988) reported pelagic larval periods ranging between <20 days at 22°C and 30 days at 19°C in Pendrell Sound.

When larvae are fully developed, and a suitable substrate is found the larvae attach the left shell to the substrate with cement produced by a gland in the foot. The larvae then metamorphose, losing the eyespot, velum, foot and anterior adductor muscle and develop the gill and mantle for adult life.

Growth Rates and Life Span

It is difficult to assess growth in oysters because growth rates are affected by tidal height, temperature, substrate and aggregation, and because age cannot be determined from shells as in most clam species (Quayle 1969, 1988). Oysters attached to hard surfaces tend to follow the contours of the surface as they grow. Those grown in soft mud or arranged in dense clusters tend to be narrow and elongated, while those grown on hard gravel tend to be round and deep, often with extensive fluting on the shell. Most information on growth is from oysters of known age (i.e., whose date of settlement is known).

Pacific oysters planted in Ladysmith Harbour grew from 5 mm TL to 109 mm TL between April 1952 and June 1955 (Quayle 1969). Growth was variable between different lots of seed. Growth varies seasonally with greatest growth between April-May and October, associated with temperatures greater than 10°C.

In general, Pacific oyster growth is relatively rapid in young oysters and decreases with age; Pacific oysters in BC generally have reduced growth rates after 4-5 years of age (Quayle 1969, 1988). Maximum age was reported as 40 years with longer life attained at more northern latitudes (Pauley *et al.* 1988).

Pathways of Effects (PoE): Oil Exposure

A Pathways of Effects (PoE) oil exposure model can aid oil spill emergency response by identifying low to high-risk scenarios for species exposure. This section describes PoE for Pacific oyster through exposure paths of specific species life stages and the potential dispersion and fates of five oil groups (Table 2). The specific environmental conditions and chemical signature of the oil spill should be taken into consideration as they may cause differences in the outcomes described in this document. A summary table for this section is available in Appendix Table 3.

Habitat utilization and temporal distribution of spawning, larval and adult presence and vulnerability ranks of Pacific oyster are illustrated in Figure 12 and Figure 13 with vulnerability ranking scores for Pacific oyster generalized for all oil groupings as 5 for larvae and 6 for adult life stages (Jeffery *et al.* 2023). A summary table for this section is available in Appendix Table 3.

Group 1 Oils

Group 1 contains gasoline and marine diesel oil (MDO). Both gasoline and MDO are light, volatile, and acutely toxic oils (ITOPF 2011a). The two oils are split into subcategories due to differences in fate and behaviour, causing different potential PoE on Pacific oyster.

Gasoline

Gasoline has high concentrations of LMW hydrocarbons which may cause both acute and chronic toxic effects on aquatic organisms (ITOPF 2011b). Possible toxic effects include mortality (Keesing *et al.* 2018) decreased growth rate, damage to feeding apparatus, and other physiological decreases (Adzigbli and Yeuwen 2018). Due to gasoline remaining on the top of the water, risk of larval exposure is low during low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion throughout the water column within the intertidal and subtidal zones. This increased dispersion increases the potential of exposure to epifauna and rock dwellers throughout all life stages.

Fresh Gasoline Oil Spill

Gasoline is very light, having a specific gravity of <0.8, causing it to float and only be present on the top 1-2 mm of the water column (ITOPF 2011a). Pacific oyster (*Magallana gigas*) spawning in British Columbia occurs from June to September with the majority occurring in July and August (Gillespie *et al.* 2012). Pacific oyster larvae reach the veliger stage within 28 to 72 hours after fertilization, after which they are pelagic and free-swimming until fully developed (Gillespe *et al.* 2012). Due to gasoline remaining on the top of the water, risk of larval exposure within the water column is low.

Adult Pacific oysters are distributed high in the intertidal zone on hard substrates (Ruesink *et al.* 2005). Pacific oysters are sessile after the larval stage along with having a consistent filter-fed diet. Due to this sessile nature, the PoE and risk levels are the same for all post-larval life stages. Given the location of adult Pacific oysters and their diet, gasoline spills in the intertidal zone pose a high risk. Oil spills in intertidal zones have historically caused high mortality in molluscs such as Pacific oysters (Keesing *et al.* 2018).

Weathered Gasoline Oil Spill

Gasoline is highly volatile and can completely evaporate within 24 hours; as such, as gasoline weathers the risk to Pacific oysters decreases. Weathered gasoline is unlikely to pose any risks to Pacific oysters as it evaporates and disperses very quickly.

Marine Diesel Oils (MDO)

Fresh MDO Oil Spill

Fresh MDO has high aquatic toxicity due given high concentrations of light molecular weight hydrocarbons (Environment Canada 1999). As with gasoline, MDOs have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring in low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion and dissolution. MDO's spreading through the water column may increase the risk of exposure with larva and drift particle food sources. In high energy ocean conditions, the risk of this occurring is high. Fresh MDO has similar potential PoE to Pacific oysters as gasoline (Appendix Table 3).

Fresh MDO spills in the intertidal zone have the potential to impact post-larval Pacific oysters. Post-larval Pacific oysters are sessile and settle on the substrate within the intertidal zone, leaving them exposed when the tide recedes. Possible effects may include coating, smothering, ingestion, and habitat modification, which may inhibit spawning. Intertidal zone high volume oil spills have historically caused high mortalities in molluscs (Keesing *et al.* 2018).

Weathered MDO Oil Spill

As MDOs weather, aquatic toxicity decreases as the LMW hydrocarbons evaporate. MDO still poses potential risks to Pacific oysters, particularly in the intertidal zone, through coating, smothering and ingestion (ITOPF 2011b). The persistence of MDO causes it to pose many of the same potential effects on Pacific oysters even after weathering.

Pacific oyster larvae still have the potential to interact with the oil on the surface of the water with potential effects including coating and smothering, likely without acute toxic effects. The risk of this effect remains low.

MDO is persistent and has the potential to interact and adsorb to drift particles within the water column (ITOPF 2011a) adding high risk to Pacific oyster. Pacific oysters are obligate filter feeders, feeding on detritus floating in the water column (Gillespe *et al.* 2012). Interaction and adsorption to drift particles and detritus by MDO causes the potential for filter and suspension feeders to ingest MDOs. Ingestion of MDOs in bivalve molluscs can

lead to impaired physiological function and behaviour as well as death (Adzigbli and Yeuwen 2018). Intertidal zone oils spills can cause high mortality in molluscs (Keesing *et al.* 2018).

Group 2 Oils

Light Crude Oils (LCOs)

Group 2 oils are LCOs which contain moderate to high concentrations of hydrocarbons which cause acute and chronic toxic effects on aquatic organisms (Adzigbli and Yeuwen 2018). LCOs can cause additional negative effects through coating and smothering aquatic organisms. There are similar PoE between Group 2 and Group 1 oils (Appendix Table 3).

Fresh LCO Oil Spill

As with Group 1 oils, LCOs have a potential to interact with larvae at the water columns surface; however, there is a low risk of this occurring in low energy ocean conditions. High energy ocean conditions can increase dispersion and dissolution causing a high risk of larval exposure at depth. Free-swimming larval Pacific oysters are present during the spawning period of July and August (Gillespe *et al.* 2012).

Fresh LCO spills in the intertidal zone have a high potential to impact post-larval Pacific oysters. Post-larval Pacific oysters most commonly reside on the substrate within the intertidal zone. Due to the high interaction with the ocean surface in the intertidal zone, Pacific oysters are at high risk of being impacted by intertidal zone oil spills. Possible effects include coating, smothering, and ingestion. These effects can cause the loss of physiological ability, decreases in immunity, and possibly mortality (Adzigbli and Yeuwen 2018).

Weathered LCO Oil Spill

As LCOs weather their acute toxicity decreases as the LMW hydrocarbons evaporate; however, the same potential PoE and risks to Pacific oysters remain. Light crude oils persist and can form stable emulsions, leading to increased volume and specific gravity of the spill (ITOPF 2011a). The PoE and risk of effects for weathered light crude oils are the same as those of fresh light crude oil for Pacific oysters, with an increased risk of ingestion.

Light crude oils persist as they weather causing the potential for them to interact with drift particles throughout the water column potentially adsorbing to floating detritus. Pacific oysters are filter/suspension feeders, putting them at a high risk of ingesting oil adsorbed to detritus. The interaction between LCOs and drift algae leads to the potential for ingestion, causing toxic and potentially fatal effects (Adzigbli and Yuewen 2018).

Group 3 Oils

Group 3 contains engine/hydraulic oil, medium crude oil, heavy crude oil, and dilbit oil. Group 3 oils are heavy and persistent, while not being as toxic as Group 1 and 2 oils

(ITOPF 2011a, 2011b). There are many similar PoE between Group 3 and Group 1 oils (Table 2).

Fresh Heavy and Persistent Oil Spill

As with Group 1 oils, Group 3 oils have a potential to interact with larvae at the water columns surface; however, there is low risk of this occurring in low energy ocean conditions. As with previous oil groups, high energy ocean conditions can cause increased dispersion and dissolution causing the potential for interaction with larvae and drift particle food sources throughout the water column. Free-swimming larval Pacific oyster are present during spawning which occurs from June to September with the majority occurring in July and August in British Columbia (Gillespe *et al.* 2012). The mechanisms and details of this PoE are summarized in (Appendix Table 3).

Pacific oysters are sessile after the larval stage along with having a consistent filter-fed diet. Due to this sessile nature, the PoE and risk levels are the same for all post-larval life stages.

Fresh Group 3 oil spills have a high potential to impact post-larval Pacific oysters. Adult Pacific oysters stay on the hard substrate within high intertidal zone, with a high level of interaction with the ocean's surface. Group 3 oil spills in the intertidal zone may coat and smother Pacific oysters, leading to decreased physiological ability and possible mortality.

Weathered Heavy and Persistent Oil Spill

As Group 3 oils weather, little to no evaporation occurs; however, sedimentation can occur causing the oils to sink (ITOPF 2011a). Due to Group 3 oils persistence the PoE remain similar for all life stages of Pacific oysters.

Possible sinking due to sedimentation creates a greater risk of exposure for Pacific oysters in the upper intertidal zones. Sinking oil may interact directly with oysters on substrates through coating and smothering (ITOPF 2011b). The risk of this occurring is high.

Group 4 Oils

Group 4 oils are Bunker C oils. Bunker C oils are heavy and highly persistent oils (Environment Canada 1999). Bunker C oils contain few toxic LMW hydrocarbons meaning they have little to no acute toxic effects on aquatic organisms (Environment Canada 1999). Bunker C oils still pose risk through coating and smothering as well as chronic effects due to heavier toxic hydrocarbons (Adzigbli and Yuewen 2018).

Fresh Bunker C Oil Spill

Bunker C oils have a potential to interact with larvae at the water columns surface; however, there is a low risk of this occurring. High energy ocean conditions can cause increased dispersion and dissolution causing the potential for interaction with larvae throughout the water column. Free-swimming larval Pacific oysters are present during the

spawning period from June to September with the majority occurring in July and August (Gillespe *et al.* 2012). Negative effects that interactions may have on Pacific oysters differ from previous oils given lower concentrations of LMW hydrocarbons, causing less acute toxic effects. Physical and chronic effects may still pose a risk.

Fresh Bunker C oil spills pose a threat to Pacific oysters within the intertidal zone. As the tide recedes oysters in the intertidal zone have the potential to be coated in oil and smothered (Adzigbli and Yuewen 2018). As Pacific oysters are sessile the risk remains the same for all post-larval life stages.

Weathered Bunker C Oil Spill

There are little weathering effects on Bunker C oil given its low concentrations of volatile LMW hydrocarbons and high persistence (ITOPF 2011a). The PoE are similar between weathered and fresh Bunker C oils; however, Bunker C oils are susceptible to creation of stable emulsions, causing increased volume and specific gravity and potential for sinking and sedimentation-caused sinking (ITOPF 2011a).

PoE risks of effects that weathered Bunker C oil may have on Pacific oysters are similar between fresh and weathered oils. If sinking occurs through emulsions forming or sedimentation, Pacific oysters in the intertidal zone are at risk of oil exposure. Sinking oils could coat and smother Pacific oysters on substrates causing physiological issues or potentially mortality (Adzigbli and Yuewen 2018).

Group 5 Oils

Group 5 oils are extremely heavy and persistent oils known as sinking oils. Sinking oils have a specific gravity >1, causing them to readily sink in water (ITOPF 2011a). Group 5 oils have a high potential to negatively impacting Pacific oysters at all life stages.

Fresh Sinking Oil Spill

Free-swimming larval Pacific oysters are present during the spawning period from June to September with the majority occurring in July and August (Gillespe *et al.* 2012). Sinking oils have a high risk of interacting with Pacific oyster larvae given the potential of oil being present throughout the water column or interacting with larvae while sinking.

Sinking oils have a high risk of interacting with drift particles and being ingested by Pacific oysters. Ingestion of oils can cause physiological issues along with potential mortality in molluscs (Adzigbli and Yuewen 2018). Sinking oils may also smother Pacific oysters causing damage to feeding apparatuses and mortality. Sinking oil spills in the intertidal zone have a high risk of interacting with post-larval Pacific oysters through coating and smothering, potentially causing death (Adzigbli and Yuewen 2018).

Weathered Sinking Oil Spill

Sinking oils have little to no weathering effects; therefore, the PoE on Pacific oysters are the same for fresh and weathered sinking oils.

Figure 11. Pacific oyster, *Magallana gigas*.

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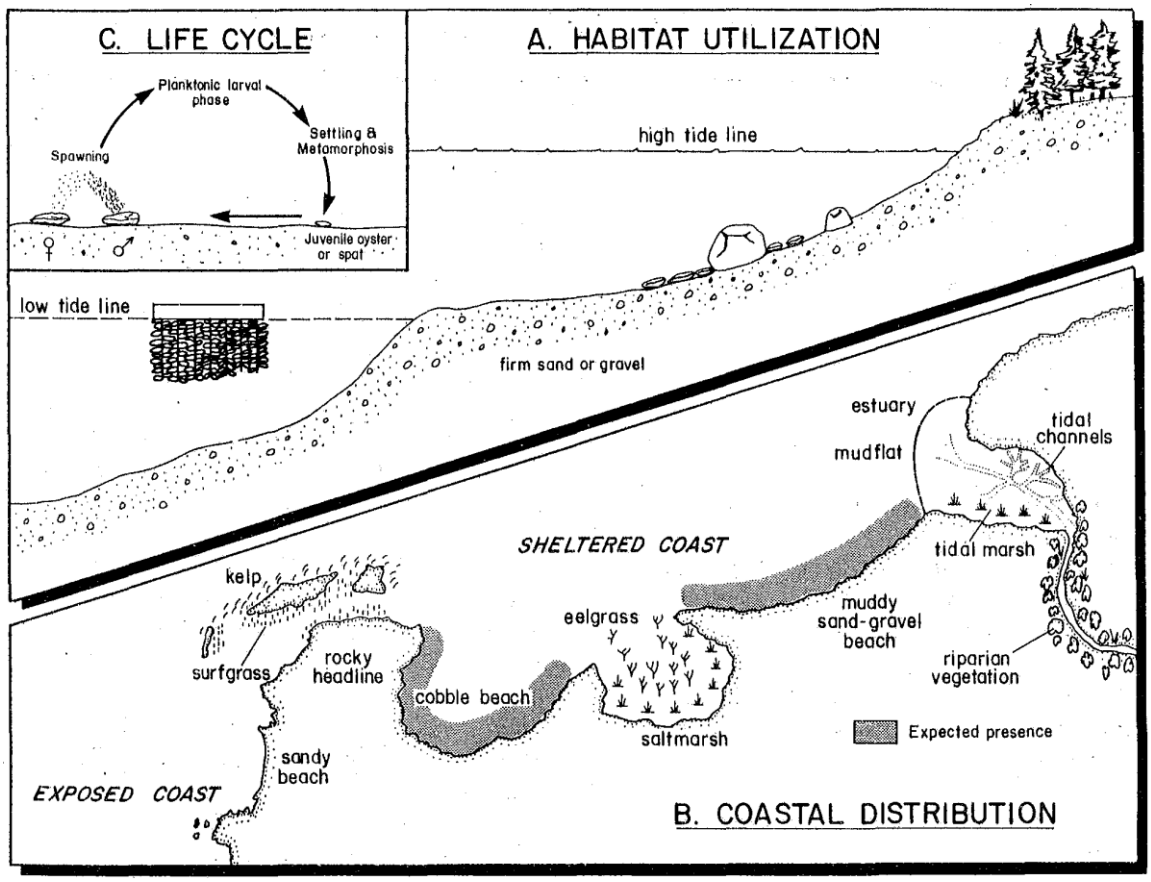

Figure 12. Habitat utilization (A), coastal distribution (B, gray polygons indicate expected presence) and life cycle (C) of Pacific oyster, *Magallana gigas* (Williams 1989).

J	F	M	A	M	J	J	A	S	O	N	D
1	1	1	1	1	2	3	3	2	1	1	1
					---Spawning---						
1	1	1	1	1	2	3	3	3	2	1	1
					---Larval Presence---						
3	3	3	3	3	3	3	3	3	3	3	3
---Adult Presence---											

Figure 13. Temporal distribution of spawning, larval and adult presence and vulnerability ranks for Pacific oyster, *Magallana gigas*.

Legend: 1 (green) = low/negligible vulnerability; 2 (yellow) = moderate vulnerability; 3 (red) = high vulnerability.

Table 5. Summary of information required to inform marine emergency response for Pacific oyster, *Magallana gigas*.

Taxonomy
Scientific Name:
Magallana gigas (Thunberg, 1793)

Common Name(s):
Pacific oyster, giant oyster, immigrant oyster, Japanese oyster, Miyagi oyster, Pacific giant oyster

Higher Taxonomy:
Mollusca; Bivalvia; Pteriomorphia; Ostreoida; Ostreidae

Description
Large oyster, shells irregular (shape determined by substrate type), may be smooth or have fluted lamellae. Lower (left) valve cupped, larger than upper (right) flat valve. Valves white, grey or light yellow with brown or purple pigment on lamellae. Inner surface white with darker pigment at adductor muscle scar. Maximum size at least 30 cm TL.

Distribution
Native
Northwestern Pacific from Sakhalin Islands through Hokaido and Honshu to Kyushu, and from Coastal Russia through Korea and China into Southeast Asia and to Pakistan.

Introductions
Widely introduced worldwide, with established naturally reproducing populations in Australia, New Zealand, Europe South Africa and Hawaii.
Currently cultured from Prince William Sound, AK to Newport Bay, CA. Locally established naturally maintained populations from BC to OR, natural sets expected inconsistently in areas that support culture. Present and locally common on the west coast of Vancouver Island and Strait of Georgia. Two occurrences on Haida Gwaii.

Habitat Preferences
Generally occur in upper intertidal zone on hard substrates. Oyster shell is preferred settlement surface; can form large aggregations or oyster reefs if undisturbed.

Table 5. continued.

Physical Tolerances Salinity Adults grow in salinities of 10-30‰ with the optimal range being 20-30‰. Spawning requirement is 10-42‰, optimally 35‰. Larvae require salinities >19‰. **Temperature** Adults grow in 3-35°C, with optimal range of 11-34°C. Spawning requirement is 16-34°C, optimally 20-25°C. Larvae can survive between 15-30°C and require temperatures >18°C for at least two weeks for normal development and settlement.
Reproductive Biology Protandric hermaphrodite, dioecious broadcast spawner. Age at maturity ca. one year. Spawn June-September, usually July-August in BC. Spawning regularly successful at limited sites in BC and Washington, occasional widespread spawning success in warm water years. Fecundity high (50-100 million eggs/female).
Growth Rate and Lifespan Growth rate variable, cannot determine age from shells. Can reach 10 cm TL in three years in BC. Growth initially rapid then decreases after 4-5 years. Maximum age approximately 40 years.
Migratory Behaviour Adults sessile, dispersal through pelagic larval stages. Larval period up to 30 days in BC, with dispersal of up to 56 km documented.
Role in the Ecosystem Obligate filter feeder, opportunistically utilizing bacteria, protozoans, diatoms, invertebrate larvae and detritus.
Interactions with Native Species Little evidence of direct competition with native oysters, although can have an effect as vectors of disease and through acting as settlement sink for native oysters in suboptimal habitat. Large aggregations serve to increase habitat complexity and support higher densities of epifaunal animals (barnacles, mussels, scaleworms) allowing increased foraging opportunities for migratory birds. Act as prey for native invertebrate and bird species.

Table 5. continued.

Significance

Pacific oysters are a primary aquaculture species and are important for First Nations and recreational harvests in the South Coast. There are limited commercial fisheries.

Vulnerability

Subgroup Classification: Intertidal; Rock and Rubble Dwellers; Sessile; Mollusca.

Adult Exposure Criteria: Aggregate in discrete beds, gregarious recruitment; Sessile; Intertidal (high interaction with sea surface); Epifaunal (high interaction with sea floor). Score: 4.

Adult Sensitivity Criteria: Filter/suspension feeders, feeding apparatus can be clogged by pollutants; Chemical sensitivity assumed to be high. Score: 2.

Adult Recovery Criteria: Populations unmonitored; Relatively high reproductive capacity; Broadly distributed in suitable habitats in southern British Columbia; Low degree of interaction with unconsolidated substrates. Score: 0.

Cumulative Total Score: 6.

Larval Exposure Criteria: Aggregate or Patchiness where large number of larvae affected; Low Mobility; Interaction with sea surface. Score: 3.

Larval Sensitivity Criteria: Larvae feeding appendages that can become clogged by oil; Chemical sensitivity assumed to be high. Score: 2.

Larval Recovery Criteria: Populations unmonitored; Relatively high reproductive capacity; Broadly distributed in suitable habitat; Low degree of interaction with unconsolidated substrates. Score: 0.

Larval Cumulative Total Score: 5.

Pacific Geoduck (Panopea generosa)

Significance

Geoducks are the focus of a valuable commercial dive fishery in BC (DFO 2000, Bureau *et al.* 2002, DFO 2021) and Puget Sound (Goodwin and Pease 1989). There are limited attempts at geoduck aquaculture in BC (Hand and Marcus 2004). Intertidal portions of the population are occasionally harvested by First Nations or recreational fishers (Harbo 1997).

Vulnerability

Subgroup classification

Pacific geoduck were included in the following subgroups: 1 – Subtidal Benthic/Intertidal location for exposure; 2 - Sediment Infauna substrate; 3 - Low mobility; and taxonomy to inform feeding types and reproductive strategies - Mollusca (Thornborough *et al.* 2017, Hannah *et al.* 2017, Jeffery *et al.* 2023).

Exposure

As with many infaunal bivalve molluscs, aggregated distributions of geoducks are a result of habitat preferences, physiological tolerances and are beneficial for spawning synchrony and fertilization success (Hannah *et al.* 2017).

Pacific geoduck have limited mobility; dispersal is through pelagic larval stages, adults are sessile and confined to the beds on which they settled. They are primarily shallow subtidal in distribution with a portion of the population found in the deep intertidal, thus their populations have a low level of interaction with the sea surface (DFO 2000). As infaunal organisms they have intimate contact with the unconsolidated sediments they inhabit.

Sensitivity

As filter/suspension feeders, geoducks are very sensitive to pollutants that may clog or damage their feeding apparatus. Numerous studies document chemical effects of pollutants on bivalve physiology, reproduction and larval survival.

Recovery

Status is actively monitored for major commercially exploited populations in British Columbia (DFO 2021). Geoducks have high fecundity and high reproductive capacity, but significant recruitment is extremely sporadic (Orensanz *et al.* 2004, Valero *et al.* 2004). They are distributed in suitable habitat throughout British Columbia and beyond. They are dependent on unconsolidated substrates which can be affected for extended periods due to difficulties removing pollutants that have seeped into the substrate.

Taxonomy

The accepted scientific name is *Panopea generosa* (Gould 1850). Until recently, it was included in the fossil species *Panopea abrupta* (Conrad 1849)(Vadopalas *et al.* 2010). The accepted common name is Pacific geoduck (Turgeon *et al.* 1998), although regularly referred to as simply geoduck or geoduck clam (DFO 2000)(Table 6).

Description

The shells are highly variable and may be thin or thick; they are quadrate, rounded anteriorly and truncate posteriorly (Goodwin and Pease 1989, Harbo 1997, Coan *et al.* 2000). The mantle and long fused siphons do not fit within the shells, which gape widely except at the hinge (Figure 14). Hinge has one cardinal tooth on each valve, the left always larger. Pallial sinus broad, anterior and posterior adductor scars of similar size. Siphons may be extended up to 1 m to access the seabed surface. Siphon openings lack tentacles and cutaneous plates. In adults, the foot is vestigial; if excavated they cannot re-establish in a new burrow. Geoducks are one of the largest burrowing bivalves in the world; maximum shell size is at least 212 mm TL, maximum weight is 3.25 kg (Goodwin and Pease 1989).

Distribution

The northeastern Pacific population is distributed from Kodiak Island AK to Newport Bay CA; the northwestern Pacific population from Sakhalin and Kurile Islands to Kyushu Japan (Coan *et al.* 2000). Geoducks are particularly abundant in Puget Sound and BC (Goodwin and Pease 1989).

Habitat Preferences

Geoducks inhabit soft substrates (mud, sand, silt and gravel) from the lower intertidal to depths of 110 m (DFO 2000, Bureau *et al.* 2002)(Figure 15). Adults inhabit burrows that extend up to one metre into the substrate.

Role in the Ecosystem

Trophic Ecology

Geoduck larvae, post-larvae and adults are filter feeders, removing live phytoplankton (diatoms and flagellates) from the water column (Goodwin and Pease 1989). Adults in water deeper than the photic zone are thought to also utilize dead organic material falling as marine snow. Post-larval geoducks are also capable of pedal feeding, using the foot to move organic material to the labial palps for sorting.

Ecological Interactions

Geoducks are closely associated with chaetopterid polychaetes (*Sphiochaetopterus costarum* and *Phyllochaetopterus prolifica*), sea cucumbers (*Apostichopus californicus*), sea pens (*Ptilosarcus gurneyi*), laminarian kelp, other bivalves (*Tresus* sp. and *Panomya ampla*), sea stars (*Pycnopodia helianthoides* and *Pisaster brevispinis*), red rock crabs (*Cancer productus*) and moon snails (*Euspira lewisii*)(Goodwin and Pease 1991). They often dominate the local community in terms of biomass (Goodwin and Pease 1989).

Geoducks are preyed upon by sea otters, fish, crustaceans, sea stars, worms and gastropods (Goodwin and Shaul 1989). Planktonic larvae are likely eaten by fishes, zooplankton and suspension-feeding invertebrates. Post-larvae and juvenile may be preyed upon by flatfishes (*Lepidopsetta bilineata*, *Parophrys vetulus*, *Platichthys stellatus*, *Psettichthys melanostictus*), pile perch (*Rhacochilus vacca*), sea stars, gastropods (*Euspira lewisii*, *Nassarius mendicus*, *Natica* sp.), coonstripe shrimp (*Pandalus danae*), red rock and graceful crabs (*Cancer productus* and *Metacarcinus gracilis*). Sea stars (in particular *Pisaster brevispinus* and *Pycnopodia helianthoides*) either preyed on whole small geoducks or attacked exposed siphons of larger geoducks (Sloan and Robinson 1983, Lambert 2000). Other fishes with geoduck siphons in their gut contents include Pacific spiny dogfish (*Squalus suckleyii*), cabezon (*Scorpaenichthys marmoratus*) and Pacific halibut (*Hippoglossus stenolepis*)(Goodwin and Pease 1989).

Geoducks are host to juvenile pinnotherid pea crabs (*Pinnixa littoralis*)(Hart 1982).

Physical Tolerances

In the laboratory, larval performance was highest at temperatures between 6.0-16.0°C and salinities between 27.5-32.5‰ (Goodwin and Pease 1989). Juveniles and adults tolerate broader ranges of temperature; late-stage larvae to 17°C, juveniles to 18°C and adults can tolerate temperatures above 20°C for brief periods. Geoduck density decreases greatly in areas with reduced dissolved oxygen levels or regular seasonal periods of hypoxia (Mcdonald *et al*. 2015).

Reproductive Biology

Geoducks are broadcast spawners with separate sexes (DFO 2000), although rare hermaphrodites have been observed (Campbell and Ming 2003). Size and age of maturity are variable; clams may be mature at 45 mm shell length but mean size at maturity was 75 mm in Washington (Goodwin and Pease 1989) and 68-71 mm in BC (Campbell and Ming 2003). Age at maturity was estimated at 2-8 years in Washington (Goodwin and Shaul 1984) and 2-3 years in southern BC (Campbell and Ming 2003). Spawning occurs annually beginning in March with peak spawning in June and July (Goodwin and Pease 1989)(Figure 16). In the laboratory, geoducks spawned at temperatures of 8.5-16.0°C, mostly between 12.0-14.0°C. Marshall *et al.* (2012) recommended maintaining geoduck broodstock at 11°C to maximize reproductive output. Although geoducks are dribble spawners (females release 1.0-2.0x10^6 eggs per event) annual fecundity ranges from 7.0x10^6 to 1.0x10^7 per female. Geoducks are long-lived and may be reproductively active for over a century (Sloan and Robinson 1983).

Early Life History

Fertilization is external and the pelagic larval stages last 40-50 days before settlement (DFO 2000, Orensanz *et al.* 2000). In the laboratory, the larval period was 25 days at 17°C. Post-larvae can actively crawl on the substrate using the foot and attach to the substrate using byssal threads (Goodwin and Pease 1989). In soft substrate they form sand anchors using short byssal threads and can utilize water currents to move longer distances using longer, free byssal threads to increase drag (termed byssal parachutes). Juveniles burrow into the substrate at a shell length of 2 mm and burrow to a depth of 60 cm in two years. Recruitment is extremely sporadic with relatively few high recruitment events; long-term trends show a general reduction in recruitment from the early 1910s to 1975 with subsequent increases in recruitment rates (Orensanz *et al.* 2004, Valero *et al.* 2004).

Growth Rates and Life Span

Growth rates are variable resulting in a wide range of sizes for any given age (Goodwin and Pease 1989). Growth for the first 10-20 years is relatively rapid (20-30 mm/y); thereafter increase in shell length virtually ceases and continued growth is in the form of thickening of the shell and increases in soft tissue weight (Breen and Shields 1983, DFO 2000, Orensanz *et al*. 2000, Bureau *et al.* 2003). Growth slows greatly in winter, when geoducks spend more time with their siphons withdrawn and not feeding but does not cease entirely (Goodwin and Pease 1989). Reported maximum age is 168 years (Bureau *et al.* 2002).

Pathways of Effects (PoE): Oil Exposure

A Pathways of Effects (PoE) oil exposure model can aid oil spill emergency response by identifying low to high-risk scenarios for species exposure. This section describes PoE for Pacific geoduck through exposure paths of specific species life stages and the potential dispersion and fates of five oil groups (Table 2). The specific environmental conditions and chemical signature of the oil spill should be taken into consideration as they may cause differences in the outcomes described in this document. A summary table for this section is available in Appendix Table 4.

Habitat utilization and temporal distribution of spawning, larval and adult presence and vulnerability ranks of Pacific geoduck are illustrated in Figure 15 and Figure 16 with vulnerability ranking scores for Pacific geoduck generalized for all oil groupings as 5 for the larval life stage and 7 for adult life stages (Jeffery *et al.* 2023).

Group 1 Oils

Group 1 contains gasoline and marine diesel oil (MDO). Both gasoline and MDO are light, volatile, and acutely toxic oils (ITOPF 2011a). The two oils are split into subcategories due to differences in fate and behaviour, causing different potential PoE on Pacific geoduck.

Gasoline

Gasoline has high concentrations of LMW hydrocarbons which may cause both acute and chronic toxic effects on aquatic organisms (ITOPF 2011b). Possible toxic effects include

mortality (Keesing *et al.* 2018), decreased locomotive ability, damage to feeding apparatuses, decreased immunity and other physiological decreases (Adzigbli and Yeuwen 2018).

Fresh Gasoline Oil Spill

Gasoline is very light, having a specific gravity of <0.8, causing it to float and only be present on the top 1-2 mm of the water column (ITOPF 2011a). Pacific geoduck spawning occurs between March and July, with the peak occurring during June and July (Goodwin and Pease 1989). Due to gasoline remaining on the top of the water, risk of larval exposure is low during low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion throughout the water column increasing the potential of exposures.

Pacific geoducks are an infaunal species with limited mobility after the larval stage, adults are sessile. They are filter/suspension feeders. Due to this sessile nature, the PoE and risk levels are grouped together for all post-larval life stages. Adult Pacific geoducks are generally located in the shallow subtidal and deep intertidal zones (DFO 2000, Bureau *et al.* 2002). Given the habitat location of Pacific geoducks, they have a low level of interaction with the sea surface and gasoline spills pose a low risk. However, during tidal events residual oils on exposed sediment may permeate burrows, stressing infaunal species and possibly leading to early post-larval geoducks to move to the surface, exposing them to greater contamination and predation (Pavia 1982).

Weathered Gasoline Oil Spill

Gasoline is highly volatile and can completely evaporate within 24 hours; as such, as gasoline weathers the risk to Pacific geoducks decreases. Weathered gasoline is unlikely to pose any risks to Pacific geoducks as it evaporates and disperses very quickly.

Marine Diesel Oils (MDO)

Fresh MDO Oil Spill

Fresh MDO has similar potential PoE to Pacific geoduck as gasoline. Fresh MDO has high aquatic toxicity due given high concentrations of LMW hydrocarbons (Environment Canada 1999). As with gasoline, MDOs have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring in low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion and dissolution. MDO's spreading through the water column may increase the risk of exposure with larva and drift particles. In high energy ocean conditions, the risk of this occurring is high. Free-swimming larval Pacific geoducks are present during the spawning period of March to July, with the peak occurring during June and July (Goodwin and Pease 1989). For further detail on PoE, see Appendix Table 4.

Pacific geoducks are an infaunal species with adults sessile after the larval stage. They filter/suspension feeders. Due to this sessile nature, the PoE and risk levels are grouped together for all post-larval life stages.

Fresh MDO spills have a low risk of impacting Pacific geoducks. MDO spills remain on the surface of the water; and due to their habitat in the deep intertidal/lower subtidal zones, Pacific geoducks have a low level of interaction with surface waters (DFO 2000, Bureau *et al.* 2002). However, during tidal events residual oils on exposed sediment may permeate burrows, stressing infaunal species and possibly causing early post-larval geoducks to move to the surface, exposing them to greater contamination and predation (Pavia 1982).

Weathered MDO Oil Spill

As MDOs weather aquatic toxicity decreases as the light molecular weight hydrocarbons evaporate. MDO still poses potential risks to Pacific geoducks through coating and ingestion (ITOPF 2011b). The persistence of MDO causes weathered MDO to pose many of the same potential effects on Pacific geoducks as fresh spills, with lower acute toxic effects. The larvae of Pacific geoducks still have the potential to interact with the oil spill at the water surface with potential effects including coating and smothering, likely without acute toxic effects. The risk of this effect remains low in low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion and dissolution, increasing the risk to larval geoduck.

MDO is persistent and has the potential to interact and adsorb to drift particles within the water column (ITOPF 2011a). Pacific geoducks at all life stages are filter feeders (Goodwin and Pease 1989). Interaction and adsorption to these drift particles by MDO causes the potential for Pacific geoducks to ingest MDOs. The risk of this occurring is high.

Group 2 Oils

Light Crude Oils (LCOs)

Group 2 oils are LCOs which contain moderate to high concentrations of hydrocarbons which cause acute and chronic toxic effects on aquatic organisms (Adzigbli and Yeuwen 2018). LCOs can cause additional negative effects through coating and smothering aquatic organisms. There are similar PoE between Group 2 and Group 1 oils (Appendix Table 4).

Fresh LCO Oil Spill

As with Group 1 oils, LCOs have a potential to interact with larvae at the water columns surface; however, there is a low risk of this occurring in low energy ocean conditions. High energy ocean conditions can increase dispersion and dissolution causing a high risk of larval exposure at depth. Free-swimming larval Pacific geoducks are present during the spawning period of March to July, with the peak occurring during June and July (Goodwin and Pease 1989).

Pacific geoducks are an infaunal species with adults sessile after the larval stage. They filter/suspension feeders. Due to this low mobility, the PoE and risk levels are grouped together for all post-larval life stages.

Fresh Group 2 oil spills have a low to moderate risk of impacting Pacific geoducks. Group 2 oil spills remain on the surface of the water; and due to their habitat in the deep intertidal/lower subtidal zones, Pacific geoducks have a low level of interaction with surface waters (DFO 2000, Bureau *et al.* 2002). However, during tidal events residual oils on exposed sediment may permeate burrows, stressing infaunal species and possibly causing early post-larvae to move to the surface, exposing them to greater contamination and predation (Pavia 1982).

Weathered LCO Oil Spill

As LCOs weather their acute toxicity decreases as the light molecular weight hydrocarbons evaporate; however, the same potential PoE and risks to Pacific geoducks remain. Light crude oils persist and can form stable emulsions, leading to increased volume and specific gravity of the spill (ITOPF 2011a). The PoE for weathered light crude oils are increased for Pacific geoducks, through its greater presence in the water column and potential for ingestion.

LCOs persist as they weather causing the potential for them to interact with floating detritus throughout the water column potentially absorbing to the floating detritus. The interaction between LCOs and floating detritus leads to the potential for ingestion by geoducks as they are filter feeders (Goodwin and Pease 1989), causing toxic and potentially fatal effects (Adzigbli and Yuewen 2018).

Group 3 Oils

Group 3 contains engine/hydraulic oil, medium crude oil, heavy crude oil, and dilbit oil. Group 3 oils are heavy and persistent, while not being as toxic as Group 1 and 2 oils (ITOPF 2011a, 2011b). There are many similar PoE between Group 3 and Group 1 oils (Appendix Table 4).

Fresh Group 3 Oil Spill

As with Group 1 oils, Group 3 oils have a potential to interact with larvae at the water column surface; however, there is low risk of this occurring in low energy ocean conditions. As with previous oil groups, high energy ocean conditions can cause increased dispersion and dissolution causing the potential for interaction with larvae and drift particle food sources throughout the water column. Free-swimming larval Pacific geoducks are present during the spawning period of March to July, with the peak occurring during June and July (Goodwin and Pease 1989). The mechanisms and details of this PoE are summarized in Appendix Table 4.

Pacific geoducks are an infaunal species with adults sessile after the larval stage. They filter/suspension feeders. Due to low mobility, the PoE and risk levels are grouped together for all post-larval life stages.

Fresh Group 3 oil spills have a low to moderate risk of impacting Pacific geoducks. Group 3 oil spills remain on the surface of the water; and due to their habitat in the deep intertidal/lower subtidal zones, Pacific geoducks have a low level of interaction with surface waters (DFO 2000, Bureau *et al.* 2002). However, during tidal events residual oils on exposed sediment may permeate burrows, stressing infaunal species and possibly causing early post-larvae to move to the surface, exposing them to greater contamination and predation (Pavia 1982).

Weathered Group 3 Oil Spill

As Group 3 oils weather, little to no evaporation occurs; however, sedimentation can occur causing the oils to sink (ITOPF 2011a). Due to Group 3 oils persistence the PoE and vulnerability effects remain similar for all life stages of Pacific geoduck.

Possible sinking due to sedimentation creates risk of exposure for Pacific geoduck of all life stages. Sinking oil may interact directly with geoduck through coating and smothering, causing feeding apparatuses to not work properly, along with inhibiting locomotion (ITOPF 2011b).

Sinking oil may also interact with floating detritus, a geoduck food source (Goodwin and Pease 1989), causing ingestion of oil. Ingestion of oil can cause damage to feeding apparatuses, decreased immunity, along with other physiological decreases (Adzigbli and Yuewen 2018). There is a high risk of this occurring.

Group 4 Oils

Group 4 oils are Bunker C oils. Bunker C oils are heavy and highly persistent oils (Environment Canada 1999). Bunker C oils contain few toxic LMW hydrocarbons meaning they have little to no acute toxic effects on aquatic organisms (Environment Canada 1999). Bunker C oils still pose risk through coating and smothering as well as chronic effects due to heavier toxic hydrocarbons (Adzigbli and Yuewen 2018).

Fresh Bunker C Oil Spill

Bunker C oils have a potential to interact with larvae at the water columns surface; however, there is a low risk of this occurring. High energy ocean conditions can cause increased dispersion and dissolution causing the potential for interaction with larvae throughout the water column. Free-swimming larval Pacific geoducks are present during the spawning period of March to July, with the peak occurring during June and July (Goodwin and Pease 1989). Negative effects that interactions may have on Pacific geoduck differ from previous oils given lower concentrations of LMW hydrocarbons, causing less acute toxic effects. Physical and chronic effects may still pose a risk.

Pacific geoducks are an infaunal species with aadults sessile after the larval stage. They filter/suspension feeders. Due to this sessile nature, the PoE are grouped together for all post-larval life stages.

Fresh Bunker C oil spills pose a moderate threat to Pacific geoduck as their burrows have the potential to be coated in oil and smothered (Adzigbli and Yuewen 2018).

Weathered Bunker C Oil Spill

There are little weathering effects on Bunker C oil given its low concentrations of volatile LMW hydrocarbons and high persistence (ITOPF 2011a). The PoE are similar between weathered and fresh Bunker C oils; however, Bunker C oils are susceptible to creation of stable emulsions, causing increased volume and specific gravity and potential for sinking and sedimentation-caused sinking (ITOPF 2011a).

PoE and risks of effects that weathered Bunker C oil are increased in weathered oils. If sinking occurs through emulsions forming or sedimentation, Pacific geoduck are at a greater risk of oil exposure. Sinking oils could coat and smother larval Pacific geoduck causing locomotion and feeding issues or potentially mortality, even in the lower intertidal and subtidal zones (Adzigbli and Yuewen 2018).

Group 5 Oils

Group 5 oils are extremely heavy and persistent oils known as sinking oils. Sinking oils have a specific gravity >1, causing them to readily sink in water (ITOPF 2011a). Group 5 oils have a high potential to negatively impacting Pacific geoduck at all life stages.

Fresh Sinking Oil Spill

Free-swimming larval Pacific geoduck are present during the spawning period of March to July, with the peak occurring during June and July (Goodwin and Pease 1989). Sinking oils have a high risk of interacting with the larvae of Pacific geoduck given the potential of oil being present throughout the water column and interacting with larvae while sinking.

Pacific geoduck are an infaunal species with adults sessile after the larval stage. They filter/suspension feeders. Due to this sessile nature, the PoE and risk levels are grouped together for all post-larval life stages.

Sinking oils have a high risk of oil interacting with drift particles and being ingested by post-larval Pacific geoduck. Ingestion of oils can cause physiological issues along with potential mortality in molluscs (Adzigbli and Yuewen 2018). Sinking oil spills in the deep intertidal and subtidal zones have a high risk of interacting with all life stages of

Pacific geoduck through coating and smothering, potentially causing death (Adzigbli and Yuewen 2018).

Weathered Sinking Oil Spill

Sinking oils have little to no weathering effects; therefore, the PoE on Pacific geoduck are the same for fresh and weathered sinking oils.

Figure 14. Pacific geoduck, *Panopea generosa*.

Image © R.M. Harbo

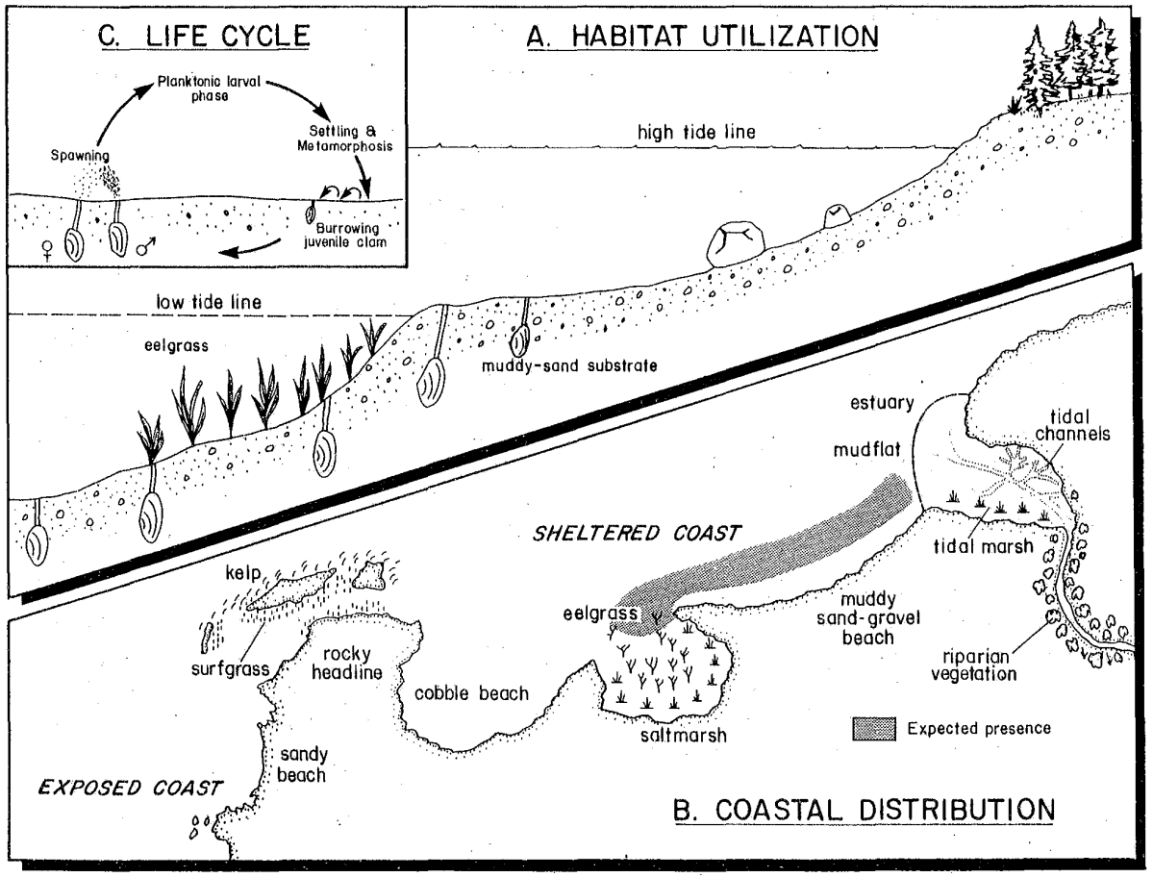

Figure 15. Habitat utilization (A), coastal distribution (B, gray polygons indicate expected presence) and life cycle (C) of Pacific geoduck, *Panopea generosa* (Williams 1989).

J	F	M	A	M	J	J	A	S	O	N	D
1	1	3	3	3	3	3	1	1	1	1	1
		---Spawning---									
1	1	3	3	3	3	3	3	2	1	1	1
		---Larval Presence---									
3	3	3	3	3	3	3	3	3	3	3	3
---Adult Presence---											

Figure 16. Temporal distribution of spawning, larval and adult presence and vulnerability ranks of Pacific geoduck, *Panopea generosa*.

Legend: 1 (green) = low/negligible vulnerability; 2 (yellow) = moderate vulnerability; 3 (red) = high vulnerability.

Table 6. Summary of information required to inform marine emergency response for Pacific oyster, *Panopea generosa.*

Taxonomy
Scientific Name:
Panopea generosa Gould, 1850

Common Name(s):
Pacific geoduck, geoduck, geoduck clam, geoduc, king clam

Higher Taxonomy:
Mollusca; Bivalvia; Apidonta; Hiatellidae

Description
Shell heavy, subquadrate, marked with irregular commarginate striae, gape wide. Siphons long and heavy. Maximum size at least 20 cm shell length, maximum weight 5 kg.

Distribution
Kodiak Island AK to Newport Bay CA, also in the northwestern Pacific.

Habitat Preferences
Infaunal in sand/gravel/mud substrates from lower intertidal to 110 m. Aggregate into high density beds in appropriate habitat.

Physical Tolerances
Salinity
Larvae perform best in salinity near normal seawater, 27.5-32.5‰.

Temperature
Larvae perform best between 6.0-16.0°C, adults can tolerate temperatures above 20°C for limited times. Adult density decreases markedly in areas of low oxygen levels or seasonal hypoxia.

Reproductive Biology
Broadcast spawner with separate sexes. Spawning seasonal, beginning in March and peaking in June-July. Length at maturity approximately 68-75 mm shell length, age at maturity 2-8 years. Fecundity estimated at $7.0x10^6$ to $1.0x10^7$ annually. Individuals may be reproductively active for over a century.

Growth Rate and Lifespan
Growth is rapid in the first 10-20 years, shell growth virtually ceases thereafter other than increasing thickness. Maximum age ~168 years.

Table 6. continued.

Migratory Behaviour Juveniles have some ability to move limited distances and rebury, adults are sessile.
Role in the Ecosystem Filter feeder utilizing phytoplankton and marine organic debris. Post-larvae also exhibit pedal-palp feeding.
Interactions with Native Species Preyed upon by a wide range of invertebrates, fishes and sea otters. Often dominates local communities in terms of biomass.
Significance Target of a major commercial dive fishery in BC and Puget Sound; intertidal portions of populations occasionally harvested by First Nations and recreational harvesters. Some small-scale aquaculture.
Vulnerability **Subgroup Classification**: Subtidal Benthic/Intertidal; Sediment Infauna; Sessile; Mollusca. **Adult Exposure Criteria**: Aggregate in discrete beds; Adults sessile; Primarily subtidal (limited interaction with sea surface); Infaunal (high interaction with sea floor). Score: 3. **Adult Sensitivity Criteria**: Filter/suspension feeder (feeding apparatus can be clogged or damaged by pollutants); Chemical sensitivity assumed to be high. Score: 2. **Adult Recovery Criteria**: Commercial populations monitored, no special status; High age at maturity, successful recruitment sporadic; Broadly distributed in suitable habitats; High degree of interaction with unconsolidated substrates. Score: 2. Adult Cumulative Total Score: 7. **Larval Exposure Criteria**: Aggregate or Patchiness where large number of larvae affected; Low Mobility; Interaction with sea surface. Score: 3. **Larval Sensitivity Criteria**: Larvae feeding appendages that can become clogged by oil; Chemical sensitivity assumed to be high. Score: 2. **Larval Recovery Criteria**: Commercial populations monitored; Relatively high reproductive capacity; Broadly distributed; Low degree of interaction with unconsolidated substrates. Score: 0. Larval Cumulative Total Score: 5

Manila Clam (Venerupis philippinarum)

Significance

Manila clams are an important commercial species in the South and Central Coasts, an important component of recreational and First Nations fisheries and are the primary clam in the aquaculture industry (Gillespie *et al.* 2012).

Vulnerability

Subgroup classification

Manila clams were included in the following subgroups: 1 - Intertidal location for exposure; 2 - Sediment Infauna substrate; 3 - Low mobility; and taxonomy to inform feeding types and reproductive strategies - Mollusca (Thornborough *et al.* 2017, Hannah *et al.* 2017, Jeffery *et al.* 2023).

Exposure

As with many infaunal bivalve molluscs, aggregated distributions of Manila clams are a result of habitat preferences, physiological tolerances and are beneficial for spawning synchrony and fertilization success (Hannah *et al.* 2017).

Manila clams have limited mobility; dispersal is through pelagic larval stages; adults may move short distances but are confined to the beaches on which they settled. They are intertidal in distribution; thus, their populations have a high level of interaction with the sea surface. As infaunal organisms they have intimate contact with the unconsolidated sediments they inhabit.

Sensitivity

As filter/suspension feeders, Manila clams are very sensitive to pollutants that may clog or damage their feeding apparatus. Numerous studies document chemical effects of pollutants on bivalve physiology, reproduction and larval survival.

Recovery

Population status is not actively monitored in British Columbia. Manila clams have high fecundity and high reproductive capacity, but inconsistent recruitment (e.g., Gillespie *et al.* 1998). They are broadly distributed in suitable habitat in southern and central British Columbia (Strait of Georgia, west coast of Vancouver Island and central coast mainland inlets). They are dependent on unconsolidated substrates which can be affected for extended periods due to difficulties removing pollutants that have seeped into the substrate.

Taxonomy

The Manila clam continues to suffer taxonomic confusion in even the most recent literature. The accepted scientific name is *Venerupis* (*Ruditapes*) *philippinarum* (A. Adams and Reeve, 1850)(Coan *et al.* 2000). However, the species still appears in recent literature as *Ruditapes philippinarum* (China, France, Hong Kong, Italy, Japan, Korea, Norway, Spain and the United States); and as *Tapes philippinarum* (Canada, England, Italy, Korea and Spain)(Gillespie *et al.* 2012). This species has also historically been reported under the trivial name *semidecussata* and was previously assigned to the trivial name *japonica*. Coan *et al.* (2000) listed 11 junior synonyms and one subspecies that is no longer valid, with the comment that additional synonyms were known from western Pacific literature.

The common name accepted by the American Fisheries Society in the United States is Japanese littleneck (Turgeon *et al.* 1998, Coan *et al.* 2000), although the vernacular Manila clam is commonly used in Canada and Pacific Northwest states (Table 7). Some agency documents and websites refer to this species as Manila littleneck.

Description

Manila clams are generally longer than they are high, resulting in an oblong profile (as compared to the more circular profile of the native Pacific littleneck clam, *Leukoma staminea*). The valves are thick and marked with both radial and concentric sculpture with the radial striae more pronounced on the posterior part of the valves (Figure 17). A lunule is present as a flat area or depressed pit anterior to the umbo and lacks the ridge present in *L. staminea*. The inner margin of the shell is smooth and lacks crenulations on the ventral margin that are present in the Pacific littleneck clam (Figure 18). The interior of the valves is white or yellow with deep purple at the posterior end. The outer surface of the valves varies from uniform gray or brown to brightly coloured individuals with two red radial markings surrounded by darker blue. Larger animals are generally less colourful. Maximum size is approximately 75 mm (Quayle and Bourne 1972, Quayle 1974, Abbott 1974, Kozloff 1996, Harbo 1997, Coan *et al.* 2000).

Distribution

Native Distribution

The native range of *V. philippinarum* is the western Pacific from the Kuril Islands, Sakhalin Island, and Russia, through Japan and Korea to China and Hong Kong (Coan *et al.* 2000, Gillespie *et al.* 2012).

Introductions

Manila clams were unintentionally introduced to Ladysmith Harbour, BC, with Pacific oyster seed in the 1930s where they were initially described as a new species, *Paphia bifurcata* (Quayle 1938, 1941). They quickly spread through the Strait of Georgia (Neave 1949) and the west coast of Vancouver Island from Barkley Sound to Esperanza Inlet (Quayle 1964). Carlton (1979) indicated that Manila clams were found throughout the southern Strait of Georgia by the mid-1940s and to Jervis Inlet and Cortes Island prior to 1950. Bourne (1979) implied that Manila clams had made their way to the west coast of

Vancouver Island with Pacific oysters; Manila clams had spread at least as far as Esperanza Inlet in the 1950s (Quayle 1974) and were found in Quatsino Sound in the 1960s (Quayle and Bourne 1972; Bourne 1979, 1982, 1997).

Manila clams are the primary clam species cultured in BC. Most aquaculture tenures are in the Strait of Georgia (primarily Baynes Sound) and the west coast of Vancouver Island (Gillespie *et al.* 2012).

Manila clam stocks on the west coast of Vancouver Island are well established and of sufficient abundance and productivity to support large commercial fishery landings in addition to recreational and First Nations utilization (Bourne and Farlinger 1982, Adkins and Harbo 1991). Recent exploratory surveys showed Manila clams to be abundant on selected beaches in Barkley, Clayoquot and Kyuquot Sounds and in Winter Harbour, Klaskino and Ououkinsh Inlets (Gillespie and Bourne 2005a, Gillespie *et al.* 2004). They were less abundant in Esperanza, Nasparti and Klaskish Inlets and a survey in 1993 found them to be present at low densities in Quatsino Sound (Bourne and Heritage 1997).

Manila clams were reported from the North Coast of BC at Spider Anchorage in 1972 and the Bella Bella area in 1980 (Bourne 1979, 1982). Numerous exploratory surveys between 1990 and 2004 documented widespread and abundant Manila clam populations near Bella Bella (Bourne and Cawdell 1992, Bourne *et al.* 1994, Heritage *et al.* 1998, Gillespie and Bourne 2000, 2005b; Gillespie *et al.* 2004) and a fishery was developed in 1992 that continues to the present (Gillespie *et al.* 1999a, 2001a).

Exploratory surveys did not locate Manila clams in the extreme north coast of BC (Bourne and Cawdell 1992, Gillespie and Bourne 1998, 2000; Gillespie 2007). Manila clams were present at low to moderate abundances on selected beaches in the central coast of BC (Bourne and Cawdell 1992, Heritage *et al.* 1998, Gillespie and Bourne 2000, 2005b; Gillespie *et al.* 2004).

The current northern limit in the eastern Pacific is Laredo Inlet, BC (Gillespie and Bourne 2000, Gillespie *et al.* 2004). Attempted introductions further north in Masset Inlet and Naden Harbour in 1962 and Cosine Island in 1969 were not successful (Bourne 1979, 1982; Gillespie and Bourne 1998, 2000). Eight specimens from the southern Queen Charlotte Islands (Burnaby Narrows and Murchison-Faraday Passage) attributed to this species (Sloan *et al.* 2001) were re-examined at the Royal BC Museum and found to be small *Leukoma staminea* (Gillespie *et al.* 2012). An anecdotal record of Manila clams north of Prince Rupert at Pearl Harbour, was not verified by voucher specimens or by brief visits by DFO staff to the area on at least three occasions.

On the west coast of the United States, Manila clams are found in Puget Sound, Grays Harbour and Willapa Bay, Washington, and from Humboldt Bay to Elkhorn Slough in California (Coan *et al.* 2000, Wasson *et al.* 2005). The intimation of Nosho and Chew (1972) that Manila clams occurred in Southeast Alaska are either in error or a mis-interpretation of an adventitious record (Carlton 1979).

Manila clams have been introduced to all the major seas of Europe (Aegean, Arctic, Atlantic, Baltic, Black, Mediterranean and North)(Albayrak *et al.* 2001, Jensen *et al.* 2004, Streftaris *et al.* 2005). Naturally sustained populations exist in England, France, Italy, Turkey (Albayrak *et al.* 2001, Breber 2002, Blanchet *et al.* 2004, Jensen *et al.* 2004). They

have also been introduced to Hawaii, Tahiti and the US Virgin Islands and naturally sustained populations still exist in Kaneohe Bay and Pearl Harbour (Gillespie *et al.* 2012).

Habitat Preferences

Manila clams are found in the upper half of the intertidal zone in substrates of gravel, sand and mud, primarily in inside or protected waters (Quayle 1974)(Figure 19). Because their siphons are short, they live in shallow (maximum 10 cm depth, Harbo 1997), transitory burrows in the substrate and are susceptible to extremes of temperature, including catastrophic mortalities termed "winter kills". These can occur when night-time low tides coincide with low air temperatures and prevailing winds (Bower 1992).

Role in the Ecosystem

Trophic Ecology

Manila clams are filter feeders, collecting microscopic prey and organic matter from the water column (Purchon 1968). Water is drawn into the mantle cavity through the inhalant siphon and food particles are collected on the ctenidia (gills) and moved to the mouth on ciliary strands of mucous. Materials that arrive at the mouth are sorted by the labial palps and either ingested or rejected and passed to the exhalent siphon. Feeding occurs only when the clam is immersed in water; when the tide recedes, the valves are closed tightly and feeding is suspended until the tide covers the clam again (Cesari and Pellizzato 1990). Most of the respiratory exchange in filter feeding bivalve molluscs takes place through the mantle rather than the ctenidia (Purchon 1968, Cesari and Pellizzato 1990).

Unlike some bivalves that browse organic matter from the surface layers of the substrate (e.g., *Tellina*, *Macoma*) or collect organic matter from deep in the substrate by pedal feeding (e.g., *Lucina*, *Thyasira*, *Nuttallia*), adult Manila clams are obligate filter feeders (Purchon 1968, Gillespie *et al.* 1999b).

Ecological Interactions

Greatest concentrations of Manila clams are generally found higher in the intertidal zone than where most native species occur. There is some overlap with Pacific littleneck clams (*Leukoma staminea*) although greatest concentrations of this species occur on the middle to lower intertidal zone. There is little to no overlap with butter clams (*Saxidomus giganteus*).

Manila clams are prey for Lewis' moonsnail (*Euspira lewisi*), sunstar (*Pycnopodia helianthoides*), pink (*Pisaster brevispinis*) and mottled stars (*Evasterias trochellii*), although less so than native species that live lower in the intertidal zone (Quayle and Bourne 1972, Harbo 1997). Lambert (2000) reported several species of sea stars that ate bivalve molluscs (e.g., sand star (*Luidia foliata*), rose star (*Crossaster papposus*), rainbow star (*Orthasterias koehleri*)), but few venture high enough in the intertidal zone to seriously impact Manila clams. Another potential predator listed by Quayle and Bourne (1972), the ochre star (*Pisaster ochraceus*) is found intertidally but prefers hard substrates where it

feeds primarily on mussels, barnacles, limpets and snails. Chew (1989) reported predation of Manila clams by red rock (*Cancer productus*) and graceful (*Metacarcinus gracilis*) crabs and Toba *et al.* (1992) indicated that Dungeness crab (*Metacarcinus magister*) and kelp crab (*Pugettia producta*) were potential predators. Small Manila clams were also preyed on by shore crabs (*Hemigrapsus nudus* and *H. oregonensis*) in a laboratory setting, but this has not been observed in the field (Bourne and Lee 1973, Toba *et al.* 1992). European green crabs prey on Manila clams (Palacios and Ferraro 2003, Curtis *et al.* 2012).

Small Manila clams are eaten whole by rock sole (*Lepidopsetta bilineata*), English sole (*Parophrys vetulus*), starry flounder (*Platichthys stellatus*) and pile perch (*Rachochilus vacca*) and siphons of adult Manila clams may be cropped by Pacific staghorn sculpin (*Leptocottus armatus*), which are known to crop *Protothaca* siphons in California (Anderson *et al.* 1982, Peterson and Quammen 1982). Clams with the siphon tips removed burrow shallower and may be subject to increased lethal predation (Meyer and Byers 2005).

Many ducks utilize a wide range of bivalves in their diets and some may make limited use of Manila clams, including greater scaup (*Aythya marila*), Barrow's and common goldeneye (*Bucephala islandica* and *B. clangula*) and long-tailed duck (*Clangula hyemalis*)(Vermeer 1981, Anderson *et al.* 1982, Gibbons and Blogoslawski 1989). However the primary anatid predators on Manila clams are surf scoters (*Melanitta deglandi*), white-winged scoters (*M. fusca*) and black scoters (*M. nigra*)(Glude 1963, Vermeer 1981, Bourne 1984, 1989; Vermeer and Ydenberg 1989).

Numerous species of migratory shorebirds may make use of Manila clams as prey; in particular dunlin (*Caladris alpina*), which have been documented to utilize other intertidal bivalves (*Macoma*, *Mytilus* and *Protothaca*) in the Strait of Georgia (Verbeek and Butler 1989). They are also eaten by northwestern crow (*Corvus caurinus*)(Richardson 1985, Verbeek and Butler 1989, O'Brien *et al.* 2005) and glaucous-winged gull (*Larus glaucescens*), who remove them from the substrate and drop them on hard surfaces to break the shells (Bourne 1989, Gibbons and Blogoslawski 1989).

Potential mammalian predators include sea otter (*Enhydrus lutra*) and racoon (*Procyon lotor*)(Gibbons and Blogoslawski 1989). Humans also affect Manila clam populations through transplants, enhancement, harvests or habitat impacts.

Several species of pea crabs are known to occur in British Columbia (Hart 1982), some of which (*Pinnixia faba*, *Fabia subquadrata*) have been found in the mantle cavity of Manila clams. However the prevalence and intensity of pea crabs in most Manila clam populations is low (Bower *et al.* 1992, Marshall *et al.* 2003).

Physical Tolerances

It is common for the early embryos and larvae of bivalve molluscs to have narrower environmental requirements than adults (Malouf and Bricelj 1989). Malouf and Bricelj (1989) reported thermal tolerances of 4-30°C for adult Manila clams and 14-27°C for larvae. Chew (1989) reported temperature tolerance for larval Manila clams as 0-36°C with the optimum being 23-24°C. Ohba (1959) reported decreased size and lifespan in natural populations where temperatures exceeded 15°C for much of the year, exceeded 20°C for four months of the year and reached a maximum of 26°C. Holland and Chew (1974)

reported broader ranges of size and age in a natural population where temperatures exceeded 15°C for four months of the year, but only exceeded 20°C for limited periods. Mann (1979) reported increased mortality and decreased dry meat weight in clams maintained at 21°C, coincident with the onset of spawning. This led Mann to postulate that large animals suffered a large negative energy balance under conditions of temperature stress (>20°C) post-spawning. Shpigel and Fridman (1990) reported good growth, spawning and low mortality for Manila clams grown at mean monthly temperatures of 13-23°C (range 11-31°C) in Israel.

Minimum temperature required for gonadal activation was 8°C (Mann 1979; Bourne 1982). Minimum temperature required for gonadal development was 12°C and for spawning was 14°C (Mann 1979). Helm and Pellizzato (1990) reported commencement of gonad maturation at 8-10°C and spawning at 20-31°C in Italian hatcheries.

Manila clams are euryhaline and occur throughout a wide range of salinities. Haderlie and Abbott (1980) reported that Manila clams were tolerant of salinities 30-50% of pure seawater. Malouf and Bricelj (1989) reported salinity tolerance for adult Manila clams to be 14-35‰. Chew (1989) reported salinity tolerances of 13.5-35‰ for adult Manila clams with the optimum being 24-32‰. Elston *et al.* (2003) reported that salinities ≤10‰ were lethal to adult clams and that 12.5‰ was marginal for survival; they also noted that mortality rate may depend in part on the rate at which they are re-acclimated to higher salinities. Manila clams grown in mariculture pond effluent in Israel survived well and grew in a salinity of 41‰ (Shpigel and Fridman 1990).

In a hatchery setting, salinities of 25-35‰ are recommended; although juveniles and adults can tolerate greater or lesser salinities for short periods of time, larvae and newly settled seed cannot (Helm and Pellizzato 1990). Malouf and Bricelj (1989) did not report a range for larvae, only stating that rearing had been successful at 35‰. Larvae held at 8‰ failed to survive, those held at 12‰ survived but did not behave normally, while larvae held at ≥15.5‰ behaved and survived like larvae held at higher salinities (Numaguchi 1998, cited in Elston *et al.* 2003).

In Italian hatcheries, Manila clam larvae developed from D-hinge stage through veliger and pediveliger to settlement as spat in approximately 16 days at 25°C and 30-33%(Helm and Pellizzato 1990, their Figure 2). Fertilized eggs developed best at salinities of 26-33‰ and temperatures of 18-23°C, although the optimal temperature was stated to be 23-26°C (Helm and Pellizzato 1990). Lower temperatures slowed development while higher temperatures increased bacterial infection (Helm and Pellizzato 1990).

Reproductive Biology

Manila clams in British Columbia and Puget Sound begin gonadal development in the spring, with late active clams appearing in mid-April and ripe clams by mid-June (Holland and Chew 1974; Bourne 1982). Spawning began in Puget Sound in late May and peaked in August, and began in June in BC as larvae were found in plankton samples taken at the end of June (Figure 20). Spawning ended in October-November, when temperatures declined, and partially spawned individuals resorbed residual gametes. Spawning occurs over several months with two peaks of settlement observed in Puget Sound; a minor event in July and a major event in September (Bourne 1982).

Manila clams are reported to spawn once a year in northern Japan, twice a year (late spring and early-late fall) in southern Japan, twice a year in Italy and France, and three times a year in Spain (Bourne 1982, Breber 2002). Ponurovsky and Yakolev (1992) reported spawning periods of May-August in southwestern Russia, June-August in Hokkaido, February-May and July-December in southern Japan, May-August in Korea, September-December in China, May-September in France, February-April and August-September or November-December in US Virgin Islands, and year-round in Israel and Hawaii. Clams that were ripe year-round in the US Virgin Islands and Israel were cultured at relatively high temperatures and constant food supplies (Rodde *et al.* 1976, Shpigel and Fridman 1990).

Size at first maturity is considered to be 15-20 mm total length (TL), which corresponds to an age of approximately one year (Holland and Chew 1974). Some smaller clams (5-10 mm TL) developed sperm and oocytes but did not spawn. There is evidence of serial hermaphrodism in Mania clams from Primorye, Russia on the northwest Sea of Japan (Ponurovsky and Yakolev 1992). Small clams (<15 mm TL) produced sperm in their first spawning season, the sexes were balanced in later spawnings and there was a larger proportion of females in older age classes of some populations. Helm and Pellizzato (1990) reported that Manila clams were protandric hermaphrodites with older clams either turning into females or remaining as functional males.

Partially spawned clams have been collected in northern BC as early as May, although these may be clams that did not spawn the previous fall, did not fully resorb the unspawned gametes and overwintered in this condition (N.F. Bourne, DFO, pers. comm). Development is slower in Johnstone Strait and Quatsino Sound, as most clams were in late active or ripe stages in July. This is in contrast to Hood Canal, where peak spawning was recorded July through September (Holland and Chew 1974).

In Ireland, although adult clams were able to ripen, it was uncertain whether ripe gametes were released by spawning or resorbed (Xie and Burnell 1994). They also noted that spawning was delayed (peak spawning from September to February) due to low temperatures and that reproduction was not successful, likely because water temperatures post-spawning were not conducive to larval development. It is likely that delayed spawning in northern BC would result in larvae failing to develop due to low water temperatures in the fall.

Fecundity increases with size in Manila clams, with estimates ranging from 432,000 eggs (20 mm TL) to 2,350,000 eggs (40 mm TL)(Hawaii), 188,000 eggs (19 mm TL) to 1,503,000 (42 mm TL)(China) and 945,000 (34 mm TL) to 11,794,000 (42 mm TL)(Korea)(Gillespie *et al.* 2012).

Early Life History

Larval development requires approximately three weeks in BC (Bourne 1982) and two to four weeks in Washington State (Toba *et al.* 1992); exact duration depends on temperature

and food supply. Larvae settle at sizes of 165-235 μm (Chew 1989); they actively seek suitable substrate, attach with a byssal thread and undergo metamorphosis to an infaunal juvenile.

Growth Rates and Life Span

Bourne (1982) calculated growth rates for Manila clams in different areas of BC. Growth was most rapid in the Strait of Georgia, followed by the west coast of Vancouver Island, the Central Coast and Queen Charlotte Strait. Manila clams reached the legal size limit (38 mm TL) in 3.5 years in the Strait of Georgia, 4.0 years on the west coast of Vancouver Island, 5.0 years in the Central Coast and 5.5 years in Queen Charlotte Strait. Growth rates calculated from recent exploratory surveys provide similar information; legal size (38 mm TL) was attained after 3.5-6.0 years in PFMA 6 and 7, after 3.0-4.5 years in PFMA 8 through 11, after 3.5-6.5 years in Johnstone Strait (PFMA 12 and portions of 13), and 3.5-5.5 years on the west coast of Vancouver Island with growth being somewhat slower in some northern locations (Winter Harbour, Quatsino Sound and Ououkinsh Inlet). For comparative purposes, age to legal size was approximately 4.0-5.0 years in Clayoquot Sound (Bourne and Farlinger 1982), 3.5-5.3 for four beaches in southern Strait of Georgia (Gillespie and Bond 1997) and 4.0-6.5 years for Savary Island in the northern Strait of Georgia (Gillespie *et al.* 1998).

Growth is rapid for the first 4-5 years and slower thereafter. Growth is dependent on substrate type and tidal height occupied on the beach, so growth rates often vary within populations on a given beach depending on where on the beach the clams are found. Maximum size reported from BC is 79 mm TL, although most clams in a population are considerably smaller. Maximum age reported from BC is 14 years (Bourne 1987). Under culture conditions, growth is much more rapid; Manila clams reached sizes of 38 mm TL in 13 months in an upwelling system in the US Virgin Islands (Rodde *et al.* 1976) and 30-35 mm TL in 16-18 months in a tray system in Israel (Shpigel and Fridman 1990).

Pathways of Effects (PoE): Oil Exposure

A Pathways of Effects (PoE) oil exposure model can aid oil spill emergency response by identifying low to high-risk scenarios for species exposure. This section describes PoE for Manila clam through exposure paths of specific species life stages and the potential dispersion and fates of five oil groups (Table 2). The specific environmental conditions and chemical signature of the oil spill should be taken into consideration as they may cause differences in the outcomes described in this document. A summary table for this section is available in Appendix Table 5.

Habitat utilization and temporal distribution of spawning, larval and adult presence and vulnerability ranks of Manila clam are illustrated in Figure 19 and Figure 20 with vulnerability ranking scores for Manila clam generalized for all oil groupings as 5 for the larval life stage and 7 for adult life stages (Jeffery *et al.* 2023).

Group 1 Oils

Group 1 contains gasoline and marine diesel oil (MDO). Both gasoline and MDO are light, volatile, and acutely toxic oils (ITOPF 2011a). The two oils are split into subcategories due to differences in fate and behaviour, causing different potential PoE on Manila clams.

Gasoline

Gasoline has high concentrations of LMW hydrocarbons which may cause both acute and chronic toxic effects on aquatic organisms (ITOPF, 2011b). Possible toxic effects include mortality (Keesing *et al.* 2018), decreased locomotive ability, damage to feeding apparatuses, decreased immunity and other physiological decreases (Adzigbli and Yeuwen 2018).

Fresh Gasoline Oil Spill

Gasoline is very light, having a specific gravity of <0.8, causing it to float and only be present on the top 1-2 mm of the water column (ITOPF 2011a). Manila clam spawning occurs in summer (June - September) in BC (DFO 2018). Successful fertilization and larval development occurs only under the appropriate water conditions which may be impacted by properties of a spill material (Table 7). Clam eggs and larvae are dispersed by currents with the trochophore larval phase extending three to four weeks post fertilization. Mature larvae settle during a "spatting" phase on appropriate sandy to gavel substrate in the upper intertidal zone (Harbo 2011). Due to gasoline remaining on the top of the water, risk of larval exposure is low during low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion throughout the water column increasing the potential of exposures.

Mature Manila clams are infaunal and can move through the substrate using a long muscular foot. They feed and breathe by extending a short dual-pipe siphon towards the surface. Clams are very sensitive to pollutants that may clog or damage their feeding apparatus. Manila clams also pedal feed by collecting organic detritus from the sediment using the foot. Larval Manila clams filter feed and continue with a suspension fed diet in the mature and adult phases. They draw water into the body filtering out phytoplankton, zooplankton and detritus as their food source. Due to their general infaunal nature, the PoE and risk levels are the same for all post-larval life stages.

Adult Manila clams are irregularly distributed close to the substrate surface (10 cm) due to their shorter siphon length (DFO 2018). They are found in a wide variety of unconsolidated substrates, but the typical medium is a porous mixture of substrates including of gravel, sand and mud, which can enable contaminants such as gasoline to infiltrate during tidal activity. Given the intertidal habitat of adult Manila clams, gasoline spills in the intertidal zone pose a high risk. Oil spills in intertidal zones have historically caused high mortality in bivalve molluscs such as Manila clam (Keesing *et al.* 2018).

Weathered Gasoline Oil Spill

Gasoline is highly volatile and can completely evaporate within 24 hours; as gasoline weathers the risk to Manila clams decreases. Weathered gasoline is unlikely to pose any risks to Manila clams as it evaporates and disperses very quickly.

Marine Diesel Oils (MDO)

Fresh MDO Oil Spill

Fresh MDO has similar potential PoE for Manila clam as gasoline. Fresh MDO has high aquatic toxicity due to high concentrations of LMW hydrocarbons (Environment Canada 1999). As with gasoline, MDOs have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring in low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion and dissolution. MDO's spreading through the water column may increase the risk of exposure with larva and drift particles. In high energy ocean conditions, the risk of this occurring is high. Free-swimming larvae are present during the spawning period of June to September (DFO 2018).

Post-larval Manila clams burrow and move through the substrate using a long muscular foot. Due to general low mobility and infaunal nature, the PoE and risk levels are the same for all post-larval life stages.

Fresh MDO spills in the intertidal zone have a high risk of impacting Manila clams. MDO spills remain on the surface of the water; however, when tide recedes the intertidal zone will be exposed to the MDO spilled on the surface. Possible effects may include coating, smothering, ingestion and habitat modification, which may inhibit spawning. Intertidal zone oil spills have historically caused high mortalities in molluscs (Keesing *et al.* 2018).

Weathered MDO Oil Spill

As MDOs weather aquatic toxicity decreases as the light molecular weight hydrocarbons evaporate. MDO still poses potential risks to Manila clams through coating, smothering and ingestion (ITOPF 2011b). The persistence of MDO causes weathered MDO to pose many of the same potential effects on Manila clams as fresh spills. Manila clam larvae still have the potential to interact with the oil spill on the surface of the water with potential effects including coating and smothering, likely without acute toxic effects. The risk of this effect remains low in low energy ocean conditions. In high energy ocean conditions, the risk of this occurring is high.

MDO is persistent and has the potential to interact and adsorb to drift particles within the water column (ITOPF 2011a). Mature Manila clams mainly feed on drift particles including detritus (organic materials) and plankton. As such, interaction and adsorption to these drift particles by MDO causes the potential for Manila clams to ingest MDOs. The risk of this occurring is high.

Given the persistence of MDO, weathered MDO in the intertidal zone still poses a risk to Manila clams. Effects include coating, smothering, and habitat modification. Intertidal zone oils spills can cause high mortality in molluscs (Keesing *et al.* 2018).

Group 2 Oils

Light Crude Oils (LCOs)

Group 2 oils are LCOs which contain moderate to high concentrations of hydrocarbons which cause acute and chronic toxic effects on aquatic organisms (Adzigbli and Yeuwen 2018). LCOs can cause additional negative effects through coating and smothering aquatic organisms. There are similar PoE between Group 2 and Group 1 (Appendix Table 5).

Fresh LCO Oil Spill

As with Group 1 oils, LCOs have a potential to interact with larvae at the water column surface; however, there is a low risk of this occurring in low energy ocean conditions. High energy ocean conditions can increase dispersion and dissolution causing a high risk of larval exposure at depth. Free-swimming larval Manila clams are present during the spawning period of March to July, with the peak occurring June to September (DFO 2018).

Post-larval Manila clams burrow and move through the substrate using a long muscular foot. Due to the general low mobile and fossorial nature, the PoE and risk levels are the same for all post-larval life stages.

Fresh LCO spills in the intertidal zone have a high potential to impact mature Manila clams. Mature Manila clams reside in the substrate within the upper intertidal with high potential for interaction with an oil spill at the water's surface. Manila clams would be exposed to the oil spill as the tide recedes.

Weathered LCO Oil Spill

As LCOs weather their acute toxicity decreases as the LMW hydrocarbons evaporate; however, the same potential PoE and risks to Manila clams remain. LCOs persist and can form stable emulsions, leading to increased volume and specific gravity of the spill (ITOPF 2011a). The PoE for weathered light crude oils are increased for Manila clams, through its greater presence in the water column and potential for ingestion.

Light crude oils persist as they weather causing the potential for them to interact with drift particles throughout the water column potentially absorbing to drift algae. The interaction between light crude oils and drift algae leads to the potential for ingestion, causing toxic and potentially fatal effects (Adzigbli and Yuewen 2018). The risk of this occurring is high.

Group 3 Oils

Group 3 contains engine/hydraulic oil, medium crude oil, heavy crude oil, and dilbit oil. Group 3 oils are heavy and persistent, while not being as toxic as Group 1 and 2 oils (ITOPF

2011a, 2011b). There are many similar PoE between Group 3 and Group 1 oils (Appendix Table 5).

Fresh Group 3 Oil Spill

As with Group 1 oils, Group 3 oils have a potential to interact with larvae at the water surface; however, there is low risk of this occurring in low energy ocean conditions. As with previous oil groups, high energy ocean conditions can cause increased dispersion and dissolution causing the potential for interaction with larvae and drift particle food sources throughout the water column. Free-swimming larval Manila clams are present during the spawning period of June to September (DFO 2018). The mechanisms and details of this PoE are summarized in Appendix Table 5.

Post-larval Manila clams burrow and move through the substrate using a long muscular foot. Due to the general low mobile and fossorial nature, the PoE and risk levels are the same for all post-larval life stages.

Fresh Group 3 oil spills in the intertidal zone have a high potential to impact post-larval Manila clams. Manila clams reside under the substrate within the upper intertidal zone, with high potential for interaction with an oil spill at the water's surface. They are dependent on substrates which can be affected for extended periods due to difficulties removing pollutants that have seeped into the substrate. Manila clams would be fully exposed to the oil spill as the tide recedes.

Weathered Group 3 Oil Spill

As Group 3 oils weather, little to no evaporation occurs; however, sedimentation can occur causing the oils to sink (ITOPF 2011a). Due to Group 3 oils persistence the PoE and risks of effects remain similar for all life stages of Manila clam.

Possible sinking due to sedimentation creates a greater risk of exposure for larval Manila clams. Sinking oil may interact directly with larvae through coating and smothering, causing feeding apparatuses to not work properly (ITOPF 2011b). Sinking oil may also interact with detritus and plankton, a mussel food source causing mussels to ingest the oil. Ingestion of oil can cause damage to feeding apparatuses, decreased immunity, along with other physiological decreases (Adzigbli and Yuewen 2018). There is a high risk of this occurring.

Group 4 Oils

Group 4 oils are Bunker C oils. Bunker C oils are heavy and highly persistent oils (Environment Canada 1999). Bunker C oils contain few toxic light molecular weight hydrocarbons meaning they have little to no acute toxic effects on aquatic organisms (Environment Canada 1999). Bunker C oils still pose risk through coating and smothering as well as chronic effects due to heavier toxic hydrocarbons (Adzigbli and Yuewen 2018).

Fresh Bunker C Oil Spill

Bunker C oils have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring. High energy ocean conditions can cause increased dispersion and dissolution causing the potential for interaction with larvae throughout the water column. Larval Manila clams are present during the spawning period June to September (DFO 2018). Negative effects that interactions may have on Manila clam differ from previous oils given lower concentrations of LMW hydrocarbons, causing less acute toxic effects. Physical and chronic effects may still pose a risk.

Post-larval Manila clams burrow and move through the substrate using a long muscular foot. Due to the general low mobile and fossorial nature, the PoE and risk levels are the same for all post-larval life stages.

Bunker C oil spills in the intertidal zone have potential to cause high bivalve mortalities, including Manila clams, through coating and smothering (Adzigbli and Yuewen 2018). Manila clams would be exposed to the Bunker C oil spill as the tide recedes in the intertidal zone.

Weathered Bunker C Oil Spill

There are little weathering effects on Bunker C oil given its low concentrations of volatile LMW hydrocarbons and high persistence (ITOPF 2011a). The PoE are similar between weathered and fresh Bunker C oils; however, Bunker C oils are susceptible to creation of stable emulsions, causing increased volume and specific gravity and potential for sinking and sedimentation-caused sinking (ITOPF 2011a).

PoE risks that weathered Bunker C oil may have on Manila clams are increased in weathered oils. If sinking occurs through emulsions forming or sedimentation, Manila clams are at a greater risk of oil exposure. Sinking oils could coat and smother larval Manila clams causing locomotion and feeding issues or potentially mortality, even in the lower intertidal and subtidal zones (Adzigbli and Yuewen 2018). There is a high risk of this occurring.

Group 5 Oils

Group 5 oils are extremely heavy and persistent oils known as sinking oils. Sinking oils have a specific gravity <1, causing them to readily sink in water (ITOPF 2011a). Group 5 oils have a high potential to negatively impacting Manila clams at all life stages.

Fresh Sinking Oil Spill

Free-swimming larval Manila clams are present during the spawning period of June to September (DFO 2018). Sinking oils have a high risk of interacting with the larvae of Manila clams at all potential ocean energy scenarios, given the potential of oil being present throughout the water column and interacting with larvae while sinking, particularly during the spatting phases.

Post-larval Manila clams burrow and move through the substrate using a long muscular foot. Due to the general low mobile and fossorial nature, the PoE and risk levels are the same for all post-larval life stages.

Sinking oils have a high risk of oil interacting with drift particles and being ingested by post-larval Manila clams. Ingestion of oils can cause physiological issues along with potential mortality in molluscs (Adzigbli and Yuewen 2018). Sinking oil spills in the deep intertidal and subtidal zones have a high risk of interacting with all life stages of Manila clams through coating and smothering, potentially causing death (Adzigbli and Yuewen 2018).

Weathered Sinking Oil Spill

Sinking oils have little to no weathering effects; therefore, the PoE on Manila clams are the same for fresh and weathered sinking oils particularly where there are difficulties removing pollutants that have seeped into the substrate.

Figure 17. Manila clam, *Venerupis philippinarum*.

Images © Rick Harbo.

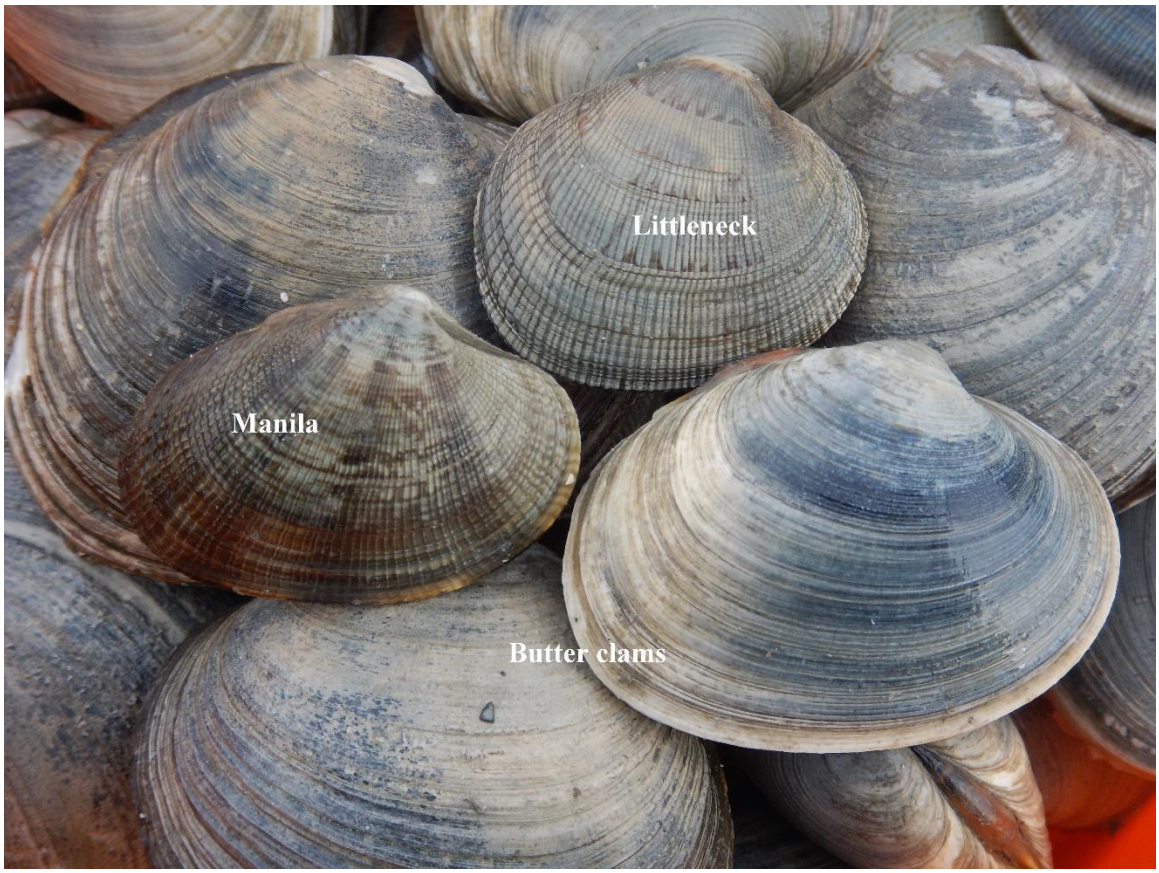

Figure 18. Comparison of exterior sculpture of littleneck (*Leukoma staminea*), butter (*Saxidomus gigantea*) and Manila (*Venerupis philippinarum*) clams

Image © R.M. Harbo

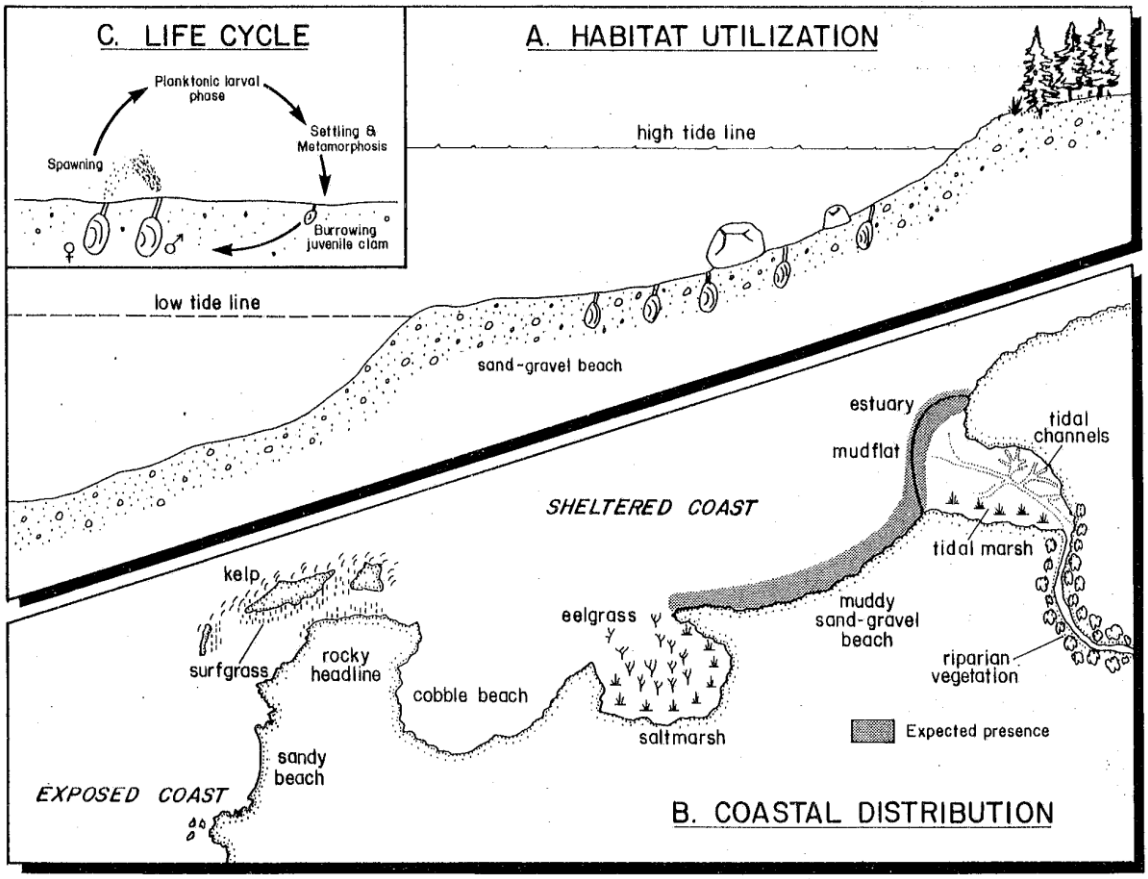

Figure 19. Habitat utilization (A), coastal distribution (B, gray polygons indicate expected presence) and life cycle (C) of Manila clam, *Venerupis philippinarum* (Williams 1989).

J	F	M	A	M	J	J	A	S	O	N	D
1	1	1	1	1	3	3	3	2	2	1	1
					---Spawning---						
1	1	1	1	1	3	3	3	3	2	1	1
					---Larval Presence---						
3	3	3	3	3	3	3	3	3	3	3	3
---Adult Presence---											

Figure 20. Temporal distribution of spawning, larval and adult presence and vulnerability ranks of Manila clam, *Venerupis philippinarum*.

Legend: 1 (green) = low/negligible vulnerability; 2 (yellow) = moderate vulnerability; 3 (red) = high vulnerability.

Table 7. Summary of information required to inform marine emergency response for Manila clam, *Venerupis philippinarum*.

Taxonomy
Scientific Name:
Venerupis (*Ruditapes*) *philippinarum* (A. Adams and Reeve, 1850)

Common Name(s):
Japanese littleneck, asari, Asian littleneck, Japanese carpet shell, Japanese cockle, Filipino venus, Manila clam, Manila littleneck, Pacific carpet clam, Pacific palourde, ribbed carpet shell, short-neck clam, steamer clam.

Higher Taxonomy:
Mollusca; Bivalvia; Heterodonta; Veneroida; Veneroidea; Veneridae.

Description
Medium sized venerid clam, oval in outline, radial and concentric sculpture, lunule flat or concave, variable color on outside of valves from uniform grey or brown to red and black radial rays, inside of valves yellow or white with purple stain at posterior end, lacks crenulations on inner ventral margin, siphon tips split.

Distribution
Native
Sakhalin Island and Kuril Islands, southwestern Russia and northern Japan through Korea to China and Hong Kong.

Introductions
Central and southern British Columbia from Laredo Inlet (51°59'N) to Puget Sound, Grays Harbour and Willapa Bay, Washington, and from Humboldt Bay to Elkhorn Slough in California. Also, Tahiti, US Virgin Islands, Hawaii, U.K., France, Spain, Italy, Germany Belgium, Israel and Tunisia. Established populations in western North America, Hawaii, England, France and Italy.

Habitat Preferences
Intertidal, from approximately 1 m above MLLW to the upper third of the intertidal zone. Protected beaches, preferring gravel, sand and mud.

Physical Tolerances
Salinity
Euryhaline. Adults tolerant of salinities 13.5-35‰, optimally 24-32‰. Salinities ≤10‰ lethal to adult clams, 12.5‰ marginal for survival. Larvae develop optimally at 25-35‰.

Temperature
Minimum temperatures for gonadal activation was 8°C, for gonadal development was 12°C and for spawning was 14°C. Thermal tolerance of adults 4-30°C and for larvae 0-36°C with optimum 23-24°C.

Table 7. continued.

Reproductive Biology Sexes separate, broadcast spawner with external fertilization. Extended spawning period in south and central BC, June-November. Successful recruitment sporadic. Fecundity high (1.5-11.7 million eggs/female).
Growth Rate and Lifespan Eggs developed best at 26-33‰ and 18-23°C, optimal temperature 23-26°C. Larvae developed to settlement in approximately 16 days at 25°C and 30-33‰. Growth rapid through 4-5 years, slower at greater ages. Individual growth variable dependent on substrate and tidal height. In BC, reach legal size (38 mm TL) in 3.5-5.0 years. Maximum age in BC approximately 14 years.
Migratory Behaviour Adults are confined to beaches they settle on. Dispersal only through pelagic larval stages. Pelagic larval stage approximately three weeks in BC.
Role in the Ecosystem Obligate filter feeder ingesting plankton and suspended organic matter from the water column. Preyed upon by gastropods, sea stars, crabs, flatfish, seaperch, sculpins diving ducks, shorebirds, racoons and sea otters. Some fishes engage in siphon cropping. Host juvenile pinnotherid pea crabs.
Interactions with Native Species Generally found higher in the intertidal zone than most native species. Some overlap with littleneck clams although greatest concentrations of this species occur on the middle to lower intertidal zone. Little to no overlap with butter clams. Little evidence of competition with *Leukoma* and *Saxidomus*. When found together, varnish clams extend higher in the intertidal or varnish clams burrow deeper than Manila clams. No evidence of hybridization with native species.
Significance Important commercial species in the South and Central Coasts, important component of recreational and First Nations fisheries. Primary clam in the aquaculture industry.

Table 7. continued.

Vulnerability **Subgroup Classification**: Intertidal/Subtidal Benthic; Sediment Infauna; Low Mobility; Mollusca. **Adult Exposure Criteria**: High Aggregation; Low Mobility; Intertidal (high interaction with sea surface); Infaunal (high interaction with sea floor). Score: 4. **Adult Sensitivity Criteria**: Filter feeder (feeding apparatus can be clogged or damaged by pollutants); Chemical sensitivity assumed to be high. Score: 2. **Adult Recovery Criteria**: Population status unmonitored; Relatively high reproductive capacity; Broadly distributed in suitable habitats in southern and central British Columbia; High degree of interaction with unconsolidated substrates. Score: 1. Cumulative Total Score: 7. **Larval Exposure Criteria**: Aggregate or Patchiness where large number of larvae affected; Low Mobility; Interaction with sea surface. Score: 3. **Larval Sensitivity Criteria**: Larvae feeding appendages that can become clogged by oil; Chemical sensitivity assumed to be high. Score: 2. **Larval Recovery Criteria**: Populations unmonitored; Relatively high reproductive capacity; Broadly distributed in suitable habitat; Low degree of interaction with unconsolidated substrates. Score: 0. Larval Cumulative Total Score: 5.

Pacific Littleneck (Leukoma staminea)

Significance

Littlenecks are a component of the commercial intertidal clam fishery in southern BC, particularly in the Broughton Archipelago (although harvests were temporarily restricted due to low stock levels). There is evidence that littleneck populations are declining along the Pacific coast including BC (Dunham *et al.* 2007, Bendell 2014).

Vulnerability

Subgroup classification

Pacific littlenecks were included in the following subgroups: 1 - Intertidal/Subtidal Benthic location for exposure; 2 - Sediment Infauna substrate; 3 - Low mobility; and taxonomy to inform feeding types and reproductive strategies - Mollusca (Thornborough *et al.* 2017, Hannah *et al.* 2017, Jeffery *et al.* 2023).

Exposure

As with many infaunal bivalve molluscs, aggregated distributions of Pacific littlenecks are a result of habitat preferences, physiological tolerances and are beneficial for spawning synchrony and fertilization success (Hannah *et al.* 2017).

Pacific littlenecks have limited mobility; dispersal is through pelagic larval stages, adults may move short distances but are confined to the beaches on which they settled. They are primarily intertidal in distribution with some extension into the shallow subtidal, thus their populations have a high level of interaction with the sea surface. As infaunal organisms they have intimate contact with the unconsolidated sediments they inhabit.

Sensitivity

As filter/suspension feeders, Pacific littlenecks are very sensitive to pollutants that may clog or damage their feeding apparatus. Numerous studies document chemical effects of pollutants on bivalve physiology, reproduction and larval survival.

Recovery

Population status is not actively monitored in British Columbia. Pacific littlenecks have high fecundity and high reproductive capacity, but inconsistent recruitment. They are broadly distributed in suitable habitat throughout British Columbia and beyond. They are dependent on unconsolidated substrates which can be affected for extended periods due to difficulties removing pollutants that have seeped into the substrate (DFO 1999).

Taxonomy

The accepted scientific name is *Leukoma staminea* (Conrad 1837), although until recently it was placed in the genus *Protothaca* (Coan *et al.* 2000, Coan and Valentich-Scott 2007). Originally described in the genus *Venus*, synonyms have also been placed in *Paphia*, *Tapes* and *Chione*. Frizzell (1930) described *Paphia restorationensis* from fossil material with the comment that it was present but rare in Puget Sound; it has variously been cited as a synonym of *L. staminea*, a valid species or a hybrid of *L. staminea* and *Callithaca tenerrima*. The accepted vernacular name is Pacific littleneck (Turgeon *et al.* 1998); also commonly referred to as native littleneck clam (Table 8).

Description

Oval to round in outline, inflated, outer surface of valves marked with radial and concentric (cancellate) sculpture (Quayle 1974, Quayle and Bourne 1972, Harbo 1997, Coan *et al.* 2000). Color ranges from white to brown, sometimes with angular patterns of brown (Figure 21). Ventral margin of the valve is crenulate internally, ligament external, umbone prominent and lunule obscure. Three cardinal teeth in each valve. Adductor muscle scars are subequal and the pallial sinus is deep. Siphons are short and fused. Maximum size to 80 mm, usually to 40 mm.

The three primary hardshell clams, littleneck, butter and Manila, can be distinguished by the external shape and sculpture of the valves; butter clams lack radial sculpture while littleneck and Manila clams have both radial and concentric (cancellate) sculpture (Figure 18). Littlenecks are more round in outline while Manilas are longer than deep and are tapered anteriorly.

Distribution

Littlenecks are distributed from the Aleutian Islands through the Gulf of Alaska and British Columbia and south to Baja California; also, in the western Pacific from the Commander Islands to Hokkaido, Japan (Coan *et al.* 2000). Widespread in British Columbia, particularly on Vancouver Island, less abundant in northern BC (Quayle 1974). Found from the mid-intertidal to 10 m depths.

Habitat Preferences

Littleneck clams are most commonly found in protected gravel-mud beaches, often around large rocks in less protected shores (Quayle 1974, Coan *et al.* 2000)(Figure 22). Burrows are shallow, usually less than 20 cm deep; they tend to burrow 2-4 cm deeper than co-occurring Manila clams (Meyer and Byers 2005, Hiebert *et al*. 2016). They are occasionally found on the surface and can move short distances and rebury. They also occasionally inhabit empty pholad holes, in which case the concentric sculpture on the outer surface of the valves is greatly exaggerated (Harbo 1997).

Role in the Ecosystem

Trophic Ecology

Littlenecks are suspension feeders, filtering organic materials from the water column when submerged (Hiebert *et al*. 2016).

Ecological Interactions

Littlenecks are preyed on by Lewis' moonsnails (*Euspira lewisii*), giant Pacific octopus (*Enteroctopus dofleini*), sunstars (*Pycnopodia helianthoides*), Dungeness (*Metacarcinus magister*), graceful (*M. gracilis*), red rock (*Cancer productus*) and European green (*Carcinus maenas*) crabs, black (*Melanitta nigra*), surf (*Melanitta perspicillata*) and white-winged (*Melanitta deglandi*) scoters, long-tailed ducks (*Clangula hyemalis*), Barrow's goldeneyes (*Bucephala islandica*) and sea otters (*Enhydra lutris*)(Quayle and Bourne 1972, Vermeer and Levings 1977, Vermeer 1981, Shaw 1986, Lambert 2000, Meyer and Byers 2005, Newsome *et al.* 2015). Pelagic larvae are likely preyed on by zooplankton and suspension feeders.

Flatfish, Pacific staghorn (*Leptocottus armatus*) and great (*Myoxocephalus polyacanthocephalus*) sculpins may nip off the siphon tips without ingesting the entire clam (Peterson and Quammen 1982, Meyer and Byers 2005). Clams with shortened siphons burrow shallower and may be subject to increased lethal predation.

Littlenecks are host to juvenile pinnotherid pea crabs (*Pinnixa faba* and *P. littoralis*)(Rathbun 1918, Hart 1982). They are also parasitized by the introduced copepod *Mytilicola orientalis* (Bernard 1968). The tiny snail *Iselica obtusa* can be found attached to the shell by a gelatinous compound secreted by the snail (Quayle 1974).

Physical Tolerances

Littlenecks prefer high salinity habitats and are not found in the upper reaches of estuaries where salinities vary. Larvae develop optimally at 10-15°C at salinities of 32‰; survival decreases with increasing temperature (e.g., 20°C) or at lower salinities (e.g., 27‰) (Hiebert *et al*. 2016). Adults can tolerate temperatures from near freezing to 25°C and salinities from 20-30‰ (Shaw 1986)

Reproductive Biology

Littlenecks are broadcast spawners, and the sexes are generally separate, although hermaphrodism occasionally occurs (Hiebert *et al*. 2016). Gametes are expelled through the exhalent siphon and fertilization is external. Maturity is achieved at approximately 2 years of age (Hiebert *et al*. 2016). Spawning period in BC is April-October (Quayle 1943)(Figure 23); in Oregon it is March-August (Robinson and Breese 1982) and in Alaska it is late May-September (Nickerson 1977). Previous literature (McLean Fraser and Smith 1928, McLean Fraser 1929) had indicated a February-March spawning period in BC and

this information was perpetuated (e.g., Ricketts and Calvin 1968). Females may spawn several times in a season while males release all gametes in one spawning (Quayle 1943).

Early Life History

Littlenecks exhibit typical bivalve mollusc life history (Hiebert *et al.* 2016). Fertilization is external and eggs develop through pelagic larval stages (trochophore, veliger, pediveliger) and finally settle as post-larvae. Duration of the pelagic larval period is 3-4 weeks (Shaw 1986). Larvae are present in the water column between April and October (Dunham *et al.* 2007, Hiebert *et al.* 2016). Recruitment is variable and sporadic (Shaw 1986).

Growth Rates and Life Span

Growth rate is variable and dependent on tidal elevation, latitude and habitat (Shaw 1986, Hiebert *et al*. 2016). Growth is initially rapid and slows with increasing age. Littlenecks reach 38 mm TL in approximately 4-6 years in BC (Gillespie and Bourne 1998, 2005a,b); growth was quicker in the Strait of Georgia (3.5-4.0 years, Quayle and Bourne 1972) but considerably slower in Haida Gwaii (>6 years, Gillespie and Bourne 1998). Littlenecks in Alaska reached 38 mm TL in 7-8 years (Nickerson 1977). Maximum age is at least 14 years (Harbo 1997). Extensive surveys of BC beaches reported maximum size and age of 69 mm and 13 years (Heritage *et al.* 1998, Gillespie and Bourne 1998, 2000, 2005a,b; Gillespie *et al.* 2004).

Pathway of Effects (PoE): Oil Exposure

A Pathways of Effects (PoE) oil exposure model can aid oil spill emergency response by identifying low to high-risk scenarios for species exposure. This section describes PoE for Pacific littlenecks through exposure paths of specific life stages and the potential dispersion and fates of five oil groups (Table 2). The specific environmental conditions and chemical signature of the oil spill should be taken into consideration as they may cause differences in the outcomes described in this document. A summary of this section is in Appendix Table 6.

Habitat utilization and temporal distribution of spawning, larval and adult presence and vulnerability ranks of littlenecks are illustrated in Figure 22 and Figure 23 with vulnerability ranking scores for littlenecks generalized for all oil groupings as 5 for the larval life stage and 7 for adult life stages (Jeffery *et al.* 2023).

Group 1 Oils

Group 1 contains gasoline and marine diesel oil (MDO). Both gasoline and MDO are light, volatile, and acutely toxic oils (ITOPF 2011a). The two oils are split into subcategories due to differences in fate and behaviour, causing different potential PoE on Pacific littlenecks.

Gasoline

Gasoline has high concentrations of LMW hydrocarbons which may cause both acute and chronic toxic effects on aquatic organisms (ITOPF 2011b). Possible toxic effects on aquatic organisms include mortality (Keesing *et al.* 2018), decreased locomotive ability, damage to feeding apparatuses, decreased immunity and other physiological functioning (Adzigbli and Yeuwen 2018).

Fresh Gasoline Oil Spill

Pacific littleneck spawning and presence of larvae occurs between April and October (Quayle 1943). Successful fertilization for clams and larval development occurs only under the appropriate water conditions which may be impacted by the properties of the spilled oil. Eggs and larvae are dispersed by currents with the trochophore larval phase extending three to four weeks post fertilization. Mature larvae settle during a "spatting" phase to ultimately remain in unconsolidated substrate within the intertidal zone (Shaw 1986). Gasoline is very light, having a specific gravity of <0.8, causing it to float and only be present on the top 1-2 mm of the water column (ITOPF 2011a). Due to gasoline remaining on the top of the water, risk of larval exposure is low during low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion throughout the water column increasing the risk of exposure.

Littlenecks burrow and move throughout the substrate using a muscular foot. They feed and breathe by extending a short dual-pipe organ called a siphon towards the surface. Due to the fossorial and low mobility behaviour, the PoE and vulnerability levels are the same for all post-larval life stages.

Littlenecks are irregularly distributed in depths ranging from the mid-intertidal to 10 m in protected areas made up of mud and gravel, or around large rocks. They burrow close to the substrate surface (<20 cm). They are occasionally found on the surface and confined to the beach on which the immature form settled. Littlenecks inhabit unconsolidated porous substrates including gravel, sand and mud which enable contaminants such as gasoline to infiltrate during tidal activity. Given the intertidal habitat of post-larval littlenecks, gasoline spills in the intertidal zone pose a high risk. During tidal events residual oils on exposed sediment may permeate burrows, stressing fossorial species to move to the surface, exposing them to greater contamination and predation (Pavia 1982). Oil spills in intertidal zones have historically caused high mortality in molluscs (Keesing *et al.* 2018).

Weathered Gasoline Oil Spill

Gasoline is highly volatile and can completely evaporate within 24 hours; as such, as gasoline weathers the risk to littlenecks decreases. Weathered gasoline is unlikely to pose any risks to littlenecks as it evaporates and disperses very quickly.

Marine Diesel Oils (MDO)

Fresh MDO Oil Spill

Fresh MDO has high aquatic toxicity due given high concentrations of light molecular weight hydrocarbons (Environment Canada 1999). Fresh MDO has similar potential PoE to littlenecks as gasoline (Appendix Table 6).

Littleneck larvae are present during the spawning period (April to October, Quayle 1943). Eggs and larvae are dispersed by currents with the trochophore larval phase extending three to four weeks post fertilization. Mature larvae settle during a "spatting" phase to ultimately remain on unconsolidated substrate within the intertidal zone (Shaw 1986). As with gasoline, MDOs have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring during low energy ocean conditions, as they would need to swim to the sea's surface. Medium and high energy ocean conditions can cause increased dispersion throughout the water column within the intertidal and subtidal zones, increasing the risk of exposure to littleneck larvae.

Littlenecks burrow and move throughout the substrate using a muscular foot. They feed and breathe by extending a short dual-pipe organ called a siphon towards the surface. Due to the fossorial and low mobility behaviour, the PoE and vulnerability levels are the same for all post-larval life stages.

Pacific littlenecks are irregularly distributed in depths ranging from the mid-intertidal to 10 m, in protected areas made up of mud and gravel, or around large rocks. Littlenecks burrow close to the substrate surface (<20 cm). They are occasionally found on the surface and confined to the beach on which they settled. The unconsolidated porous mixture of substrates including gravel, sand and mud, that Littleneck reside can enable contaminants to infiltrate during tidal activity. Fresh MDO spills in the intertidal and subtidal zone have a high risk of impacting littlenecks. MDO spills remain on the surface of the water; however, when tides recede the intertidal zone will be exposed to the MDO spilled on the surface. Possible effects may include coating, smothering, ingestion, and habitat modification. Intertidal zone oil spills have historically caused high mortalities in molluscs (Keesing *et al.* 2018).

Weathered MDO Oil Spill

As MDOs weather aquatic toxicity decreases as the LMW hydrocarbons evaporate. MDO still poses potential risks to littlenecks through coating, smothering and ingestion (ITOPF 2011b). The persistence of MDO causes weathered MDO to pose many of the same potential effects on littlenecks as fresh spills. The larvae of littlenecks still have the potential to interact with the oil spill on the surface of the water with potential effects including coating and smothering, likely without acute toxic effects. As specific gravity increases the potential risk to littleneck larvae in low and moderate ocean energy conditions increases, as the oil may be present deeper in the water column.

MDO is persistent and has the potential to interact and adsorb to drift particles within the water column (ITOPF 2011a). Littleneck larvae are filter feeders and continue with suspension feeding in post-larval stages. They draw water into the body filtering out

phytoplankton, zooplankton and detritus as their food source. Post-larval littlenecks also pedal feed by directing organic detritus from the sediment using the foot. Interaction and adsorption to these drift particles by MDO causes the potential for Pacific littlenecks to ingest MDOs. Ingestion of oils by molluscs can lead to effects such as impaired physiological function and behaviour as well as death (Adzigbli and Yeuwen 2018). The risk of this occurring is moderate.

Given the persistence of MDO, weathered MDO in the intertidal zone still poses a risk to littlenecks. Effects include coating, smothering, and habitat modification. As littlenecks burrow into the substrate, contaminated substrate may prevent this behaviour or increase their exposure to this oil long term. Intertidal zone oils spills can cause high mortality in molluscs (Keesing *et al.* 2018).

Group 2 Oils

Light Crude Oils (LCOs)

Group 2 oils are LCOs which contain moderate to high concentrations of hydrocarbons and can cause acute, chronic toxic effects on aquatic organisms (Adzigbli and Yeuwen 2018). LCOs can cause additional negative effects through coating and smothering aquatic organisms. There are similar PoE between Group 2 and Group 1 oils (Appendix Table 6).

Fresh LCO Oil Spill

Littleneck larvae are present during the spawning period (April to October; Quayle 1943). Eggs and larvae are dispersed by currents with the trochophore larval phase extending three to four weeks post fertilization. Mature larvae settle during a "spatting" phase to ultimately remain on unconsolidated substrate within the intertidal zone (Shaw 1986). LCOs have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring during low energy ocean conditions, as they would need to swim to the surface. Medium and high energy ocean conditions can cause increased dispersion throughout the water column within the intertidal and subtidal zones, increasing the risk of exposure to littleneck larvae.

Littlenecks burrow and move throughout the substrate using a muscular foot. They feed and breathe by extending a short dual-pipe organ called a siphon towards the surface. Due to the fossorial and low mobility behaviour, the PoE and vulnerability levels are the same for all post-larval life stages.

Fresh LCO spills in the intertidal zone have a high potential to impact post-larval littlenecks. Post-larval Pacific littlenecks reside in the substrate within the mid-intertidal to shallow subtidal zones, with high potential for interaction with an oil spill at the water's surface. They are occasionally found on the surface and confined to the beach on which they settled. The unconsolidated porous mixture of substrates including gravel, sand and mud where littlenecks reside can enable contaminants to infiltrate during tidal activity. Littlenecks would be exposed to the oil spill as the tide recedes. Possible effects may

include coating, smothering, ingestion, and habitat modification. Intertidal zone oil spills have historically caused high mortalities in molluscs (Keesing *et al.* 2018).

Weathered LCO Oil Spill

As LCOs weather their acute toxicity decreases as the LMW hydrocarbons evaporate; however, the same potential PoE and risks to littlenecks remain. LCOs persist and can form stable emulsions, leading to increased volume and specific gravity of the spill (ITOPF 2011a). The PoE for weathered LCO are similar as those of fresh LCO for littleneck larvae (Appendix Table 6). Littleneck larvae still have the potential to interact with the oil spill on the surface of the water with potential effects including coating and smothering, likely without acute toxic effects. The potential increased specific gravity increases the potential risk to larval littlenecks in low and moderate ocean energy conditions, as the oil may disperse further into the water column.

LCOs persist as they weather causing the potential for them to interact with drift particles throughout the water column potentially adsorbing to drift algae (ITOPF 2011a). Littleneck larvae are filter feeders and continue with suspension feeding in the post-larval stages. They draw water into the body filtering out phytoplankton, zooplankton and detritus as their food source. Post-larval littlenecks also pedal feed by directing organic detritus from the sediment using the foot. Interaction and adsorption to these drift particles by LCO causes the potential for ingestion by littlenecks. Ingestion of oils by molluscs can lead to effects such as impaired physiological function and behavior as well as death (Adzigbli and Yeuwen 2018). The risk of this occurring is moderate.

Given the persistence of LCO, weathered LCO in the intertidal zone still pose a risk to littlenecks. Effects include coating, smothering, and habitat modification. As littlenecks burrow into the substrate, contaminated substrate may prevent this behavior or increase their exposure to this oil long term. Intertidal zone oils spills can cause high mortality in molluscs (Keesing *et al.* 2018).

Group 3 Oils

Heavy and Persistent Oils

Group 3 contains engine/hydraulic oil, medium crude oil, heavy crude oil, and dilbit oil. Group 3 oils are heavy and persistent, while not being as toxic as Group 1 and 2 oils, due to decreased levels of LMW hydrocarbons (ITOPF 2011a, 2011b). There are many similar PoE between Group 3 and Group 1 oils (Appendix Table 6).

Fresh Heavy and Persistent Oil Spill

Littleneck larvae are present during the spawning period (April to October; Quayle 1943). Eggs and larvae are dispersed by currents with the trochophore larval phase extending three to four weeks post fertilization (Shaw 1986). Mature larvae settle during a “spatting” phase to ultimately remain on unconsolidated substrate within the intertidal zone. As with Group 1 oils, Group 3 oils have a potential to interact with larvae at the water columns surface; however, there is a low risk of this occurring during low energy ocean conditions, as they

would need to swim to the sea's surface. Medium and high energy ocean conditions can cause increased dispersion throughout the water column within the intertidal and subtidal zones, increasing the risk of exposure to larval littlenecks.

Littlenecks burrow and move through the substrate using a muscular foot. They feed and breathe by extending a short dual-pipe organ called a siphon towards the surface. Due to the fossorial and low mobility behaviour, the PoE and vulnerability levels are the same for all post-larval life stages (Appendix Table 6).

Fresh Group 3 oil spills in the intertidal zone have a high potential to impact all life stages of littlenecks. Post-larval littlenecks reside in the substrate within the mid-intertidal to shallow subtidal zone, with high potential for interaction with an oil spill at the water's surface. Littlenecks burrow close to the substrate surface (<20 cm). They are occasionally found on the surface and are confined to the beach on which they settled. The unconsolidated porous mixture of substrates including gravel, sand and mud where littleneck reside can enable contaminants to infiltrate during tidal activity. Littlenecks would be exposed to the oil spill as the tide recedes. Effects may include coating, smothering and ingestion, leading to physiological decreases or mortality (Adzigbli and Yuewen 2018).

Weathered Heavy and Persistent Oil Spill

As Group 3 oils weather, little to no evaporation occurs; however, sedimentation can occur causing the oils to sink (ITOPF 2011a). Due to Group 3 oils persistence the PoE and risks of effects remain similar for littlenecks, with increased risks due to possible sinking. Littleneck larvae still have the potential to interact with the oil spill on the surface of the water with potential effects including coating and smothering, likely without acute toxic effects. As specific gravity increases the potential risk to littleneck larvae in low and moderate ocean energy conditions, as the oil may be present deeper in the water column. Sinking oil may interact directly with larvae through coating and smothering (ITOPF 2011b).

Group 3 oils persist as they weather causing the potential for them to interact with drift particles throughout the water column potentially adsorbing to drift algae (ITOPF 2011a). Littleneck larvae are filter feeders and continue suspension feeding in the post-larval stages. They draw water into the body filtering out phytoplankton, zooplankton and detritus as their food source. Post-larval littlenecks also pedal feed by directing organic detritus from the sediment using the foot. Interaction and adsorption to these drift particles by oils causes the potential for ingestion by littlenecks. Ingestion of oils by molluscs can cause physiological decreases such as clogging of feeding apparatuses and decreased immunity (Adzigbli and Yuewen 2018). The risk of this occurring is moderate.

Given the persistence of Group 3 oils, exposure in the intertidal zone still poses a risk to littlenecks. Effects include coating, smothering, and habitat modification. As littlenecks burrow into the substrate, contaminated substrate may prevent this behaviour or increase

their exposure to this oil long term. Intertidal zone oils spills can cause high mortality in molluscs (Keesing *et al.* 2018).

Group 4 Oils

Bunker C Oils

Group 4 oils are Bunker C oils. Bunker C oils are heavy and highly persistent oils (Environment Canada 1999). Bunker C oils contain few toxic LMW hydrocarbons and have little to no acute toxic effects on aquatic organisms. Bunker C oils still pose risk through coating and smothering as well as chronic effects due to heavier toxic hydrocarbons (Adzigbli and Yuewen 2018).

Fresh Bunker C Oil Spill

Littleneck larvae are present during the spawning period (April to October; Quayle 1943). Eggs and larvae are dispersed by currents with the trochophore larval phase extending three to four weeks post fertilization. Mature larvae settle during a "spatting" phase to unconsolidated substrate in the intertidal zone (Shaw 1986). As with Group 1 oils, Bunker C oils have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring during low energy ocean conditions, as they would need to swim to the sea's surface. Medium and high energy ocean conditions can cause increased dispersion throughout the water column within the intertidal and subtidal zones, increasing the risk of exposure to littleneck larvae. Negative effects on littlenecks that this interaction may have differ from previous oils given lower concentrations of LMW hydrocarbons, causing less acute toxic effects.

Littlenecks burrow and move throughout the substrate using a muscular foot. They feed and breathe by extending a short dual-pipe organ called a siphon towards the surface. Due to the fossorial and low mobility behaviour, the PoE and vulnerability levels are the same for all post-larval life stages.

Bunker C oil spills in the intertidal zone have potential to cause high littleneck mortalities through coating and smothering (Adzigbli and Yuewen 2018). Littlenecks are distributed in the mid-intertidal and shallow subtidal zones, shallowly burrowed in the substrate (Shaw 1986, Quayle 1943). Littlenecks would be exposed to a Bunker C oil spill as the tide recedes in the intertidal zone. Possible effects may include coating, smothering, ingestion, and habitat modification. Intertidal zone oil spills have historically caused high mortalities in molluscs (Keesing *et al.* 2018).

Weathered Bunker C Oil Spill

There are little weathering effects on Bunker C oil given its low concentrations of volatile LMW hydrocarbons and high persistence (ITOPF 2011a). The PoE are similar between weathered and fresh Bunker C oils; however, Bunker C oils are susceptible to creation of stable emulsions, causing increased volume and specific gravity and potential for sinking

and sedimentation-caused sinking (ITOPF 2011a). PoE and vulnerability of risks that weathered Bunker C oil may have on Pacific Littlenecks are similar between fresh and weathered oils, with increased risk due to sinking.

If sinking occurs through emulsions forming or sedimentation, larval littlenecks are at greater risk of oil exposure. As specific gravity increases the potential risk to littleneck larvae in low and moderate ocean energy conditions increases, as the oil may be present deeper in the water column. Sinking oils could coat and smother the larval littlenecks causing locomotion and feeding issues or potentially mortality (Adzigbli and Yuewen 2018).

Bunker C oils persist as they weather causing the potential for them to interact with drift particles throughout the water column potentially adsorbing to drift algae (ITOPF 2011a). Littleneck larvae are filter feeders and continue with suspension feeding in the post-larval stages. They draw water into the body filtering out phytoplankton, zooplankton and detritus as their food source. Post-larval littlenecks also pedal feed by directing organic detritus from the sediment using the foot. Interaction and adsorption to these drift particles by Bunker C oils causes the potential for ingestion by littlenecks. Ingestion of oils by molluscs can lead to effects such as impaired physiological function and behaviour as well as death (Adzigbli and Yeuwen 2018). The risk of this occurring is moderate.

Given the persistence of Bunker C oil, weathered oil in the intertidal zone still poses a risk to littlenecks. Effects include coating, smothering, and habitat modification. As littlenecks burrow into the substrate, contaminated substrate may prevent this behaviour or increase their exposure to this oil long term. Intertidal zone oils spills can cause high mortality in molluscs (Keesing *et al.* 2018).

Group 5 Oils

Sinking Oils

Group 5 oils are extremely heavy and persistent oils known as sinking oils. Sinking oils have a specific gravity >1, causing them to readily sink in water (ITOPF 2011a). Due to high specific gravity, sinking oils have a high potential to negatively impact littlenecks at all life stages.

Fresh Sinking Oil Spill

Littleneck larvae are present during the spawning period (April to October; Quayle 1943). Eggs and larvae are dispersed by currents with the trochophore larval phase extending three to four weeks post fertilization. Mature larvae settle during a “spatting” phase to ultimately remain on unconsolidated substrate within the intertidal zone (Shaw 1986). Sinking oils have a high risk of interacting with the littleneck larvae in all ocean energy conditions, given the potential of oil being present throughout the water column or interacting with larvae while sinking.

Littlenecks burrow and move throughout the substrate using a muscular foot. They feed and breathe by extending a short dual-pipe organ called a siphon towards the surface. Due to the fossorial and low mobility behaviour, the PoE and vulnerability levels are the same for all post-larval life stages.

Sinking oils have a high risk of oil interacting with drift particles and being ingested by littlenecks through filter and pedal feeding. Ingestion of oils can cause physiological issues along with potential mortality in molluscs (Adzigbli and Yuewen 2018). Sinking oil spills in the intertidal and shallow subtidal zones have a high risk of interacting with littlenecks through coating, smothering and habitat modification, potentially causing death (Adzigbli and Yuewen 2018). Littlenecks are irregularly distributed in depths ranging from the mid-intertidal to 10 meters, in protected areas made up of mud and gravel, or around large rocks. Littlenecks burrow close to the substrate surface (<20 cm). They are occasionally found on the surface and confined to the beach on which they settled. The unconsolidated porous mixture of substrates including gravel, sand and mud where littlenecks reside can enable contaminants to infiltrate during tidal activity.

Weathered Sinking Oil Spill

Sinking oils have little to no weathering effects; therefore, the PoE and risks on littlenecks are the same for fresh and weathered sinking oils.

Figure 21. Pacific littleneck, *Leukoma staminea*.

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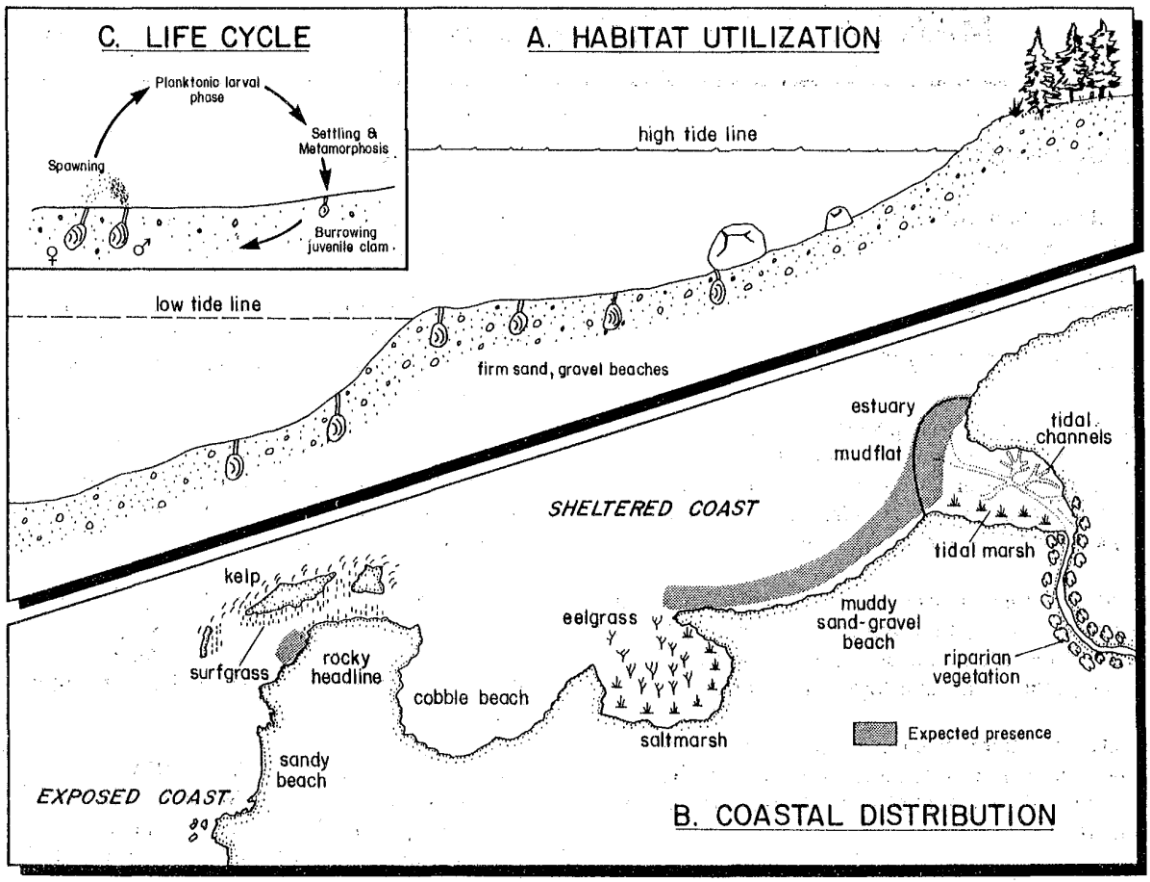

Figure 22. Habitat utilization (A), coastal distribution (B, gray polygons indicate expected presence) and life cycle (C) of Pacific littleneck, *Leukoma staminea* (Williams 1989).

J	F	M	A	M	J	J	A	S	O	N	D
1	1	1	3	3	3	3	3	2	2	1	1
			---Spawning---								
1	1	1	3	3	3	3	3	2	2	1	1
			---Larval Presence---								
3	3	3	3	3	3	3	3	3	3	3	3
---Adult Presence---											

Figure 23. Temporal distribution of spawning, larval and adult presence and vulnerability ranks of Pacific littleneck, *Leukoma staminea*.

Legend: 1 (green) = low/negligible vulnerability; 2 (yellow) = moderate vulnerability; 3 (red) = high vulnerability.

Table 8. Summary of information required to inform marine emergency response for Pacific littleneck, *Leukoma staminea*.

Taxonomy
Scientific Name:
Leukoma staminea (Conrad, 1837)

Common Name(s):
Pacific littleneck, common littleneck clam, common Pacific littleneck, hardshell clam, littleneck clam, native littleneck, ribbed carpet shell, rock clam, rock cockle, rock venus, Tomales Bay cockle

Higher Taxonomy:
Mollusca; Bivalvia; Venerida; Veneridae

Description
Subovate and inflated shells, white to brown in colour, occasionally with brown chevron patterns. Exterior marked with radial and concentric sculpture. Ligament external, lunule obscure. Interior white, crenulate ventral margin. Maximum size at least 75 mm TL.

Distribution
From the Aleutian Islands to Baja California, also in the northwestern Pacific from the Commander Islands to Japan.

Habitat Preferences
Protected and semi-protected beaches, sand/gravel/mud substrates, often around large rocks in more exposed situations. Intertidal to 10 m.

Physical Tolerances
Salinity
Littlenecks prefer higher salinities, they are less common in upper estuaries where salinities vary. Adults can tolerate salinities from 20-30‰.

Temperature
Larvae develop optimally at 10-15°C and 32‰. Survival decreases at higher temperatures and lower salinity. Adults can tolerate temperatures from near freezing to 25°C.

Physical Tolerances
Salinity
Littlenecks prefer higher salinities, they are less common in upper estuaries where salinities vary. Adults can tolerate salinities from 20-30‰.

Temperature
Larvae develop optimally at 10-15°C and 32‰. Survival decreases at higher temperatures and lower salinity. Adults can tolerate temperatures from near freezing to 25°C.

Table 8. continued.

Reproductive Biology
Broadcast spawner with external fertilization. Sexes are usually separate, occasional hermaphrodism reported. Spawn April-October. Larvae are pelagic for 3-4 weeks.

Growth Rate and Lifespan
Growth initially rapid and declines with increasing age. Littlenecks in BC reach 38mm TL in approximately 4-6 years; growth is slower in northern BC. Maximum age approximately 14 years.

Migratory Behaviour
Adults can move short distances and rebury and are confined to the beach they live on. Dispersal is through pelagic larval stages.

Role in the Ecosystem
Suspension feeders filtering organic material from the water column. Preyed upon by gastropods, crabs, diving ducks and sea otters.

Significance
Littlenecks are a minor component of intertidal clam fisheries in southern BC, but are an important species in fisheries in Queen Charlotte and Johnstone Straits.

Vulnerability
Subgroup Classification: Intertidal/Subtidal Benthic; Sediment Infauna; Low Mobility; Mollusca.

Adult Exposure Criteria: High Aggregation; Low Mobility; Intertidal (high interaction with sea surface); Infaunal (high interaction with sea floor). Score: 4.

Adult Sensitivity Criteria: Filter feeder (feeding apparatus can be clogged or damaged by pollutants); Chemical sensitivity assumed to be high. Score: 2.

Adult Recovery Criteria: Population status unmonitored; Relatively high reproductive capacity; Broadly distributed in suitable habitats; High degree of interaction with unconsolidated substrates. Score: 1.

Cumulative Total Score: 7.

Larval Exposure Criteria: Aggregate or Patchiness where large number of larvae affected; Low Mobility; Interaction with sea surface. Score: 3.

Larval Sensitivity Criteria: Larvae feeding appendages that can become clogged by oil; Chemical sensitivity assumed to be high. Score: 2.

Larval Recovery Criteria: Populations unmonitored; Relatively high reproductive capacity; Broadly distributed in suitable habitat; Low degree of interaction with unconsolidated substrates. Score: 0.

Larval Cumulative Total Score: 5.

Butter Clam (Saxidomus gigantea)

Significance

Butter clams are important in First Nations harvests (e.g., Ellis and Swan 1981). They also support commercial harvests in the Strait of Georgia and Queen Charlotte Strait (Dunham *et al.* 2007). They are utilized in recreational fisheries throughout BC. Prior to the shift in market preference in the late 1970s to live steamers (Manila and littleneck clams), butter clams were the primary commercial clam species in BC (Bourne 1997).

Vulnerability

Subgroup classification

Butter clams were included in the following subgroups: 1 - Intertidal/Subtidal Benthic location for exposure; 2 - Sediment Infauna substrate; 3 - Low mobility; and taxonomy to inform feeding types and reproductive strategies - Mollusca (Thornborough *et al.* 2017, Hannah *et al.* 2017, Jeffery *et al.* 2023).

Exposure

As with many infaunal bivalve molluscs, aggregated distributions of butter clams are a result of habitat preferences, physiological tolerances and are beneficial for spawning synchrony and fertilization success (Hannah *et al.* 2017).

Butter clams have limited mobility; dispersal is through pelagic larval stages, juveniles may move short distances but are confined to the beaches on which they settled, adults are sessile. They are distributed from the lower intertidal to the shallow subtidal, thus their populations have a high level of interaction with the sea surface. As infaunal organisms they have intimate contact with the unconsolidated sediments they inhabit.

Sensitivity

As filter/suspension feeders, butter clams are very sensitive to pollutants that may clog or damage their feeding apparatus. Numerous studies document chemical effects of pollutants on bivalve physiology, reproduction and larval survival.

Recovery

Population status is not actively monitored in British Columbia. Butter clams have high fecundity and high reproductive capacity, but inconsistent recruitment (e.g., Kingzett and Bourne 1998). They are broadly distributed in suitable habitat throughout British Columbia and beyond. They are dependent on unconsolidated substrates which can be affected for extended periods due to difficulties removing pollutants that have seeped into the substrate.

Taxonomy

The accepted scientific name is *Saxidomus gigantea* (Deshayes 1839, Coan *et al.* 2000). Historically referred to as *Saxidomus giganteus* (e.g., Quayle 1974, Quayle and Bourne

1972) due to confusion over the gender of the genus name; *Saxidomus* is feminine (Turgeon *et al.* 1998, Heibert *et al.* 2016). The accepted vernacular name is Washington butterclam (Turgeon *et al.* 1998); this was coined to distinguish the species' distribution relative to the California butterclam, *Saxidomus nuttallii*, but is an unfortunate choice for a species that is found from California to the Bering Sea. There are many local names in use (Breese and Phibbs 1970, Harbo 1997). The vernacular name butter clam is in common use (Table 9).

Description

The valves are thick, square to subovate and slightly truncated posteriorly, adults with a small posterior gape (Quayle 1974, Quayle and Bourne 1972, Heibert *et al*. 2016)(Figure 24). The outer surfaces are yellow-white in juveniles; adults are gray to white, occasionally with dark stains, and are marked with concentric striae and deep winter checks. Inner surface is white and smooth, not glossy, pallial sinus is deep and adductor scars are deeply marked. There are three large cardinal teeth and a long anterior lateral tooth. The ligament is external and large and the umbones prominent. Flesh is yellow to reddish, siphon tips dark. Siphons are long and fused. Maximum size is 130 mm (Harbo 1997, Kingzett and Bourne 1998, Heibert *et al.* 2016).

Distribution

Butter clams are found from St. Lawrence Island in the Bering Sea and the Aleutian Islands through the Gulf of Alaska to Capitola in Central California, although they are rare south of Humboldt Bay (Harbo 1997, Coan *et al.* 2000, Heibert *et al.* 2016). They are found from the mid- to low-intertidal to 40 m. They are ubiquitous in appropriate habitat throughout BC (Quayle 1974, Quayle and Bourne 1972).

Habitat Preferences

Butter clams inhabit sand/gravel/shell beaches, generally in well protected bays and estuaries (Quayle 1974, Nickerson 1977, Quayle and Bourne 1972, Harbo 1997, Heibert 2016)(Figure 25). When present on exposed beaches growth rates are often reduced, resulting in morphological changes (stunting). They are found from the lower third of the intertidal zone to depths of 30-40 m. Juveniles are found just below the sediment surface, adults burrow to approximately 30 cm.

Role in the Ecosystem

Trophic Ecology

Butter clams are suspension feeders, filtering organic material from the water column (Quayle and Bourne 1972). Phytoplankton are the primary food, but small zooplankton, bivalve larvae, bacteria and organic debris also contribute.

Ecological Interactions

Butter clams are preyed on by moonsnails (e.g., *Euspira lewisi*), sunstars (*Pycnopodia helianthoides*), pink stars (*Pisaster brevispinus*) and crabs (unspecified)(Quayle and Bourne 1972, Lambert 2000). They are a preferred prey for sea otters in Southeast Alaska (Kvitek *et al.* 1993). Juvenile stages are most vulnerable, adults less though as they grow thicker shells and are able to burrow deeper.

Butter clams are host to juvenile pinnotherid pea crabs (*Pinnixa faba* and *P. littoralis*) and adult *Fabia subquadrata* (Rathbun 1918, Quayle 1974, Quayle and Bourne 1972, Hart 1982, Jensen 2014). They are also parasitized by the introduced copepod *Mytilicola orientalis* (Bernard 1969, Quayle and Bourne 1972).

Physical Tolerances

Larvae developed optimally between 15-20°C and 20-29‰ (Bourne 1971). Adults experience temperatures of near freezing in winter and brief periods of up to 25°C in the summer; salinities range from 30‰ to short exposures below 20‰ (Quayle and Bourne 1972). Butter clams prefer higher salinity environments (Goong and Chew 2001).

Reproductive Biology

Butter clams are broadcast spawners with separate sexes; fertilization is external (Quayle and Bourne 1972). Butter clams mature in 3-4 years at approximately 55 mm TL (McLean Fraser and Smith 1928). Neave (1944) estimated average size at maturity to be 38-42 mm TL, which increased with increasing latitude.

Peak spawning occurs August-September in the Strait of Georgia (McLean Fraser 1929) (Figure 26). Significant spawning may occur as early as April or May and some spent individuals may be found throughout the year (Quayle and Bourne 1972). Spawning occurred February-July in Oregon with peak spawning March-June, and mid-June to September in Alaska (Nickerson 1977, Robinson and Breese 1982, Heibert *et al.* 2016).

Early Life History

After fertilization it takes approximately two weeks to achieve the veliger stage and four additional weeks to settlement (McLean Fraser 1929). Post-larvae do not commence rapid growth until the following spring. In the laboratory, larvae grew well at 15 and 20°C, although survival was higher at the lower temperature; growth was relatively poor at 10 and 25°C (Bourne 1971). Breese and Phibbs (1970) reported development to the trochophore stage in 24 hours and the veliger stage in 48 hours at 18°C and 25-31‰; settlement occurred in 22-30 days.

Recruitment is sporadic with many years of poor recruitment and few years of strong recruitment (Bourne 1971, Quayle and Bourne 1972, Paul *et al.* 1976, Kingzett and Bourne 1998).

Growth Rates and Life Span

Growth decreases with increasing latitude, which over the broad range of butter clams is strongly correlated with seasonal temperatures (Paul *et al.* 1976). Butter clams reach 63 mm TL in 4.5-13 years in BC (4.5-5 years in Barkley Sound, 5-6.5 years in the Strait of Georgia, 6.5-8.5 years in Queen Charlotte Strait and 9 years in Prince Rupert), and 63-64 mm TL in 8.0-9.0 years in Southeast Alaska (Quayle and Bourne 1972, Paul *et al.* 1976, Kingzett and Bourne 1998, Gillespie *et al.* 2004, Gillespie and Bourne 2005a,b). Growth may be positively correlated with increasing salinity (Goong and Chew 2001). Butter clams are relatively long-lived, regularly approaching 20 years in age (McLean Fraser and Smith 1929, Quayle and Bourne 1972).

Pathways of Effects (PoE): Oil Exposure

A Pathways of Effects (PoE) oil exposure model can aid oil spill emergency response by identifying low to high-risk scenarios for species exposure. This section describes PoE for butter clams through exposure paths of specific species life stages and the potential dispersion and fates of five oil groups (Table 2). The specific environmental conditions and chemical signature of the oil spill should be taken into consideration as they may cause differences in the outcomes described in this document. A summary table for this section is available in Appendix Table 7.

Habitat utilization and temporal distribution of spawning, larval and adult presence and vulnerability ranks of butter clams are illustrated in Figure 25 and Figure 26 with vulnerability ranking scores for butter clams generalized for all oil groupings as 5 for the larval life stage and 7 for adult life stages (Jeffery *et al.* 2023).

Group 1 Oils

Group 1 contains gasoline and marine diesel oil (MDO). Both gasoline and MDO are light, volatile, and acutely toxic oils (ITOPF 2011a). The two oils are split into subcategories due to differences in fate and behaviour, causing different potential PoE on butter clams.

Gasoline

Gasoline has high concentrations of LMW hydrocarbons which may cause both acute and chronic toxic effects on aquatic organisms (ITOPF 2011b). Possible toxic effects on aquatic organisms include mortality (Keesing *et al.* 2018), decreased locomotive ability and other physiological functioning (Adzigbli and Yeuwen 2018).

Fresh Gasoline Oil Spill

Butter clams generally spawn period in late spring (April – July) in British Columbia with the spawning period extended to late summer (October) further north (McLean Fraser 1929, Nickerson 1977, Robinson and Breese 1982, Heibert *et al.* 2016). Successful fertilization occurs only under the appropriate water conditions and dependent on water

temperature rising above 15°C (Bourne 1971). Larval development is dependent on optimal salinity and temperature conditions which may be impacted by the spilled oils properties. Eggs and larvae are dispersed by currents with the trochophore larval phase extending three to eight weeks post fertilization. Mature larvae settle primarily between spring and summer during a "spatting" phase which may take up to two weeks to ultimately settle on an appropriate sandy to gravel substrate within the lower intertidal to the shallow subtidal, to depths of 40 m (Sept 2019).

Gasoline is very light, having a specific gravity of <0.8, causing it to float and only be present on the top 1-2 mm of the water column (ITOPF 2011a). Due to gasoline remaining on the top of the water, there is a low risk of larval exposure during low energy ocean conditions, as they would need to swim to the sea's surface. Medium and high energy ocean conditions can cause increased dispersion throughout the water column within the intertidal and subtidal zones, increasing the risk of exposure to larval clams.

Butter clams burrow into the substrate using a long muscular foot. Juveniles burrow just below the surface, and adults burrow deeper, to depths of around 30 cm. They feed and breathe by extending a dual-pipe organ called a siphon towards the surface. Due to this generally fossorial behaviour and low mobility, the PoE and vulnerability levels are the same for all post-larval life stages.

Post-larval butter clams are irregularly distributed under the substrate surface in the intertidal zone to the subtidal zone (DFO 2018). They are found in a wide variety of unconsolidated substrate, but the typical medium is a porous mixture of sand, broken shell, and small gravel which can enable contaminants such as gasoline to infiltrate particularly during tidal activity. Given the intertidal habitat and high level of interaction with the ocean's surface of post-larval butter clams, gasoline spills in the intertidal zone pose a high risk. Oil spills in intertidal zones have historically caused high mortality in gastropod molluscs such as butter clams (Keesing *et al.* 2018).

Weathered Gasoline Oil Spill

Gasoline is highly volatile and can completely evaporate within 24 hours; as such, as gasoline weathers the risk to butter clams decreases. Weathered gasoline is unlikely to pose risks to butter clams as it evaporates and disperses very quickly.

Marine Diesel Oils (MDO)

Fresh MDO Oil Spill

Fresh MDO has high aquatic toxicity due given high concentrations of light molecular weight hydrocarbons (Environment Canada 1999). Fresh MDO has similar potential PoE to butter clams as gasoline (Appendix Table 7).

Butter clam larvae are present during the spawning period (April to September; McLean Fraser 1929). The larval stage lasts for three to eight weeks post-fertilization, during which

larvae will be present in the water column. As with gasoline, MDOs have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring during low energy ocean conditions, as they would need to swim to the sea's surface. Medium and high energy ocean conditions can cause increased dispersion throughout the water column within the intertidal and subtidal zones, increasing the risk of exposure to larval clams.

Butter clams burrow into the substrate using a long muscular foot. Juveniles burrow just below the surface, and adults burrow deeper, to depths of around 30 cm. They feed and breathe by extending a dual-pipe organ called a siphon towards the surface. Due to this generally fossorial behaviour and low mobility, the PoE and vulnerability levels are the same for all post-larval life stages.

Fresh MDO spills in the intertidal zone have a high risk of impacting butter clams. MDO spills remain on the surface of the water; however, when tides recede the intertidal zone will be exposed to the MDO spilled on the surface. Post-larval butter clams are irregularly distributed under the substrate surface in the intertidal zone to the subtidal zone (DFO 2018). They are found in a wide variety of unconsolidated porous substrate, which can enable contaminants such as MDO to infiltrate particularly during tidal activity. Possible effects may include coating, smothering, ingestion and habitat modification. Intertidal zone oil spills have historically caused high mortalities in molluscs (Keesing *et al.* 2018).

Weathered MDO Oil Spill

As MDOs weather aquatic toxicity decreases as the LMW hydrocarbons evaporate. MDO still poses potential risks to butter clams through coating, smothering and ingestion (ITOPF 2011b). The persistence of MDO causes weathered MDO to pose many of the same potential effects on butter clams as fresh spills. Butter clam larvae still have the potential to interact with the oil spill on the surface of the water with potential effects including coating and smothering, likely without acute toxic effects. The potential increased specific gravity increases the potential risk to larval butter clams in low and moderate ocean energy conditions, as the oil may be present further down into the water column.

Larval butter clams filter feed and continue with a suspension fed diet in the post-larval life stages. They draw water into the body filtering out phytoplankton, zooplankton and detritus as their food source. Mature butter clams are also filter feeders, mainly feeding on drift particles including detritus (organic materials) and plankton (Quayle and Bourne 1972). MDO is persistent and has the potential to interact and adsorb to drift particles within the water column (ITOPF 2011a). Interaction and adsorption to these drift particles by MDO causes the potential for butter clams to ingest MDOs. The risk of this occurring is high.

Given the persistence of MDO, weathered MDO in the intertidal zone still poses a risk to butter clams. Effects include coating, smothering, and habitat modification. Persistent oil buildup may prevent burrowing and increase exposure to butter clams. Intertidal zone oil spills can cause high mortality in molluscs (Keesing *et al.* 2018).

Group 2 Oils

Light Crude Oils (LCOs)

Group 2 oils are LCOs which contain moderate to high concentrations of hydrocarbons which cause acute and chronic toxic effects on aquatic organisms (Adzigbli and Yeuwen 2018). LCOs can cause additional negative effects through coating and smothering aquatic organisms. There are similar PoE between Group 2 and Group 1 oils (Appendix Table 7).

Fresh LCO Oil Spill

Butter clam larvae are present during the spawning period (April to September; McLean Fraser 1929). The larval stage lasts for three to eight weeks post-fertilization, during which larvae will be present in the water column. As with Group 1 oils, LCOs have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring during low energy ocean conditions, as they would need to swim to the sea's surface. Medium and high energy ocean conditions can cause increased dispersion throughout the water column within the intertidal and subtidal zones, increasing the risk of exposure to larval clams.

Butter clams burrow into the substrate using a long muscular foot. Juveniles burrow just below the surface, and adults burrow deeper, to depths of around 30 cm. They feed and breathe by extending a dual-pipe organ called a siphon towards the surface. Due to this generally fossorial behaviour and low mobility, the PoE and vulnerability levels are the same for all post-larval life stages.

Fresh LCO spills in the intertidal zone have a high risk of impacting butter clams. LCO spills remain on the surface of the water; however, when tides recede the intertidal zone will be exposed to the LCO spilled on the surface. Post-larval butter clams are irregularly distributed under the substrate surface in the intertidal zone to the subtidal zone (DFO 2018). They are found in a wide variety of unconsolidated substrates, but the typical medium is a porous mixture of sand, broken shell, and small gravel, which can enable contaminants such as LCO to infiltrate particularly during tidal activity. Possible effects may include coating, smothering, ingestion and habitat modification. Intertidal zone oil spills have historically caused high mortalities in molluscs (Keesing *et al.* 2018).

Weathered LCO Oil Spill

As LCOs weather their acute toxicity decreases as the light molecular weight hydrocarbons evaporate; however, similar potential PoE and risks to butter clams remain. LCOs persist and can form stable emulsions, leading to increased volume and specific gravity of the spill (ITOPF 2011a). The increased specific gravity increases the potential risk to larval butter clams in low and moderate ocean energy conditions, as the oil may be present further down into the water column.

Larval butter clams filter feed and continue with a suspension fed diet in the post-larval life stages. They draw water into the body filtering out phytoplankton, zooplankton and detritus as their food source. Mature butter clams are also filter feeders, mainly feeding on drift particles including detritus (organic materials) and plankton (Quayle and Bourne 1972). LCO is persistent and has the potential to interact and adsorb to drift particles within

the water column (ITOPF 2011a). The interaction between LCOs and drift algae leads to the potential for ingestion, causing toxic and potentially fatal effects (Adzigbli and Yuewen 2018).

Given the persistence of LCOs, weathered LCOs in the intertidal zone still poses a risk to butter clams. Effects include coating, smothering, and habitat modification. Persistent oil buildup may prevent burrowing and increase exposure to butter clams. Intertidal zone oils spills can cause high mortality in molluscs (Keesing *et al.* 2018).

Group 3 Oils

Heavy and Persistent Oils

Group 3 contains engine/hydraulic oil, medium crude oil, heavy crude oil, and dilbit oil. Group 3 oils are heavy and persistent, while not being as toxic as Group 1 and 2 oils, due to decreased levels of LMW hydrocarbons (ITOPF 2011a, 2011b). There are many similar PoE between Group 3 and Group 1 oils (Appendix Table 7).

Fresh Heavy and Persistent Oil Spill

Butter clam larvae are present during the spawning period (April to September; McLean Fraser 1929). The larval stage lasts for three to eight weeks post-fertilization, during which larvae will be present in the water column. As with Group 1 oils, Group 3 oils have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring during low energy ocean conditions, as they would need to swim to the sea's surface. Medium and high energy ocean conditions can cause increased oil dispersion throughout the water column within the intertidal and subtidal zones, increasing the risk of exposure to larval clams.

Butter clams burrow into the substrate using a long muscular foot. Juveniles burrow just below the surface, and adults burrow deeper, to depths of around 30 cm. They feed and breathe by extending a dual-pipe organ called a siphon towards the surface. Due to this generally fossorial behaviour and low mobility, the PoE and vulnerability levels are the same for all post-larval life stages.

Fresh Group 3 oil spills in the intertidal zone have a high potential to impact butter clams at all life stages. Post-larval butter clams reside under the substrate within the lower intertidal to the shallow subtidal, with high potential for interaction with an oil spill at the water's surface. They are dependent on substrates which can be affected for extended periods due to difficulties removing pollutants that have seeped into the substrate. Butter clams in the intertidal zone would be fully exposed to the oil spill as the tide recedes. Possible effects may include coating, smothering, ingestion and habitat modification. Intertidal zone oil spills have historically caused high mortalities in molluscs (Keesing *et al.* 2018).

Weathered Heavy and Persistent Oil Spill

As Group 3 oils weather, little to no evaporation occurs; however, sedimentation can occur causing the oils to sink (ITOPF 2011a). Due to Group 3 oils persistence the PoE and vulnerability risks remain similar for butter clams.

Possible sinking due to sedimentation creates a greater risk of exposure for larval butter clams in low and medium energy ocean conditions, due to the oil being present throughout more of the water column. Sinking oil may interact directly with larvae through coating and smothering, causing feeding apparatuses to not work properly (ITOPF 2011b).

Larval butter clams filter feed and continue with a suspension fed diet in the post-larval life stages. They draw water into the body filtering out phytoplankton, zooplankton and detritus as their food source. Mature butter clams are also filter feeders, mainly feeding on drift particles including detritus (organic materials) and plankton (Quayle and Bourne 1972). Group 3 oils are persistent and have the potential to interact and adsorb to drift particles within the water column (ITOPF 2011a). The interaction between crude oils and drift algae leads to the potential for ingestion, causing toxic and potentially fatal effects (Adzigbli and Yuewen 2018). There is a moderate risk of this occurring.

Group 4 Oils

Bunker C Oils

Group 4 oils are Bunker C oils. Bunker C oils are heavy and highly persistent oils (Environment Canada 1999). Bunker C oils contain few toxic LMW hydrocarbons meaning they have little to no acute toxic effects on aquatic organisms. Bunker C oils still pose risk through coating and smothering as well as chronic effects due to heavier toxic hydrocarbons (Adzigbli and Yuewen 2018).

Fresh Bunker C Oil Spill

Butter clam larvae are present during the spawning period (April to September; McLean Fraser 1929). The larval stage lasts for three to eight weeks post-fertilization, during which larvae will be present in the water column. As with Group 1 oils, Bunker C oils have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring during low energy ocean conditions, as they would need to swim to the sea's surface. Medium and high energy ocean conditions can cause increased oil dispersion throughout the water column within the intertidal and subtidal zones, increasing the risk of exposure to larval clams. Negative effects on butter clams that this interaction may have differ from previous oils given lower concentrations of LMW hydrocarbons, causing less acute toxic effects.

Butter clams burrow into the substrate using a long muscular foot. Juveniles burrow just below the surface, and adults burrow deeper, to depths of around 30 cm. They feed and breathe by extending a dual-pipe organ called a siphon towards the surface. Due to this generally fossorial behaviour and low mobility, the PoE and vulnerability levels are the same for all post-larval life stages.

Fresh Bunker C oil spills in the intertidal zone have a high potential to impact butter clams at all life stages. Post-larval butter clams reside under the substrate within the lower

intertidal to the shallow subtidal, with high potential for interaction with an oil spill at the water's surface. They are dependent on substrates which can be affected for extended periods due to difficulties removing pollutants that have seeped into the substrate. Butter clams in the intertidal zone would be fully exposed to the oil spill as the tide recedes. Bunker C oil spills in the intertidal zone have potential to cause high bivalve mortalities, including butter clams, through coating and smothering (Adzigbli and Yuewen 2018).

Weathered Bunker C Oil Spill

There are little weathering effects on Bunker C oil given PoE are similar between weathered and fresh Bunker C oils; however, Bunker C oils are susceptible to creation of stable emulsions, causing increased volume and specific gravity and potential for sinking and sedimentation-caused sinking (ITOPF 2011a).

If sinking occurs through emulsions forming or sedimentation, larval butter clams are at a greater risk of oil exposure throughout the water column and at low and medium energy ocean conditions. Sinking oils could coat and smother larval butter clams causing locomotion and feeding issues or potentially mortality (Adzigbli and Yuewen 2018).

Larval butter clams filter feed and continue with a suspension fed diet in the post-larval life stages. They draw water into the body filtering out phytoplankton, zooplankton and detritus as their food source. Mature butter clams are also filter feeders, mainly feeding on drift particles including detritus (organic materials) and plankton (Quayle and Bourne 1972). Bunker C oils are persistent and have the potential to interact and adsorb to drift particles within the water column (ITOPF 2011a). The interaction between Bunker C oils and drift algae leads to the potential for ingestion, causing toxic and potentially fatal effects (Adzigbli and Yuewen 2018). There is a high risk of this occurring.

Group 5 Oils

Sinking Oils

Group 5 oils are extremely heavy and persistent oils known as sinking oils. Sinking oils have a specific gravity >1, causing them to readily sink in water (ITOPF 2011a). Due to high specific gravity, sinking oils have a high potential to negatively impact butter clams at all life stages.

Fresh Sinking Oil Spill

Butter clam larvae are present during the spawning period (April to September; McLean Fraser 1929). The larval stage lasts for three to eight weeks post-fertilization, during which larvae will be present in the water column. Sinking oils have a high risk of interacting with the larvae of butter clams at all potential ocean energy scenarios, given the potential of oil being present throughout the water column or interacting with larvae while sinking, particularly during the spatting phases. Possible negative effects on butter clams differ from previous oils given lower concentrations of LMW hydrocarbons, causing less acute toxic effects.

Sinking oils have a high risk of oil interacting/adsorbing with drift particles and being ingested by butter clams. Larval butter clams filter feed and continue with a suspension fed

diet in the post-larval life stages. They draw water into the body filtering out phytoplankton, zooplankton and detritus as their food source. Mature butter clams are also filter feeders, mainly feeding on drift particles including detritus (organic materials) and plankton (Quayle and Bourne 1972). Ingestion of oils can cause physiological issues along with potential mortality in molluscs (Adzigbli and Yuewen 2018).

Sinking oil spills in the intertidal zone have a high risk of interacting with butter clams through coating, smothering, and habitat modification potentially causing death (Adzigbli and Yuewen 2018). Persistent oil buildup may prevent burrowing and increase exposure to Butter clams.

Weathered Sinking Oil Spill

Sinking oils have little to no weathering effects; therefore, the PoE on butter clams are the same for fresh and weathered sinking oils particularly where there are difficulties removing pollutants that have seeped into the substrate.

Figure 24. Butter clam, *Saxidomus gigantea*.

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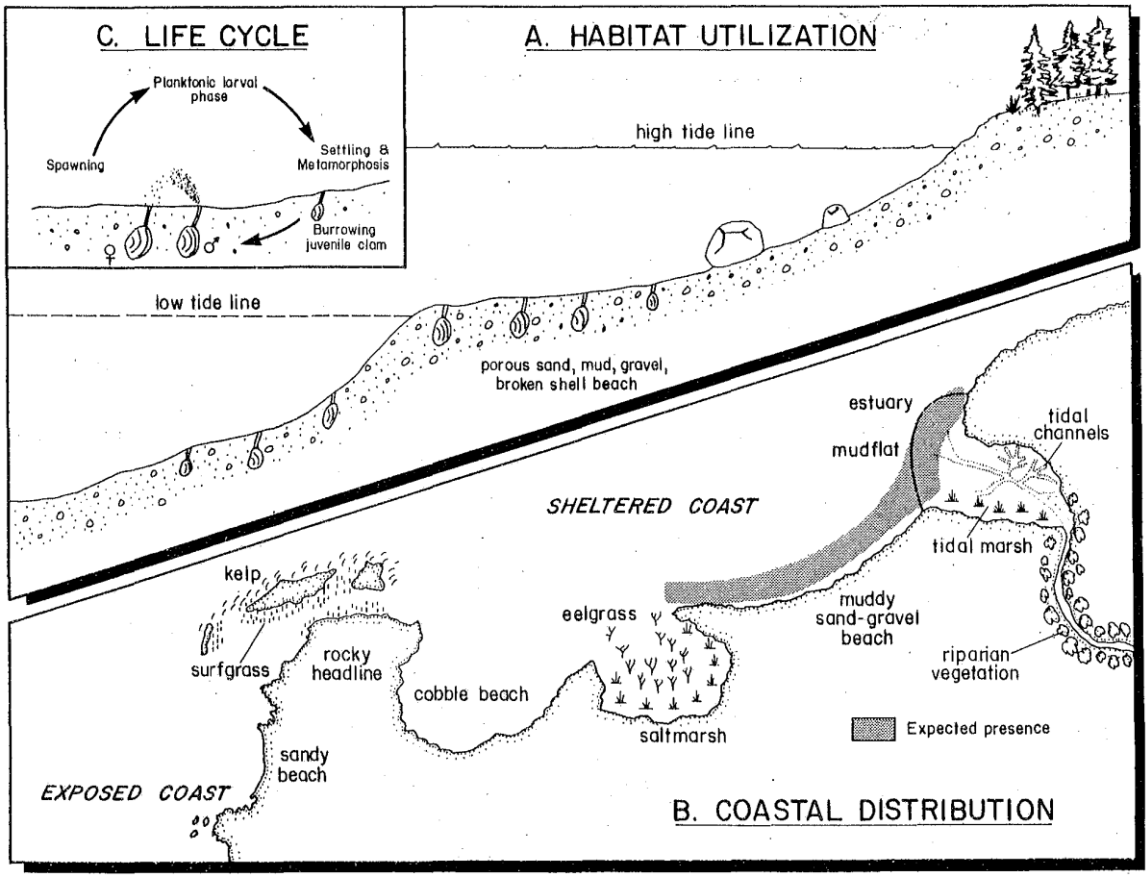

Figure 25. Habitat utilization (A), coastal distribution (B, gray polygons indicate expected presence) and life cycle (C) of butter clam, *Saxidomus gigantea* (Williams 1989).

J	F	M	A	M	J	J	A	S	O	N	D
1	1	1	3	3	3	3	3	3	1	1	1
			---Spawning---								
1	1	1	3	3	3	3	3	3	2	1	1
			---Larval Presence---								
3	3	3	3	3	3	3	3	3	3	3	3
---Adult Presence---											

Figure 26. Temporal distribution of spawning, larval and adult presence and vulnerability ranks of butter clam, *Saxidomus gigantea*.

Legend: 1 (green) = low/negligible vulnerability; 2 (yellow) = moderate vulnerability; 3 (red) = high vulnerability.

Table 9. Summary of information required to inform marine emergency response for butter clam, *Saxidomus gigantea*.

Taxonomy
Scientific Name:
Saxidomus gigantea (Deshayes, 1839)

Common Name(s):
Washington butterclam, beefsteak clam, butter clam, Coney Island clam, great Oregon clam, quahog, smooth Washington clam, Washington clam

Higher Taxonomy:
Mollusca; Bivalvia; Venerida; Veneridae

Description
Valves thick, square to subovate, slightly truncated posteriorly, adults with a small posterior gape. Outer surfaces yellow-white in juveniles; adults gray-white, occasionally with dark stains, marked with concentric striae and deep winter checks. Inner surface white and smooth, not glossy, pallial sinus deep and adductor scars deeply marked. Three large cardinal teeth and a long anterior lateral tooth. Ligament external, large, umbones prominent. Flesh yellow to reddish, siphon tips dark. Siphons long and fused. Maximum size 130 mm TL.

Distribution
Bering Sea and Aleutian Islands to Central California, rare south of Humboldt Bay. Ubiquitous in appropriate habitat throughout BC.

Habitat Preferences
Inhabit sand/gravel/shell beaches, generally protected bays and estuaries. Lower third of the intertidal to 30-40 m. Juveniles just below the sediment surface, adults to 30 cm. Generally occur lower in the intertidal than littleneck, Manila and varnish clams.

Physical Tolerances
Salinity
Larvae developed optimally between 20-29‰. Butter clams prefer higher salinity environments; suitable range is from 30‰ to short exposures below 20‰.

Temperature
Larvae developed optimally between 15-20°C. Adults experience temperatures of near freezing in winter and brief periods of up to 25°C in the summer.

Reproductive Biology
Broadcast spawners with separate sexes; fertilization is external. Mature in 3-4 years at approximately 38-55 mm TL, size at maturity increases with increasing latitude. Peak spawning August-September in the Strait of Georgia, February-July in Oregon with peak spawning March-June, mid-June to September in Alaska. Fecundity undocumented.

Table 9. continued.

Growth Rate and Lifespan Growth decreases with increasing latitude, strongly correlated with seasonal temperatures. Reach 63 mm TL in 4.5-13 years in BC (4.5-5 years in Barkley Sound, 5-6.5 years in the Strait of Georgia, 6.5-8.5 years in Queen Charlotte Strait and 9 years in Prince Rupert) and 63-64 mm TL in 8.0-9.0 years in Southeast Alaska. Growth positively correlated with increasing salinity. Relatively long-lived, regularly approaching 20 years in age.
Migratory Behaviour Juveniles and adults restricted to resident beach, dispersal through pelagic larval stages.
Role in the Ecosystem Suspension feeder, filtering phytoplankton, zooplankton, bivalve larvae, bacteria and organic debris. Preyed on by moonsnails, sea stars, and crabs. Host juvenile pea crabs, parasitized by an introduced copepod.
Significance Important species in First Nations and recreational fisheries throughout BC, important commercial species in Queen Charlotte Strait.
Vulnerability **Subgroup Classification**: Intertidal/Subtidal Benthic; Sediment Infauna; Low Mobility; Mollusca. **Adult Exposure Criteria**: High Aggregation; Low Mobility; Intertidal (high interaction with sea surface); Infaunal (high interaction with sea floor). Score: 4. **Adult Sensitivity Criteria**: Filter feeder (feeding apparatus can be clogged or damaged by pollutants); Chemical sensitivity assumed to be high. Score: 2. **Adult Recovery Criteria**: Population status unmonitored; Relatively high reproductive capacity; Broadly distributed in suitable habitats; High degree of interaction with unconsolidated substrates. Score: 1. Cumulative Total Score: 7. **Larval Exposure Criteria**: Aggregate or Patchiness where large number of larvae affected; Low Mobility; Interaction with sea surface. Score: 3. **Larval Sensitivity Criteria**: Larvae feeding appendages that can become clogged by oil; Chemical sensitivity assumed to be high. Score: 2. **Larval Recovery Criteria**: Populations unmonitored; Relatively high reproductive capacity; Broadly distributed in suitable habitat; Low degree of interaction with unconsolidated substrates. Score: 0. Larval Cumulative Total Score: 5.

Pacific Razor (Siliqua patula)

Significance

Razor clams support locally important First Nations, commercial and recreational fisheries in northern Haida Gwaii and also support First Nations and recreational fisheries on the west coast of Vancouver Island (Bourne and Quayle 1972, Bourne 1997, Jones *et al.* 1998, 2001). Although the fishery initially canned razors for human consumption, the current commercial catch is processed for bait in crab fisheries.

Vulnerability

Subgroup classification

Razor clams were included in the following subgroups: 1 - Intertidal/Subtidal Benthic location for exposure; 2 - Sediment Infauna substrate; 3 - Low mobility; and taxonomy to inform feeding types and reproductive strategies - Mollusca (Thornborough *et al.* 2017, Hannah *et al.* 2017, Jeffery *et al.* 2023).

Exposure

As with many infaunal bivalve molluscs, aggregated distributions of razor clams are a result of habitat preferences, physiological tolerances and are beneficial for spawning synchrony and fertilization success (Hannah *et al.* 2017).

Razor clams have limited mobility; dispersal is through pelagic larval stages, adults may move short distances but are confined to the beaches on which they settled. They are intertidal to shallow subtidal in distribution, thus their populations have a high level of interaction with the sea surface. As infaunal organisms they have intimate contact with the unconsolidated sediments they inhabit.

Sensitivity

As filter/suspension feeders, razor clams are very sensitive to pollutants that may clog or damage their feeding apparatus. Numerous studies document chemical effects of pollutants on bivalve physiology, reproduction and larval survival.

Recovery

Population status is actively monitored for major commercially exploited in British Columbia (Jones *et al.* 1998, 2001). Razor clams have high fecundity and high reproductive capacity, but recruitment is variable. They are locally distributed in suitable habitat on the west coast of Vancouver Island, Haida Gwaii and Calvert Island. They are dependent on unconsolidated substrates which can be affected for extended periods due to difficulties removing pollutants that have seeped into the substrate.

Taxonomy

The accepted scientific name is *Siliqua patula* Dixon, 1789 (Coan *et al.* 2000). The accepted vernacular name is Pacific razor (Turgeon *et al.* 1998), although the name razor clam is regularly used (Table 10).

Description

Razor clam valves are long and narrow in shape (length approximately 2.5 times width), thin and fragile (Quayle 1974, Quayle and Bourne 1972, Harbo 1997, Coan *et al.* 2000, Heibert *et al.* 2016). The external surface is covered by a thick periostracum, greenish to dark brown, which may be worn off near the umbone in older individuals (Figure 27). The interior surface is white to pale purple. The ligament is external, the umbones not prominent and placed 2/3 the shell length towards the anterior end. The hinge supported by a single prominent rib extending slightly anterior and then to the ventral margin. Four cardinal teeth in the left valve and two in the right valve. Flesh and siphons yellow-white, siphons short and fused except at tips. Maximum size at least 190 mm TL.

Distribution

Razor clams are distributed from Cook Inlet AK through the Gulf of Alaska, BC, Washington, Oregon and to Morro Bay CA, although they are uncommon in California (Coan *et al.* 2000, Hiebert *et al.* 2016). Important populations in BC occur along Long Beach on the west coast of Vancouver Island and northwestern Graham Island in Haida Gwaii, primarily from Masset to Rose Spit; smaller populations are also found on the eastern shore between Rose Spit and Cape Ball, the western shore of Graham Island and the western shore of Calvert Island (Bourne 1969, Bourne and Quayle 1970, Quayle and Bourne 1972).

Habitat Preferences

Razor clams inhabit wave-swept sandy shores directly exposed to the open ocean, in fine, clean sand substrate with aeration (Quayle 1974, Quayle and Bourne 1972, Harbo 1997, Heibert *et al.* 2016)(Figure 28). They are found from the upper intertidal to 55 m and are more abundant near the low tide level than higher on the beach. They are found near the substrate surface, oriented vertically and consistently oriented with the dorsal surface (hinge) facing the ocean. They do not establish permanent burrows due the high energy habitat, but lateral movement of adults is uncommon; juveniles have been observed crawling short distances across the sediment surface (Bourne and Quayle 1970). They have the ability to re-bury if left on the surface and burrow rapidly through the sand when disturbed.

Role in the Ecosystem

Trophic Ecology

Razor clams are suspension feeders, filtering diatoms, organic matter and other small organisms from the water column (McMillan 1924).

Ecological Interactions

Adult razor clams are preyed on by gulls, ducks, crabs, sea stars, gastropods, octopus, rays, surfperch and flatfish (ADFG 1985, Jones *et al.* 1998, Heibert 2016).

Razor clams are host to juvenile pinnotherid pea crabs (*Pinnixa faba* and *P. littoralis*)(Hart 1982, Jensen 2014).

Physical Tolerances

Razor clams inhabit open ocean beaches with salinities of approximately 30‰ (Heibert *et al.* 2016). They are found in cold temperate waters from California to Alaska. Salinity near the beaches on Haida Gwaii were 20-30‰ while those near Long Beach were 28-31‰ (Bourne and Quayle 1970). Razor clams exposed to 25°C temperatures in the lab died after eight hours (Sayce and Tufts 1972).

Reproductive Biology

Razor clams are dioecious, and fertilization is external (McMillan 1924). Fecundity has been estimated at $6.0x10^6$ to $1.0x10^7$ eggs per female (McMillan 1924), although some estimates are as high as $1.2x10^8$ (ADFG 1985).

Razor clams generally mature at 97-103 mm TL and 2-4 years of age (Weymouth *et al.* 1926); age and size of maturity increase with increasing latitude.

Peak spawning is late May-early June in Washington and July-August in BC and Alaska (Heibert *et al.* 2016). On Haida Gwaii spawning occurred from mid-June (one male) to September with peak spawning July-August; on the west coast of Vancouver Island spawning occurred from April to October with peak spawning in August (Bourne and Quayle 1970)(Figure 29).

Bourne and Quayle (1970) and Quayle and Bourne (1972) reported sporadic high recruitment events with long intervening periods of poor recruitment on Long Beach. Recruitment was reported to decrease with increasing latitude between Washington and Alaska (Weymouth *et al.* 1926, Weymouth and McMillin 1931).

Early Life History

Pelagic larval period is approximately eight weeks (Weymouth *et al.* 1926). Weymouth *et al.* (1926) speculated that much of the "pelagic" larval period was spent at or just within the substrate surface.

Mortality is high in the first winter as post-larvae and juveniles that settle in the late summer and fall are easily dislodged from the substrate by winter storms or stressed by low temperatures (Bourne and Quayle 1970, ADFG 1985).

Growth Rates and Life Span

Growth is initially rapid and slows after 3-4 years of age (Weymouth *et al.* 1926, Weymouth and McMillin 1931). Growth decreases with increasing latitude with razors reaching "breeding size" in two years in Washington and four years in Alaska; razor clams on Vancouver Island and Haida Gwaii reached 90 mm TL in their second and third years, respectively (Weymouth and McMillin 1931, Bourne 1969, Bourne and Quayle 1970). Growth is initially more rapid in southern populations but is not sustained and maximum size and age are lower than northern populations (Weymouth *et al.* 1931).

Maximum age increased with increasing latitude; maximum age was five years at Pismo and seven years at Crescent City CA, nine years at Copalis WA, 10 years at Masset and 13-19 years at sites sampled in Alaska (Weymouth and McMillin 1931, Weymouth *et al.* 1931).

Pathways of Effects (PoE): Oil Exposure

A Pathways of Effects (PoE) oil exposure model can aid oil spill emergency response by identifying low to high-risk scenarios for species exposure. This section describes PoE for razor clams through exposure paths of specific species life stages and the potential dispersion and fates of five oil groups (Table 2). The specific environmental conditions and chemical signature of the oil spill should be taken into consideration as they may cause differences in the outcomes described in this document. A summary for this section is in Appendix Table 8.

Habitat utilization and temporal distribution of spawning, larval and adult presence and vulnerability ranks of razor clams are illustrated in Figure 28 and Figure 29, with vulnerability ranking scores for razor clams generalized for all oil groupings as 5 for the larval life stage and 7 for adult life stages (Jeffery *et al.* 2023).

Group 1 Oils

Group 1 contains gasoline and marine diesel oil (MDO). Both gasoline and MDO are light, volatile, and acutely toxic oils (ITOPF 2011a). The two oils are split into subcategories due to differences in fate and behaviour, causing different potential PoE on razor clams.

Gasoline

Gasoline has high concentrations of LMW hydrocarbons which may cause both acute and chronic toxic effects on aquatic organisms (ITOPF 2011b). Possible toxic effects on aquatic organisms include mortality (Keesing *et al.* 2018), decreased locomotive ability and other physiological functioning (Adzigbli and Yeuwen, 2018).

Fresh Gasoline Oil Spill

Razor clams spawn in British Columbia between April and October with a peak in July and August (Bourne and Quayle 1970; Heibert *et al.* 2016). Razor clams have a pelagic larval stage lasting eight weeks, during which larvae are present in the water column (Weymouth *et al.* 1926). Razor clam larvae spend the majority of this larval period close to the substrate (Weymouth *et al.* 1926). Gasoline is very light, having a specific gravity of <0.8, causing it to float and only be present on the top 1-2 mm of the water column (ITOPF 2011a). Due to gasoline remaining on the top of the water, risk of larval exposure is low during low energy ocean conditions, as they would need to swim to the sea's surface. Medium and high energy ocean conditions can cause increased dispersion throughout the water column within the intertidal and subtidal zones, increasing the risk of exposure for larval clams. Due to the larval clam's tendency to stay near the substrate, the risk of exposure remains low in all ocean energy conditions.

Razor clams have limited mobility after the larval stage along with having a consistent suspension feeding diet of small organisms. Due to this low mobility, the PoE and vulnerability levels are the same for all post-larval life stages.

Post-larval razor clams are distributed in depths ranging from the upper intertidal to 55 m, in exposed areas made up of fine clean sand substrate (Quayle 1974, Quayle and Bourne 1972, Harbo 1997, Heibert *et al.* 2016). They are more commonly found at lower tide levels, burrowed near the substrate surface, with high levels of interaction with the substrate and ocean surface (Quayle 1974, Quayle and Bourne 1972, Harbo 1997, Heibert *et al.* 2016). Given the habitat of post-larval razor clams, gasoline spills in the intertidal zone pose a high risk. Oil spills in intertidal zones have historically caused high mortality in molluscs (Keesing *et al.* 2018).

Weathered Gasoline Oil Spill

Gasoline is highly volatile and can completely evaporate within 24 hours; as such, as gasoline weathers the risk to razor clams decreases. Weathered gasoline is unlikely to pose any risks to razor clams as it evaporates and disperses very quickly.

Marine Diesel Oils (MDO)

Fresh MDO Oil Spill

Fresh MDO has high aquatic toxicity due given high concentrations of light molecular weight hydrocarbons (Environment Canada 1999). Fresh MDO has similar potential PoE to razor clams as gasoline (Appendix Table 8).

Razor clam larvae are present during the spawning period of April to October, peaking in July and August with their larval stage lasting eight weeks (Weymouth *et al.* 1926, Bourne and Quayle 1970, Heibert *et al.* 2016). As with gasoline, MDOs have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring during low energy ocean conditions, as they would need to swim to the sea's surface. Medium and high energy ocean conditions can cause increased dispersion throughout the water column within the intertidal and subtidal zones, increasing the risk of exposure to larval clams; however, due to the larval clam's tendency to stay near the substrate, the risk of exposure remains relatively low in all ocean energy conditions.

Razor clams have limited mobility after the larval stage. Due to this sessile nature, the PoE and vulnerability levels are the same for all post-larval life stages.

Fresh MDO spills in the intertidal and subtidal zone have a high risk of impacting razor clams. MDO spills remain on the surface of the water; however, when tides recede the intertidal zone will be exposed to the MDO spilled on the surface. Post-larval razor clams are distributed in depths ranging from the upper intertidal to 55 m, in exposed areas made up of fine clean sand substrate (Quayle 1974, Quayle and Bourne 1972, Harbo 1997, Heibert *et al.* 2016). They are more commonly found at lower tide levels, burrowed near the substrate surface, with high levels of interaction with the substrate and ocean surface (Quayle 1974, Quayle and Bourne 1972, Harbo 1997, Heibert *et al.* 2016). Possible effects may include coating, smothering, ingestion, and habitat modification. Intertidal zone oil spills have historically caused high mortalities in molluscs (Keesing *et al.* 2018).

Weathered MDO Oil Spill

As MDOs weather aquatic toxicity decreases as the LMW hydrocarbons evaporate. MDO still poses potential risks to razor clams through coating, smothering and ingestion (ITOPF 2011b). The persistence of MDO causes weathered MDO to pose many of the same potential effects on razor clams as fresh spills. Razor clam larvae still have the potential to interact with the oil spill on the surface of the water with potential effects including coating and smothering, likely without acute toxic effects. The risk of this effect remains low in low energy ocean conditions. The risk is slightly increased to moderate in high-energy ocean conditions, due to increased mixing and dispersion and larval clams' behaviour of staying close to the substrate.

MDO is persistent and has the potential to interact and adsorb to drift particles within the water column (ITOPF 2011a). Post-larval razor clams are suspension feeders, filtering small organisms out of the water column (Heibert 2016). Interaction and adsorption to these drift particles by MDO creates the potential for razor clams to ingest MDOs. Ingestion of oils by molluscs can lead to effects such as impaired physiological function and behaviour as well as death (Adzigbli and Yeuwen, 2018). The risk of this occurring is high.

Given the persistence of MDO, weathered MDO still poses a risk to razor clams. Effects include coating, smothering, and habitat modification. As razor clams burrow into the

substrate and rely on clean sand (Quayle 1974, Quayle and Bourne 1972, Harbo 1997, Heibert *et al.* 2016), contaminated substrate may prevent this behaviour or increase their exposure to this oil long term. Intertidal zone oils spills can cause high mortality in molluscs (Keesing *et al.* 2018).

Group 2 Oils

Light Crude Oils (LCOs)

Group 2 oils are LCOs which contain moderate to high concentrations of hydrocarbons which cause acute and chronic toxic effects on aquatic organisms (Adzigbli and Yeuwen 2018). LCOs can cause additional negative effects through coating and smothering aquatic organisms. There are similar PoE between Group 2 and Group 1 oils (Appendix Table 8).

Fresh LCO Oil Spill

Razor clam larvae are present during the spawning period of April to October, peaking in July and August, with their larval stage lasting eight weeks (Weymouth *et al.* 1926, Bourne and Quayle 1970, Heibert *et al.* 2016). As with Group 1 oils, LCOs have a potential to interact with larvae at the water columns surface; however, there is a low risk of this occurring in low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion throughout the water column within the intertidal and subtidal zones, increasing the risk of exposure to larval clams; however, due to the tendency of larvae to stay near the substrate, the risk of exposure remains relatively low in all ocean energy conditions.

Razor clams have limited mobility after the larval stage. Due to this sessile nature, the PoE and vulnerability levels are the same for all post-larval life stages.

Fresh LCO spills in the intertidal zone have a high potential to impact post-larval razor clams. Post-larval razor clams reside in the substrate within the mid-intertidal to subtidal zones, with high potential for interaction with an oil spill at the water's surface. Razor clams would be exposed to the oil spill as the tide recedes. LCO interaction with the substrate may cause habitat modification, contaminating the sand, causing increased exposure during burrowing behaviour.

Weathered LCO Oil Spill

As LCOs weather their acute toxicity decreases as the LMW hydrocarbons evaporate; however, the same potential PoE and risks to razor clams remain. Light crude oils persist and can form stable emulsions, leading to increased volume and specific gravity of the spill (ITOPF 2011a). The PoE and risk of effects for weathered LCOs are the same as those of fresh LCOs for larval razor clams. Razor clam larvae still have the potential to interact with the oil spill on the surface of the water with potential effects including coating and smothering, likely without acute toxic effects. The risk of this effect remains low in low energy ocean conditions. The risk is slightly increased to moderate in high-energy ocean

conditions, due to increased mixing and dispersion and larval clams' behaviour of staying close to the substrate.

LCOs persist as they weather causing the potential for them to interact with drift particles throughout the water column potentially adsorbing to drift particles. Post-larval razor clams are suspension feeders, filtering small organisms out of the water column (Heibert 2016). The interaction between LCOs and drift particles leads to the potential for ingestion by razor clams, causing toxic and potentially fatal effects (Adzigbli and Yuewen 2018). The risk of this occurring is high.

Effects of weathered LCO on post-larval clams include coating, smothering, and habitat modification. As razor clams burrow into the substrate and rely on clean sand (Quayle 1974, Quayle and Bourne 1972, Harbo 1997, Heibert *et al.* 2016), contaminated substrate may prevent this behaviour or increase their exposure to this oil long term. Intertidal zone oils spills can cause high mortality in molluscs (Keesing *et al.* 2018).

Group 3 Oils

Heavy and Persistent Oils

Group 3 contains engine/hydraulic oil, medium crude oil, heavy crude oil, and dilbit oil. Group 3 oils are heavy and persistent, while not being as toxic as Group 1 and 2 oils, due to decreased levels of LMW hydrocarbons (ITOPF 2011a, 2011b). There are many similar PoE between Group 3 and Group 1 oils (Appendix Table 8).

Fresh Heavy and Persistent Oil Spill

Pelagic larval razor clams are present during the spawning period of April to October, peaking in July and August (Bourne and Quayle 1970, Heibert *et al.* 2016). The pelagic larval stage lasts for around 8 weeks (Weymouth *et al.* 1926). As with Group 1 oils, LCOs have a potential to interact with larvae at the water columns surface; however, there is a low risk of this occurring in low energy ocean conditions. Medium and high energy ocean conditions can cause increased oil dispersion throughout the water column within the intertidal and subtidal zones, increasing the risk of exposure to larvae; however, due to the larvae's tendency to stay near the substrate, the risk of exposure remains relatively low in all ocean energy conditions.

Razor clams have limited mobility after the larval stage. Due to this sessile nature, the PoE and vulnerability levels are the same for all post-larval life stages.

Fresh Group 3 oil spills in the intertidal zone have a high potential to impact all life stages of razor clams. Post-larval razor clams reside in the substrate within the mid-intertidal to shallow subtidal zone, with high potential for interaction with an oil spill at the water's surface. Razor clams would be exposed to the oil spill as the tide recedes. Effects may

include coating, smothering and ingestion, leading to physiological decreases or mortality (Adzigbli and Yuewen 2018).

Weathered Heavy and Persistent Oil Spill

As Group 3 oils weather, little to no evaporation occurs; however, sedimentation can occur causing the oils to sink (ITOPF 2011a). Due to Group 3 oils persistence the PoE and vulnerability remain similar for razor clams, with increased risks due to possible sinking.

Possible sinking due to sedimentation creates a greater risk of exposure for larval razor clams. Sinking oil may interact directly with larvae through coating and smothering (ITOPF 2011b). Sinking oil may also interact with drift particles and adsorb to them. Razor clams are suspension feeders, filtering small organisms from the water column (McMillan 1924). Adsorption of oil to these particles causes the potential for ingestion of oil while filter feeding, causing physiological decreases such as clogging of feeding apparatuses and decreased immunity (Adzigbli and Yuewen 2018). There is a high risk of this occurring.

Group 4 Oils

Bunker C Oils

Group 4 oils are Bunker C oils. Bunker C oils are heavy and highly persistent oils (Environment Canada 1999). Bunker C oils contain few toxic light molecular weight hydrocarbons meaning they have little to no acute toxic effects on aquatic organisms. Bunker C oils still pose risk through coating and smothering as well as chronic effects due to heavier toxic hydrocarbons (Adzigbli and Yuewen 2018).

Fresh Bunker C Oil Spill

Pelagic larval razor clams are present during the spawning period of April to October, peaking in July and August (Bourne and Quayle 1970, Heibert *et al.* 2016). The pelagic larval stage lasts for around 8 weeks (Weymouth *et al.* 1926). As with Group 1 oils, LCOs have a potential to interact with larvae at the water columns surface; however, there is a low risk of this occurring in low energy ocean conditions. Medium and high energy ocean conditions can cause increased oil dispersion throughout the water column within the intertidal and subtidal zones, increasing the risk of exposure to larval clams; however, due to the larval clam's tendency to stay near the substrate, the risk of exposure remains relatively low in all ocean energy conditions. Negative effects on razor clams may differ from previous oils given lower concentrations of LMW hydrocarbons, causing less acute toxic effects.

Razor clams have limited mobility after the larval stage. Due to this sessile nature, the PoE and vulnerability levels are the same for all post-larval life stages.

Bunker C oil spills in the intertidal zone have potential to cause high razor clam mortalities through coating and smothering (Adzigbli and Yuewen 2018). Razor clams are distributed in the intertidal and shallow subtidal zones, shallowly burrowed in the clean sandy substrate (Quayle 1974, Quayle and Bourne 1972, Harbo 1997, Heibert *et al.* 2016). Razor clams would be exposed to the Bunker C oil spill as the tide recedes in the intertidal zone. Bunker C oil interaction with the substrate may cause habitat modification, contaminating the sand, causing increased exposure during burrowing behaviour.

Weathered Bunker C Oil Spill

There are little weathering effects on Bunker C oil given its low concentrations of volatile LMW hydrocarbons and high persistence (ITOPF 2011a). The PoE are similar between weathered and fresh Bunker C oils; however, Bunker C oils are susceptible to creation of stable emulsions, causing increased volume and specific gravity and sedimentation-caused sinking. PoE and risks of effects that weathered Bunker C oil may have on razor clams are similar between fresh and weathered oils, with increased risk due to sinking. If sinking occurs through emulsions forming or sedimentation, larval razor clams are at a greater risk of oil exposure. Sinking oils could coat and smother the pelagic larval razor clams throughout the water column causing locomotion and feeding issues or potentially mortality (Adzigbli and Yuewen 2018). Sinking Bunker C oil increases the risk of exposure to post-larval razor clams located deeper than the intertidal zone.

Sinking oil may also interact with drift particles and adsorb to them. Razor clams are suspension feeders, filtering small organisms from the water column (McMillan 1924). Adsorption of oil to these particles causes the potential for ingestion of oil while filter feeding, causing physiological decreases such as clogging of feeding apparatuses and decreased immunity (Adzigbli and Yuewen 2018). There is a high risk of this occurring.

Group 5 Oils

Sinking Oils

Group 5 oils are extremely heavy and persistent oils known as sinking oils. Sinking oils have a specific gravity >1, causing them to readily sink in water (ITOPF 2011a). Due to high specific gravity, sinking oils have a high potential to negatively impacting razor clams at all life stages.

Fresh Sinking Oil Spill

Pelagic larval razor clams are present during the spawning period of April to October, peaking in July and August (Bourne and Quayle 1970, Heibert *et al.* 2016). Razor clam larval stage lasts around 8 weeks (Weymouth *et al.* 1926). Sinking oils have a high risk of interacting with the larvae of razor clams at all potential ocean energy scenarios, given the

potential of oil being present throughout the water column or interacting with larvae while sinking.

Razor clams have limited mobility after the larval stage. Due to this sessile nature, the PoE and vulnerability levels are the same for all post-larval life stages.

Sinking oils have a high risk of oil interacting with drift particles and being ingested by filter-feeding post-larval razor clams. Ingestion of oils can cause physiological issues along with potential mortality in molluscs (Adzigbli and Yuewen 2018). Sinking oil spills in the intertidal and shallow subtidal zones have a high risk of interacting with razor clams through coating and smothering, potentially causing death. There is a high risk of this occurring.

Weathered Sinking Oil Spill

Sinking oils have little to no weathering effects; therefore, the PoE on razor clams are the same for fresh and weathered sinking oils.

Figure 27. Pacific razor, *Siliqua patula*.

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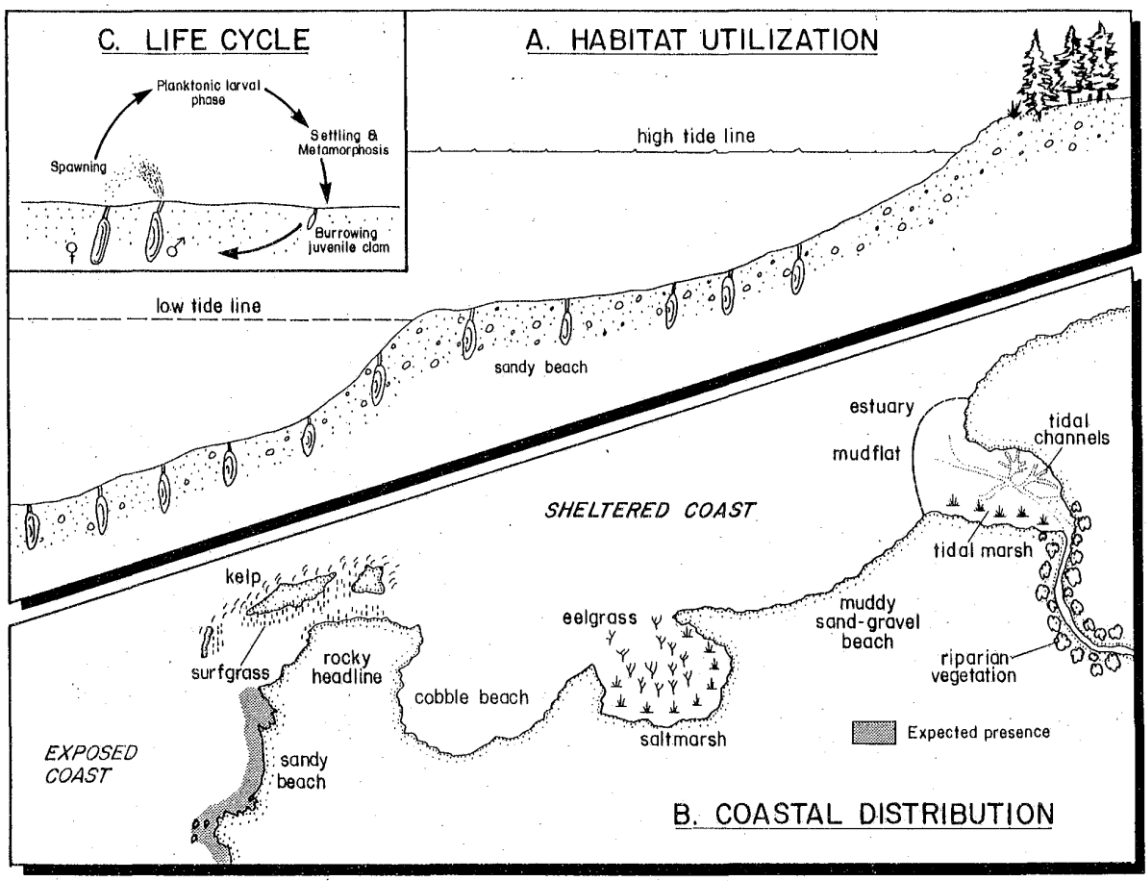

Figure 28. Habitat utilization (A), coastal distribution (B, gray polygons indicate expected presence) and life cycle (C) of Pacific razor, *Siliqua patula* (Williams 1989).

J	F	M	A	M	J	J	A	S	O	N	D
1	1	1	2	2	3	3	3	2	2	1	1
			---Spawning---								
1	1	1	2	2	3	3	3	3	2	2	1
			---Larval Presence---								
3	3	3	3	3	3	3	3	3	3	3	3
---Adult Presence---											

Figure 29. Temporal distribution of spawning, larval and adult presence and vulnerability ranks of Pacific razor, *Siliqua patula*.

Legend: 1 (green) = low/negligible vulnerability; 2 (yellow) = moderate vulnerability; 3 (red) = high vulnerability.

Table 10. Summary of information required to inform marine emergency response for Pacific razor, *Silliqua patula*.

Taxonomy
Scientific Name:
Siliqua patula (Dixon, 1789)

Common Name(s):
Pacific razor, flat razor clam, northern razor-clam, razor clam

Higher Taxonomy:
Mollusca; Bivalvia; Adapedonta; Pharidae

Description

Shell long and thin, posterior end much longer than anterior end. Thin, brown shiny periostracum. Internal shell white to purple; internal radial rib directed anteriorly, increasing in width from umbone. Maximum size at least 190 mm TL.

Distribution

Cook Inlet AK to Morro Bay CA, in exposed sandy foreshores. Upper intertidal to 55 m.

Habitat Preferences

Inhabit wave-swept sandy shores directly exposed to the open ocean, in fine, clean sand substrate with aeration. Found from the upper intertidal to 55 m; are more abundant near the low tide level than higher on the beach. Burrow near the substrate surface, oriented vertically and consistently oriented with hinge facing the ocean. Lateral movement of adults uncommon; juveniles can crawl short distances across the sediment surface. Can re-bury if left on the surface; burrow rapidly through the sand when disturbed.

Physical Tolerances

Salinity
Found on exposed beaches with salinities usually near 30‰ and generally above 20‰.

Temperature
Found in cold temperate waters from California to Alaska. Can tolerate 25°C temperatures only briefly.

Table 10. continued.

Reproductive Biology Sexes separate, fertilization external. Generally mature at 97-103 mm TL and 2-4 years of age; age and size of maturity increase with increasing latitude. Peak spawning late May-early June in Washington and July-August in BC and Alaska. Spawning occurred mid-June to September with peak spawning July-August on Haida Gwaii; west coast of Vancouver Island spawning occurred April-October with peak spawning in August. Recruitment sporadic with long intervening periods of poor recruitment. Recruitment decreased with increasing latitude between Washington and Alaska. Fecundity estimated at 6-10 million eggs per female, one estimate of 120 million eggs per female. Pelagic larval period approximately eight weeks, may be spent on or just within the substrate surface.
Growth Rate and Lifespan Growth initially rapid, slows after 3-4 years of age. Growth decreases with increasing latitude; razors reach "breeding size" in two years in Washington and four years in Alaska. Razors on Vancouver Island and Haida Gwaii reached 90 mm TL in their second and third years, respectively Growth initially more rapid in southern populations but is not sustained and maximum size and age are lower than northern populations. Maximum age increases with increasing latitude from 5-7 years in California, nine years in Washington, 10 years at Masset and 13-19 years in Alaska.
Migratory Behaviour Adults can move limited distances in their resident beach, juveniles may move laterally in response to substrate disturbance. Dispersal between populations limited to pelagic larval stages.
Role in the Ecosystem Suspension feeders, filtering diatoms, organic matter and other small organisms from the water column. Preyed on by gulls, ducks, crabs, sea stars, gastropods, octopus, rays, surfperch and flatfish. Host to juvenile pinnotherid pea crabs.
Significance Supports important commercial fishery on northern Haida Gwaii. First Nations and recreational species there and elsewhere.

Table 10. continued.

Vulnerability
Subgroup Classification: Intertidal/Subtidal Benthic; Sediment Infauna; Low Mobility; Mollusca.

Adult Exposure Criteria: High Aggregation; Low Mobility; Intertidal (high interaction with sea surface); Infaunal (high interaction with sea floor). Score: 4.

Adult Sensitivity Criteria: Filter feeder (feeding apparatus can be clogged or damaged by pollutants); Chemical sensitivity assumed to be high. Score: 2.

Adult Recovery Criteria: Haida Gwaii population regularly assessed, other populations unmonitored; Relatively high reproductive capacity; Distributed in open oceanic sandy beaches in Haida Gwaii, Calvert Island and west coast of Vancouver Island; High degree of interaction with unconsolidated substrates. Score: 1.

Cumulative Total Score: 7.

Larval Exposure Criteria: Aggregate or Patchiness where large number of larvae affected; Low Mobility; Interaction with sea surface. Score: 3.

Larval Sensitivity Criteria: Larvae feeding appendages that can become clogged by oil; Chemical sensitivity assumed to be high. Score: 2.

Larval Recovery Criteria: Populations unmonitored; Relatively high reproductive capacity; Broadly distributed in suitable habitat; Low degree of interaction with unconsolidated substrates. Score: 0.

Larval Cumulative Total Score: 5.

Varnish Clam (Nuttallia obscurata)

Significance

Varnish clams may be taken in First Nations and recreational fisheries; small amounts may be harvested from aquaculture tenures. Attempts at commercial fishery development in British Columbia were not successful (Gillespie *et al.* 1999b, 2001b).

Vulnerability

Subgroup classification

Varnish clams were included in the following subgroups: 1 - Intertidal location for exposure; 2 - Sediment Infauna substrate; 3 - Low mobility; and taxonomy to inform feeding types and reproductive strategies - Mollusca (Thornborough *et al.* 2017, Hannah *et al.* 2017, Jeffery *et al.* 2023).

Exposure

As with many infaunal bivalve molluscs, aggregated distributions of varnish clams are a result of habitat preferences, physiological tolerances and are beneficial for spawning synchrony and fertilization success (Hannah *et al.* 2017).

Varnish clams have limited mobility; dispersal is through pelagic larval stages, adults may move short distances but are confined to the beaches on which they settled. They are intertidal in distribution, thus their populations have a high level of interaction with the sea surface. As infaunal organisms they have intimate contact with the unconsolidated sediments they inhabit.

Sensitivity

As filter/suspension feeders, varnish clams are very sensitive to pollutants that may clog or damage their feeding apparatus. Numerous studies document chemical effects of pollutants on bivalve physiology, reproduction and larval survival.

Recovery

Population status is not actively monitored in British Columbia. Varnish clams have high fecundity and high reproductive capacity, but consistency of recruitment is unknown. They are broadly distributed in suitable habitat in southern British Columbia (Strait of Georgia and west coast of Vancouver Island). They are dependent on unconsolidated substrates which can be affected for extended periods due to difficulties removing pollutants that have seeped into the substrate.

Taxonomy

The accepted scientific name is *Nuttallia obscurata* (Reeve 1857, Coan *et al.* 2000). Literature from the northwestern Pacific often uses the synonym *N. olivaceus* (Roth 1978). The common name preferred by the American Fisheries Society is purple mahogany clam (Turgeon *et al.* 1998), although the name varnish clam is used regularly in British Columbia and the Pacific Northwest (Table 11). Savoury clam is a market name (Gillespie *et al.* 2001b).

Description

Varnish clams have compressed valves, nearly oval in outline, shell height is approximately 0.80 of shell length, and shell thickness approximately 0.35 of shell length (Gillespie *et al.* 1999). Both ends of the shells are rounded, the posterior longer and more angular than the anterior. Outer surfaces of the valves are covered with a thick, shiny brown periostracum, often eroded to expose the chalky, purplish-white shell near the umbo. The valves are unequally inflated, the right valve flatter than the left, though more equally convex than in *N. nuttalli* or *N. japonica*, both of which have distinctly flattened right valves (Fitch 1953; Roth 1978). The hinge ligament is external and large. Smaller specimens may be light tan in color, exhibiting dark purple rays from the umbo to the margin or may be uniformly dark brown or dark purple (Figure 30).

The interior surface is purple, ranging from deep royal purple to light violet in different individuals (Coan *et al.* 2000). The purple fades as the shell dries, and older dead shell may appear white inside (Gillespie *et al.* 1999). Less than 1% of varnish clams examined by Gillespie *et al.* (1999) lacked purple pigment and were white or yellowish inside the valves. These individuals had a noticeably lighter periostracum (colloquially termed “blondes”). The anterior adductor muscle scar is long and vaguely crescentic. The posterior muscle scar is nearly rectangular in outline. The pallial sinus, which is obliquely oval, narrowing on the dorsal margin to become somewhat angular anteriorly, extends anterior to a position directly beneath, or very slightly anterior to, the umbo. The ventral margin of the sinus extends posterior to a point directly beneath the posterior margin of the posterior adductor scar. The body, foot, siphons and mantle are white.

Maximum size recorded by Gillespie *et al.* (1999) was 64 mm TL, weighing 45.1 g, taken at Newcastle Island, Nanaimo in 1998. Maximum size observed at Fidalgo Bay was 68 mm TL (P. Dinnel, Western Washington University, pers. comm.). Gillespie and Bourne (2005a) reported a maximum size of 66 mm TL.

Distribution

Native

Varnish clams are a northwestern Pacific species distributed from Korea and the Japanese islands of Kyushu, Honshu and Shikoku to the Yellow and Bohai Seas of China and southern Russia (Bernard *et al.* 1993, Coan *et al.* 2000, Kolpakov and Kolpakov 2005).

Introductions

The varnish clam is a recently introduced exotic bivalve that has become well established in southern British Columbia (Strait of Georgia and east and west coasts of Vancouver Island)(Forsyth 1993, 1997; Merilees and Gillespie 1995; Gillespie *et al.* 1999b, 2001b). They have also been recorded from Puget Sound, WA and in most major estuaries in Oregon (Coan *et al.* 2000). Current latitudinal limits are Stories Beach, Fort Rupert (50°41'N) and Alsea Bay, OR (43°04'N) (Gillespie and Bourne 2005b, Dudas and Dower 2006). Shells of varnish clam were found at Indian Island, Smith Sound (51°17'N) and Pruth Bay, Calvert Island (51°40), but no live clams were found (Gillespie and Bourne 2005b, Christou *et al.* 2011).

Habitat Preferences

Varnish clams prefer mixed sand/gravel/mud substrates and are generally found higher on the beach than native species (Gordon *et al.* 2018)(Figure 31). Densities were highest in samples collected at 2.8 and 3.5 m above chart datum at Whaling Station Bay, Hornby Island (Gordon *et al.* 2018) and 1.5-2.0 m above mean low low water in the San Juan Islands (Byers 2002). They are often associated with areas of freshwater run-off or seepage (Gillespie *et al.* 1999b, 2001b).

Role in the Ecosystem

Trophic Ecology

Varnish clams use three means of feeding: they filter organic material from the water column, collect organic debris from the substrate through pedal feeding and vacuum organic debris from the surface of the substrate with their siphons (Tsuchiya and Kurihara 1980; Gillespie *et al.* 1999b, 2001b; Sorber 2013). Pedal feeding decreased the attractiveness of the species as a commercial product as the clams would continue to ingest sand in the tanks where they were stored to purge (Gillespie *et al.* 2001b).

Ecological Interactions

Varnish clams are found in association with introduced Manila clams and native littleneck clams, although varnish clams are generally found at higher tidal levels than these species (Gillespie et al 1999b, Siegrist 2010). When distributions of varnish clams and Manila or littleneck clams overlap, varnish clams are generally found deeper in the substrate than the other species (Gillespie *et al.* 2001b).

Varnish clams are preyed upon by Lewis' moon snails (*Euspira lewisii*), cancrid and European green (*Carcinus maenas*) crabs, black oystercatchers (*Haematopus bachmanni*), surf and white-winged scoters (*Mellanita perspicillata* and *M. fusca*), glaucous-winged gulls (*Larus glaucescens*), northwestern crows (*Corvus caurinus*), racoons, (*Procyon lotor*) and sea otters (*Enhydra lutris*)(Byers 2002, Palacios and Ferraro 2003, Dudas *et al.* 2005, Lewis *et al.* 2007a, Ryder 2007, Curtis *et al.* 2012, Palm *et al.* 2012, Simmons *et al.* 2014,

Hollenberg and Demers 2017, G. Gillespie, pers. obs.). In the northwestern Pacific, varnish clams are preyed upon by juvenile flatfishes, which crop the siphons of the clams (Sasaki *et al.* 1999); clams with the siphon tips removed burrow shallower and may be subject to increased lethal predation (Meyer and Byers 2005).

Varnish clams are host to juvenile pinnotherid pea crabs (*Pinnixa littoralis* and presumably *P. faba*)(Jensen 2014).

Physical Tolerances

Varnish clams exhibit a broad tolerance of temperature and salinity. Using gill tissue as a proxy for whole animals, Siegrist (2010) demonstrated greater tolerance at high temperatures in varnish clams than in Manila and littleneck clams. Gill ciliary activity declined in salinities below 20‰ for littleneck clams and 10‰ for Manila clams while tissues from varnish clams showed little reduction in ciliary activity even at 1‰. Tissues of Manila and littleneck clams died within 48 hours over salinities ranging from 1-30‰ while varnish clam tissues survived for more than two weeks. Oxygen consumption rates of gill tissues of varnish clams were lower than those of littleneck clams over a broad range of salinities and were highest at 5‰ and lowest at 55‰ (Sorber 2013). Filtration rates of varnish clams greatly exceeded those of littleneck clams at reduced salinities (Talkington 2015).

Kolpakov and Kolpakov (2005) studied varnish clams living in a brackish lake (8-22‰) and found that they responded to seasonal changes in temperature by changing their depth in the substrate.

Reproductive Biology

Varnish clams are broadcast spawners, the sexes are generally separate, but hermaphrodites have been reported (Dudas and Dower 2006). In their native range, spawning peaks in the spring and clams achieve sexual maturity in one year (Dudas and Dower 2006). In BC, the spawning period was May to August or September, depending on location (Figure 32). Fecundity ranged from $9.0x10^4$ to $6.0x10^6$ per female or $4.0x10^4$ to $4.0x10^6$, depending on location.

Early Life History

Larval period is at least three weeks and perhaps as long as eight weeks (Dudas and Dower 2006). Larvae grew to D-hinge veliger stage in approximately 43 hours and commenced feeding. In trials held at three temperatures and 31-32‰ salinity, juveniles settled in 33 days at 15°C and 19 days at 20°C; larvae did not survive to settlement at 9°C. In trials held at 15°C, juveniles settled in 31 days at 20‰; larvae reared at 10 and 15‰ did not survive to settlement. In their native range, larvae can develop at temperatures of 15-25°C and metamorphose in temperatures between 10 and 30°C; they can only survive in salinities of 24-31‰ (Dudas and Dower 2006). Varnish clams may experience fairly regular recruitment or sporadic episodes of high recruitment (Dudas *et al.* 2007).

Growth Rates and Life Span

Varnish clams generally reach 38 mm TL in four years (Gillespie and Bourne 2005a). Estimates of maximum age were five years (Yates 1999), six years (Gordon *et al.* 2018) and eight years (Gillespie and Bourne 2005a).

Pathways of Effects (PoE): Oil Exposure

A Pathways of Effects (PoE) oil exposure model can aid oil spill emergency response by identifying low to high-risk scenarios for species exposure. This section describes PoE for varnish clams through exposure paths of specific species life stages and the potential dispersion and fates of five oil groups (Table 2). The specific environmental conditions and chemical signature of the oil spill should be taken into consideration as they may cause differences in the outcomes described in this document. A summary table for this section is in Appendix Table 9.

Habitat utilization and temporal distribution of spawning, larval and adult presence and vulnerability ranks of varnish clams are illustrated in Figure 31 and Figure 32 with vulnerability ranking scores for varnish clams generalized for all oil groupings as 5 for the larval life stage and 7 for adult life stages (Jeffery *et al.* 2023).

Group 1 Oils

Group 1 contains gasoline and marine diesel oil (MDO). Both gasoline and MDO are light, volatile, and acutely toxic oils (ITOPF 2011a). The two oils are split into subcategories due to differences in fate and behaviour, causing different potential PoE on varnish clams.

Gasoline

Gasoline has high concentrations of LMW hydrocarbons which may cause both acute and chronic toxic effects on aquatic organisms (ITOPF 2011b). Possible toxic effects on aquatic organisms include mortality (Keesing *et al.* 2018), decreased locomotive ability and other physiological functioning (Adzigbli and Yeuwen 2018).

Fresh Gasoline Oil Spill

Varnish clam spawning in British Columbia occurs between May and September (Gillespie *et al.* 1999b). Varnish clams have a pelagic larval stage lasting 3-8 weeks, during which larvae are present in the water column (Dudas and Dower 2006). Gasoline is very light, having a specific gravity of <0.8, causing it to float and only be present on the top 1-2 mm of the water column (ITOPF 2011a). Due to gasoline remaining on the top of the water, risk of larval exposure is low during low energy ocean conditions, as they would need to swim to the sea's surface. Medium and high energy ocean conditions can cause increased dispersion throughout the water column within the intertidal and subtidal zones, increasing the risk of exposure to larval clams.

Varnish clams have limited mobility after the larval stage. Due to this sessile nature, the PoE and vulnerability levels are the same for all post-larval life stages.

Post-larval varnish clams preferred habitats are mixed substrates (sand/gravel/mud) at shallow depths within the intertidal zone (Byers 2022, Gordon *et al.* 2018). Varnish clams burrow into the substrate at shallow depths, therefore having a high level of interaction with the substrate. Given the habitat of post-larval varnish clams, gasoline spills in the intertidal zone pose a high risk. Spills in the intertidal zone also pose a risk of ingestion by varnish clams. Varnish clams are known to pedal and vacuum feed organic debris from the substrate surface (Tsuchiya and Kurihara 1980; Gillespie *et al.* 1999b, 2001b; Sorber 2013). Due to their habitat and feeding behaviour, varnish clams are at a high risk of exposure and ingestion of oils spilled in the intertidal zone. Oil spills in intertidal zones have historically caused high mortality in molluscs (Keesing *et al.* 2018).

Weathered Gasoline Oil Spill

Gasoline is highly volatile and can completely evaporate within 24 hours; as such, as gasoline weathers the risk to Varnish clams decreases. Weathered gasoline is unlikely to pose any risks to varnish clams as it evaporates and disperses very quickly.

Marine Diesel Oils (MDO)

Fresh MDO Oil Spill

Fresh MDO has high aquatic toxicity due given high concentrations of light molecular weight hydrocarbons (Environment Canada 1999). Fresh MDO has similar potential PoE to varnish clams as gasoline (Appendix Table 9).

Varnish clams spawn in British Columbia between May and September (Gillespie *et al.* 1999b). Varnish clams have a pelagic larval stage lasting 3-8 weeks, during which larvae are present in the water column (Dudas and Dower 2006). As with gasoline, MDOs have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring during low energy ocean conditions, as they would need to swim to the sea's surface. Medium and high energy ocean conditions can cause increased dispersion throughout the water column within the intertidal and subtidal zones, increasing the risk of exposure to larval varnish clams.

Varnish clams have limited mobility after the larval stage. Due to this sessile nature, the PoE and vulnerability levels are the same for all post-larval life stages.

Post-larval varnish clams preferred habitats are mixed substrates (sand/gravel/mud) at shallow depths within the intertidal zone (Byers 2022, Gordon *et al.* 2018). Varnish clams burrow into the substrate at shallow depths, therefore having a high level of interaction with the substrate. MDO spills remain on the surface of the water; however, when tides recede the intertidal zone will be exposed to the MDO spilled on the surface. Given the habitat of post-larval varnish clams, MDO spills in the intertidal zone pose a high risk.

Possible effects may include coating, smothering, ingestion, and habitat modification. Heavily oiled substrate may inhibit burrowing behaviour and increase exposure levels of varnish clams.

Spills in the intertidal zone also pose a risk of ingestion by varnish clams. Varnish clams are known to pedal and vacuum feed organic debris from the substrate surface (Tsuchiya and Kurihara 1980, Gillespie *et al.* 1999b, 2001b, Sorber 2013). Due to their habitat and feeding behaviour, varnish clams are at a high risk of exposure and ingestion of oils spilled in the intertidal zone. Oil ingestion in molluscs can cause damage to feeding apparatuses, decreased immunity, along with other physiological decreases (Adzigbli and Yuewen 2018). Oil spills in intertidal zones have historically caused high mortality in molluscs (Keesing *et al.* 2018).

Weathered MDO Oil Spill

As MDOs weather aquatic toxicity decreases as the LMW hydrocarbons evaporate. MDO still poses potential risks to varnish clams through coating, smothering, ingestion, and habitat modification (ITOPF 2011b). The persistence of MDO causes weathered MDO to pose many of the same potential effects on varnish clams as fresh spills. The larvae of varnish clams still have the potential to interact with the oil spill with potential effects including coating and smothering, likely without acute toxic effects. The risk of this effect remains low in low energy ocean conditions and high in high-energy conditions.

MDO is persistent and has the potential to interact and adsorb to drift particles within the water column (ITOPF 2011a). One of post-larval varnish clams feeding strategies is suspension feeding, feeding on these drift particles. Interaction and adsorption to these drift particles by MDO increases potential for varnish clams to ingest MDOs. Ingestion of oils by molluscs can lead to effects such as impaired physiological function and behaviour as well as death (Adzigbli and Yeuwe 2018). The risk of this occurring is high.

Given the persistence of MDO, weathered MDO in the intertidal zone still poses a risk to varnish clams. Effects include coating, smothering, and habitat modification. As varnish clams burrow into the substrate, contaminated substrate may prevent this behaviour or increase their exposure to this oil long term. Intertidal zone oils spills can cause high mortality in molluscs (Keesing *et al.* 2018).

Group 2 Oils

Light Crude Oils (LCOs)

Group 2 oils are LCOs which contain moderate to high concentrations of hydrocarbons which cause acute and chronic toxic effects on aquatic organisms (Adzigbli and Yeuwen 2018). LCOs can cause additional negative effects through coating and smothering aquatic organisms. There are similar PoE between Group 2 and Group 1 oils (Appendix Table 9).

Fresh LCO Oil Spill

Varnish clam larvae are present during the spawning period of May to September, with their pelagic stage lasting 3-8 weeks (Gillespie *et al.* 1999b, Dudas and Dower 2006). As with Group 1 oils, LCOs have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring in low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion and dissolution. LCOs spreading through the water column may increase the risk of exposure with larvae and drift particle food sources. In high energy ocean conditions, the risk of this occurring is high.

Varnish clams have limited mobility after the larval stage. Due to this sessile nature, the PoE and vulnerability levels are the same for all post-larval life stages.

Post-larval varnish clams preferred habitats are mixed substrates (sand/gravel/mud) at shallow depths within the intertidal zone (Byers 2022, Gordon *et al.* 2018). Varnish clams burrow into the substrate at shallow depths, therefore having a high level of interaction with the substrate. LCO spills remain on the surface of the water; however, when tides recede the intertidal zone will be exposed to the LCO spilled on the surface. Given the habitat of post-larval varnish clams, LCO spills in the intertidal zone pose a high risk. Possible effects may include coating, smothering, ingestion, and habitat modification. Heavily oiled substrate may inhibit burrowing behaviour and increase exposure levels of varnish clams.

Spills in the intertidal zone also pose a risk of ingestion by varnish clams. Varnish clams are known to pedal and vacuum feed organic debris from the substrate surface (Tsuchiya and Kurihara 1980; Gillespie *et al.* 1999b, 2001b; Sorber 2013). Due to their habitat and feeding behaviour, varnish clams are at a high risk of exposure and ingestion of oils spilled in the intertidal zone. Oil ingestion in molluscs can cause damage to feeding apparatuses, decreased immunity, along with other physiological decreases (Adzigbli and Yuewen 2018). Oil spills in intertidal zones have historically caused high mortality in molluscs (Keesing *et al.* 2018).

Weathered LCO Oil Spill

As LCOs weather their acute toxicity decreases as the light molecular weight hydrocarbons evaporate; however, the same potential PoE risks to varnish clams remain. Light crude oils persist and can form stable emulsions, leading to increased volume and specific gravity of the spill (ITOPF 2011a). The PoE for weathered LCO's are similar as those of fresh LCOs for larval varnish clams, with an increased risk of exposure in the water column due to the potential increased specific gravity of LCO emulsions.

LCOs persist as they weather causing the potential for them to interact with drift particles throughout the water column potentially absorbing to drift algae. The interaction between LCOs and drift algae leads to a greater potential for ingestion by varnish clams through filter feeding, causing toxic and potentially fatal effects (Adzigbli and Yuewen 2018). Given the persistence of LCO, weathered LCO in the intertidal zone still poses a risk to

varnish clams. Effects include coating, smothering, and habitat modification. As varnish clams burrow into the substrate, contaminated substrate may prevent this behaviour or increase their exposure to this oil long term. Intertidal zone oil spills can cause high mortality in molluscs (Keesing *et al.* 2018).

Group 3 Oils

Heavy and Persistent Oils

Group 3 contains engine/hydraulic oil, medium crude oil, heavy crude oil, and dilbit oil. Group 3 oils are heavy and persistent, while not being as toxic as Group 1 and 2 oils, due to decreased levels of LMW hydrocarbons (ITOPF 2011a, 2011b). There are many similar PoE between Group 3 and Group 1 oils (Appendix Table 9).

Fresh Heavy and Persistent Oil Spill

Varnish clam larvae are present during the spawning period of May to September, with their pelagic stage lasting 3-8 weeks (Gillespie *et al.* 1999b, Dudas and Dower 2006). As with Group 1 oils, Group 3 oils have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring in low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion and dissolution. Group 3 oils spreading through the water column may increase the risk of exposure with larvae and drift particle food sources. In high energy ocean conditions, the risk of this occurring is high.

Varnish clams have limited mobility after the larval stage. Due to this sessile nature, the PoE and vulnerability levels are the same for all post-larval life stages.

Fresh Group 3 oil spills in the intertidal zone have a high potential to impact all life stages of varnish clams. Post-larval varnish clams reside in the substrate within the mid-intertidal to shallow subtidal zone, with high potential for interaction with an oil spill at the water surface. Varnish clams would be exposed to the oil spill as the tide recedes. Effects may include coating, smothering, ingestion, and habitat modification leading to physiological decreases or mortality (Adzigbli and Yuewen 2018).

Weathered Heavy and Persistent Oil Spill

As Group 3 oils weather, little to no evaporation occurs; however, sedimentation can occur causing the oils to sink (ITOPF 2011a). Due to Group 3 oils persistence the PoE remain similar for varnish clams, with increased risks due to possible sinking.

Possible sinking due to sedimentation creates a greater risk of exposure for larval varnish clams through direct interaction in low energy ocean scenarios, and greater risk of ingestion by post-larval clams. Sinking oil may interact directly with larvae through coating and smothering (ITOPF 2011b). Sinking oil may also interact with drift particles causing varnish clams to ingest oil while filter feeding, causing physiological decreases such as

clogging of feeding apparatuses and decreased immunity (Adzigbli and Yuewen 2018). There is a high risk of this occurring.

Group 4 Oils

Bunker C Oils

Group 4 oils are Bunker C oils. Bunker C oils are heavy and highly persistent oils (Environment Canada 1999). Bunker C oils contain few toxic LMW hydrocarbons meaning they have little to no acute toxic effects on aquatic organisms. Bunker C oils still pose risk through coating and smothering as well as chronic effects due to heavier toxic hydrocarbons (Adzigbli and Yuewen 2018).

Fresh Bunker C Oil Spill

Varnish clam larvae are present during the spawning period of May to September, with their pelagic stage lasting 3-8 weeks (Gillespie *et al.* 1999b, Dudas and Dower 2006). As with Group 1 oils, Bunker C oils have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring in low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion and dissolution. Group 3 oils spreading through the water column may increase the risk of exposure with larvae and drift particle food sources. In high energy ocean conditions, the risk of this occurring is high. Negative effects on varnish clams that this interaction may have differ from previous oils given lower concentrations of LMW hydrocarbons, causing less acute toxic effects.

Varnish clams have limited mobility after the larval stage. Due to this sessile nature, the PoE and vulnerability levels are the same for all post-larval life stages.

Bunker C oil spills in the intertidal zone have potential to cause high varnish clam mortalities through coating and smothering (Adzigbli and Yuewen 2018). Varnish clams preferred habitat is mixed substrates in the shallow intertidal zone (Gordan *et al.* 2018). Varnish clams would be exposed to a Bunker C oil spill as the tide recedes in the intertidal zone.

There is also a high potential of oil ingestion by varnish clams. Varnish clams are known to pedal feed using their foot to collect organics from the substrate, along with vacuuming organic debris off of the substrate, which increase the possibility of oil ingestion (Tsuchiya and Kurihara 1980 Gillespie *et al.* 1999b, 2001b; Sorber 2013). Oil ingestion in molluscs can cause damage to feeding apparatuses, decreased immunity, along with other physiological decreases (Adzigbli and Yuewen 2018).

Weathered Bunker C Oil Spill

There are little weathering effects on Bunker C oil given its low concentrations of volatile LMW hydrocarbons and high persistence (ITOPF 2011a). The PoE are similar between weathered and fresh Bunker C oils; however, Bunker C oils are susceptible to creation of

stable emulsions, causing increased volume and specific gravity, and sedimentation-caused sinking (ITOPF 2011a). Risks of effects that weathered Bunker C oil may have on varnish clams are similar between fresh and weathered oils, with increased risk due to sinking.

If sinking occurs through emulsions forming or sedimentation, larval varnish clams are at a greater risk of oil exposure at all ocean energy conditions. Sinking oils could coat and smother pelagic larval varnish clams causing locomotion and feeding issues or potentially mortality (Adzigbli and Yuewen 2018). Sinking oils have a high risk of oil interacting with drift particles and being ingested by varnish clams during filter-feeding. Sinking oils additionally increase the risk of exposure for varnish clams at all tidal zones. There is a high risk of these exposure pathways occurring.

Group 5 Oils

Sinking Oils

Group 5 oils are extremely heavy and persistent oils known as sinking oils. Sinking oils have a specific gravity >1, causing them to readily sink in water (ITOPF 2011a). Due to high specific gravity, sinking oils have a high potential to negatively impacting varnish clams at all life stages.

Fresh Sinking Oil Spill

Varnish clam larvae are present during the spawning period of May to September, with their pelagic stage lasting 3-8 weeks (Gillespie *et al.* 1999, Dudas and Dower 2006). Sinking oils have a high risk of interacting with the larvae of varnish clams during all potential ocean energy conditions given the potential of oil being present throughout the water column or interacting with larvae while sinking.

Varnish clams have limited mobility after the larval stage. Due to this sessile nature, the PoE and vulnerability levels are the same for all post-larval life stages.

Varnish clams are also at risk of ingesting oil through filter-feeding, as well as pedal and vacuum feeding off of contaminated substrates. Ingestion of oils can cause physiological issues along with potential mortality in molluscs (Adzigbli and Yuewen 2018). Sinking oil spills in the intertidal zone have a high risk of interacting with Varnish clams through coating and smothering, potentially causing death (Adzigbli and Yuewen 2018).

Weathered Sinking Oil Spill

Sinking oils have little to no weathering effects; therefore, the PoE on varnish clams are the same for fresh and weathered sinking oils.

Figure 30. Varnish clam, *Nuttallia obscurata*.

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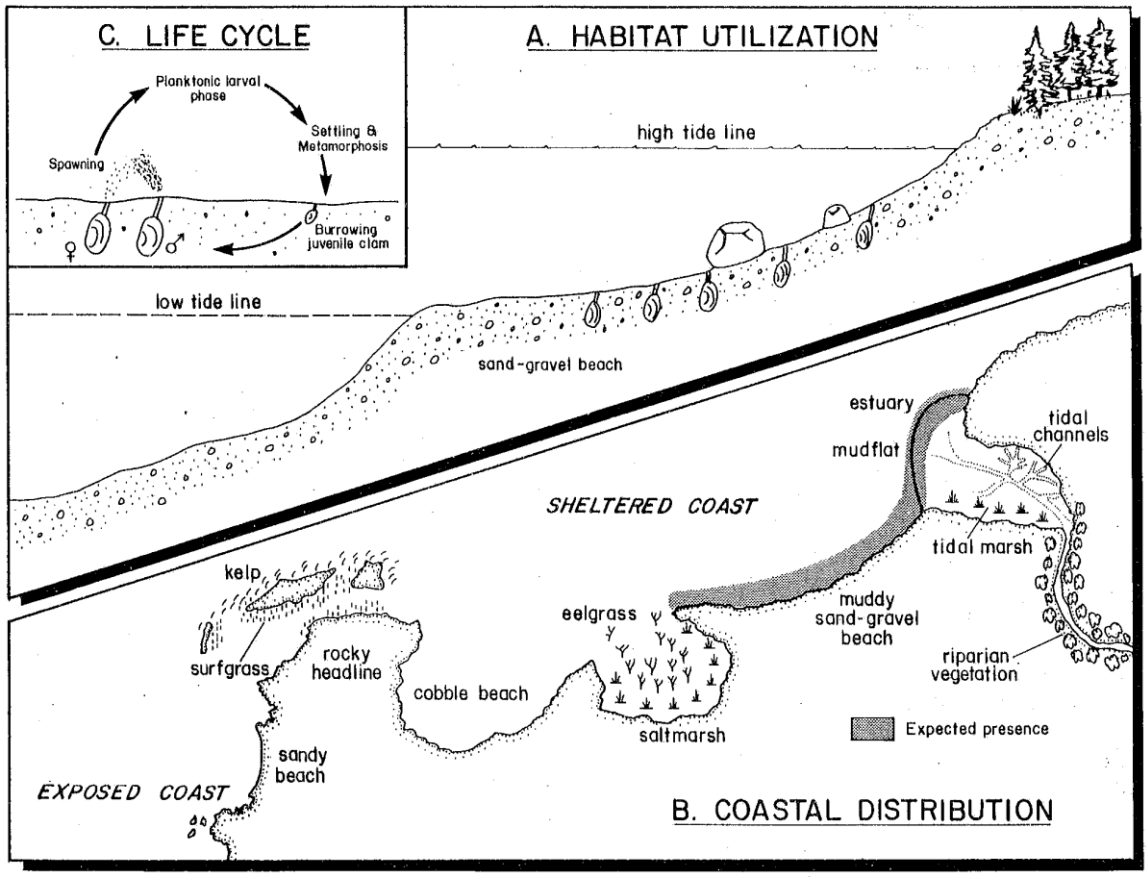

Figure 31. Habitat utilization (A), coastal distribution (B, gray polygons indicate expected presence) and life cycle (C) of varnish clam, *Nuttallia obscurata* (Williams 1989).

J	F	M	A	M	J	J	A	S	O	N	D
1	1	1	1	3	3	3	3	2	1	1	1
				---Spawning---							
1	1	1	1	3	3	3	3	2	1	1	1
				---Larval Presence---							
3	3	3	3	3	3	3	3	3	3	3	3
---Adult Presence---											

Figure 32. Temporal distribution of spawning, larval and adult presence and vulnerability ranks of varnish clam, *Nuttallia obscurata*.

Legend: 1 (green) = low/negligible vulnerability; 2 (yellow) = moderate vulnerability; 3 (red) = high vulnerability.

Table 11. Summary of information required to inform marine emergency response for varnish clam, *Nuttallia obscurata*.

Taxonomy
Scientific Name:
Nuttallia obscurata (Reeve 1857)

Common Name(s):
Purple Mahogany-clam, dark mahogany clam, mahogany clam, purple varnish clam, savoury clam, varnish clam

Higher Taxonomy:
Mollusca; Bivalvia; Cardiida; Psammobiidae

Description
Oval in outline and compressed laterally. Brown periostracum thick and shiny. Pronounced external ligament. Inner surface purple. Body, foot, siphons and mantle white. Maximum size at least 68 mm TL.

Distribution
Native
Northwestern Pacific from Korea and Japan to China and southern Russia.

Introductions
Unintentionally introduced to BC and the Pacific Northwest, likely in ballast water. Established in the Strait of Georgia, and west coast of Vancouver Island.

Habitat Preferences
Sand/gravel/mud beaches, higher in the intertidal than native species, often in areas of freshwater run-off. Found deeper in the substrate where they overlap with native hardshell clams.

Physical Tolerances
Salinity
Broad salinity tolerance from full seawater (32‰) to freshwater (1‰) for short periods. Larvae can only survive in salinities of 24-31‰.

Temperature
Larvae develop at temperatures of 15-25°C and metamorphose in temperatures between 10 and 30°C.

Reproductive Biology
Broadcast spawner, sexes are generally separate. Spawning period is May to August or September. Fecundity was 4×10^4 to 6×10^6, depending upon size and location.

Table 11. continued.

Growth Rate and Lifespan
Generally reach 38 mm TL in four years. Maximum age is 5-8 years.

Migratory Behaviour
Adults have limited motility and they are confined to the beach they inhabit, dispersal is through the planktonic larval stage.

Role in the Ecosystem
Filter feeder, also pedal feeder in the substrate and siphonal sweeper from the substrate surface. Preyed on by moon snails, crabs, flatfish, birds and mammals.

Interactions with Native Species
Intertidal distribution overlaps with Manila and littleneck clams, although highest densities generally occur at higher tidal levels. Where overlap occurs, varnish clams can be found deeper in the substrate.

Significance
May be harvested by First Nations or in recreational fisheries. Very limited commercial harvests, largely from aquaculture tenures.

Vulnerability
Subgroup Classification: Intertidal/Subtidal Benthic; Sediment Infauna; Low Mobility; Mollusca.

Adult Exposure Criteria: High Aggregation; Low Mobility; Intertidal (high interaction with sea surface); Infaunal (high interaction with sea floor). Score: 4.

Adult Sensitivity Criteria: Filter feeder (feeding apparatus can be clogged or damaged by pollutants); Chemical sensitivity assumed to be high. Score: 2.

Adult Recovery Criteria: Population status unmonitored; Relatively high reproductive capacity; Broadly distributed in suitable habitats in southern British Columbia; High degree of interaction with unconsolidated substrates. Score: 1.

Cumulative Total Score: 7.

Larval Exposure Criteria: Aggregate or Patchiness where large number of larvae affected; Low Mobility; Interaction with sea surface. Score: 3.

Larval Sensitivity Criteria: Larvae feeding appendages that can become clogged by oil; Chemical sensitivity assumed to be high. Score: 2.

Larval Recovery Criteria: Populations unmonitored; Relatively high reproductive capacity; Broadly distributed in suitable habitat; Low degree of interaction with unconsolidated substrates. Score: 0.

Larval Cumulative Total Score: 5.

Nuttall Cockle (Clinocardium nuttallii)

Significance

Cockles are harvested in First Nations and recreational fisheries; they are not a target species in commercial fisheries (Bourne 1997, Quayle and Bourne 1972). There is interest in developing cockle culture in British Columbia (Gurney-Smith *et al.* 2009, Liu *et al.* 2008a, 2008b, 2010; Epelbaum *et al.* 2011).

Vulnerability

Subgroup classification

Nuttall cockles were included in the following subgroups: 1 - Intertidal/Subtidal Benthic location for exposure; 2 - Sediment Infauna substrate; 3 - Low mobility; and taxonomy to inform feeding types and reproductive strategies - Mollusca (Thornborough *et al.* 2017, Hannah *et al.* 2017, Jeffery *et al.* 2023).

Exposure

As with many infaunal bivalve molluscs, aggregated distributions of Nuttall cockles are a result of habitat preferences, physiological tolerances and are beneficial for spawning synchrony and fertilization success (Hannah *et al.* 2017).

Nuttall cockles have limited mobility; dispersal is through pelagic larval stages; adults may move short distances but are confined to the beaches on which they settled. They are primarily intertidal in distribution with some extension into the shallow subtidal, thus their populations have a high level of interaction with the sea surface. As infaunal organisms they have intimate contact with the unconsolidated sediments they inhabit.

Sensitivity

As filter/suspension feeders, Nuttall cockles are very sensitive to pollutants that may clog or damage their feeding apparatus. Numerous studies document chemical effects of pollutants on bivalve physiology, reproduction and larval survival.

Recovery

Population status is not actively monitored in British Columbia. Nuttall cockles have high fecundity and high reproductive capacity, but inconsistent recruitment. They are broadly distributed in suitable habitat throughout British Columbia and beyond. They are dependent on unconsolidated substrates which can be affected for extended periods due to difficulties removing pollutants that have seeped into the substrate.

Taxonomy

The accepted scientific name is *Clinocardium* (*Clinocardium*) *nuttallii* (Conrad, 1837)(Coan *et al.* 2000). Some early literature (e.g., Weymouth and Thompson 1931) used the name *Cardium corbis* (Martyn) and the species was also placed in the genera *Laevicardium* and *Cerstoderma* (Dunham *et al.* 2013a,b). The accepted vernacular name is Nuttall cockle (Turgeon *et al.* 1988), although the names basket cockle and heart cockle are in common use (Table 12)(Harbo 1997).

Description

Nuttall cockles are large, heavy shelled bivalves (Quayle 1974, Harbo 1997, Hiebert *et al.* 2016)(Figure 33). The valves are roughly triangular in profile, cross-section is heart shaped. Outer surfaces are marked with 37-38 prominent radial ribs crossed by concentric sculpture. Perisotracum thin and brownish. Ligament is external, pallial sinus is absent. Siphons very short, essentially gaps in the mantle margin; this limits burrowing depth. Foot is large and muscular, capable of rapid burrowing and movement across the substrate to avoid predators. Quayle (1974) reported a maximum size of 114 mm total length (TL); Harbo (1997) reported maximum size as 140 mm TL.

Distribution

Nuttall cockles are distributed from the southern Bering Sea through the Gulf of Alaska to San Diego CA, with a disjunct population ranging from Kamchatka to southeastern Hokkaido (Coan *et al.* 2000). They are generally found from the intertidal to 30 m, occasionally to 180 m. They are widely distributed in British Columbia but usually at low densities (Quayle 1974, Quayle and Bourne 1972, Harbo 1997).

Habitat Preferences

Nuttall cockles are found on exposed or sheltered beaches in mud, sand, or gravel substrates (Harbo 1997, Hiebert *et al.* 2016)(Figure 34). They are often associated with eelgrass on muddy tide flats (Quayle and Bourne 1972). As they do not possess long siphons, they are present at or just below the sediment surface (Gallucci and Gallucci 1982).

Role in the Ecosystem

Trophic Ecology

Cockles are suspension feeders; organic material from the water column is filtered by the gills and delivered to the labial palps for sorting. They are known to ingest invertebrate larvae (e.g., sea lice *Lepeophtheirus salmonis*) (Hiebert *et al.* 2016).

Ecological Interactions

Predators include sea otters (*Enhydra lutris*), sunstars (*Pycnopodia helianthoides*), sand stars (*Luidia foliolata*), giant Pacific octopus (*Enteroctopus dofleini*), glaucous-winged gulls (*Larus glaucescens*), black (*Melanitta nigra*), surf (*Melanitta perspicillata*) and white-winged scoters (*Melanitta deglandi*), long-tailed ducks (*Clangula hyemalis*) and Barrow's goldeneyes (*Bucephala islandica*) (Vermeer and Levings 1977, Vermeer 1977, 1981, Lambert 2000, Hiebert *et al.* 2016). Small cockles are preyed on by Dungeness (*Metacarcinus magister*) and graceful (*Metacarcinus gracilis*) crabs and flatfish and pelagic larvae are preyed upon by zooplanktonic predators and suspension feeders (Hiebert *et al.* 2016). Cockles exposed and moving across the substrate surface may lose foot tissue to fish predators, which impedes their ability to burrow and thus leaves them more vulnerable to other predators (Mouritson 2004, Meyer and Byers 2005).

Juvenile cockles serve as hosts to juvenile pinnotherid pea crabs (*Pinnixa faba* and *P. littloralis*) (Hart 1982). They are also parasitized by the introduced copepod *Mytilicola orientalis* (Bernard 1968).

Physical Tolerances

Cockles are not common in upper estuarine areas where salinities vary (Hiebert *et al.* 2016). Adult cockles are intolerant of high temperature and/or anoxic conditions which may develop under green algal mats at low tide; cockles leaving the substrate to avoid these conditions suffer high mortality due to predation and inability to avoid high temperatures (Lewis and DeWitt 2017). Adult cockles maintained at 16°C failed to develop gonads, while those held at 2.5°C matured normally (Liu *et al.* 2008b). In the laboratory, larval growth increased with increased temperature (5.9-21.9°C) but survival to settlement was not affected except at the highest temperature treatment (26.3°C)(Liu *et al.* 2010). Larval development ceased at temperatures below 2.8-2.9°C (Liu *et al.* 2008a).

Reproductive Biology

Cockles are simultaneous hermaphrodites with male and female follicles maturing at the same time (Gallucci and Gallucci 1982). Spawning period in the Salish Sea is April-November with peak spawning in July-September (Figure 35). In Oregon, cockles spawn June-October (Robinson and Breese 1982). They usually reach size of maturity in the second year but occasionally mature in their first year; these early-maturing cockles exhibit maturity of male follicles only (protandry)(Ratti 1978). Sperm performance decreases with increasing temperature; sperm motility remained high when tested at 4°C and decreased rapidly at 19°C (Liu *et al.* 2008a). Self-fertilization is common (Liu *et al.* 2008a).

Early Life History

Cockles exhibit typical bivalve mollusc life history (Hiebert *et al.* 2016). Fertilization is external and eggs develop through pelagic larval stages (trochophore, veliger, pediveliger)

and finally settle as post-larvae. In the laboratory, eggs developed to the veliger stage in 18 hours at 15°C (Hiebert *et al.* 2016). Epelbaum *et al.* (2011) spawned cockles in the laboratory at 14°C; eggs developed to D-hinge veligers in 48 hours and subsequently settled as pediveligers 14 days later.

Growth Rates and Life Span

Post-larval growth is initially rapid and decreases with increasing age (McLean Fraser 1931, Weymouth and Thompson 1931). Growth rate increases with decreasing tidal exposure with maximum growth rates in subtidal portions of populations (Ratti 1978). Growth varies with latitude; northern populations (Alaska) grow slower but live longer and achieve greater maximum size than southern populations (Washington and Oregon)(Weymouth and Thompson 1931). Growth varies seasonally with temperature and food supply; growth is rapid in the spring and slow in the winter. Intertidal portions of populations in BC are dominated by younger cockles, the usual lifespan was reported as seven years (McLean Fraser 1931, Quayle and Bourne 1972). Ratti (1978) also observed that smaller, younger cockles dominated intertidal portions of the population with larger, older cockles making up a higher proportion of subtidal portions. Maximum age was reported as seven years in Washington and Oregon and 10-17 years in Alaska (Weymouth and Thompson 1931). Growth rates and lifespan varied greatly between sites and areas of British Columbia; maximum age of 10 years and 88 mm shell height were reported from Borrowman Bay, Aristazibal Island (Gillespie and Bourne 1988, 2000, 2005a,b; Gillespie *et al.* 2004).

Pathways of Effects (PoE): Oil Exposure

A Pathways of Effects (PoE) oil exposure model can aid oil spill emergency response by identifying low to high-risk scenarios for species exposure. This section describes PoE for Nuttall cockle through exposure paths of specific species life stages and the potential dispersion and fates of five oil groups (Table 2). The specific environmental conditions and chemical signature of the oil spill should be taken into consideration as they may cause differences in the outcomes described in this document. A summary table for this section is available in Appendix Table 10.

Habitat utilization and temporal distribution of spawning, larval and adult presence and vulnerability ranks of Nuttall cockle are illustrated in Figure 34 and Figure 35 with vulnerability ranking scores for Nuttall cockle generalized for all oil groupings as 5 for the larval life stage and 7 for adult life stages (Jeffery *et al.* 2023).

Group 1 Oils

Group 1 contains gasoline and marine diesel oil (MDO). Both gasoline and MDO are light, volatile, and acutely toxic oils (ITOPF 2011a). The two oils are split into subcategories due to differences in fate and behaviour, causing different potential PoE on Nuttall cockles.

Gasoline

Gasoline has high concentrations of LMW hydrocarbons which may cause both acute and chronic toxic effects on aquatic organisms (ITOPF 2011b). Possible toxic effects include mortality (Keesing *et al.* 2018), damage to feeding apparatuses, decreased immunity, and other physiological functioning (Adzigbli and Yeuwen 2018).

Fresh Gasoline Oil Spill

Nuttall cockles spawn in British Columbia between April to November with a spike in July to September (Gallucci and Gallucci 1982). The pelagic larval stage lasts around 14 days before settling as pediveligers (Epelbaum *et al.* 2011). Gasoline is very light, having a specific gravity of <0.8, causing it to float and only be present on the top 1-2 mm of the water column (ITOPF 2011a). Due to gasoline remaining on the top of the water, risk of larval exposure is low during low energy ocean conditions. Medium and high energy ocean conditions can cause increased oil dispersion throughout the water column within the intertidal and subtidal zones, increasing the risk of exposure to larval cockles.

Nuttall cockles have limited mobility after the larval stage along with having a consistent filter-fed diet. Due to this sessile nature, the PoE and vulnerability levels are the same for all post-larval life stages.

Post-larval Nuttall cockles are generally distributed in depths ranging from the intertidal zone to 30 m deep, and occasionally found at depths up to 180 m. Nuttall cockles preferred habitats are muddy, sandy, or gravelly substrates, and are found on the surface or burrowed very shallow (Gallucci and Gallucci 1982, Harbo 1997, Hiebert *et al.* 2016). Given the location of post-larval Nuttall cockles, gasoline spills in the intertidal zone pose a high potential risk. Oil spills in intertidal zones have historically caused high mortality in molluscs (Keesing *et al.* 2018).

Weathered Gasoline Oil Spill

Gasoline is highly volatile and can completely evaporate within 24 hours; as such, as gasoline weathers the risk to Nuttall cockles decreases. Weathered gasoline is unlikely to pose any risks to Nuttall cockles as it evaporates and disperses very quickly.

Marine Diesel Oils (MDO)

Fresh MDO Oil Spill

Fresh MDO has high aquatic toxicity due given high concentrations of LMW hydrocarbons (Environment Canada 1999). Fresh MDO has similar potential PoE to Nutall cockles as gasoline (Appendix Table 10).

Free-swimming larval Nuttall cockles are present during the spawning period April to November (Gallucci and Gallucci 1982). The pelagic larval stage then lasts around 14 days

(Epelbaum *et al.* 2011). As with gasoline, MDOs have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring during low energy ocean conditions. Medium and high energy ocean conditions can cause increased oil dispersion throughout the water column within the intertidal and subtidal zones, increasing the risk of exposure to larval cockles.

Nuttall cockles have limited mobility after the larval stage along with having a consistent filter-fed diet. Due to this sessile nature, the PoE and vulnerability levels are the same for all post-larval life stages.

Post-larval Nuttall cockles are generally distributed in depths ranging from the intertidal zone to 30 m deep, and occasionally found at depths up to 180 m. Nuttall cockles preferred habitats are muddy, sandy, or gravelly substrates, and are found on the surface or burrowed very shallow (Gallucci and Gallucci 1982, Harbo 1997, Hiebert *et al.* 2016). Given the location of post-larval Nuttall cockles, MDO spills in the intertidal zone pose a high potential risk. Oil spills in intertidal zones have historically caused high mortality in molluscs (Keesing *et al.* 2018).

Weathered MDO Oil Spill

As MDOs weather aquatic toxicity decreases as the LMW hydrocarbons evaporate. MDO still poses potential risks to Nuttall cockles through coating, smothering and ingestion (ITOPF 2011b). The persistence of MDO causes weathered MDO to pose many of the same potential effects on Nuttall cockles as fresh spills. The larvae of Nuttall cockles still have the potential to interact with the oil spill on the surface of the water with potential effects including coating and smothering, likely without acute toxic effects. The risk of this effect remains low in low energy oceans, as the larvae would need to swim to the ocean's surface, and high in high-energy ocean scenarios.

MDO is persistent and has the potential to interact and adsorb to drift particles within the water column (ITOPF 2011a). Post-larval Nuttall cockles are obligate filter feeders and mainly feed on these drift particles. Interaction and adsorption to these drift particles by MDO causes the potential for Nuttall cockles to ingest MDOs. Ingestion of oil by filter-feeders can cause damage to the feeding apparatus, along with cell and DNA destruction (Adzigbli and Yuewen 2018). The risk of this occurring is high.

Given the persistence of MDO, weathered MDO in the intertidal zone still poses a risk to Nuttall cockles. Effects include coating, smothering, and habitat modification. Intertidal zone oils spills can cause high mortality in molluscs (Keesing *et al.* 2018).

Group 2 Oils

Light Crude Oils (LCOs)

Group 2 oils are LCOs which contain moderate to high concentrations of hydrocarbons which cause acute and chronic toxic effects on aquatic organisms (Adzigbli and Yeuwen

2018). LCOs can cause additional negative effects through coating and smothering aquatic organisms. There are similar PoE between Group 2 and Group 1 oils (Appendix Table 10).

Fresh LCO Oil Spill

Free-swimming larval Nuttall cockles are present during the spawning period (April to November; Gallucci and Gallucci 1982). The pelagic larval stage then lasts around 14 days (Epelbaum *et al.* 2011). As with Group 1 oils, LCOs have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring in low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion and dissolution. LCOs spreading through the water column may increase the risk of exposure with larvae and drift particle food sources. In high energy ocean conditions, the risk of this occurring is high.

Nuttall cockles have limited mobility after the larval stage along with having a consistent filter-fed diet. Due to this sessile nature, the PoE and vulnerability levels are the same for all post-larval life stages.

Fresh LCO spills in the intertidal zone have a high potential to impact mature Nuttall cockles. Post-larval Nuttall cockles reside shallowly burrowed in mixed substrates within the mid-intertidal zone to subtidal zone with high potential for interaction with an oil spill at the water's surface (Gallucci and Gallucci 1982, Harbo 1997, Hiebert *et al.* 2016). Nuttall cockles in the intertidal zone would have their siphon fully exposed to the oil spill as the tide recedes.

Weathered LCO Oil Spill

As LCOs weather their acute toxicity decreases as the light molecular weight hydrocarbons evaporate; however, similar potential PoE and risks to Nutall cockles remain. Light crude oils persist and can form stable emulsions, leading to increased volume and specific gravity of the spill (ITOPF 2011a). The PoE risk of for weathered light crude oils are similar as those of fresh LCO for larval cockles, with an increased risk in low energy ocean scenarios due to the emulsions potentially being present deeper in the water column.

Weathered LCO spills pose similar risks of effects as fresh LCO spills to post-larval cockles, with an increased risk of ingestion. LCOs persist as they weather causing the potential for them to interact with drift particles throughout the water column potentially adsorbing to drift algae. Cockles are suspension feeders, feeding on organic material pulled from the water column (Heibert *et al.* 2016). The interaction between LCOs and particles in the water column leads to the potential for ingestion, causing toxic and potentially fatal effects (Adzigbli and Yuewen 2018). The risk of this occurring is high.

Group 3 Oils

Heavy and Persistent Oils

Group 3 contains engine/hydraulic oil, medium crude oil, heavy crude oil, and dilbit oil. Group 3 oils are heavy and persistent, while not being as toxic as Group 1 and 2 oils, due to decreased levels of LMW hydrocarbons (ITOPF 2011a, 2011b). There are many similar PoE between Group 3 and Group 1 oils (Appendix Table 10).

Fresh Heavy and Persistent Oil Spill

Free-swimming Nuttall cockle larvae are present during the spawning period (April to November; Gallucci and Gallucci 1982). The pelagic larval stage lasts approximately 14 days (Epelbaum *et al.* 2011). As with Group 1 oils, Group 3 oils have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring in low energy ocean conditions. Medium and high energy ocean conditions can cause increased oil dispersion and dissolution. Group 3 oils spreading through the water column may increase the risk of exposure with larvae and drift particle food sources. In high energy ocean conditions, the risk of this occurring is high.

Nuttall cockles have limited mobility after the larval stage along with having a consistent filter-fed diet. Due to this sessile nature, the PoE and vulnerability levels are the same for all post-larval life stages.

Fresh Group 3 oil spills in the intertidal zone have the potential to impact Nuttall cockles. Post-larval Nuttall cockles reside on the substrate surface, or in shallow burrows, within the intertidal zone, with high potential for interaction with an oil spill at the water's surface. Nuttall cockles in the intertidal zone would have their siphon fully exposed to the oil spill as the tide recedes.

Weathered Heavy and Persistent Oil Spill

As Group 3 oils weather, little to no evaporation occurs; however, sedimentation can occur causing the oils to sink (ITOPF 2011a). Due to Group 3 oils persistence the PoE remain mostly the same Nuttall cockles, with an increased risk of ingestion.

Possible sinking due to sedimentation creates a greater risk of exposure for larval Nuttall cockles at all ocean energy conditions. Sinking oil may interact directly with larvae through coating and smothering (ITOPF 2011b).

Weathered LCO spills pose similar risks of effects as fresh LCO spills to post-larval cockles, with an increased risk of ingestion. LCOs persist as they weather causing the potential for them to interact with drift particles throughout the water column potentially adsorbing to drift algae. Cockles are suspension feeders, feeding on organic material pulled from the water column (Heibert *et al.* 2016). The interaction between LCOs and particles in the water column leads to the potential for ingestion, causing toxic and potentially fatal effects (Adzigbli and Yuewen 2018). The risk of this occurring is high.

Group 4 Oils

Bunker C Oils

Group 4 oils are Bunker C oils. Bunker C oils are heavy and highly persistent oils (Environment Canada 1999). Bunker C oils contain few toxic light molecular weight hydrocarbons meaning they have little to no acute toxic effects on aquatic organisms (Environment Canada 1999). Bunker C oils still pose risk through coating and smothering as well as chronic effects due to heavier toxic hydrocarbons (Adzigbli and Yuewen 2018).

Fresh Bunker C Oil Spill

Free-swimming Nuttall cockle larvae are present during the spawning period (April to November; Gallucci and Gallucci 1982). The pelagic larval stage then lasts approximately 14 days (Epelbaum *et al.* 2011). As with Group 1 oils, Group 3 oils have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring in low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion and dissolution. Bunker C oils spreading through the water column may increase the risk of exposure with larvae and drift particle food sources. In high energy ocean conditions, the risk of this occurring is high. Negative effects on Nuttall cockles that this interaction may differ from previous oils given lower concentrations of LMW hydrocarbons, causing less acute toxic effects.

Nuttall cockles have limited mobility after the larval stage along with having a consistent filter-fed diet. Due to this sessile nature, the PoE and vulnerability levels are the same for all post-larval life stages.

Bunker C oil spills in the intertidal zone have potential to cause high Nuttall cockle mortalities through coating and smothering (Adzigbli and Yuewen 2018). Nuttall cockles in the intertidal zone would be exposed to the Bunker C oil as the tide recedes.

Weathered Bunker C Oil Spill

There are little weathering effects on Bunker C oil given its low concentrations of volatile LMW hydrocarbons and high persistence (ITOPF 2011a). The PoE are similar between weathered and fresh Bunker C oils; however, Bunker C oils are susceptible to creation of stable emulsions, causing increased volume and specific gravity and potential for sinking and sedimentation-caused sinking.

The PoE that weathered Bunker C oil may have on Nuttall cockles are similar between fresh and weathered oils. If sinking occurs through emulsions forming or sedimentation, Nuttall cockles at all life stages are at a greater risk of oil exposure. Nuttall cockles in the intertidal zone would have their siphon fully exposed to the oil spill. Sinking oils could coat and smother larval Nuttall cockles causing feeding issues or potentially mortality (Adzigbli and Yuewen 2018). The risk of this occurring is high.

Group 5 Oils

Sinking Oils

Group 5 oils are extremely heavy and persistent oils known as sinking oils. Sinking oils have a specific gravity >1, causing them to readily sink in water (ITOPF 2011a). Due to high specific gravity, sinking oils have a high potential to negatively impacting Nuttall cockles at all life stages.

Fresh Sinking Oil Spill

Free-swimming larval Nuttall cockles are present during the spawning period (April to November; Gallucci and Gallucci 1982). The pelagic larval stage then lasts around 14 days (Epelbaum *et al.* 2011). Sinking oils have a high risk of interacting with the larvae of Nuttall cockles at all potential ocean conditions given the potential of oil being present throughout the water column and interacting with larvae while sinking.

Nuttall cockles have limited mobility after the larval stage along with having a consistent filter-fed diet. Due to this sessile nature, the PoE and vulnerability levels are the same for all post-larval life stages.

Sinking oils have a high risk of oil interacting with floating detritus and being ingested by Nuttall cockles while filter-feeding. Ingestion of oils can cause physiological issues along with potential mortality in molluscs (Adzigbli and Yuewen 2018). Sinking oil spills in the intertidal zone have a high risk of interacting with Nuttall cockles through coating and smothering, potentially causing death.

Weathered Sinking Oil Spill

Sinking oils have little to no weathering effects; therefore, the PoE on Nuttall cockles are the same for fresh and weathered sinking oils.

Figure 33. Nuttall cockle, *Clinocardium nuttallii*.

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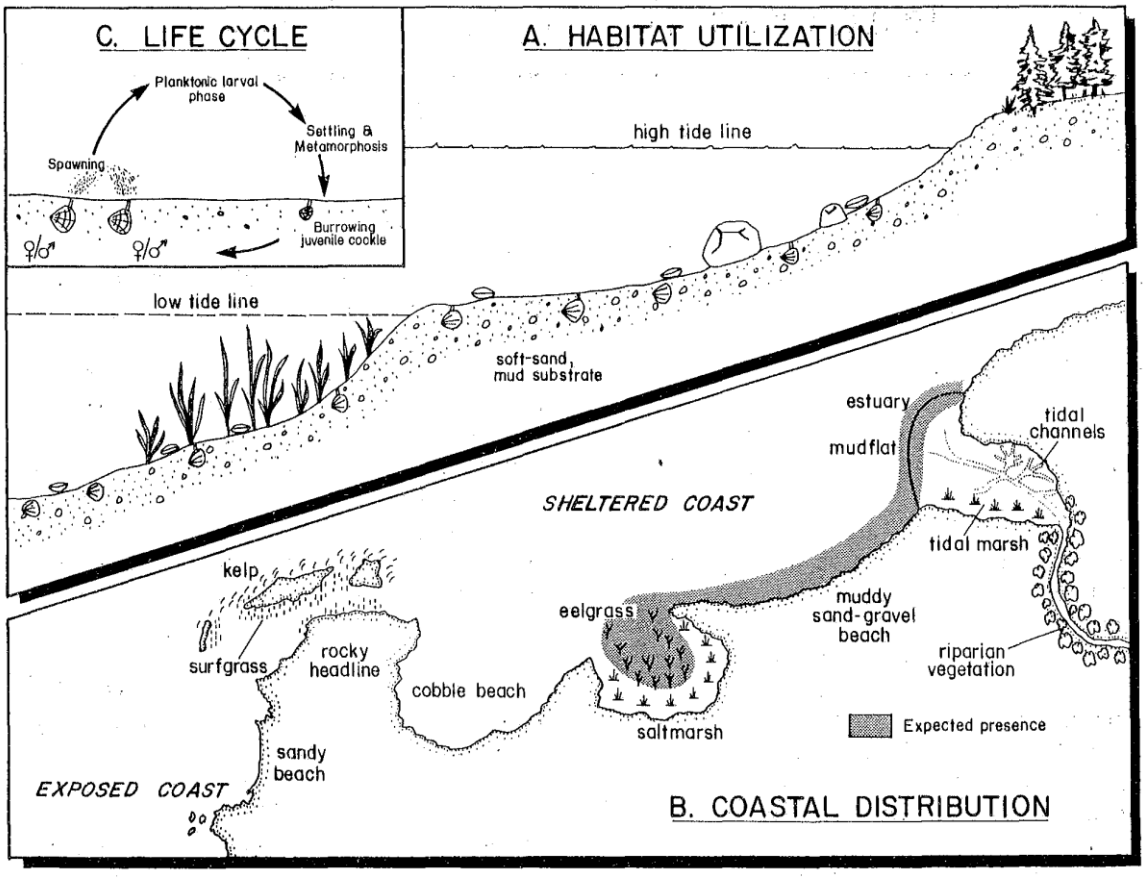

Figure 34. Habitat utilization (A), coastal distribution (B, gray polygons indicate expected presence) and life cycle (C) of Nuttall cockle, *Clinocardium nuttallii* (Williams 1989).

J	F	M	A	M	J	J	A	S	O	N	D
1	1	1	2	2	2	3	3	3	2	2	1
			---Spawning---								
1	1	1	2	2	2	3	3	3	2	2	1
			---Larval Presence---								
3	3	3	3	3	3	3	3	3	3	3	3
---Adult Presence---											

Figure 35. Temporal distribution of spawning, larval and adult presence and vulnerability ranks of Nuttall cockle, *Clinocardium nuttallii*.

Legend: 1(green) = low/negligible vulnerability; 2(yellow) = moderate vulnerability; 3(red) = high vulnerability.

Table 12. Summary of information required to inform marine emergency response for Nuttall cockle, *Clilnocardium nuttallii*.

Taxonomy
Scientific Name:
Clinocardium (*Clinocardium*) *nuttallii* (Conrad, 1837)

Common Name(s):
Nuttall cockle, basket cockle, heart cockle, Nuttall's cockle, Pacific basket-cockle, Pacific cockle

Higher Taxonomy:
Mollusca; Bivalvia; Cardiida; Cardiidae

Description
Large clam, valves triangular in profile and heart-shaped in cross-section. Valves marked with 37 strong radial ribs and commarginate striaea. Periostracum thin and brown. Siphons short, foot large and muscular. Maximum size at least 140 mm TL.

Distribution
Bering Sea to southern California, also Kamchatka to Japan. Broadly distributed in BC but not generally abundant.

Habitat Preferences
Exposed or sheltered beaches in mud, sand or gravel substrates, often associated with eelgrass on muddy tide flats.

Physical Tolerances
Salinity
Not generally found in upper estuarine habitats where salinity is variable.

Temperature
Adult cockles maintained at 16°C failed to develop gonads, while those held at 2.5°C matured normally. Larval growth increased with increased temperature (5.9-21.9°C) but larvae reared at 26.3°C did not survive. Larval development ceased at temperatures below 2.8-2.9°C.

Reproductive Biology
Broadcast spawner, simultaneous hermaphrodite. Spawning occurs April-November with peak spawning July-September. No information on fecundity available.

Growth Rate and Lifespan
Growth initially rapid and decreases with increasing age. Growth increases with decreasing tidal exposure, latitude, seasonally with temperature and food supply. Intertidal portions of populations dominated by younger cockles, older cockles making up a higher proportion of subtidal portions. Maximum age approximately 17 years.

Table 12. continued.

Migratory Behaviour
Adults have low mobility, dispersal is through pelagic larval stages.

Role in the Ecosystem
Suspension feeder, dependent on organic matter from the water column. Preyed upon by sea otters, birds, fish, crabs, sea stars and octopus.

Significance
Not targeted in commercial fisheries, harvested by First Nations and recreational fishers. Potential as an aquaculture species.

Vulnerability
Subgroup Classification: Intertidal/Subtidal Benthic; Sediment Infauna; Low Mobility; Mollusca.

Adult Exposure Criteria: High Aggregation; Low Mobility; Intertidal (high interaction with sea surface); Infaunal (high interaction with sea floor). Score: 4.

Adult Sensitivity Criteria: Filter feeder (feeding apparatus can be clogged or damaged by pollutants); Chemical sensitivity assumed to be high. Score: 2.

Adult Recovery Criteria: Population status unmonitored; Relatively high reproductive capacity; Broadly distributed in suitable habitats; High degree of interaction with unconsolidated substrates. Score: 1.

Cumulative Total Score: 7.

Larval Exposure Criteria: Aggregate or Patchiness where large number of larvae affected; Low Mobility; Interaction with sea surface. Score: 3.

Larval Sensitivity Criteria: Larvae feeding appendages that can become clogged by oil; Chemical sensitivity assumed to be high. Score: 2.

Larval Recovery Criteria: Populations unmonitored; Relatively high reproductive capacity; Broadly distributed in suitable habitat; Low degree of interaction with unconsolidated substrates. Score: 0.

Larval Cumulative Total Score: 5.

Softshell (Mya arenaria)

Significance

Softshells are an important commercial species in eastern North America; they have limited commercial and recreational use in British Columbia (Bourne 1997). They have supported small historic commercial fisheries in Washington, Oregon and California (Schink *et al.* 1983, Shaw 1997, Robinson 1997, Lindsay and Simons 1997).

Vulnerability

Subgroup classification

Softshells were included in the following subgroups: 1 - Intertidal location for exposure; 2 - Sediment Infauna substrate; 3 - Low mobility; and taxonomy to inform feeding types and reproductive strategies - Mollusca (Thornborough *et al.* 2017, Hannah *et al.* 2017, Jeffery *et al.* 2023).

Exposure

As with many infaunal bivalve molluscs, aggregated distributions of softshells are a result of habitat preferences, physiological tolerances and are beneficial for spawning synchrony and fertilization success (Hannah *et al.* 2017).

Softshells have limited mobility; dispersal is through pelagic larval stages, juveniles may move short distances but are confined to the beaches on which they settled, adults are sessile. They are intertidal in distribution; thus, their populations have a high level of interaction with the sea surface. As infaunal organisms they have intimate contact with the unconsolidated sediments they inhabit.

Sensitivity

As filter/suspension feeders, softshells are very sensitive to pollutants that may clog or damage their feeding apparatus. Numerous studies document chemical effects of pollutants on bivalve physiology, reproduction and larval survival.

Recovery

Population status is not actively monitored in British Columbia. Softshells have high fecundity and high reproductive capacity, but consistency of recruitment in British Columbia is not known. They are broadly distributed in suitable habitat throughout British Columbia and beyond. They are dependent on unconsolidated substrates which can be affected for extended periods due to difficulties removing pollutants that have seeped into the substrate.

Taxonomy

The accepted scientific name is *Mya arenaria* Linnaeus, 1758 (Coan *et al.* 2000). There is an extensive list of synonyms from the Atlantic and Pacific (Bernard 1979, Coan *et al.* 2000, Heibert *et al.* 2016). Many authors (e.g., Coan *et al.* 2000) place *M. japonica* in synonymy with *M. arenaria*, however see Zhang *et al.* (2018). Additional common names include eastern softshell, mud clam, soft-shell, softshell-clam and steamer clam (Table 13).

Description

Shells ovate, posterior extended and narrowed, anterior short and rounded (Coan *et al.* 2000)(Figure 36). Shells chalky, soft (hence "softshell") with thin brown periostracum on margins (Heibert *et al.* 2016). Shells with only commarginal sculpture, often stained black in anoxic substrates. Open siphonal and pedal gapes, siphons do not retract into shell. Left valve with horizontal chondrophore that extends into right valve, aligned with subumbonal resilifer, anterior buttress absent. Ligament is internal between the chondrophore and resilifer. Long, large siphons are fused, non-retractile and dark in colour.

Distribution

The softshell has a circumboreal distribution (Bernard 1979, Coan *et al.* 2000). The species occurred in the eastern Pacific in the Miocene and Pleistocene but became extinct. It persisted in Japan and the North Atlantic and was accidentally re-introduced to the Pacific coast of North America with transplants of Atlantic oysters in the late 1800s. It subsequently spread and currently is found from Icy Cape Alaska throughout the southern Bering Sea to the Yukon delta and south to Elkhorn Slough California. Also found in the North Atlantic from Iceland to Spain and the Black Sea, Newfoundland to Virginia.

First reported from British Columbia from Victoria, Comox and Clayoquot Sound in the late 1800s (Newcombe 1891). Quickly established to become one of the commonest clams in British Columbia (Taylor 1895, 1899).

Habitat Preferences

Intertidal in sand, mud and gravel; softshells grow more rapidly in sand substrate but the shells are thinner and lighter (Swan 1952a,b, Coan *et al.* 2000). Often found at higher tidal elevations and lower salinities than other bivalves but recorded to depths of 20 m (Swan 1952a, Heritage *et al.* 1998, Heibert *et al.* 2016)(Figure 37). Generally, on low energy beaches, as adults cannot rebury in shifting substrates.

Role in the Ecosystem

Trophic Ecology

Softshells are suspension feeders and filter algae and detritus from the water column (Heibert *et al.* 2016).

Ecological Interactions

Preyed on by black, surf and white-winged scoters, long-tailed ducks and Barrow's goldeneyes; also red rock crabs (Vermeer and Levings 1977, Vermeer 1981, Smith *et al.* 1999). In Europe they are preyed on by flatfish, shrimp, sandworms, crabs, gastropods, gulls and wading birds.

Softshells are host to juvenile pinnotherid pea crabs (*Fabia subquadrata*, *Pinnixa faba* and *P. littoralis* and occasionally *Scleroplax granulata*)(Rathbun 1918, Hart 1982, Jensen 2014).

Physical Tolerances

Tolerant of anaerobic conditions, low salinity and low temperatures, as well as full seawater (Heibert *et al.* 2016). The southern distribution limit in the western North Atlantic coincided with a critical temperature of 28°C.

Reproductive Biology

The sexes are separate, although occasional hermaphrodites have been reported (e.g., Porter 1972). They are broadcast spawners and gametes are simultaneously shed into the water column; fertilization is external.

Softshells are generally summer spawners, although some populations have exhibited two spawning peaks in spring and fall (Cross *et al.* 2012). In Ireland, softshells spawned April-November (Cross *et al.* 2012). Spawning in Skagit Bay, northern Puget Sound, occurred from late May to early September with peak spawning in June-July (Porter 1972) (Figure 38).

First reproduction usually occurs at 20-50 mm TL, which corresponds with 1-5 years of age depending on environmental conditions (Cross *et al.* 2012). Fecundity estimated at three million eggs per female per year (Ayres 1956).

Early Life History

Pelagic larvae metamorphose to benthic juveniles at lengths of 170-230 µm, approximately two weeks after fertilization (Ayres 1956, Heibert *et al.* 2016). Juvenile mortality is high initially but decreases markedly when they reach a size refuge from epibenthic predators

Growth Rates and Life Span

Softshell growth measurements indicated that 3.5-5.0 years was required to achieve 50 mm TL in northern coastal British Columbia (Gillespie and Bourne 1998, 2005a,b). Size ranged from 19-110 mm TL and age from 1-13 years in northern British Columbia mainland inlets, approximately 30-116 mm TL and 1-12 years in Queen Charlotte Strait and 13-87 mm TL

and 1-10 years on the west coast of Vancouver Island (Gillespie and Bourne 2005a,b). Size ranged from 19-64 mm TL and age from 1-8 years in Masset Inlet, Haida Gwaii (Gillespie and Bourne 1998). Maximum age reported to be at least 28 years (Heibert 2016).

Pathways of Effects (PoE): Oil Exposure

A Pathways of Effects (PoE) oil exposure model can aid oil spill emergency response by identifying low to high-risk scenarios for species exposure. This section describes PoE for Softshells through exposure paths of specific species life stages and the potential dispersion and fates of five oil groups (Table 2). The specific environmental conditions and chemical signature of the oil spill should be taken into consideration as they may cause differences in the outcomes described in this document. A summary table for this section is available in Appendix Table 11.

Habitat utilization and temporal distribution of spawning, larval and adult presence and vulnerability ranks of softshells are illustrated in Figure 37 and Figure 38 with vulnerability ranking scores for softshells generalized for all oil groupings as 5 for the larval life stage and 7 for adult life stages (Jeffery *et al.* 2023).

Group 1 Oils

Group 1 contains gasoline and marine diesel oil (MDO). Both gasoline and MDO are light, volatile, and acutely toxic oils (ITOPF 2011a). The two (2) oils are split into subcategories due to differences in fate and behaviour, causing different potential PoE on softshells.

Gasoline

Gasoline has high concentrations of LMW hydrocarbons which may cause both acute and chronic toxic effects on aquatic organisms (ITOPF, 2011b). Possible toxic effects include mortality (Keesing *et al.* 2018), and physiological functioning (Adzigbli and Yeuwen 2018).

Fresh Gasoline Oil Spill

Softshells spawn in the summer, from late May to September with a peak in June and July (Porter 1972). Free-swimming pelagic larvae are present for two weeks after fertilization before metamorphizing into benthic juveniles (Heibert *et al.* 2016). Gasoline is very light, having a specific gravity of <0.8, causing it to float and only be present on the top 1-2 mm of the water column (ITOPF 2011a). Due to gasoline remaining on the top of the water, risk of larval exposure is low during low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion of oils throughout the water column within the intertidal and subtidal zones, increasing the risk of exposure to larval softshells.

Softshells have limited mobility after the larval stage along with having a consistent filter-fed diet. Due to this sessile nature, the PoE and vulnerability levels are the same for all post-larval life stages.

Juvenile softshells have a small amount of mobility, however, they are confined to where they settled after metamorphosis. Mature softshells are sessile and inhabit the high intertidal zone in sandy, muddy and gravel areas, occasionally being found at depths up to 20 meters (Swan 1952a, Heritage *et al.* 1998, Heibert *et al.* 2016). Softshells are infaunal, having a high level of interaction with the sea floor in shallow burrows. Given the location of post-larval softshells, gasoline spills in the intertidal zone pose a high risk. Oil spills in intertidal zones have historically caused high mortality in molluscs such as softshells (Keesing *et al.* 2018).

Weathered Gasoline Oil Spill

Gasoline is highly volatile and can completely evaporate within 24 hours; as such, as gasoline weathers the risk to softshells decreases. Weathered gasoline is unlikely to pose any risks to softshells as it evaporates and disperses very quickly.

Marine Diesel Oils (MDO)

Fresh MDO Oil Spill

Fresh MDO has high aquatic toxicity due given high concentrations of LMW hydrocarbons (Environment Canada 1999). Fresh MDO has similar potential PoE to softshells as gasoline (Appendix Table 11).

Softshells spawn in the summer, from late May to September with a peak in June and July (Porter 1972). Free-swimming pelagic larvae are present for two weeks after fertilization before metamorphizing into benthic juveniles (Heibert *et al.* 2016). Gasoline is very light, having a specific gravity of <0.8, causing it to float and only be present on the top 1-2 mm of the water column (ITOPF 2011a). As with gasoline, MDOs have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring in low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion of oils throughout the water column within the intertidal and subtidal zones, increasing the risk of exposure to larval softshells.

Softshells have limited mobility after the larval stage along with having a consistent filter-fed diet. Due to this sessile nature, the PoE and vulnerability levels are the same for all post-larval life stages.

Fresh MDO spills in the intertidal zone have a high risk of impacting post-larval softshells. Both juvenile and mature softshells inhabit the high intertidal zone in sandy, muddy, and gravelly areas (Swan 1952a, Heritage *et al.* 1998, Heibert *et al.* 2016). MDO spills remain on the surface of the water; however, when tides recede the intertidal zone will be exposed to the MDO spilled on the surface. Possible effects may include coating, smothering, and ingestion, causing damage to feeding apparatuses, decreased immunity, along with other physiological issues (Adzigbli and Yuewen 2018). Intertidal zone oil spills have historically caused high mortalities in molluscs (Keesing *et al.* 2018).

Weathered MDO Oil Spill

As MDOs weather aquatic toxicity decreases as the LMW hydrocarbons evaporate. MDO still poses potential risks to softshells through coating, smothering and ingestion (ITOPF 2011b). The persistence of MDO causes weathered MDO to pose many of the same potential effects on softshells as fresh spills. The larvae of softshells still have the potential to interact with the oil spill on the surface of the water with potential effects including coating and smothering, likely without acute toxic effects. The risk of this effect remains low in low energy oceans, as the larvae would need to swim to the ocean's surface, and high risk in high-energy ocean scenarios.

MDO is persistent and has the potential to interact and adsorb to drift particles within the water column (ITOPF 2011a). Mature softshells are suspension filter-feeders with drift particles making up their diet (Heibert et al 2016). Interaction and adsorption to these drift particles by MDO causes the potential for softshells to ingest MDOs. The risk of this occurring is high. Given the persistence of MDO, weathered MDO in the intertidal zone still poses a risk to softshells. Effects include coating and smothering. Intertidal zone oils spills can cause high mortality in molluscs (Keesing *et al.* 2018).

Group 2 Oils

Light Crude Oils (LCOs)

Group 2 oils are LCOs which contain moderate to high concentrations of hydrocarbons which cause acute and chronic toxic effects on aquatic organisms (Adzigbli and Yeuwen 2018). LCOs can cause additional negative effects through coating and smothering aquatic organisms. There are similar PoE between Group 2 and Group 1 oils (Appendix Table 11).

Fresh LCO Oil Spill

Softshells spawn in the summer, from late May to September with a peak in June and July (Porter 1972). Free-swimming pelagic larvae are present for two weeks after fertilization before metamorphizing into benthic juveniles (Heibert *et al.* 2016). As with Group 1 oils, LCOs have a potential to interact with larvae at the water column surface; however, there is a low risk of this occurring in low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion of oils throughout the water column within the intertidal and subtidal zones, increasing the risk of exposure to larval softshells.

Softshells have limited mobility after the larval stage along with having a consistent filter-fed diet. Due to this sessile nature, the PoE and vulnerability levels are the same for all post-larval life stages.

Fresh LCO spills in the intertidal zone have a high potential to impact post-larval softshells. Post-larval softshells generally reside shallow burrows within the substrate in the high

intertidal zone, with high potential for interaction with an oil spill at the water's surface. Softshells would be fully exposed to the oil spill as the tide recedes.

Weathered LCO Oil Spill

As LCOs weather their acute toxicity decreases as the LMW hydrocarbons evaporate; however, the same potential PoE for softshells remain. Light crude oils persist and can form stable emulsions, leading to increased volume and specific gravity of the spill (ITOPF 2011a). The PoE for weathered LCOs are similar as those of fresh LCOs for larval softshells, with an increased risk due to sedimentation. Increased specific gravity of weathered LCOs causes the potential for larval exposure during all ocean energy conditions.

LCOs persist as they weather causing the potential for them to interact with floating drift particles throughout the water column potentially absorbing to them. The interaction between LCOs and floating drift particles leads to the potential for ingestion, causing toxic and potentially fatal effects (Adzigbli and Yuewen 2018). The risk of this occurring is high.

Group 3 Oils

Heavy and Persistent Oils

Group 3 contains engine/hydraulic oil, medium crude oil, heavy crude oil, and dilbit oil. Group 3 oils are heavy and persistent, while not being as toxic as Group 1 and 2 oils, due to decreased levels of LMW hydrocarbons (ITOPF 2011a, 2011b). There are many similar PoE between Group 3 and Group 1 oils (Appendix Table 11).

Fresh Heavy and Persistent Oil Spill

Softshells spawn in the summer, from late May to September with a peak in June and July (Porter 1972). Free-swimming pelagic larvae are present for two weeks after fertilization before metamorphizing into benthic juveniles (Heibert *et al.* 2016). As with Group 1 oils, Group 3 oils have a potential to interact with larvae at the water column surface; however, there is a low risk of this occurring in low energy ocean conditions. Medium and high energy ocean conditions can cause increased oil dispersion throughout the water column within the intertidal and subtidal zones, increasing the risk of exposure to larval softshells.

Softshells have limited mobility after the larval stage along with having a consistent filter-fed diet. Due to this sessile nature, the PoE and vulnerability levels are the same for all post-larval life stages.

Fresh Group 3 oil spills in the intertidal zone have a high potential to impact post-larval softshells. Post-larval softshells reside in the substrate within the high intertidal zone, with high potential for interaction with an oil spill at the water's surface. Softshells would be fully exposed to the oil spill as the tide recedes.

Weathered Heavy and Persistent Oil Spill

As Group 3 oils weather, little to no evaporation occurs; however, sedimentation can occur causing the oils to sink (ITOPF 2011a). Due to Group 3 oils persistence the PoE remain the same for softshells, with the addition of higher risk of ingestion.

Possible sinking due to sedimentation creates a greater risk of exposure for larval softshells. Sinking oil may interact directly with larvae through coating and smothering (ITOPF 2011b). Sinking oil may also interact with floating detritus, adsorbing to it. The interaction between this sinking oil and floating drift particles leads to the potential for ingestion, causing toxic and potentially fatal effects (Adzigbli and Yuewen 2018). There is a high risk of this occurring.

Group 4 Oils

Bunker C Oils

Group 4 oils are Bunker C oils. Bunker C oils are heavy and highly persistent oils (Environment Canada 1999). Bunker C oils contain few toxic light molecular weight hydrocarbons meaning they have little to no acute toxic effects on aquatic organisms. Bunker C oils still pose risk through coating and smothering as well as chronic effects due to heavier toxic hydrocarbons (Adzigbli and Yuewen 2018).

Fresh Bunker C Oil Spill

Softshells spawn in the summer, from late May to September with a peak in June and July (Porter 1972). Free-swimming pelagic larvae are present for two weeks after fertilization before metamorphizing into benthic juveniles (Heibert *et al.* 2016). As with Group 1 oils, Bunker C oils have a potential to interact with larvae at the water column surface; however, there is a low risk of this occurring in low energy ocean conditions. Medium and high energy ocean conditions can cause increased oil dispersion throughout the water column within the intertidal and subtidal zones, increasing the risk of exposure to larval softshells. Negative effects on softshells that this interaction may have differ from previous oils given lower concentrations of LMW hydrocarbons, causing less acute toxic effects.

Softshells have limited mobility after the larval stage along with having a consistent filter-fed diet. Due to this sessile nature, the PoE and vulnerability levels are the same for all post-larval life stages.

Bunker C oil spills in the intertidal zone still have potential to cause high softshell mortalities through coating and smothering (Adzigbli and Yuewen 2018). Softshells would be fully exposed to the Bunker C oil spill as the tide recedes in the intertidal zone.

Weathered Bunker C Oil Spill

There are little weathering effects on Bunker C oil given its low concentrations of volatile LMW hydrocarbons and high persistence (ITOPF 2011a). The PoE are similar between weathered and fresh Bunker C oils; however, Bunker C oils are susceptible to creation of stable emulsions, causing increased volume and specific gravity and potential for sinking and sedimentation-caused sinking.

PoE that weathered Bunker C oil may have on softshells are similar between fresh and weathered oils. If sinking occurs through emulsions forming or sedimentation, larval softshells are at a greater risk of oil exposure. Sinking oils could coat and smother all life stages of softshells causing locomotion issues (juvenile), feeding apparatus damage or potentially mortality (Adzigbli and Yuewen 2018).

Group 5 Oils

Sinking Oils

Group 5 oils are extremely heavy and persistent oils known as sinking oils. Sinking oils have a specific gravity >1, causing them to readily sink in water (ITOPF 2011a). Due to high specific gravity, sinking oils have a high potential to negatively impact softshells at all life stages.

Fresh Sinking Oil Spill

Softshells spawn in the summer, from late May to September with a peak in June and July (Porter 1972). Free-swimming pelagic larvae are present for two weeks after fertilization before metamorphizing into benthic juveniles (Heibert *et al.* 2016). Sinking oils have a high risk of interacting with the larvae of softshells in all potential ocean energy scenarios, given the potential of oil being present throughout the water column.

Softshells have limited mobility after the larval stage along with having a consistent filter-fed diet. Due to this sessile nature, the PoE and vulnerability levels are the same for all post-larval life stages.

Sinking oils have a high risk of oil interacting with drift particles and being ingested by mature softshells, as they are suspension filter feeders (Hiebert *et al*. 2016). Ingestion of oils can cause physiological issues along with potential mortality in molluscs (Adzigbli and Yuewen 2018). There is a high risk of this occurring. Sinking oil spills in the intertidal zone have a high risk of interacting with softshells through coating and smothering, potentially causing death (Adzigbli and Yuewen 2018).

Weathered Sinking Oil Spill

Sinking oils have little to no weathering effects; therefore, the PoE on softshells are the same for fresh and weathered sinking oils.

Figure 36. Softshell, *Mya arenaria*.

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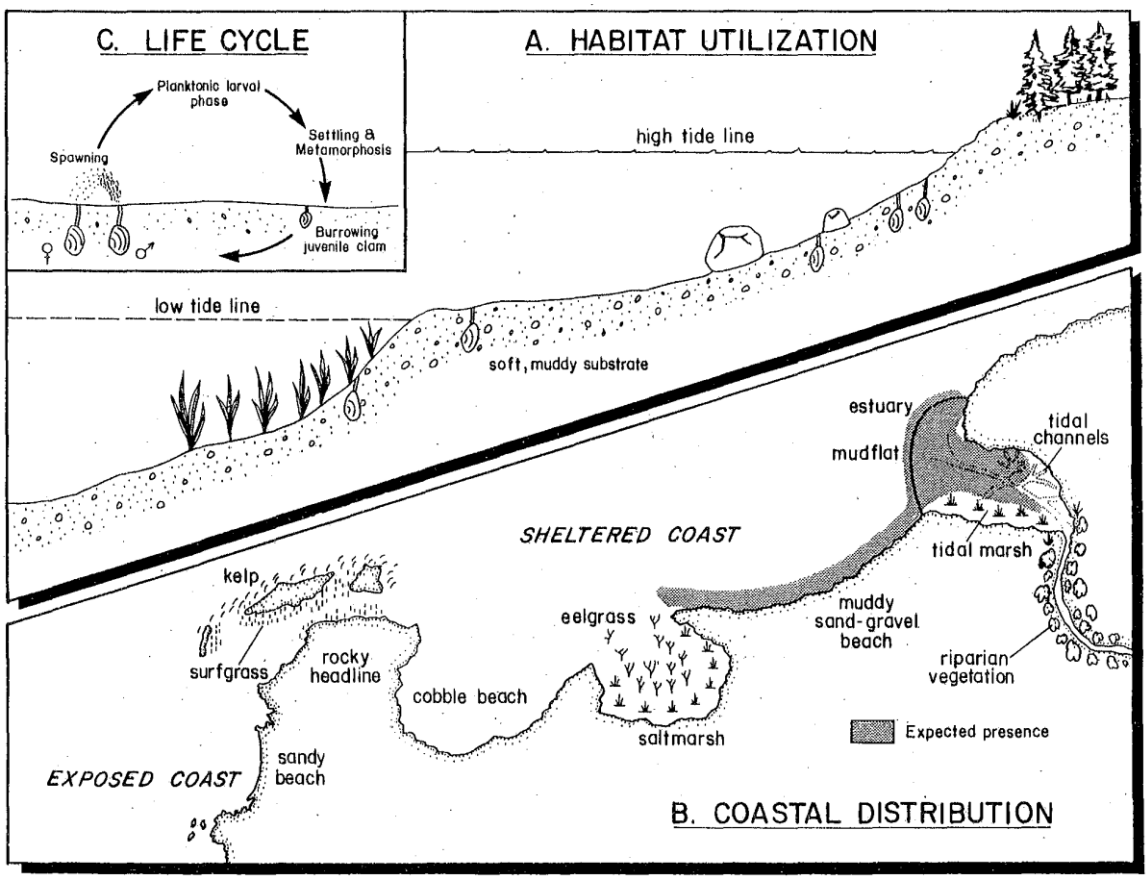

Figure 37. Habitat utilization (A), coastal distribution (B, gray polygons indicate expected presence) and life cycle (C) of softshell, *Mya arenaria* (Williams 1989).

J	F	M	A	M	J	J	A	S	O	N	D
1	1	1	1	2	3	3	2	2	1	1	1
---Spawning---											
1	1	1	1	2	3	3	3	2	1	1	1
---Larval Presence---											
3	3	3	3	3	3	3	3	3	3	3	3
---Adult Presence---											

Figure 38. Temporal distribution of spawning, larval and adult presence and vulnerability ranks of softshell, *Mya arenaria*.

Legend: 1 (green) = low/negligible vulnerability; 2 (yellow) = moderate vulnerability; 3 (red) = high vulnerability.

Table 13. Summary of information to inform marine emergency response for softshell, *Mya arenaria*.

Taxonomy
Scientific Name:
Mya arenaria Linnaeus, 1758

Common Name(s):
Softshell, eastern softshell, mud clam, soft-shell, softshell-clam, steamer clam

Higher Taxonomy:
Mollusca; Bivalvia; Myoida; Myidae

Description
Shell ovate and elongated, posterior end longer and pointed, anterior end short and rounded. Left valve with horizontal chondrophore extending under margin of right valve, aligned with resilifer. Anterior buttress absent. Shells chalky with thin periostracum. Pallial sinus extends to or slightly beyond umbones. Maximum size at least 150 mm TL.

Distribution
Native
North Atlantic species distributed from Iceland to Spain and the Black Sea, Newfounldland to Virginia. Also Korea, Kurile Islands and northern Japan. Known as fossil from Miocene to Pleistocene in the eastern Pacific.

Introductions
Introduced accidentally with Atlantic oysters to California in 1874, subsequently spread northwards. Currently distributed from Icy Cape AK in the Chukchi Sea through the Bering Sea to Elkhorn Slough CA.

Habitat Preferences
Intertidal to 20 m depth in mud, sand and gravel substrates of protected beaches.

Physical Tolerances
Salinity
Tolerates full seawater to greatly reduced salinity in upper estuarine habitats. Also tolerant of anoxic water and substrates.

Temperature
Tolerates freezing temperatures, upper critical limit estimated at 28°C.

Reproductive Biology
Dioescious, broadcast spawner. Summer spawner, primarily April-September. Fecundity estimated at three million eggs per female per year. Pelagic larval period estimated at two weeks.

Table 13. continued.

Growth Rate and Lifespan Growth initially rapid, decreases with age. Size at maturity (approximately 50 mm TL) reached between 1-5 years, depending on environmental conditions. Maximum age approximately 28 years.
Migratory Behaviour Dispersal through pelagic larval stages, juvenile and adult stages confined to the beach they settle on. Juveniles can rebury if dislodged from shifting substrates. Adults are sessile.
Role in the Ecosystem Suspension feeder; filters algae and detritus from the water column.
Interactions with Native Species Preyed on by fish, crabs, gastropods, sandworms, gulls, wading birds, diving ducks and sea otters.
Significance Minor component of recreational fisheries. Important commercial species in eastern North America.
Vulnerability **Subgroup Classification**: Intertidal/Subtidal Benthic; Sediment Infauna; Low Mobility; Mollusca. **Adult Exposure Criteria**: High Aggregation; Low Mobility; Intertidal (high interaction with sea surface); Infaunal (high interaction with sea floor). Score: 4. **Adult Sensitivity Criteria**: Filter feeder (feeding apparatus can be clogged or damaged by pollutants); Chemical sensitivity assumed to be high. Score: 2. **Adult Recovery Criteria**: Population status unmonitored; Relatively high reproductive capacity; Broadly distributed in suitable habitats; High degree of interaction with unconsolidated substrates. Score: 1. Cumulative Total Score: 7. **Larval Exposure Criteria**: Aggregate or Patchiness where large number of larvae affected; Low Mobility; Interaction with sea surface. Score: 3. **Larval Sensitivity Criteria**: Larvae feeding appendages that can become clogged by oil; Chemical sensitivity assumed to be high. Score: 2. **Larval Recovery Criteria**: Populations unmonitored; Relatively high reproductive capacity; Broadly distributed in suitable habitat; Low degree of interaction with unconsolidated substrates. Score: 0. Larval Cumulative Total Score: 5.

California Mussel (Mytilus californianus)

Significance

California mussels are a desired species in First Nations harvests (e.g., Ellis and Swan 1981). They are also significant as habitat engineers and biogenic habitat (Gillespie 1999). Attempts to develop commercial fisheries are inadvisable (Paine 1989); attempts at fishery development in BC were not successful (Bourne 1997, Gillespie 1999, Schmidt 1999).

Vulnerability

Subgroup classification

California mussels were included in the following subgroups: 1 - Intertidal/Subtidal Benthic location for exposure; 2 - Rock and Rubble Dwellers substrate; 3 - Sessile; and taxonomy to inform feeding types and reproductive strategies - Mollusca (Thornborough *et al.* 2017, Hannah *et al.* 2017, Jeffery *et al.* 2023).

Exposure

As with many epifaunal bivalve molluscs, aggregated distributions of California mussels are a result of habitat preferences, physiological tolerances and ecological interactions and are beneficial for spawning synchrony and fertilization success (Hannah *et al.* 2017).

California mussels have low mobility; dispersal is through pelagic larval stages, adults are essentially sessile, attached to hard substrate and each other to form dense beds on the substrate surface. They are largely intertidal in distribution; thus their populations have a high level of interaction with the sea surface. As epifaunal organisms they have intimate contact with the consolidated sediments they inhabit.

Sensitivity

As filter/suspension feeders, California mussels are very sensitive to pollutants that may clog or damage their feeding apparatus. Numerous studies document chemical effects of pollutants on bivalve physiology, reproduction and larval survival.

Recovery

Population status is not actively monitored in British Columbia. California mussels have high fecundity and high reproductive capacity, but inconsistent recruitment. They are broadly distributed in suitable habitat on exposed rocky shores throughout British Columbia (primarily west coast of Vancouver Island, Haida Gwaii and exposed rocky shorelines of Queen Charlotte Strait and northern British Columbia) and beyond. They are dependent on hard substrates and established beds of adults for settlement, they generally do not occur on unconsolidated substrates.

Taxonomy

The accepted scientific name is *Mytilus californianus* (Conrad 1837, Coan *et al.* 2000). The accepted common name is California mussel (Turgeon *et al.* 1998), although the name sea mussel is often used (Table 14).

Description

The California mussel is large and thick shelled (Shaw *et al.* 1988, Coan *et al.* 2000)(Figure 39). The umbones are terminal. The shells are elongate and inflated with a slightly expanded dorsal margin. The shell is marked with 12 strong radial ribs, distinctive in the family. The periostracum is thick and black, tending to fade to blue in older, worn individuals. The flesh is bright orange. The byssus is large, strong and flexible, allowing secure attachment on wave swept rocky shores. It is the largest mussel in the genus *Mytilus*, reaching lengths of up to 270 mm (Paine 1976b).

Distribution

California mussels are distributed from Cook Inlet Alaska to Punta Rompiente Baja California (Coan *et al.* 2000). Northern and southern limits are believed to be a result of temperatures; cold temperatures establishing the northern limit and warm temperatures establishing the southern limit (Seed 1976). They are found on exposed, outer coast rocky shores; also, in tidal channels and on seamounts (Paine 1976b).

Habitat Preferences

California mussels are intolerant of low salinity and siltation, and thus are confined to exposed coastlines, where they form densely aggregated beds from the upper intertidal to subtidal depths (Seed 1976, Seed and Suchanek 1992)(Figure 40). Mature mussel beds are spatially complex, generally with a single layer of mussels near the margins and several layers in the center of the bed. The mussels attach to the substrate and each other by strong byssal threads; mobility is low, but mussels can expand bed margins and fill gaps by dissolving existing byssal threads and laying down new ones. Adult California mussels are essentially sessile. Populations are increased through successful settlement of new recruits and growth: exchange of adult individuals between distinct beds is not thought to occur. California mussels do form subtidal beds under special conditions, but intertidal and subtidal populations are not contiguous (Paine 1976b, 1989).

The upper limit of intertidal distribution is determined by the physiological tolerances of the mussels (temperature extremes, desiccation, length of time exposed during low tides); the lower limit of mussel distribution is thought to be determined by predation, and thus is dependent on the physiological tolerances of predators, primarily the sea star *Pisaster ochraceus* (Paine 1966, 1974, 1989).

Role in the Ecosystem

Trophic Ecology

California mussels are filter feeders, relying on suspended plankton (dinoflagellates, small diatoms, silicoflagellates, flagellates, tintinnids, protozoa, unicellular algae, algal spores, spermatozoa and ova, bacteria), organic debris and inorganic particles such as sand and shell fragments (Coe and Fox 1942, 1944; Fox and Coe 1943, Shaw *et al.* 1988). California mussels efficiently extract and concentrate toxins from harmful algal blooms and faecal coliform organisms, and thus present a human health risk if not monitored carefully.

Ecological Interactions

California mussels are preyed upon by sea stars (particularly *Pisaster ochraceus*, but also *P. giganteus, Lepasterias hexactis* and *Picnopodia helianthoides*), predatory whelks (*Nucella canaliculata* and *N. emarginata*), crabs (three species in California, including *Pugettia producta*, which occurs in B.C.), fish, oystercatchers (*Haematopus bachmani*), black turnstones (*Arenaria melanocephala*), surfbirds (*Apriza virgata*), glaucous-winged gulls (*Larus glaucescens*) and sea otters (*Enhydra lutris*) (Harger 1972, Paine 1976a, Shaw *et al.* 1988, Seed and Suchanek 1992).

California mussels are host to juvenile pinnotherid pea crabs (*Fabia subquadrata*)(Hart 1982). They are also parasitized by the introduced copepod *Mytilicola orientalis* (Bernard 1968).

California mussel beds are biogenic habitat for a large community of associated species (Suchanek 1981, 1992, 1994; Paine 1989, Seed and Suchanek 1992). Local neighbourhood diversity ranged from approximately 20 species at high intertidal protected sites to approximately 140 species at low intertidal exposed sites on the Washington coast. In total, over 300 species inhabit the interstices of established sea mussel beds. The physical complexity of mussel beds increase as they grow older, progressively increasing spatial complexity and availability of microhabitats for use by associated species (Seed and Suchanek 1992). Species richness increases with increasing mussel bed age and thickness and decreases with increased intertidal elevation. Mussel beds also serve as a protective matrix which increases survival of small sea mussels, and thus increases recruitment rates.

Physical Tolerances

Mussel larvae show reasonable survival between 13-19°C and 26-34‰ with maximum survival at 28‰ and 16°C for the first seven days and 14°C prior to metamorphosis (Falmagne 1984).

Optimal growth temperatures for adult *M. californianus* are between 15-19^{o}C, and growth declines sharply above 20^{o}C and below 14^{o}C (Coe and Fox 1942, 1944). Growth in northern populations decreases or ceases during winter.

Reproductive Biology

The sexes are separate and California mussels are broadcast spawners with external fertilization. Some spawning occurs throughout the year, with major peaks in spring and fall (Young 1942, Yamada and Dunham 1989, Seed and Suchanek 1992)(Figure 41). Gametes are liberated into the water column, and are likely short-lived (3-4 hr), limiting gene exchange through reproduction to relatively small areas (likely adults from the same bed, or from immediately adjacent beds).

Total annual fecundity is difficult to estimate in animals that spawn continuously throughout the year. It is safe to say, however, that California mussels are extremely fecund, at least on the order of tens of millions of eggs (Seed 1976). Fecundity is known to increase with size in other *Mytilus* species, and gonad weight increases exponentially with shell length in California mussels (Suchanek 1981).

Early Life History

Mussel larvae are planktonic for approximately 3-5 weeks, during which time they pass through several distinct stages (trochophore, veliger, conchiveliger and pediveliger) and finally settle as plantigrades. California mussel larvae have been reared to settlement in the laboratory in 17-24 days (Shaw *et al.* 1988). Dispersal of larvae is thought to be determined by the prevailing current structure at the time of spawning and the long planktonic larval period could allow larvae to potentially drift far from their natal bed.

As spawning occurs throughout the year, recruitment is also possible throughout the year. Several authors have described seasonal recruitment of sea mussels beginning in winter and becoming more conspicuous in midsummer (e.g., Paine 1974, Seed and Suchanek 1992). Pediveligers can settle on a broad range of substrates but settle preferentially on spatially complex substrates, including clumps of adult bay mussels and the algae *Endocladia muricata* Peterson (1984a,b). Juvenile sea mussels were more abundant in clumps of adult sea mussels (Petraitis 1978). It is unclear whether this is the result of selective settlement or differential mortality, but it is clear that the structural protection provided by existing beds of adult mussels is required for successful recruitment. Recruitment rates are generally a pattern of years of low recruitment with occasional episodes of high recruitment (Paine 1974, 1976a; Seed and Suchanek 1992).

Growth Rates and Life Span

Growth rates vary with age, food availability, degree of exposure, temperature and degree of competition for food. Growth rates are dependent upon intertidal elevation which is highly correlated with exposure time and thus time available for respiration and feeding. Crowding and competition for food affect growth rates of mussels within the same bed: individuals at the edge of patches grow more quickly than those in the center of patches. Overgrowth by algal epiphytes was found to decrease rates of growth and reproduction. Growth in juvenile mussels is rapid relative to adult mussels (Seed 1976, Seed and Suchanek 1992). As growth is temperature dependent, growth decreases with increasing latitude with Alaskan and BC populations growing slower than California and Pacific Northwest populations.

Seed and Suchanek (1992) suggested that maximum ages of 50-100 years are highly possible.

Pathways of Effects (PoE): Oil Exposure

A Pathways of Effects (PoE) oil exposure model can aid oil spill emergency response by identifying low to high-risk scenarios for species exposure. This section describes PoE for California mussels' through exposure paths of specific species life stages and the potential dispersion and fates of five oil groups (Table 2). The specific environmental conditions and chemical signature of the oil spill should be taken into consideration as they may cause differences in the outcomes described in this document. A summary table for this section is available in Appendix Table 12.

Habitat utilization and temporal distribution of spawning, larval and adult presence and vulnerability ranks of California mussels are illustrated in Figure 40 and Figure 41 with vulnerability ranking scores for California mussels generalized for all oil groupings as 5 for the larval life stage and 6 for adult life stages (Jeffery *et al.* 2023).

Group 1 Oils

Group 1 contains gasoline and marine diesel oil (MDO). Both gasoline and MDO are light, volatile, and acutely toxic oils (ITOPF 2011a). The two oils are split into subcategories due to differences in fate and behaviour, causing different potential PoE on California mussels.

Gasoline

Gasoline has high concentrations of LMW hydrocarbons which may cause both acute and chronic toxic effects on aquatic organisms (ITOPF 2011b). Possible toxic effects on mussels include mortality (Keesing *et al.* 2018), decreased cell immunity, DNA destruction, and other physiological functioning (Adzigbli and Yeuwen 2018).

Fresh Gasoline Oil Spill

California mussels spawn year-round, with major peaks occurring in the spring and fall (Young 1942). California mussels have a planktonic larval stage lasting three to five weeks before settling as plantigrades. Gasoline is very light, having a specific gravity of <0.8, causing it to float and only be present on the top 1-2 mm of the water column (ITOPF 2011a). Due to gasoline remaining on the top of the water, risk of larval exposure is low during low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion throughout the water column increasing the risk of exposure to larval mussels within the intertidal and subtidal zones.

California mussels have limited mobility after the larval stage along with having a consistent filter-fed diet. California mussels are able to move very short distances by dissolving their byssal threads. Due to this low mobility and consistent feeding strategy, the PoE and vulnerability risk are grouped together all post-larval life stages.

Post-larval California mussels are epifauanal and distributed in the intertidal and subtidal zones; however, remain on the sea floor or rock substrates in dense mussel beds. Given the location of post-larval California mussels and their diet, gasoline spills pose little risk unless in the intertidal zone. Within the intertidal zone, gasoline spills have a high potential risk to California mussels. Gasoline spills remain on the surface of the water; however, when tides recede the intertidal zone will be exposed to the gasoline spilled on the surface. Oil spills in intertidal zones have historically caused high mortality in molluscs such as California mussels (Keesing *et al.* 2018).

Weathered Gasoline Oil Spill

Gasoline is highly volatile and can completely evaporate within 24 hours; as such, as gasoline weathers the risk to California mussels decreases. Weathered gasoline is unlikely to pose any risks to California mussels as it evaporates and disperses very quickly.

Marine Diesel Oils (MDO)

Fresh MDO Oil Spill

Fresh MDO has high aquatic toxicity due given high concentrations of light molecular weight hydrocarbons (Environment Canada 1999). Fresh MDO has similar PoE to California mussels as gasoline (Appendix Table 12).

California mussels spawn year-round, with major peaks occurring in the spring and fall (Young 1942). California mussels have a planktonic larval stage lasting three to five weeks before settling as plantigrades. As with gasoline, MDOs have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring during low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion throughout the water column within the intertidal and subtidal zones, increasing the risk of exposure to larval mussels.

California mussels have limited mobility after the larval stage along with having a consistent filter-fed diet. California mussels are able to move very short distances by dissolving their byssal threads. Due to this low mobility and consistent feeding strategy, the PoE and vulnerability risks are grouped together all post-larval life stages.

Fresh MDO spills have the potential to impact post-larval California mussels in the intertidal zone. Post-larval California mussels are epifaunal, distributed on hard surfaces within the intertidal and subtidal zones. Within the intertidal zone, California mussels are left vulnerable even where oil remains on the water surface. Possible effects may include coating, smothering, and ingestion. Intertidal zone oil spills have historically caused high mortalities in molluscs (Keesing *et al.* 2018).

Weathered MDO Oil Spill

As MDOs weather aquatic toxicity decreases as the LMW hydrocarbons evaporate. MDO spills still pose potential risks to mussels through coating, smothering and ingestion

(ITOPF 2011b). The persistence of MDO causes weathered MDO to pose many of the same potential effects on California mussels as fresh spills. Mussel larvae still have the potential to interact with the oil spill on the surface of the water with potential effects including coating and smothering, likely without acute toxic effects. The risk of this effect remains low in low energy oceans, as the larvae would need to swim to the ocean's surface, and high in high-energy ocean scenarios.

MDO is persistent and has the potential to interact and adsorb to detritus within the water column (ITOPF 2011a). Post-larval California mussels are filter feeders, feeding on suspended detritus. Interaction and adsorption to this suspended detritus causes the potential for the ingestion of MDOs. The risk of this occurring is high. Ingestion of MDOs in mussels can lead to effects such as impaired physiological function and behaviour as well as death (Adzigbli and Yeuwen 2018).

Given the persistence of MDO, weathered MDO still poses a high risk to California mussels in the intertidal zone. Effects include coating, smothering, and habitat modification. Intertidal zone oils spills can cause high mortality in molluscs (Keesing *et al.* 2018).

Group 2 Oils

Light Crude Oils (LCOs)

Group 2 oils are LCOs which contain moderate to high concentrations of hydrocarbons which cause acute and chronic toxic effects on aquatic organisms (Adzigbli and Yeuwen 2018). LCOs can cause additional negative effects through coating and smothering aquatic organisms. There are similar PoE between Group 2 and Group 1 oils (Appendix Table 12).

Fresh LCO Oil Spill

Free-swimming larval California mussels are present year-round with major spikes in the spring and fall (Younge 1942). Their planktonic larval stage lasts for three to five weeks before settling as plantigrades. As with Group 1 oils, LCOs have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring during low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion throughout the water column within the intertidal and subtidal zones, increasing the risk of exposure to larval mussels.

California mussels have limited mobility after the larval stage along with having a consistent filter-fed diet. California mussels are able to move very short distances by dissolving their byssal threads. Due to this mostly sessile nature and feeding strategy, the PoE and vulnerability levels are grouped together all post-larval life stages.

Fresh LCO spills have a high potential to impact California mussels in the intertidal zone. Post-larval California mussels reside on hard substrates within the shallow subtidal zone

and intertidal zone. Due to their habitat, LCO spills in the intertidal zone have a high potential to cause coating and smothering of California mussels.

Weathered LCO Oil Spill

As LCOs weather their acute toxicity decreases as the light molecular weight hydrocarbons evaporate; however, similar potential PoE to California mussels remain. Light crude oils persist and can form stable emulsions, leading to increased volume and specific gravity of the spill (ITOPF 2011a). The PoE for weathered light crude oils are similar as those of fresh LCO for larval mussels, with an increased risk in low energy ocean scenarios due to the emulsions potentially being present deeper in the water column.

LCOs persist as they weather, causing the potential for them to interact with drift particles throughout the water column potentially adsorbing to floating detritus. Detritus is a common food source for mature California mussels (Younge 1942). The interaction between LCOs and drift algae leads to the potential for ingestion, causing toxic and potentially fatal effects (Adzigbli and Yuewen 2018). The risk of this occurring is high.

Group 3 Oils

Heavy and Persistent Oils

Group 3 contains engine/hydraulic oil, medium crude oil, heavy crude oil, and dilbit oil. Group 3 oils are heavy and persistent, while not being as toxic as Group 1 and 2 oils, due to decreased levels of LMW hydrocarbons (ITOPF 2011a, 2011b). There are many similar PoE between Group 3 and Group 1 oils (Appendix Table 12).

Fresh Heavy and Persistent Oil Spill

Free-swimming larval California mussels are present year-round with major spikes in the spring and fall (Younge 1942). Their planktonic larval stage lasts for three to five weeks before settling as plantigrades. As with Group 1 oils, Group 3 oils have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring during low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion throughout the water column within the intertidal and subtidal zones, increasing the risk of oil exposure to larval mussels.

California mussels have limited mobility after the larval stage along with having a consistent filter-fed diet. California mussels are able to move very short distances by dissolving their byssal threads. Due to this mostly sessile nature and feeding strategy, the PoE and vulnerability levels are grouped together all post-larval life stages.

Fresh Group 3 oil spills have a high potential to impact California mussels in the intertidal zone. Post-larval California mussels reside on hard substrates within the shallow subtidal zone and intertidal zone. Due to their habitat, LCO spills in the intertidal zone have a high potential to cause coating and smothering of California mussels.

Weathered Heavy and Persistent Oil Spill

As Group 3 oils weather, little to no evaporation occurs; however, sedimentation can occur causing the oils to sink (ITOPF 2011a). Due to Group 3 oils persistence the PoE remain similar for all life stages of California mussels with an increased risk of ingestion due to sedimentation.

Possible sinking due to sedimentation creates a greater risk of exposure for California mussels. Sinking oil may interact directly with mussels of all life stages through coating and smothering (ITOPF 2011b). Sinking oil may also interact with detritus, a mussel food source, causing ingestion of oil. Ingestion of oil can cause decreased cell immunity, DNA destruction, and damage to feeding structures (Adzigbli and Yuewen 2018). There is a high risk of this occurring.

Group 4 Oils

Bunker C Oils

Group 4 oils are Bunker C oils. Bunker C oils are heavy and highly persistent oils (Environment Canada 1999). Bunker C oils contain few toxic LMW hydrocarbons meaning they have little to no acute toxic effects on aquatic organisms. Bunker C oils still pose risk through coating and smothering as well as chronic effects due to heavier toxic hydrocarbons (Adzigbli and Yuewen 2018).

Fresh Bunker C Oil Spill

Free-swimming larval California mussels are present year-round with major spikes in the spring and fall (Younge 1942). Their planktonic larval stage lasts for three to five weeks before settling as plantigrades. As with Group 1 oils, Bunker C oils have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring during low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion throughout the water column within the intertidal and subtidal zones, increasing the risk of exposure to larval mussels. Negative effects on California mussels that this interaction may differ from previous oils given lower concentrations of LMW hydrocarbons, causing less acute toxic effects.

California mussels have limited mobility after the larval stage along with having a consistent filter-fed diet. California mussels are able to move very short distances by dissolving their byssal threads. Due to this low mobility and consistent feeding strategy, the PoE and vulnerability levels are grouped together all post-larval life stages.

The risk of a fresh Bunker C oil spill to cause harm to post-larval California mussels is high. California mussel habitat is generally located in the intertidal zone, causing a high level of interaction with the ocean surface. Bunker C oil spills in the intertidal zone would cause coating and smothering of California mussels.

Weathered Bunker C Oil Spill

There are little weathering effects on Bunker C oil given its low concentrations of volatile LMW hydrocarbons and high persistence (ITOPF 2011a). The PoE are similar between weathered and fresh Bunker C oils; however, Bunker C oils are susceptible to creation of stable emulsions, causing increased volume and specific gravity and potential for sinking and sedimentation-caused sinking (ITOPF 2011a).

If sinking occurs through emulsions forming or sedimentation, post-larval California mussels are at greater risk of oil exposure, especially in the shallow subtidal zone. Sinking oils could coat and smother California mussels on substrates in shallow subtidal or intertidal zones causing feeding issues, reduced immunity, DNA destruction and potentially mortality (Adzigbli and Yuewen 2018). Sinking oil may also interact with a floating detritus, causing ingestion of the oil by filter feeding mussels. There is a high risk of this occurring.

Group 5 Oils

Sinking Oils

Group 5 oils are extremely heavy and persistent oils known as sinking oils. Sinking oils have a specific gravity >1, causing them to readily sink in water (ITOPF 2011a). Due to high specific gravity, sinking oils have a high potential to negatively impacting California mussels at all life stages.

Fresh Sinking Oil Spill

Free-swimming larval California mussels are present year-round with major spikes in the spring and fall (Younge 1942). Their planktonic larval stage lasts for three to five weeks before settling as plantigrades. Sinking oils have a high risk to interact with larvae throughout the water column for all ocean energy scenarios.

California mussels have limited mobility after the larval stage along with having a consistent filter-fed diet. California mussels are able to move very short distances by dissolving their byssal threads. Due to this mostly sessile nature and feeding strategy, the PoE and vulnerability levels are grouped together all post-larval life stages.

Sinking oils have a high risk of oil interacting with detritus and being ingested by post-larval California mussels while filter feeding. Ingestion of oils can cause physiological issues along with potential mortality in molluscs (Adzigbli and Yuewen 2018). Sinking oils may also smother post-larval California mussels, in both the intertidal and subtidal zone, causing mortality.

Weathered Sinking Oil Spill

Sinking oils have little to no weathering effects; therefore, the PoE on California mussels are the same for fresh and weathered sinking oils.

Figure 39. California mussel, *Mytilus californianus*.

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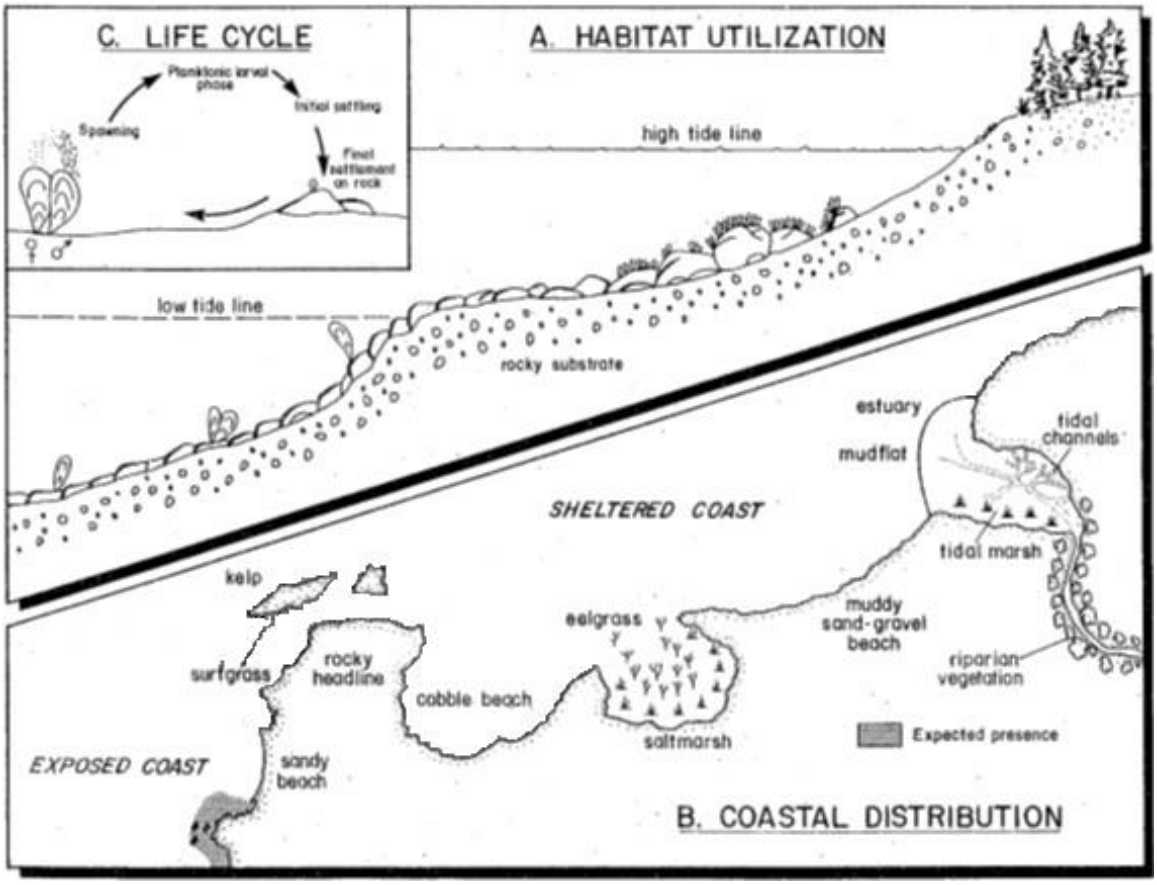

Figure 40. Habitat utilization (A), coastal distribution (B, gray polygons indicate expected presence) and life cycle (C) of California mussel, *Mytilus californianus* (adapted from Williams 1989).

J	F	M	A	M	J	J	A	S	O	N	D
2	2	2	3	3	2	2	2	3	3	3	3
---Spawning---											
2	2	2	3	3	2	2	2	3	3	3	3
---Larval Presence---											
3	3	3	3	3	3	3	3	3	3	3	3
---Adult Presence---											

Figure 41. Temporal distribution of spawning, larval and adult presence and vulnerability ranks of California mussel, *Mytilus californianus*.

Legend: 1 (green) = low/negligible vulnerability; 2 (yellow) = moderate vulnerability; 3 (red) = high vulnerability.

Table 14. Summary of information required to inform marine emergency response for California mussel, *Mytilus californianus*.

Taxonomy
Scientific Name:
Mytilus californianus Conrad, 1837

Common Name(s):
California mussel, big mussel, ribbed mussel, rock mussel, sea mussel

Higher Taxonomy:
Mollusca; Bivalvia; Mytiloida; Mytilidae

Description
Large mussel with elongate, thick shells. Shells marked with radial ribs and commarginate crenulations. Thick black periostracum, blue in worn areas. Flesh orange. Maximum size at least 27 cm TL.

Distribution
Northeastern Pacific from Alaska to Baja California. Intertidal and subtidal to 100 m.

Habitat Preferences
Exposed rocky foreshore and tidal channels, also seamounts, intolerant of decreased salinity and increased siltation. Form dense beds limited by exposure in the upper intertidal and predation in the lower intertidal.

Physical Tolerances
Salinity
Larval survival best between 26-34‰ with a maximum at 28‰.

Temperature
Larval survival decreases outside 13-19°C with maximum between 14-16°C. Adult growth maximized between 15-19°C, decreased below 14°C and above 20°C

Reproductive Biology
Sexes are separate, broadcast spawner with external fertilization. Some trickle spawning year-round, with peaks in the summer and fall. Larvae planktonic for 3-5 weeks. Pediveligers settle selectively in complex habitats, primarily existing mussel beds.

Growth Rate and Lifespan
Growth is dependent on age, temperature, exposure, and competition for food. Growth is generally rapid in juveniles and decreases with age. Maximum age approximately 50-100 years.

Table 14. continued.

Migratory Behaviour
Adults essentially sessile, dispersal through pelagic larval stages.

Role in the Ecosystem
Obligate filter feeder. Preyed on by sea stars, whelks, crabs, birds and mammals. Habitat engineer, providing biogenic habitat for over 300 species in mature beds.

Significance
A desired species for First Nations harvests; no commercial fisheries at present. Ecologically significant as biogenic habitat and habitat engineers.

Vulnerability
Subgroup Classification: Intertidal/Subtidal; Sediment Epifauna; Sessile; Mollusca.

Adult Exposure Criteria: Aggregate in discrete beds, gregarious recruitment; Sessile; Intertidal (high interaction with sea surface); Epifaunal (high interaction with sea floor). Score: 4.

Adult Sensitivity Criteria: Filter/suspension feeders (feeding apparatus can be clogged or damaged by pollutants); Chemical sensitivity assumed to be high. Score: 2.

Adult Recovery Criteria: Populations unmonitored; Relatively high reproductive capacity; Broadly distributed in suitable habitats, primarily exposed coast; Low degree of interaction with unconsolidated substrates. Score: 0.

Cumulative Total Score: 6.

Larval Exposure Criteria: Aggregate or Patchiness where large number of larvae affected; Low Mobility; Interaction with sea surface. Score: 3.

Larval Sensitivity Criteria: Larvae feeding appendages that can become clogged by oil; Chemical sensitivity assumed to be high. Score: 2.

Larval Recovery Criteria: Populations unmonitored; Relatively high reproductive capacity; Broadly distributed in suitable habitat; Low degree of interaction with unconsolidated substrates. Score: 0.

Larval Cumulative Total Score: 5.

Bay Mussels (Mytilus trossulus, M. edulis and M. galloprovincialis)

Significance

Bay mussels are not harvested commercially in British Columbia, they may be harvested by First Nations or recreationally and are cultured in some areas (Gurney-Smith *et al.* 2017).

Vulnerability

Subgroup classification

Bay mussels were included in the following subgroups: 1 - Intertidal/Subtidal Benthic location for exposure; 2 - Rock and Rubble Dwellers substrate; 3 - Sessile; and taxonomy to inform feeding types and reproductive strategies - Mollusca (Thornborough *et al.* 2017, Hannah *et al.* 2017, Jeffery *et al.* 2023).

Exposure

As with many epifaunal bivalve molluscs, aggregated distributions of bay mussels are a result of habitat preferences, physiological tolerances and ecological interactions and are beneficial for spawning synchrony and fertilization success (Hannah *et al.* 2017).

Bay mussels have low mobility; dispersal is through pelagic larval stages, adults are essentially sessile, attached to hard substrate and each other to form dense beds on the substrate surface. They are largely intertidal in distribution, thus their populations have a high level of interaction with the sea surface. As epifaunal organisms they have intimate contact with the consolidated sediments they inhabit.

Sensitivity

As filter/suspension feeders, bay mussels are very sensitive to pollutants that may clog or damage their feeding apparatus. Numerous studies document chemical effects of pollutants on bivalve physiology, reproduction and larval survival.

Recovery

Population status is not actively monitored in British Columbia. Bay mussels have high fecundity and high reproductive capacity, but variable recruitment. They are broadly distributed in suitable habitat throughout British Columbia and beyond but are less common on exposed outer shores where California mussels dominate (primarily west coast of Vancouver Island, Haida Gwaii and exposed rocky shorelines of Queen Charlotte Strait and northern British Columbia). They are primarily dependent on hard substrates (natural and artificial) for settlement, although they also occur on unconsolidated substrates.

Taxonomy

The recognized scientific names are *Mytilus trossulus* Gould, 1850, *Mytilus galloprovincialis* Lamarck, 1819 and *Mytilus edulis* Linnaeus, 1758 (Turgeon *et al.* 1998). Accepted common names are foolish mussel (*M. trossulus*), Mediterranean mussel (*M. galloprovincialis*) and blue mussel (*M. edulis*). Additional common names include bay mussel, Pacific blue mussel and smooth mussel (Table 15)(Harbo 1997, Heibert *et al.* 2016).

Description

The shells are triangular, narrow and elongate or somewhat inflated, anterior end blunt in *M. edulis*, pointed in the other species and may be curved in *M. galloprovincialis* (Coan *et al.* 2000, Coan and Valentich Scott 2007)(Figure 42, Figure 43). Anterior adductor scar large in *M. edulis*, relatively small to tiny in other species. Posterior byssal retractor scar broad in *M. galloprovincialis*, long and narrow in other species. Outer surface of shell marked only by commarginal striaea, periostracum black or blue to brown. Maximum size to 90 mm TL in *M. trossulus*, 115 mm TL in *M. edulis* and 150 mm TL in *M. galloprovincialis*. Quayle (1978) reported a maximum length of 85 mm TL in British Columbia, while Emmett *et al.* (1987) indicated that British Columbia *Mytilus* rarely exceed 60 mm TL (reported as *M. edulis* but likely *M. trossulus*).

The species cannot be reliably distinguished based on external morphology (Seed 1992, Geller 2007), the *M. galloprovincialis* specimen in Figure 43 is a tentative identification.

Distribution

Mytilus trossulus is distributed from the Arctic Ocean through the Bering Sea to central California, where it is largely replaced by *M. galloprovincialis*, and possibly to southern California (Coan *et al.* 2000, Coan and Valentich Scott 2007, Geller 2007). Range extends westward through the Aleutian Islands to at least Siberia and possibly to northern Japan. Also reported from northeastern Canada and the Baltic Sea.

The native range of *M. galloprovincialis* includes the Mediterranean, western France, Britain and Ireland (Coan *et al.* 2000). They have been widely introduced including South Africa, Australia, New Zealand and Asia (Japan and Korea to Hong Kong), as well as the northeast Pacific (Seed 1992). Mediterranean mussels replace foolish mussels from central California to Baja California but have also been reported from Puget Sound and British Columbia (Suchanek *et al.* 1997, McDonald and Koehn 1988, Wonham 2004, Heibert *et al.* 2016).

Mytilus edulis is native to the North Atlantic but has been widely introduced either intentionally for aquaculture or unintentionally as an invasive species (Coan and Scott 2007, Crego-Prieto *et al.* 2015).

Where *M. trossulus*, *M. galloprovincialis* and *M. edulis* co-occur they hybridize freely (Seed 1992, Heath *et al.* 1995, Suchanek *et al.* 1997, Shields *et al.* 2008).

Habitat Preferences

Bay mussels are found attached to hard substrates (rock, wood, barnacles, fiberglass and firm mud) by byssal threads (Suchanek 1978, Heibert *et al.* 2016). On the open coast they are found higher in the intertidal (+3.2 m to +2.9 m above MLLW) than *M. californianus* (+2.9 m to +1.7 m above MLLW), more often in protected microhabitats rather than directly on exposed rock in areas of tidal surge and turbulence (Figure 44). They also occur in gaps in the *M. californianus* matrix, associated with tufts of the red algae *Endocladia muricata*, other filamentous algae and coralline algae. These gaps are eventually overgrown by *M. californianus*. Bay mussels are found deeper than the mussel band associated with filamentous and coralline algae, kelp holdfasts, branched hydroids and ectoprocts that provide spatial refuge from predation. Some scattered individuals are found in tide pools to a tidal height of +3.7 m (above MLLW). Significant biofouling organism on man-made structures, including floating docks and vertical pilings (Quayle 1978, Neisen 2007).

Role in the Ecosystem

Trophic Ecology

Bay mussels are filter feeders, ingesting primarily organic detritus as well as phyto- and zooplankton (Quayle 1978, Heibert *et al.* 2016).

Ecological Interactions

Bay mussels are a dominant species in a diverse community of associated invertebrates (Quayle 1978, Neisen 2007, Heibert *et al.* 2016). These include acorn barnacles (on mussel shells), nematodes, polychaetes, nemerteans, flatworms, limpets, bryozoans, anemones, gastropods, red algae, tunicates, sea cucumbers and hydrozoans. Bay mussels are also a component of the larger, more diverse *M. californianus* community on exposed rocky coasts.

Bay mussels are preyed on by muricid snails (*Nucella canaliculata* and *N. emarginata*), sea stars (*Pisaster ochraceus* and *Leptasterias hexactis*), European green crabs (*Carcinus maenas*), pile perch (*Rhacochilus vacca*) black, surf and white-winged scoters, long-tailed ducks, buffleheads, Barrow's and common goldeneyes, wandering tattlers, surfbirds and black oystercatchers (Vermeer and Levings 1977, Quayle 1978, Suchanek 1978, Vermeer 1981,1982, Palacios and Ferraro 2003, Curtis *et al.* 2012). Mussels that die or gape due to heat stress are scavenged by glaucous-winged gulls (Suchanek 1978). In Alaska, where *M. californianus* is absent, the upper limit of distribution is determined through mortality due to freezing during winter low tides and the lower limit by predation; additional predators include the snails *Nucella lamellosa* and *N. lima* and sea stars *Evasterias troschelli* and *Picnopodium helianthoides*.

Where *M. edulis* and *M. californianus* co-occur, the latter species eventually out-competes and excludes the former (Suchanek 1978).

Foolish mussels (and presumably Mediterranean mussels) are host to juvenile pinnotherid pea crabs (*Fabia subquadrata*)(Hart 1982). They are also parasitized by the introduced copepod *Mytilicola orientalis* (Bernard 1968, Quayle 1978).

Physical Tolerances

Bay mussel species have different temperature tolerances (Heibert *et al.* 2016). *Mytilus trossulus* is a northern cold temperate species and optimal growth temperatures are 10-20°C. *Mytilus galloprovincialis* is a warm water species that is firmly established in California and northern Mexico. Optimal larval growth in *M. edulis* occurs between 16-22°C (Widdows 1991). Bay mussels at the upper margin of the bed suffered high mortality during prolonged exposure and direct sunlight during summer (Suchanek 1978).

Bay mussels are tolerant of a broader range of salinities than *M. californianus* (Quayle 1978, Heibert *et al.* 2016). Adults prefer salinities of 2-33‰ and larvae cannot tolerate salinities >45‰ or less than 10‰, maximum larval growth in *M. edulis* between 30-35‰ and declines to 50% of maximum at 15‰ (Widdows 1991).

Reproductive Biology

The sexes are generally separate (some hermaphrodism has been reported) and bay mussels are broadcast spawners; gametes are released simultaneously, and fertilization occurs in the water column (Quayle 1978, Heibert *et al.* 2016). Fecundity is high, approximately $8.0x10^6$ and eggs are small 70 µm diameter (Widdows 1991). Larvae are planktotrophic, and larvae are capable of settling at approximately 300 µm TL. Bay mussels spawn and settle in late winter and early spring in California and late winter in Washington (Suchanek 1978). In British Columbia, spawning occurred from May to October with minor peaks in June and October and a major peak in August and September (Quayle 1978, Emmett *et al.* 1987)(Figure 45). Depending on temperature, the pelagic larval stage can last at least three weeks, but may be extended to seven weeks in the absence of suitable settlement substrates (Quayle 1978, Widdows 1991, Suchanek *et al.* 1997).

Early Life History

Larvae generally settle preferentially on biological or artificial filamentous substrates, although they may settle massively on newly available rock substrate (Suchanek 1978). Factors influencing settlement include macroalgal/barnacle cover, water flux, tidal height and flushing time (Hunt and Scheibling 1996). With growth, juvenile mussels move into established beds of adult mussels. The late winter spawning and settlement may provide increased settlement opportunities (newly opened habitat following winter storms) and refuge from predation due to decreased predator activity during cold weather.

Growth Rates and Life Span

Growth is most rapid in the early months post-settlement and more rapid during times of increased water temperature and dinoflagellate abundance (Heibert *et al.* 2016). Growth slows markedly after 2-3 years; sizes of 76 and 96 mm TL in the first and second years respectively were reported. Emmett *et al.* (1987) reported total lengths of 45-50 mm 14-16

months after settlement at two experimental sites (one in the Strait of Georgia and one in Barkley Sound). Bay mussel growth rates decrease with increasing tidal height, likely due to limited feeding opportunities and physiological tolerances to temperature and desiccation (Suchanek 1978).

Bay mussels on the west coast of North America have been reported to suffer high mortality in the second summer of growth, after their first spawning, possibly linked to high prevalence of haemocytic neoplasia (e.g., Emmett *et al.* 1987, Bower 1989, Barber 2004). Populations in the Strait of Georgia suffered up to 90% mortality due to "summer mortality syndrome". Maximum age for the *Mytilus edulis* complex is at least 20 years with older reported ages from the Arctic North Atlantic (Seed 1976).

Pathways of Effects (PoE): Oil Exposure

A Pathways of Effects (PoE) oil exposure model can aid oil spill emergency response by identifying low to high-risk scenarios for species exposure. This section describes PoE for bay mussels, *Mytilus trossulus, M. edulis* and *M. galloprovincialis* through exposure paths of specific species life stages and the potential dispersion and fates of five oil groups (Table 2). The specific environmental conditions and chemical signature of the oil spill should be taken into consideration as they may cause differences in the outcomes described in this document. A summary table for this section is available in Appendix Table 13.

Habitat utilization and temporal distribution of spawning, larval and adult presence and vulnerability ranks of bay mussels, *Mytilus trossulus, M. edulis* and *M. galloprovincialis* are illustrated in Figure 44 and Figure 45 with vulnerability ranking scores for bay mussels, *Mytilus trossulus, M. edulis* and *M. galloprovincialis* generalized for all oil groupings as 5 for the larval life stage and 6 for adult life stages (Jeffery *et al.* 2023).

Group 1 Oils

Group 1 contains gasoline and marine diesel oil (MDO). Both gasoline and MDO are light, volatile, and acutely toxic oils (ITOPF 2011a). The two (2) oils are split into subcategories due to differences in fate and behaviour, causing different potential PoE on bay mussels.

Gasoline

Gasoline has high concentrations of LMW hydrocarbons which may cause both acute and chronic toxic effects on aquatic organisms (ITOPF 2011b). Possible toxic effects on mussels include mortality (Keesing *et al.* 2018), decreased cell immunity, DNA destruction, and other physiological functioning (Adzigbli and Yeuwen 2018, Fedato et al 2010).

Fresh Gasoline Oil Spill

Bay mussels spawn in British Columbia between May and October with minor spawning rate spikes occurring in July and October and major spikes in August and September (Quayle 1978, Emmett *et al.* 1987). Bay mussel larvae are planktonic, allowing for free movement throughout the water column (Quayle 1978). This larval stage lasts for between three and seven weeks dependent on temperature and the presence of suitable substrate to

settle on (Quayle 1978, Widdows 1991, Suchanek *et al.* 1997). Gasoline is very light, having a specific gravity of <0.8, causing it to float and only be present on the top 1-2 mm of the water column (ITOPF 2011a). Due to gasoline remaining on the top of the water, risk of larval exposure is low during low energy ocean conditions, as larvae would need to swim to the ocean's surface. Medium and high energy ocean conditions can cause increased dispersion throughout the water column within the intertidal and subtidal zones, increasing the risk of exposure to larval bay mussels.

Bay mussels have limited mobility after the larval stage along with having a consistent filter-fed diet. Juvenile bay mussels have small amounts of mobility but are largely sessile after growing to the adult stage. Due to this low mobility nature, the PoE and vulnerability are the same for all post-larval life stages.

Post-larval bay mussels are epifaunal. They are generally found in the intertidal zone and occasionally in the shallow subtidal zone, settling in large groupings on hard substrates such as rock, wood, barnacles, and firm mud (Suchanek 1978, Heibert *et al.* 2016). Given that post-larval bay mussels are epifuanal and their habitat, gasoline spills in the intertidal zone pose a high risk. Once the tide recedes, bay mussels would be fully exposed. High volume oil spills in intertidal zones have historically caused high mortality in molluscs such as bay mussels (Keesing *et al.* 2018).

Weathered Gasoline Oil Spill

Gasoline is highly volatile and can completely evaporate within 24 hours; as such, as gasoline weathers the risk to bay mussels decreases. Weathered gasoline is unlikely to pose any risks to bay mussels as it evaporates and disperses very quickly.

Marine Diesel Oils (MDO)

Fresh MDO Oil Spill

Fresh MDO has high aquatic toxicity due to high concentrations of LMW hydrocarbons (Environment Canada 1999). Fresh MDO has similar potential PoE to bay mussels as gasoline (Appendix Table 13).

Free-swimming larval bay mussels are present during the spawning period of May to September, with the larval stage lasting between three and seven weeks (Quayle 1978, Emmett *et al.* 1987, Widdows 1991, Suchanek *et al.* 1997). As with gasoline, MDOs have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion and dissolution. MDO's spreading through the water column may increase the risk of exposure with larvae and drift particle food sources. In high energy ocean conditions, the risk of this occurring is high.

Bay mussels have limited mobility after the larval stage along with having a consistent filter-fed diet. Juvenile bay mussels have small amounts of mobility but are largely sessile

after growing to the adult stage. Due to this low mobility, the PoE and vulnerability levels are the same for all post-larval life stages.

Post-larval bay mussels are epifaunal. They are generally found in the intertidal zone and occasionally in the shallow subtidal zone, settling in large groupings on hard substrates such as rock, wood, barnacles, and firm mud (Suchanek 1978, Heibert *et al.* 2016). Fresh MDO spills in the intertidal zone have a high risk of impacting bay mussels. MDO spills remain on the surface of the water; however, when tides recede the intertidal zone will be exposed to the MDO spilled on the surface. Possible effects may include coating, smothering, ingestion, and habitat modification, which may inhibit spawning. Intertidal zone oil spills have historically caused high mortalities in molluscs (Keesing *et al.* 2018).

Weathered MDO Oil Spill

As MDOs weather aquatic toxicity decreases as the LMW hydrocarbons evaporate. MDO spills still pose potential risks to bay mussels through coating, smothering and ingestion (ITOPF 2011b). The persistence of MDO causes weathered MDO to pose many of the same potential effects on bay mussels as fresh spill. Larval bay mussels still have the potential to interact with the oil spill on the surface of the water with potential effects including coating and smothering, likely without acute toxic effects due to the evaporation of LMW hydrocarbons. The risk of this effect remains low in low energy oceans, as the larvae would need to swim to the ocean surface, and high risk in high-energy ocean scenarios.

MDO is persistent and has the potential to interact and adsorb to drift particles within the water column (ITOPF 2011a). Post-larval bay mussels are filter feeders, feeding on detritus and plankton (Quayle 1978, Heibert *et al.* 2016). Interaction and adsorption to these drift particles by MDO causes the potential for bay mussels to ingest MDOs. The risk of this occurring is high.

Mature bay mussels attach to hard substrates such as rock, wood, and firm mud generally in the intertidal zone (Suchanek 1978). Chronic effects through accumulation in substrates is unlikely to affect bay mussels due to the hard substrates they reside on. Given the persistence of MDO and bay mussel habitat, weathered MDO in the intertidal zone still poses a risk to bay mussels. Effects include coating, smothering, and habitat modification. Intertidal zone oils spills can cause high mortality in molluscs (Keesing *et al.* 2018).

Group 2 Oils

Light Crude Oils (LCOs)

Group 2 oils are LCOs which contain moderate to high concentrations of hydrocarbons which cause acute and chronic toxic effects on aquatic organisms (Adzigbli and Yeuwen 2018). LCOs can cause additional negative effects through coating and smothering aquatic organisms. There are similar PoE between Group 2 and Group 1 oils (Appendix Table 13).

Fresh LCO Oil Spill

Free-swimming larval bay mussels are present during the spawning period of May to September, with the larval stage lasting between three and seven weeks (Quayle 1978, Emmett *et al.* 1987, Widdows 1991, Suchanek *et al.* 1997). As with Group 1 oils, LCOs have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion and dissolution. LCO's spreading through the water column may increase the risk of exposure with larvae and drift particle food sources. In high energy ocean conditions, the risk of this occurring is high.

Bay mussels have limited mobility after the larval stage along with having a consistent filter-fed diet. Juvenile bay mussels have small amounts of mobility but are largely sessile after growing to the adult stage. Due to this low mobility, the PoE and vulnerability levels are the same for all post-larval life stages.

Fresh LCO spills in the intertidal zone have a high risk of impacting bay mussels. Post-larval bay mussels are epifaunal and generally found in the intertidal zone and occasionally in the shallow subtidal zone. They settle in large groupings on hard substrates such as rock, wood, barnacles, and firm mud and having a high level of interaction with the sea surface (Suchanek 1978, Heibert *et al.* 2016). Possible effects may include coating, smothering, ingestion, and habitat modification. Intertidal zone oil spills have historically caused high mortalities in molluscs (Keesing *et al.* 2018).

Weathered LCO Oil Spill

As LCOs weather their acute toxicity decreases as the LMW hydrocarbons evaporate; however, similar potential PoE and vulnerability to bay mussels remain. Light crude oils persist and can form stable emulsions, leading to increased volume and specific gravity of the spill (ITOPF 2011a). The PoE for weathered light crude oils are similar as those of fresh LCO for larval bay mussels, with an increased risk in low energy ocean scenarios due to the emulsions potentially being present deeper in the water column.

Weathered LCO spills pose similar risks of effects as fresh LCO spills to post-larval bay mussels, with an increased risk of ingestion. LCOs persist as they weather causing the potential for them to interact with drift particles throughout the water column potentially adsorbing to detritus. The interaction between LCOs and detritus leads to the potential for ingestion by bay mussels, causing toxic and potentially fatal effects (Adzigbli and Yuewen 2018). The risk of this occurring is high.

Group 3 Oils

Heavy and Persistent Oils

Group 3 contains engine/hydraulic oil, medium crude oil, heavy crude oil, and dilbit oil. Group 3 oils are heavy and persistent, while not being as toxic as Group 1 and 2 oils, due

to decreased levels of LMW hydrocarbons (ITOPF 2011a, 2011b). There are many similar PoE between Group 3 and Group 1 oils (Appendix Table 13).

Fresh Heavy and Persistent Oil Spill

Free-swimming larval bay mussels are present during the spawning period of May to September, with the larval stage lasting between three and seven weeks (Quayle 1978, Emmett *et al.* 1987, Widdows 1991, Suchanek *et al.* 1997). As with Group 1 oils, Group 3 oils have a potential to interact with larvae at the water column surface; however, there is a low risk of this occurring in low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion and dissolution of oils. Group 3 oils spreading through the water column may increase the risk of exposure with larvae and drift particle food sources. In high energy ocean conditions, the risk of this occurring is high.

Bay mussels have limited mobility after the larval stage along with having a consistent filter-fed diet. Juvenile bay mussels have small amounts of mobility but are largely sessile after growing to the adult stage. Due to this low mobility, the PoE and vulnerability levels are the same for all post-larval life stages.

Fresh Group 3 oil spills in the intertidal zone have a high potential to impact post-larval bay mussels. Post-larval bay mussels are epifaunal, generally residing on hard substrates within the intertidal zone, with high potential for interaction with an oil spill at the water's surface. Bay mussels would be fully exposed to the oil spill as the tide recedes.

Weathered Heavy and Persistent Oil Spill

As Group 3 oils weather, little to no evaporation occurs; however, sedimentation can occur causing the oils to sink (ITOPF 2011a). Due to Group 3 oils persistence the PoE and vulnerability remain similar for post-larval bay mussels, with an increased risk of ingestion.

Possible sinking due to sedimentation creates a greater risk of exposure for larval bay mussels. Sinking oil may interact directly with larvae through coating and smothering, causing feeding apparatuses to not work properly (ITOPF 2011b). Sinking oil may also interact with detritus, a mussel food source, causing mussels to ingest the oil. Ingestion of oil can lead to reduced cell immunity, reduced development and nutrition along with other physiological decreases (Adzigbli and Yuewen 2018). There is a high risk of this occurring.

Group 4 Oils

Bunker C Oils

Group 4 oils are Bunker C oils. Bunker C oils are heavy and highly persistent oils (Environment Canada 1999). Bunker C oils contain few toxic light molecular weight hydrocarbons meaning they have little to no acute toxic effects on aquatic organisms. Bunker C oils still pose risk through coating and smothering as well as chronic effects due to heavier toxic hydrocarbons (Adzigbli and Yuewen 2018).

Fresh Bunker C Oil Spill

Free-swimming larval bay mussels are present during the spawning period of May to September, with the larval stage lasting between three and seven weeks (Quayle 1978, Emmett *et al.* 1987, Widdows 1991, Suchanek *et al.* 1997). As with Group 1 oils, Group 3 oils have a potential to interact with larvae at the water columns surface; however, there is a low risk of this occurring in low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion and dissolution of oils. Group 3 oils spreading through the water column may increase the risk of exposure with larvae and drift particle food sources. In high energy ocean conditions, the risk of this occurring is high. Negative effects on bay mussels that this interaction may differ from previous oils given lower concentrations of LMW hydrocarbons, causing less acute toxic effects.

Bay mussels have limited mobility after the larval stage along with having a consistent filter-fed diet. Juvenile bay mussels have small amounts of mobility but are largely sessile after growing to the adult stage. Due to this low mobility, the PoE and vulnerability levels are the same for all post-larval life stages.

Post-larval bay mussels are epifaunal, generally residing on hard substrates within the intertidal zone, with high potential for interaction with an oil spill at the water's surface. Bunker C oil spills in the intertidal zone have potential to cause high mortalities in bay mussels through coating and smothering (Adzigbli and Yuewen 2018). Bay mussels would be fully exposed to the Bunker C oil spill as the tide recedes in the intertidal zone.

Weathered Bunker C Oil Spill

There are little weathering effects on Bunker C oil given its low concentrations of volatile LMW hydrocarbons and high persistence (ITOPF 2011a). The PoE are similar between weathered and fresh Bunker C oils; however, Bunker C oils are susceptible to creation of stable emulsions, causing increased volume and specific gravity and potential for sinking and sedimentation-caused sinking. PoE and risks that weathered Bunker C oil may have on bay mussels are similar between fresh and weathered oils. If sinking occurs through emulsions forming or sedimentation, larval bay mussels are at a greater risk of oil exposure at all potential ocean energy scenarios. Sinking oils could coat and smother larval bay mussels causing locomotion and feeding issues or potentially mortality (Adzigbli and Yuewen 2018).

Risk of exposure would be increased for post-larval bay mussels within the subtidal zone as well. Sinking oil may also interact with floating detritus, causing ingestion of the oil by filter feeding post-larval bay mussels. There is a high risk of this occurring.

Group 5 Oils

Sinking Oils

Group 5 oils are extremely heavy and persistent oils known as sinking oils. Sinking oils have a specific gravity >1, causing them to readily sink in water (ITOPF 2011a). Due to high specific gravity, sinking oils have a high potential to negatively impact bay mussels at all life stages.

Fresh Sinking Oil Spill

Free-swimming larval bay mussels are present during the spawning period of May to September, with the larval stage lasting between three and seven weeks (Quayle 1978, Emmett *et al.* 1987, Widdows 1991, Suchanek *et al.* 1997). Sinking oils have a high risk of interacting with the larvae of bay mussels during all ocean conditions given the potential of oil being present throughout the water column or interacting with larvae while sinking.

Bay mussels have limited mobility after the larval stage along with having a consistent filter-fed diet. Juvenile bay mussels have small amounts of mobility but are largely sessile after growing to the adult stage. Due to this low mobility, the PoE and vulnerability levels are the same for all post-larval life stages.

Sinking oils have a high risk of oil interacting with drift particles and being ingested by post-larval bay mussels. Ingestion of oils can cause physiological issues along with potential mortality in molluscs (Adzigbli and Yuewen 2018). Post-larval bay mussels are epifaunal, generally residing on hard substrates in the intertidal zone. Sinking oil spills in the intertidal zone have a high risk of interacting with bay mussels through coating and smothering, potentially causing death (Adzigbli and Yuewen 2018).

Weathered Sinking Oil Spill

Sinking oils have little to no weathering effects; therefore, the PoE on bay mussels are the same for fresh and weathered sinking oils.

Figure 42. Foolish mussel, *Mytilus trossulus*.

Images © G.E. Gillespie and R.M. Harbo

Figure 43. Mediterranean mussel, *Mytilus galloprovincialis*.

Image © G.E. Gillespie

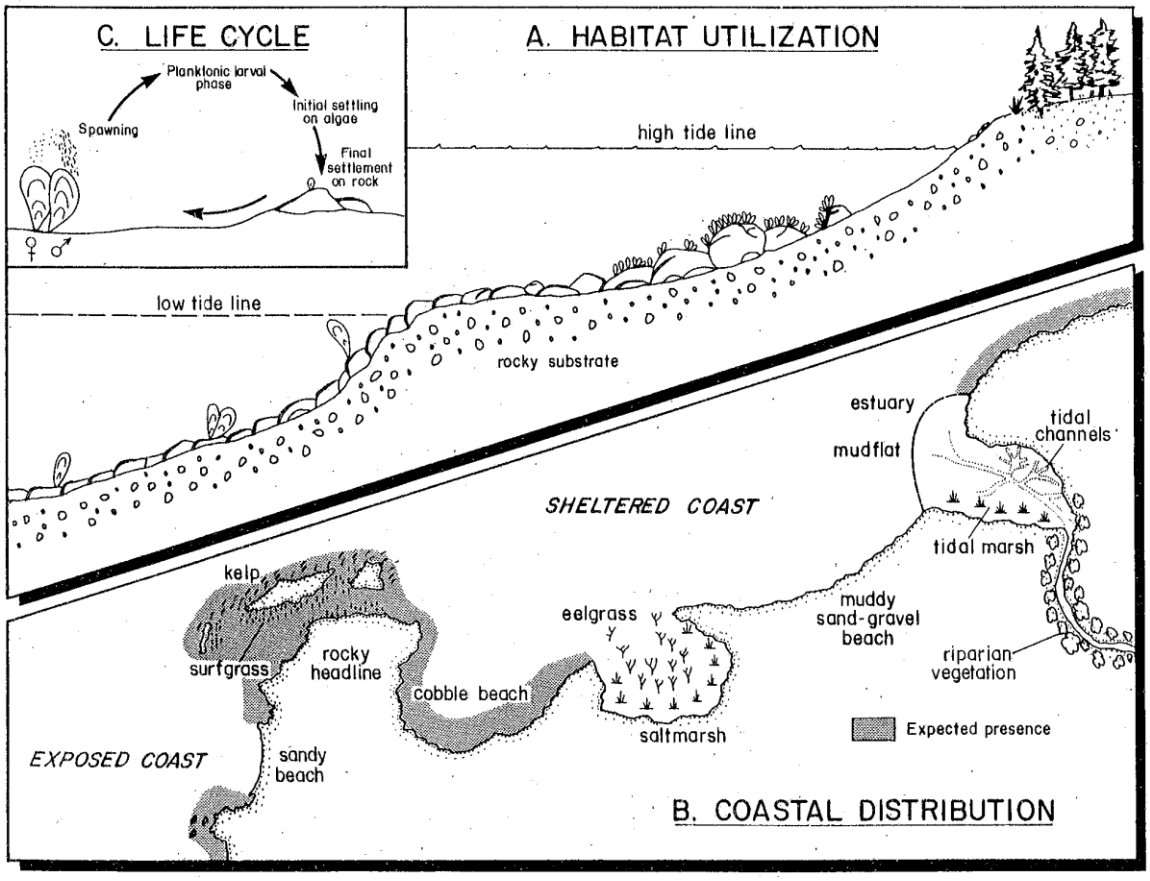

Figure 44. Habitat utilization (A), coastal distribution (B, gray polygons indicate expected presence) and life cycle (C) of bay mussels, *Mytilus trossulus, M. galloprovincialis* and *M. edulis* (Williams 1989).

J	F	M	A	M	J	J	A	S	O	N	D
1	1	1	1	2	3	2	3	3	3	1	1
				---Spawning---							
1	1	1	1	2	3	3	3	3	3	3	2
				---Larval Presence---							
3	3	3	3	3	3	3	3	3	3	3	3
---Adult Presence---											

Figure 45. Temporal distribution of spawning, larval and adult presence and vulnerability ranks of bay mussels, *Mytilus trossulus, M. galloprovincialis* and *M. edulis*.

Legend: 1 (green) = low/negligible vulnerability; 2 (yellow) = moderate vulnerability; 3 (red) = high vulnerability.

Table 15. Summary of information required to inform marine emergency response for bay mussels, *Mytilus trossulus*, *M. galloprovincialis* and *M. edulis*.

Taxonomy
Scientific Name:
Mytilus trossulus Gould, 1850

Common Name(s):
Foolish mussel, bay mussel, blue mussel, edible mussel, Pacific blue mussel

Scientific Name:
Mytilus galloprovincialis Lamarck, 1819

Common Name(s):
Mediterranean mussel, gallo mussel

Scientific Name:
Mytilus edulis Linnaeus, 1758

Common Name(s):
Blue mussel, bay mussel

Higher Taxonomy:
Mollusca; Bivalvia; Mytiloida; Mytilidae

Description

Shells triangular, narrow and elongate or somewhat inflated, anterior end blunt in *M. edulis*, pointed in the other species and may be curved in *M. galloprovincialis*. Anterior adductor scar large in *M. edulis*, relatively small to tiny in other species. Posterior byssal retractor scar broad in *M. galloprovincialis*, long and narrow in other species. Outer surface of shell marked only by commarginal striaea, periostracum black or blue to brown. Maximum size to 90 mm TL in *M. trossulus* (rarely >60 mm in British Columbia), 115 mm TL in *M. edulis* and 150 mm TL in *M. galloprovincialis*. Species cannot be reliably distinguished based on external morphology.

Table 15. continued.

Distribution

Native

Mytilus trossulus is the native mussel of the west coast of North America. Distributed from the Arctic coast of the Northwest Territories to Point Barrow AK through the Bering Sea to at least central California and possibly southern California where it hybridizes with or may be replaced by *M. galloprovincialis*. Also reported from Siberia and northern Japan, northeastern Canada and the Baltic Sea.

Mytilus galloprovincialis is native to the Mediterranean Sea, western France, Britain and Ireland.

Mytilus edulis is native to the North Atlantic.

Introductions

Mytilus galloprovincialis has been reported from southern BC and from central California to Mexico. It has also been introduced South Africa, Australia, New Zealand and from Japan and Korea to Hong Kong.

Mytilus edulis has been widely introduced for aquaculture and unintentionally introduced as a fouling organism on vessels.

Habitat Preferences

Attached to natural or man-made hard substrates by byssal threads. Form a distinct band intertidally with upper limits determined by physical tolerances and lower limit by predation. Associated with *M. californianus* on the open coast in a narrow band above the sea mussel bed, also in gaps in the sea mussel matrix. Some scattered individuals in tide pools, also occasionally subtidal. Significant biofouling organism on man-made structures, including floating docks and vertical pilings.

Physical Tolerances

Salinity

Tolerant of a broader range of salinities than *M. californianus*. Adults prefer salinities of 2-33‰ and larvae cannot tolerate salinities >45‰ or less than 10‰, maximum larval growth in *M. edulis* between 30-35‰ and declines to 50% of maximum at 15‰.

Temperature

Bay mussel species have different temperature tolerances. *Mytilus trossulus* is a northern cold temperate species; optimal growth temperatures are 10-20°C. *Mytilus galloprovincialis* is a warm water species that is firmly established in California and northern Mexico. Optimal larval growth in *M. edulis* occurs between 16-22°C.

Table 15. continued.

Reproductive Biology Sexes are generally separate, rarely hermaphroditic. Broadcast spawners with external fertilization. Fecundity approximately $8.0x10^6$, eggs 70 µm in diameter. Larvae are planktotrophic, settle at ~300 µm TL. Spawn and settle in late winter and early spring in California and late winter in Washington. Pelagic larval stage ~3 weeks, may be extended to 7 weeks in the absence of suitable settlement substrates. Settle preferentially on biological or artificial filamentous substrates or newly available rock substrate. Settlement influenced by macroalgal/barnacle cover, water flux, tidal height and flushing time. As juveniles grow they move into established beds.
Growth Rate and Lifespan Growth is rapid in the first year and declines markedly after 2-3 years. Maximum age approximately 20 years, although British Columbia populations suffer high mortality in their second year.
Migratory Behaviour Adults are capable of dissolving byssal threads and moving limited distances before re-attaching. Dispersal between metapopulations limited to the pelagic larval stage.
Role in the Ecosystem Obligate filter feeder. Preyed on by sea stars, gastropods, crabs, fish, birds and mammals. Habitat engineer, providing biogenic habitat for other species in mature beds.
Significance Not harvested commercially in British Columbia; may be harvested by First Nations or recreationally. Cultured in some areas of British Columbia.

Table 15. continued.

Vulnerability **Subgroup Classification**: Intertidal/Subtidal Benthic; Sediment Epifauna; Sessile; Mollusca. **Adult Exposure Criteria**: Aggregate in discrete beds, gregarious recruitment; Sessile; Intertidal (high interaction with sea surface); Epifaunal (high interaction with sea floor). Score: 4. **Adult Sensitivity Criteria**: Filter/suspension feeders (feeding apparatus can be clogged or damaged by pollutants); Chemical sensitivity assumed to be high. Score: 2. **Adult Recovery Criteria**: Populations unmonitored; Relatively high reproductive capacity; Broadly distributed in suitable habitats; Low degree of interaction with unconsolidated substrates. Score: 0. Cumulative Total Score: 6. **Larval Exposure Criteria**: Aggregate or Patchiness where large number of larvae affected; Low Mobility; Interaction with sea surface. Score: 3. **Larval Sensitivity Criteria**: Larvae feeding appendages that can become clogged by oil; Chemical sensitivity assumed to be high. Score: 2. **Larval Recovery Criteria**: Populations unmonitored; Relatively high reproductive capacity; Broadly distributed in suitable habitat; Low degree of interaction with unconsolidated substrates. Score: 0. Larval Cumulative Total Score: 5.

Gapers (Tresus capax and T. nuttallii)

Significance

Gapers were harvested and dried by First Nations; the shells were used as ladles or cups (Harbo 1997, Ellis and Swan 1981). Sport fishers dig gapers in the intertidal using potato forks. Gapers were harvested incidentally in the commercial dive fishery for geoduck (Harbo 1997), and at one time were kept as incidental catch in commercial butter clam fisheries.

Vulnerability

Subgroup classification

Gapers were included in the following subgroups: 1 - Subtidal Benthic/Intertidal location for exposure; 2 - Sediment Infauna substrate; 3 - Low mobility; and taxonomy to inform feeding types and reproductive strategies - Mollusca (Thornborough *et al.* 2017, Hannah *et al.* 2017, Jeffery *et al.* 2023).

Exposure

As with many infaunal bivalve molluscs, aggregated distributions of gapers are a result of habitat preferences, physiological tolerances and are beneficial for spawning synchrony and fertilization success (Hannah *et al.* 2017).

Gapers have limited mobility; dispersal is through pelagic larval stages, juveniles may move short distances but are confined to the beaches on which they settled, adults are sessile. They are intertidal to shallow subtidal in distribution, thus their populations have a high level of interaction with the sea surface. As infaunal organisms they have intimate contact with the unconsolidated sediments they inhabit.

Sensitivity

As filter/suspension feeders, gapers are very sensitive to pollutants that may clog or damage their feeding apparatus. Chemical effects of pollutants on bivalve physiology, reproduction and larval survival have been documented (Renault 2015).

Recovery

Population status is not monitored in British Columbia. Gapers have high fecundity and high reproductive capacity, but recruitment is variable. They are locally distributed in suitable habitat throughout British Columbia and beyond. They are dependent on unconsolidated substrates which can be affected for extended periods due to difficulties removing pollutants that have seeped into the substrate.

Taxonomy

The accepted scientific names are *Tresus capax* (Gould, 1850) and *Tresus nuttallii* (Conrad, 1837) (Table 16). Both have been reported in the genus *Schizothaerus* (e.g., Quayle 1974). Accepted vernacular names are fat gaper (*T. capax*) and Pacific gaper (*T. nuttallii*)(Turgeon *et al.* 1998). Additional common names for *T. capax* include Alaskan gaper, blue clam, empire clam, fat gaper clam, gaper, gaper clam, greyneck clam, horse clam, horseneck clam, otter clam and summer clam. Additional names for *T. nuttallii* include big-neck clam, blue clam, empire clam, gaper clam, great Washington clam, horseneck clam, otter-shell clam, Pacific gaper clam, rubberneck clam, and summer clam (Harbo 1997, Lauzier *et al.* 1998).

Description

The shell of *T. capax* is ovate to rhomboidal, broadly inflated, ventrally truncate with a large siphonal gape and a large ventrally-directed chondrophore (Bourne and Smith 1972b, Coan *et al.* 2000) (Figure 46). Shell colour varies from white to yellow and the periostracum is dark brown to black (Lauzier *et al.* 1998). The siphons have thick terminal perisotracal plates, visceral skirt present, labial palps are small (Pearce 1965).

The shell of *T. nuttallii* is ovate-elongate, more evenly curved and extended posteriorly than *T. capax*, with a medium-sized ventrally-directed chondrophore (Bourne and Smith 1972b, Coan *et al.* 2000). The posterior margin is truncate and siphonal gape wide. Shell colour is yellowish with a thin brown periostracum (Lauzier *et al.* 1998). Siphons have terminal periostracal plates, labial palps are small and visceral skirt absent (Pearce 1965).

Swan and Finucane (1952) described differences in the periostracum of the siphon and terminal plates; the terminal plates of *T. nuttallii* were described as thicker and heavier than those of *T. capax*. The periostracum of the siphons of *T. nuttallii* were much lighter in colour than in *T. capax*; this was attributed to regular sloughing of the out layers of peristracum and plates in *T. capax* (to the extent that *T. nuttallii* could be distinguished by the presence of barnacles on the plates that was lacking in *T. capax*).

Maximum size for *T. capax* is 280 mm TL, *T. nuttallii* reaches 225 mm TL (Coan *et al.* 2000).

Distribution

Fat gapers have been reported from the Shumagin Islands and Kachemak Bay, Alaska to Oceano, California (Coan *et al.* 2000). Pacific gapers range from Kodiak Island, Alaska to Bahia Magdalena, Baja California. The strange gaper, *T. allomyax* Coan and Valentich-Scott, 2000 (previously reported as *T. pajoroana* (Conrad 1857) by Dinnel and DeMartini (1974)) has been reported from offshore waters (7-73 m) of northern California. It has not been reported from British Columbia (Campbell and Bourne 2000, Coan *et al.* 2000, Coan and Valentich-Scott 2007).

Habitat Preferences

Both species occur in mixed (mud/shell/gravel, pea gravel, sand, silty sand or mud) substrates of protected bays and foreshore (Lauzier *et al.* 1998, Coan *et al.* 2000)(Figure 47). Both are found from the mid-intertidal to shallow subtidal; *T. capax* to 20 m and *T. nuttallii* to 80 m. Fat gapers are usually found in 25-50 cm burrows; Pacific gapers burrow deeper in the substrate (60-90 cm) or occur lower on the intertidal than fat gapers, and usually in sandier substrates (Swan and Finucane 1952, Harbo 1997, Lauzier *et al.* 1998); Pearce (1965) suggested that this is a result of higher tolerance for freezing temperatures in *T. capax* than *T. nuttallii* (near the northern limit of its distribution). Fat gapers are more common than Pacific gapers in British Columbia (Bourne and Smith 1972b). Fat gapers are more abundant in the intertidal in British Columbia; Campbell *et al.* (1990) estimated that >75% of *T. nuttallii* in British Columbia occur in the subtidal.

Role in the Ecosystem

Trophic Ecology

Gapers are obligate filter feeders; they collect suspended diatoms, flagellates, dinoflagellates in the spring summer and fall and mainly fine detritus with some diatoms and flagellates in winter (Reid 1969).

Ecological Interactions

Fat gapers are commonly found in association with butter and littleneck clams in the intertidal and Pacific geoduck subtidally (Lauzier *et al.* 1998). Throughout their ranges, both species area associated with seagrass beds; in British Columbia they are associated with seagrass and other submerged vegetation used by spawning herring (Lauzier *et al.* 1998).

Gapers are preyed on by pink stars (*Pisaster brevispinus*), Lewis' moonsnails (*Euspira lewisi*), crabs (e.g., *Metacarcinus magister*), elasmobranchs that feed on exposed siphons and sea otters (*Ehydra lutris*) that dig whole clams (Wendell *et al.* 1976, Campbell *et al.* 1990, Lambert 2000).

Adult pinnotherid pea crabs (*Fabia subquadrata*, *Pinnixa faba* and *P. littoralis*) are regularly found in fat gapers, but not in Pacific gapers (Rathbun 1918, Pearce 1965, Hart 1982, Coan *et al.* 2000, Jensen 2014).

Both species host barnacles and marine plants on the surface of the siphonal plates (Swan and Finucane 1952); Stout (1970) recorded 50 species from 10 invertebrate phyla and several plant divisions on the siphonal plates of *T. nuttallii* in California. The symbionts were either directly attached to the plate surface, associated with attached algae and hydroids or in the sand and detrital manner that accumulates between lamellae of the plates.

Physical Tolerances

Pacific gapers are found in salinities of 27-33‰ (Bourne and Smith 1972a, Lauzier *et al.* 1998). Juvenile and adults survive in temperatures ranging from 2-20°C (Bernard 1983); larvae survive at 5-18°C and die at 20°C. Differences in low temperature tolerance might explain differences in geographic and tidal height distributions between the two species (Swan and Finucane 1952, Pearce 1965).

Reproductive Biology

Gapers are broadcast spawners; the sexes are separate, sperm and eggs are released synchronously, and fertilization occurs in the water column (Bourne and Smith 1972a, Lauzier *et al.* 1998). Egg size for *T. capax* was 60-70 µm (Bourne and Smith 1972a).

Tresus capax is a winter spawner; gonadal development commenced in September and October and fat gapers spawned from mid-February to May in the Strait of Georgia (Bourne and Smith 1972b)(Figure 48). Spawning was slightly earlier, late January-April in Oregon (possibly extending through May and June) and January-March in California (Machell and DeMartini 1971, Breed-Willeke and Hancock 1980, Robinson and Breese 1982).

Spawning in *T. nuttallii* was estimated to occur in the summer, April-August, on the west coast of Vancouver Island (Campbell *et al.* 1990). Clark *et al.* (1975) documented spawning at low levels throughout the year with a peak in February-April in California.

Early Life History

In the laboratory, larvae of *T. capax* were raised at several temperatures; mortality was complete at 20°C but survival was excellent at 5-15°C (Bourne and Smith 1972a). Metamorphosis occurred in 24 days at 15°C, 26 days at 10°C and 34 days at 5°C; larvae metamorphosed at lengths of 260-280 µm.

Recruitment is highly variable and relatively few years classes dominate populations (Bourne and Smith 1972b, Wendell *et al.* 1976). Failed recruitment appears to be a function of mortality rather than supply of recruits (Wendell *et al.* 1976).

Growth Rates and Life Span

Gapers grow most rapidly in spring and summer and growth nearly ceases from October-April (Bourne and Smith 1972a, Wendell *et al.* 1976). Gaper growth rates decrease with age; growth rates for *T. capax* in Oregon averaged 22 mm/y for the first three years and linear growth virtually ceased after 7-8 years (Breed-Willeke and Hancock 1980). Growth rates were greater in subtidal populations than in intertidal populations.

Fat gapers in southern British Columbia reached shell lengths of 84-98 mm at five years, 123-132 mm in 10 years and 145-149 mm at 15 years (Bourne and Smith 1972b). Length

at 50% maturity was estimated at 70 mm in southern British Columbia, which corresponded to three to four years of age. Wendell *et al.* (1976) documented the loss of the ability to rebury to be at about 75 mm or two years of age for *T. capax* in California.

Growth of *T. nuttallii* also slows with age; Pacific gapers reached mean shell lengths of 97-106 mm at five years, 145-161 mm at 10 years and 169-187 mm at 16 years in southern British Columbia (Campbell *et al.* 1990). Size at 50% maturity for the west coast Vancouver Island population was 68 mm TL, suggesting that they mature at three years of age. Pacific gapers lose the ability to re-bury if disturbed at about 60 mm TL, probably near maturity (Pohlo 1964).

Although sampling was limited, maximum recorded age in British Columbia of *T. capax* was 18-21 years and for *T. nuttallii* was 22-24 years (Campbell *et al.* 1990, Campbell and Bourne 2000).

Pathways of Effects (PoE): Oil Exposure

A Pathways of Effects (PoE) oil exposure model can aid oil spill emergency response by identifying low to high-risk scenarios for species exposure. This section describes PoE for gapers through exposure paths of specific species life stages and the potential dispersion and fates of five oil groups (Table 2). The specific environmental conditions and chemical signature of the oil spill should be taken into consideration as they may cause differences in the outcomes described in this document. A summary table for this section is available in Appendix Table 14.

Habitat utilization and temporal distribution of spawning, larval and adult presence and vulnerability ranks of gapers are illustrated in Figure 47 and Figure 48 with vulnerability ranking scores for gapers generalized for all oil groupings as 5 for the larval life stage and 7 for adult life stages (Jeffery *et al.* 2023).

Group 1 Oils

Group 1 contains gasoline and marine diesel oil (MDO). Both gasoline and MDO are light, volatile, and acutely toxic oils (ITOPF 2011a). The two oils are split into subcategories due to differences in fate and behaviour, causing different potential PoE on gapers.

Gasoline

Gasoline has high concentrations of LMW hydrocarbons which may cause both acute and chronic toxic effects on aquatic organisms (ITOPF 2011b). Possible toxic effects include mortality (Keesing *et al.* 2018), decreased growth rate, damage to feeding apparatuses, and other physiological functioning (Adzigbli and Yeuwen 2018).

Fresh Gasoline Oil Spill

Fat gapers spawn between mid-February and May in the Strait of Georgia (Heibert 2015). Pacific gapers have a spawning period of April to August on the west coast of Vancouver Island (Campbell *et al.* 1990). Gapers have pelagic larvae, lasting between 23-34 days before metamorphosis occurs (Bourne and Smith 1972a). Gasoline is very light, having a specific gravity of <0.8, causing it to float and only be present on the top 1-2 mm of the water column (ITOPF 2011a). Due to gasoline remaining on the top of the water, risk of larval exposure is low during low energy ocean conditions. Medium and high energy ocean conditions can cause increased oil dispersion throughout the water column within the intertidal and subtidal zones, increasing the risk of exposure to larval gapers.

Gapers have limited mobility after the larval stage along with having a consistent filter-fed diet. Juvenile gapers have some mobility but are limited to the beach they settle on. Due to this low mobility, the PoE and vulnerability are grouped together all post-larval life stages.

Post-larval gapers are distributed from the mid-intertidal to shallow subtidal zones and are associated with mixed substrates in protected areas (Lauzier *et al.* 1998, Coan *et al.* 2000). Both gaper species burrow into the substrate with fat gapers burrowing to depths of 25-60 cm and Pacific gapers burrowing deeper, to 60-90 cm (Swan and Finucane 1952, Harbo 1997, Lauzier *et al.* 1998). Given the location of post-larval gapers, gasoline spills in the intertidal zone pose a moderate risk in coarser sediments and a low risk in fine sediments. Tidal activity can increase the potential residual oils to infiltrate substrates, stressing fossorial species, such as gapers, causing juveniles to move to the surface and increasing exposure risk (Pavia 1982). Adult gapers are sessile. Gasoline spills additionally pose a high risk to juvenile gapers that have not yet burrowed. Oil spills in intertidal zones have historically caused high mortality in exposed molluscs (Keesing *et al.* 2018).

Weathered Gasoline Oil Spill

Gasoline is highly volatile and can completely evaporate within 24 hours; as such, as gasoline weathers the risk to gapers decreases. Weathered gasoline is unlikely to pose any risks to gapers as it evaporates and disperses very quickly.

<u>Marine Diesel Oils (MDO)</u>

Fresh MDO Oil Spill

Fresh MDO has high aquatic toxicity due given high concentrations of LMW hydrocarbons (Environment Canada 1999). Fresh MDO has similar potential PoE to gapers as gasoline (Appendix Table 14).

Free swimming larval gapers are present during the two spawning periods of mid-February to May (*T. capax*; Heibert 2015) and April to August (*T. nuttallii*; Campbell *et al.* 1990) with the larval stage lasting between 23-34 days before metamorphosis occurs (Bourne and Smith 1972a). As with gasoline, MDOs have a potential to interact with larvae at the water

surface; however, there is a low risk of this occurring in low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion and dissolution. MDO's spreading through the water column may increase the risk of exposure with larvae and drift particle food sources. In high energy ocean conditions, the risk of this occurring is high.

Gapers have limited mobility after the larval stage along with having a consistent filter-fed diet. Juvenile gapers have some mobility but are limited to the beach they settle on. Due to their low mobility, the PoE and vulnerability levels are grouped together all post-larval life stages.

MDO spills remain on the surface of the water; however, when tides recede the intertidal zone will be exposed to the MDO spilled on the surface. Both gaper species burrow into the substrate with fat gapers burrowing to depths of 25-60 cm and Pacific gapers burrowing deeper, to 60-90 cm (Swan and Finucane 1952, Harbo 1997, Lauzier *et al.* 1998). Given the location of post-larval gapers, MDO spills in the intertidal zone pose a moderate risk in coarser sediments and a low risk in fine sediments. Tidal activity can increase the potential residual oils to infiltrate substrates, stressing fossorial species, such as gapers, causing juveniles to move to the surface and increasing exposure risk (Pavia 1982). Adult gapers are sessile. Possible effects may include coating, smothering, and ingestion. Intertidal zone oil spills have historically caused high mortalities in exposed molluscs (Keesing *et al.* 2018).

Weathered MDO Oil Spill

As MDOs weather aquatic toxicity decreases as the LMW hydrocarbons evaporate. MDO spills still pose potential risks to gapers through coating, smothering and ingestion (ITOPF 2011b). The persistence of MDO causes weathered MDO to pose many of the same potential effects on gapers as fresh spills. Gaper larvae still have the potential to interact with the oil spill at the surface of the water with potential effects including coating and smothering, likely without acute toxic effects. The risk of this effect remains low in low energy oceans, as the larvae would need to swim to the ocean's surface, and high in high-energy ocean scenarios.

MDO is persistent and has the potential to interact and adsorb to particles within the water column (ITOPF 2011a). Post-larval gapers are obligate filter-feeders. Interaction and adsorption to these drift particles by MDO causes the potential for gapers to ingest MDOs while filter-feeding. There is a high risk of this occurring.

Given the persistence of MDO, weathered MDO in the intertidal zone still poses a moderate risk to fat gapers and low risk to Pacific gapers. MDO spills additionally pose a high risk to juvenile gapers in the intertidal zone that have not yet burrowed. Effects include coating, smothering, and habitat modification. Intertidal zone oils spills can cause high mortality in exposed molluscs (Keesing *et al.* 2018).

Group 2 Oils

Light Crude Oils (LCOs)

Group 2 oils are LCOs which contain moderate to high concentrations of hydrocarbons which cause acute and chronic toxic effects on aquatic organisms (Adzigbli and Yeuwen 2018). LCOs can cause additional negative effects through coating and smothering aquatic organisms. There are similar PoE between Group 2 and Group 1 oils (Appendix Table 14).

Fresh LCO Oil Spill

Free swimming larval gapers are present during the two spawning periods of mid-February to May (*T. capax*; Heibert 2015) and April to August (*T. nuttallii*; Campbell *et al.* 1990), with the larval stage lasting between 23-34 days before metamorphosis occurs (Bourne and Smith 1972a). As with Group 1 oils, LCOs have a potential to interact with larvae at the water surface; however, there is a low risk of this occurring in low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion and dissolution of oils. LCOs spreading through the water column may increase the risk of exposure with larvae and drift particle food sources. In high energy ocean conditions, the risk of this occurring is high.

Gapers have limited mobility after the larval stage along with having a consistent filter-fed diet. Juvenile gapers have some mobility but are limited to the beach they settle on. Due to this low mobility, the PoE and vulnerability levels are grouped together all post-larval life stages.

LCO spills remain on the surface of the water; however, when tides recede the intertidal zone will be exposed to spilled oil on the surface. Post-larval gapers reside burrowed in the substrate within the intertidal zone, with fat gapers burrowing to depths of 25-60 cm and Pacific gapers burrowing deeper, to 60-90 cm (Swan and Finucane 1952, Harbo 1997, Lauzier *et al.* 1998). Given the location of post-larval gapers, LCO spills in the intertidal zone pose a moderate risk in coarser sediments and a low risk in fine sediments. Tidal activity can increase the potential for residual oil to penetrate sediments, stressing fossorial species to move to the surface, increasing their risk of exposure. LCO spills additionally pose a high risk to juvenile gapers that have not yet burrowed. Possible effects may include coating, smothering, and ingestion. Intertidal zone oil spills have historically caused high mortalities in exposed molluscs (Keesing *et al.* 2018).

Weathered LCO Oil Spill

As LCOs weather their acute toxicity decreases as the LMW hydrocarbons evaporate; however, similar potential PoE and vulnerability to gapers remain. Light crude oils persist and can form stable emulsions, leading to increased volume and specific gravity of the spill (ITOPF 2011a). The PoE for weathered light crude oils are similar as those of fresh LCO for larval gapers, with an increased risk in low energy ocean scenarios due to the emulsions potentially being present deeper in the water column.

Weathered LCO spills pose similar risks of effects as fresh LCO spills to post-larval gapers, with an increased risk of ingestion. LCOs persist as they weather causing the potential for them to interact with drift particles throughout the water column potentially adsorbing to drift algae. Gapers are obligate filter feeders, feeding on floating drift particles (Reid 1969). The interaction between LCOs and drift algae leads to the potential for ingestion, causing toxic and potentially fatal effects (Adzigbli and Yuewen 2018). There is a high risk of this occurring.

Group 3 Oils

Heavy and Persistent Oils

Group 3 contains engine/hydraulic oil, medium crude oil, heavy crude oil, and dilbit oil. Group 3 oils are heavy and persistent, while not being as toxic as Group 1 and 2 oils, due to decreased levels of LMW hydrocarbons (ITOPF 2011a, 2011b). There are many similar PoE between Group 3 and Group 1 oils (Appendix Table 14).

Fresh Heavy and Persistent Oil Spill

Free swimming larval gapers are present during the two spawning periods of mid-February to May (*T. capax*; Heibert 2015) and April to August (*T. nuttallii*; Campbell *et al.* 1990), with the larval stage lasting between 23-34 days before metamorphosis occurs (Bourne and Smith 1972a). As with Group 1 oils, Group 3 oils have a potential to interact with larvae at the water column surface; however, there is a low risk of this occurring in low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion and dissolution. Group 3 oils spreading through the water column may increase the risk of exposure with larvae and drift particle food sources. In high energy ocean conditions, the risk of this occurring is high.

Gapers have limited mobility after the larval stage along with having a consistent filter-fed diet. Juvenile gapers have some mobility but are limited to the beach they settle on. Due to this low mobility, the PoE and vulnerability levels are grouped together all post-larval life stages.

Group 3 oil spills remain on the surface of the water; however, when tides recede the intertidal zone will be exposed to spilled oil on the surface. Post-larval gapers reside burrowed in the substrate within the intertidal and subtidal zones, with fat gapers burrowing to depths of 25-60 cm and Pacific gapers burrowing deeper, to 60-90 cm (Swan and Finucane 1952, Harbo 1997, Lauzier *et al.* 1998). Tidal activity can increase the potential for residual oil to penetrate sediments, stressing fossorial species to move to the surface, increasing their risk of exposure. Given the location of post-larval gapers, Group 3 oil spills in the intertidal zone pose a moderate risk in coarser sediments and a low risk in fine sediments. Group 3 oil spills additionally pose a high risk to juvenile gapers that have not yet burrowed. Possible effects may include coating, smothering, and ingestion. Intertidal zone oil spills have historically caused high mortalities in exposed molluscs (Keesing *et al.* 2018).

Weathered Heavy and Persistent Oil Spill

As Group 3 oils weather, little to no evaporation occurs; however, sedimentation can occur causing the oils to sink (ITOPF 2011a). Due to Group 3 oils persistence the PoE and vulnerability remain the similar for post-larval gapers, with increased risk of ingestion.

Possible sinking due to sedimentation creates a greater risk of exposure for larval gapers through direct interaction in low energy ocean scenarios, and greater risk of ingestion by post-larval gapers. Sinking oil may interact directly with larvae through coating and smothering, causing feeding apparatuses to not work properly (ITOPF 2011b). Sinking oil may also interact with a floating detritus, causing ingestion of the oil by filter feeding post-larval gapers. There is a high risk of this occurring.

Group 4 Oils

Bunker C Oils

Group 4 oils are Bunker C oils. Bunker C oils are heavy and highly persistent oils (Environment Canada 1999). Bunker C oils contain few toxic LMW hydrocarbons meaning they have little to no acute toxic effects on aquatic organisms. Bunker C oils still pose risk through coating and smothering as well as chronic effects due to heavier toxic hydrocarbons (Adzigbli and Yuewen 2018).

Fresh Bunker C Oil Spill

Free swimming larval gapers are present during the two spawning periods of mid-February to May (*T. capax*; Heibert 2015) and April to August (*T. nuttallii*; Campbell *et al.* 1990), with the larval stage lasting between 23-34 days before metamorphosis occurs (Bourne and Smith 1972a). As with Group 1 oils, Bunker C oils have a potential to interact with larvae at the water column surface; there is a low risk of this occurring in low energy ocean conditions. Medium and high energy ocean conditions can cause increased dispersion and dissolution. Group 3 oils spreading through the water column may increase the risk of exposure with larvae and drift particle food sources. In high energy ocean conditions, the risk of this occurring is high. Negative effects that this interaction may have on gapers differ from previous oils given lower concentrations of LMW hydrocarbons, causing less acute toxic effects.

Gapers have limited mobility after the larval stage along with having a consistent filter-fed diet. Juvenile gapers have some mobility but are limited to the beach they settle on. Due to this low mobility, the PoE and vulnerability are grouped together all post-larval life stages.

Post-larval gapers reside burrowed in the substrate within the intertidal and subtidal zones, with fat gapers burrowing to depths of 25-60 cm and Pacific gapers burrowing deeper, to 60-90 cm (Swan and Finucane 1952, Harbo 1997, Lauzier *et al.* 1998). Given the location of post-larval gapers, Bunker C oil spills in the intertidal zone pose a moderate risk in coarser sediments and a low risk in fine sediments. Tidal activity can increase the potential for residual oil to penetrate sediments, stressing fossorial species to move to the surface, increasing risk to juveniles of exposure. Adult gapers are sessile. Bunker C oil spills

additionally pose a high risk to juvenile gapers that have not yet burrowed. Possible effects may include coating, smothering, and ingestion. Intertidal zone oil spills have historically caused high mortalities in exposed molluscs (Keesing et al 2018).

Weathered Bunker C Oil Spill

There are little weathering effects on Bunker C oil given its low concentrations of volatile LMW hydrocarbons and high persistence (ITOPF 2011a). The PoE are similar between weathered and fresh Bunker C oils; however, Bunker C oils are susceptible to creation of stable emulsions, causing increased volume and specific gravity and potential for sinking and sedimentation-caused sinking. Sinking and sedimentation increase the potential risks of Bunker C oil spills to gapers.

If sinking occurs through emulsions forming or sedimentation, larval gapers are at a greater risk of oil exposure, especially in low energy ocean scenarios. Sinking oils could coat and smother larval gapers causing damage to feeding apparatuses, lowered immunity, and potentially mortality (Adzigbli and Yuewen 2018).

Sinking Bunker C oils present a high risk of exposure to juvenile gapers that have not burrowed yet. Risk of exposure would be increased for gapers within the subtidal zone as well. Sinking oil may also interact with floating detritus, causing ingestion of the oil by filter feeding post-larval gapers. There is a high risk of this occurring.

Group 5 Oils

Sinking Oils

Group 5 oils are extremely heavy and persistent oils known as sinking oils. Sinking oils have a specific gravity >1, causing them to readily sink in water (ITOPF 2011a). Group 5 oils have a high potential to negatively impacting gapers at all life stages.

Fresh Sinking Oil Spill

Free swimming larval gapers are present during the two spawning periods of mid-February to May (*T. capax*; Heibert 2015) and April to August (*T. nuttallii*; Campbell *et al.* 1990). This larval stage lasts between 23-34 days before metamorphosis occurs (Bourne and Smith 1972a). Sinking oils have a high risk of interacting with the larvae of gapers in all potential ocean energy scenarios, given the potential of oil being present throughout the water column.

Gapers have limited mobility after the larval stage along with having a consistent filter-fed diet. Juvenile gapers have some mobility but are limited to the beach they settle on. Due to this low mobility, the PoE and vulnerability levels are grouped together all post-larval life stages.

Sinking oils have a high risk of oil interacting with particles in the water column and being ingested by post-larval gapers while filter-feeding. Ingestion of oils can cause physiological issues along with potential mortality in molluscs (Adzigbli and Yuewen 2018).

Post-larval gapers reside burrowed in the substrate within the intertidal and subtidal zones, with fat gapers burrowing to depths of 25-60 cm and Pacific gapers burrowing deeper, to 60-90 cm (Swan and Finucane 1952, Harbo 1997, Lauzier *et al.* 1998). Sinking Bunker C oils present a high risk of exposure to juvenile gapers that have not burrowed yet. Given the location of post-larval gapers, sinking oil spills in both the intertidal and subtidal zones pose a moderate risk in coarser sediments and a low risk in fine sediments. Sinking oil spills additionally pose a high risk to juvenile gapers that have not yet burrowed. Possible effects may include coating, smothering, and ingestion. Intertidal zone oil spills have historically caused high mortalities in exposed molluscs (Keesing *et al.* 2018).

Weathered Sinking Oil Spill

Sinking oils have little to no weathering effects; therefore, the PoE on gapers are the same for fresh and weathered sinking oils.

Figure 46. Fat gaper, *Tresus capax* (upper panel, lower panel left) and Pacific gaper, *T. nuttallii* (lower panel right).

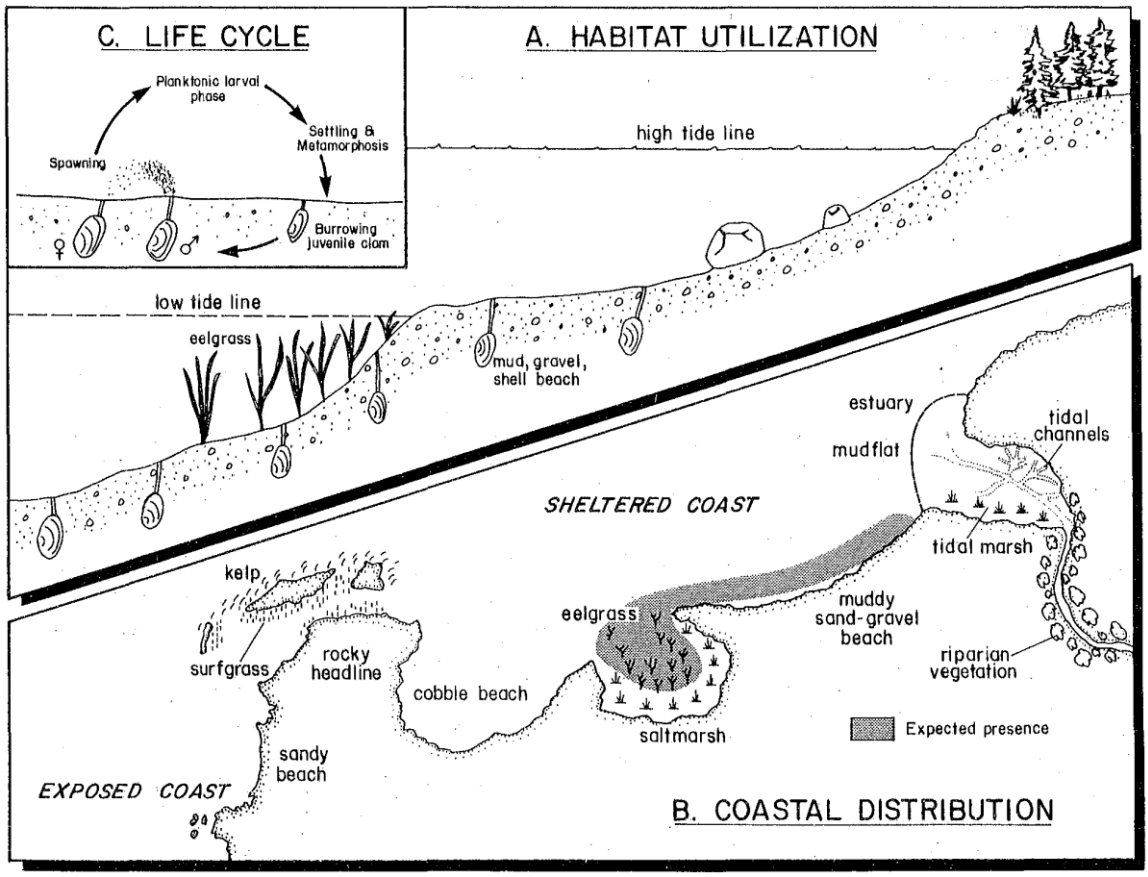

Figure 47. Habitat utilization (A), coastal distribution (B, gray polygons indicate expexcted presence) and life cycle (C) of gapers, *Tresus capax* and *T. nuttallii* (Williams 1989).

J	F	M	A	M	J	J	A	S	O	N	D
1	2	3	3	3	1	1	1	1	1	1	1
	---Spawning---										
1	2	3	3	3	2	1	1	1	1	1	1
	---Larval Presence---										
3	3	3	3	3	3	3	3	3	3	3	3
---Adult Presence---											

J	F	M	A	M	J	J	A	S	O	N	D
1	1	1	3	3	3	3	2	1	1	1	1
			---Spawning---								
1	1	1	3	3	3	3	3	2	1	1	1
			---Larval Presence---								
3	3	3	3	3	3	3	3	3	3	3	3
---Adult Presence---											

Figure 48. Temporal distribution of spawning, larval and adult presence and vulnerability ranks of fat gaper, *Tresus capax* (upper panel) and Pacific gaper, *T. nuttallii* (lower panel).

Legend: 1 (green) = low/negligible vulnerability; 2 (yellow) = moderate vulnerability; 3 (red) = high vulnerability.

Table 16. Summary of information required to inform marine emergency response for gapers, *Tresus capax* and *T. nuttallii*.

Taxonomy
Scientific Name:
Tresus capax (Gould, 1850)

Common Name(s):
Fat gaper, Alaskan gaper, gaper, horse clam, otter clam, summer clam

Scientific Name:
Tresus nuttallii (Conrad 1837)

Common Name(s):
Pacific gaper, gaper, horse clam, otter clam, Pacific horse clam, summer clam

Higher Taxonomy:
Mollusca; Bivalvia; Venerida; Mactridae

Description

Shells are ovate and broadly inflated with a large siphonal gape. *T. capax* is ventrally truncate with a large ventrally-directed chondrophore. *T. nuttallii* is more evenly curved and extended posteriorly than *T. capax* with a medium-sized ventrally-directed chondrophore. Shell colour varies from white to yellow and the periostracum is dark brown to black in *T. capax* and thin and brown in *T. nuttallii*. The siphons have terminal perisotracal plates, thicker and heavier in *T. capax*. *T. capax* has a visceral skirt that is absent in *T. nuttallii*. Maximum size for fat gaper is 280 mm TL; maximum size for Pacific gaper is 225 mm.

Distribution

Fat gapers have been reported from the Shumagin Islands and Kachemak Bay, Alaska to Oceano, California. Pacific gapers range from Kodiak Island, Alaska to Bahia Magdalena, Baja California.

Habitat Preferences

Both species occur in mixed (mud/shell/gravel, pea gravel, sand, silty sand or mud) substrates of protected bays and foreshore. Both are found from the mid-intertidal to shallow subtidal; *T. capax* to 20 m and *T. nuttallii* to 80 m. Fat gapers are usually found in 25-50 cm burrows; Pacific gapers burrow deeper in the substrate (60-90 cm) or occur lower on the intertidal than fat gapers, and usually in sandier substrates. Fat gapers are more common than Pacific gapers in British Columbia.

Table 16. continued.

Physical Tolerances

Salinity

Pacific gapers are found in salinities of 27-33‰.

Temperature

Juveniles and adults survive in temperatures ranging from 2-20°C, larvae survive at 5-18°C.

Reproductive Biology

Dioescious broadcast spawners, gametes are released synchronously and fertilization occurs in the water column. Fat gapers spawn in winter (mid-February-May in British Columbia, late January-April in Oregon and January-March in California). Pacific gapers spawn in summer (April-August) in British Columbia, but spawning peaks in winter (February-April) in California.

Growth Rate and Lifespan

Growth is initially rapid and decreases with age. Shell lengths of approximately 150 mm were estimated to take 15 years for *T. capax* and 10 years for *T. nuttallii*. Size at 50% maturity was estimated to be 68-70 mm TL, or three to four years for fat gapers and three years for Pacific gapers. Maximum age for fat gapers was approximately 18-21 years; for Pacific gapers 22-24 years.

Migratory Behaviour

Dispersal between subpopulations is limited to movements of pelagic larvae; juveniles have very low mobility (or at least the ability to re-bury if disturbed), adults are sessile and lose the ability to re-bury at or near the size of 50% maturity.

Role in the Ecosystem

Gapers are suspension feeders, consuming plankton and organic debris filtered from the water column. They are associated with other hardshell infaunal bivalves (particularly Pacific littlenecks and butter clams in the intertidal and Pacific geoducks subtidally) and seagrass beds. They are preyed on by sea stars, gastropods, crabs, fish (some of which crop portions of the exposed siphons) and sea otters.

Significance

Gapers are utilized by First Nations and recreational harvesters and are a minor component of landings in the geoduck fishery.

Table 16. continued.

Vulnerability **Subgroup Classification**: Intertidal/Subtidal Benthic; Sediment Infauna; Low Mobility; Mollusca. **Adult Exposure Criteria**: High Aggregation; Low Mobility; Intertidal (high interaction with sea surface); Infaunal (high interaction with sea floor). Score: 4. **Adult Sensitivity Criteria**: Filter feeder (feeding apparatus can be clogged or damaged by pollutants); Chemical sensitivity assumed to be high. Score: 2. **Adult Recovery Criteria**: Population status unmonitored; Relatively high reproductive capacity; Broadly distributed in suitable habitats; High degree of interaction with unconsolidated substrates. Score: 1. Cumulative Total Score: 7. **Larval Exposure Criteria**: Aggregate or Patchiness where large number of larvae affected; Low Mobility; Interaction with sea surface. Score: 3. **Larval Sensitivity Criteria**: Larvae feeding appendages that can become clogged by oil; Chemical sensitivity assumed to be high. Score: 2. **Larval Recovery Criteria**: Populations unmonitored; Relatively high reproductive capacity; Broadly distributed in suitable habitat; Low degree of interaction with unconsolidated substrates. Score: 0. Larval Cumulative Total Score: 5.

DISCUSSION

Intertidal molluscs share a number of characteristics that make them vulnerable to marine emergencies. Adult stages have low mobility; therefore, they cannot move to avoid effects of marine spills or other pollution events. Most have pelagic larval stages lasting a few days or months, putting them at risk of exposure to pollutants in the water column. Many molluscs are filter feeders and may ingest harmful compounds from the water column or sediment pore water. Given the vulnerability of molluscs to oil spills and other marine pollution, it is also important to understand species' distributions and abundance along the British Columbia coast. For most species, this information is not yet mapped to the resolution required for rapid marine emergency response. However, the information provided in this report could assist in identifying species and their habitat preferences within a spill area, enabling more effective assessment of intertidal and subtidal sensitivities and prioritization of response efforts.

Information obtained from the literature review outlines possible forms of hydrocarbon contamination that may have direct toxic or long-lasting impacts to mollusc critical habitat. Oil types (categorized by gravity (ºAPI), oil condition (fresh or weathered), species life stages (planktonic or benthic), and the pathways of effects are discussed. The PoE serve as a reference tool to quickly identify possible impacts on these species, particularly where immediate actions are required. The specific conditions of each oil spill should be considered as they may change the outcomes predicted in this document.

ACKNOWLEDGEMENTS

Dominique Bureau, Rick Harbo and Bill Merilees provided images and granted permission to use them. Kayleigh Gillespie assisted in adapting figures. We thank Dominique Bureau, Alex Dalton, Kelsey Delisle, Cory Dubetz, Dounia Hamoutene, Erin Herder, Thomas King, Alice Ortmann, and Brian Robinson (DFO) for their insightful review comments, and Varsha Rani (Keystone Environmental) for editorial support.

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APPENDIX TABLES

Appendix Table 1. Pathways of effects; northern abalone (*Haliotis kamtschatkana*) and oil in marine environments in coastal British Columbia.

Oil Type			Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 1	Group 1A	Gasoline	Fresh	Larval[1] Stages (April to July)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides / spawning PAHs causing bleaching of red algae eliminates food source Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	High
			Weathered (Evaporates completely within 24 hours)	Larval[1] Stages (April to July)	-	-	Nil
				Adult[2] Stages	-	-	Nil
	Group 1B	Marine Diesel	Fresh	Larval[1] Stages (April to July)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides / spawning PAHs causing bleaching of red algae eliminates food source Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	Low (Low energy) Low (Medium/high energy) High in Intertidal
			Weathered (up to 50% Evaporated within 5 days; aquatic toxicity decreases)	Larval[1] Stages (April to July)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides / spawning Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	Low (Low energy) Low to Moderate (Medium/high energy) or Intertidal

Appendix Table 1. (continued).

Oil Type		Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 2	Light Crude Oil	Fresh	Larval[1] Stages (April to July)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides / spawning PAHs causing bleaching of red algae eliminates food source Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	Low (Low energy) Moderate (Medium/high energy) High in Intertidal
		Weathered (Some evaporation occurs, ~10%; dispersion is limited)	Larval[1] Stages (April to July)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides / spawning Oil interacts/coats red algae, ingested Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	Low (Low energy) Low (Medium/high energy) High in Intertidal
Group 3	Engine/Hydraulic Oil Medium Crude Oil Heavy Crude Oil Dilbit Oil	Fresh	Larval[1] Stages (April to July)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides / spawning Oil interacts/coats red algae, ingested Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	Low (Low energy) Moderate to High (Medium/high energy) or within Intertidal
		Weathered (Little to no evaporation; stable emulsification; sinking if sedimentation occurs dependent on ocean conditions)	Larval[1] Stages (April to July)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides / spawning Oil interacts/coats red algae, ingested Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	Low (Low energy) Moderate to High (Medium/high energy) or within Intertidal

Appendix Table 1. (continued).

Oil Type		Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 4	Bunker C Oil	Fresh	Larval[1] Stages (April to July)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides / spawning Oil interacts/coats red algae, ingested Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	High
		Weathered (Little to no evaporation; very little to no dispersion or emulsification)	Larval[1] Stages (April to July)	Exposure throughout water column	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure during low tides / spawning Interacts with drift particles in water column, ingested	Intertidal/Shallow subtidal	High
Group 5	Sinking Oil	Fresh	Larval[1] Stages (April to July)	Exposure within water column	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure after sinking Oil interacts/coats red algae, ingested Interacts with drift particles in water column, ingested	Intertidal/Shallow subtidal	High
		Weathered (Little to no weathering effects)	Larval[1] Stages (April to July)	Exposure within water column	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure after sinking Oil interacts/coats red algae, ingested Interacts with drift particles in water column, ingested	Intertidal/Shallow subtidal	High

1. Larval stages are inclusive of all life phases within the water column (spawn, spatting and settling stages)
2. Adult stages are generalized to include the sessile or low mobile juvenile and matured life stages for the select mollusc

Appendix Table 2. Pathways of effects; Oympia oyster (*Ostrea lurida*) and oil in marine environments in coastal British Columbia.

Oil Type			Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 1	Group 1A	Gasoline	Fresh	Larval[1] Stages (July to September)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides (Intertidal) Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	High
			Weathered (Evaporates completely within 24 hours)	Larval[1] Stages (July to September)	-	-	Nil
				Adult[2] Stages	-	-	Nil
	Group 1B	Marine Diesel	Fresh	Larval[1] Stages (July to September)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides (Intertidal) Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	High
			Weathered (up to 50% Evaporated within 5 days; aquatic toxicity decreases)	Larval[1] Stages (July to September)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested	Intertidal/Shallow subtidal	High

Appendix Table 2. (continued).

Oil Type		Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 2	Light Crude Oil	Fresh	Larval[1] Stages (July to September)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	High
		Weathered (Some evaporation occurs, ~10%; dispersion is limited)	Larval[1] Stages (July to September)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested	Intertidal/Shallow subtidal	High
Group 3	Engine/Hydraulic Oil Medium Crude Oil Heavy Crude Oil Dilbit Oil	Fresh	Larval[1] Stages (July to September)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	High
		Weathered (Little to no evaporation; stable emulsification; sinking if sedimentation occurs dependent on ocean conditions)	Larval[1] Stages (July to September)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested	Intertidal/Shallow subtidal	High

Appendix Table 2. (continued).

Oil Type		Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 4	Bunker C Oil	Fresh	Larval[1] Stages (July to September)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	High
		Weathered (Little to no evaporation; very little to no dispersion or emulsification)	Larval[1] Stages (July to September)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested	Intertidal/Shallow subtidal	High
Group 5	Sinking Oil	Fresh	Larval[1] Stages (July to September)	Exposure within water column	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure on substrate Interacts with drift particles in water column, ingested	Intertidal/Shallow subtidal	High
		Weathered (Little to no weathering effects)	Larval[1] Stages (July to September)	Exposure within water column	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure on substrate Interacts with drift particles in water column, ingested	Intertidal/Shallow subtidal	High

1. Larval stages are inclusive of all life phases within the water column (spawn, spatting and settling stages)
2. Adult stages are generalized to include the sessile or low mobile juvenile and matured life stages for the select mollusc

Appendix Table 3. Pathways of effects; Pacific oyster (*Magallana gigas*) and oil in marine environments in coastal British Columbia.

Oil Type			Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 1	Group 1A	Gasoline	Fresh	Larval[1] Stages (June to September; peak in July and August)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
			Weathered (Evaporates completely within 24 hours)	Larval[1] Stages (June to September; peak in July and August)	-	-	Nil
				Adult[2] Stages	-	-	Nil
	Group 1B	Marine Diesel	Fresh	Larval[1] Stages (June to September; peak in July and August)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
			Weathered (up to 50% Evaporated within 5 days; aquatic toxicity decreases)	Larval[1] Stages (June to September; peak in July and August)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested	Intertidal	High

Appendix Table 3. (continued).

Oil Type		Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 2	Light Crude Oil	Fresh	Larval[1] Stages (June to September; peak in July and August)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
		Weathered (Some evaporation occurs, ~10%; dispersion is limited)	Larval[1] Stages (June to September; peak in July and August)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested	Intertidal	High
Group 3	Engine/Hydraulic Oil Medium Crude Oil Heavy Crude Oil Dilbit Oil	Fresh	Larval[1] Stages (June to September; peak in July and August)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
		Weathered (Little to no evaporation; stable emulsification; sinking if sedimentation occurs dependent on ocean conditions)	Larval[1] Stages (June to September; peak in July and August)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested	Intertidal	High

Appendix Table 3. (continued).

Oil Type		Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 4	Bunker C Oil	Fresh	Larval[1] Stages (June to September; peak in July and August)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
		Weathered (Little to no evaporation; very little to no dispersion or emulsification)	Larval[1] Stages (June to September; peak in July and August)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested	Intertidal	High
Group 5	Sinking Oil	Fresh	Larval[1] Stages (June to September; peak in July and August)	Exposure (coating/smothering)	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure on substrate Interacts with drift particles in water column, ingested	Intertidal	High
		Weathered (Little to no weathering effects)	Larval[1] Stages (June to September; peak in July and August)	Exposure (coating/smothering)	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure substrate Interacts with drift particles in water column, ingested	Intertidal	High

1. Larval stages are inclusive of all life phases within the water column (spawn, spatting and settling stages)
2. Adult stages are generalized to include the sessile or low mobile juvenile and matured life stages for the select mollusc

Appendix Table 4. Pathways of effects; Pacific geoduck (*Panopea generosa*) and oil in marine environments in coastal British Columbia.

Oil Type			Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 1	Group 1A	Gasoline	Fresh	Larval[1] Stages (March to July, peak in June and July)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Deep Intertidal/Shallow Subtidal	Low to Moderate within Intertidal
			Weathered (Evaporates completely within 24 hours)	Larval[1] Stages (March to July, peak in June and July)	-	-	Nil
				Adult[2] Stages	-	-	Nil
	Group 1B	Marine Diesel	Fresh	Larval[1] Stages (March to July, peak in June and July)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Deep Intertidal/Shallow Subtidal	Low to Moderate within Intertidal
			Weathered (up to 50% Evaporated within 5 days; aquatic toxicity decreases)	Larval[1] Stages (March to July, peak in June and July)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Deep Intertidal/Shallow Subtidal	High

Appendix Table 4. (continued).

Oil Type		Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 2	Light Crude Oil	Fresh	Larval[1] Stages (March to July, peak in June and July)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Deep Intertidal/Shallow Subtidal	Low to Moderate within Intertidal
		Weathered (Some evaporation occurs, ~10%; dispersion is limited)	Larval[1] Stages (March to July, peak in June and July)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested	Deep Intertidal/Shallow Subtidal	High
Group 3	Engine/Hydraulic Oil Medium Crude Oil Heavy Crude Oil Dilbit Oil	Fresh	Larval[1] Stages (March to July, peak in June and July)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Deep Intertidal/Shallow Subtidal	Low to Moderate within Intertidal
		Weathered (Little to no evaporation; stable emulsification; sinking if sedimentation occurs dependent on ocean conditions)	Larval[1] Stages (March to July, peak in June and July)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested	Deep Intertidal/Shallow Subtidal	Moderate

Appendix Table 4. (continued).

Oil Type		Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 4	Bunker C Oil	Fresh	Larval[1] Stages (March to July, peak in June and July)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested	Deep Intertidal/Shallow Subtidal	Moderate to High
		Weathered (Little to no evaporation; very little to no dispersion or emulsification)	Larval[1] Stages (March to July, peak in June and July)	Exposure at upper to mid reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Moderate (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure on substrate Interacts with drift particles in water column, ingested	Deep Intertidal/Shallow Subtidal	High
Group 5	Sinking Oil	Fresh	Larval[1] Stages (March to July, peak in June and July)	Exposure within water column	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure on substrate Interacts with drift particles in water column, ingested	Deep Intertidal/Shallow Subtidal	High
		Weathered (Little to no weathering effects)	Larval[1] Stages (March to July, peak in June and July)	Exposure within water column	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure on substrate Interacts with drift particles in water column, ingested	Deep Intertidal/Shallow Subtidal	High

1. Larval stages are inclusive of all life phases within the water column (spawn, spatting and settling stages)
2. Adult stages are generalized to include the sessile or low mobile juvenile and matured life stages for the select mollusc

Appendix Table 5. Pathways of effects; Manila clam (*Venerupis philippinarum*) and oil in marine environments in coastal British Columbia.

Oil Type			Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 1	Group 1A	Gasoline	Fresh	Larval[1] Stages (June to September)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides Ingestion through substrate collected with pedal foot Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
			Weathered (Evaporates completely within 24 hours)	Larval[1] Stages (June to September)	-	-	Nil
				Adult[2] Stages	-	-	Nil
	Group 1B	Marine Diesel	Fresh	Larval[1] Stages (June to September)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides Ingestion through substrate collected with pedal foot Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
			Weathered (up to 50% Evaporated within 5 days; aquatic toxicity decreases)	Larval[1] Stages (June to September)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides Ingestion through substrate collected with pedal foot Interacts with drift particles in water column, ingested (High energy)	Intertidal	High

Appendix Table 5. (continued).

Oil Type		Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 2	Light Crude Oil	Fresh	Larval[1] Stages (June to September)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Ingestion through substrate collected with pedal foot Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
		Weathered (Some evaporation occurs, ~10%; dispersion is limited)	Larval[1] Stages (June to September)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Ingestion through substrate collected with pedal foot Interacts with drift particles in water column, ingested	Intertidal	High
Group 3	Engine/Hydraulic Oil Medium Crude Oil Heavy Crude Oil Dilbit Oil	Fresh	Larval[1] Stages (June to September)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Ingestion through substrate collected with pedal foot Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
		Weathered (Little to no evaporation; stable emulsification; sinking if sedimentation occurs dependent on ocean conditions)	Larval[1] Stages (June to September)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Ingestion through substrate collected with pedal foot Interacts with drift particles in water column, ingested	Intertidal	High

Appendix Table 5. (continued).

Oil Type		Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 4	Bunker C Oil	Fresh	Larval[1] Stages (June to September)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Ingestion through substrate collected with pedal foot Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
		Weathered (Little to no evaporation; very little to no dispersion or emulsification)	Larval[1] Stages (June to September)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure on substrate Ingestion through substrate collected with pedal foot Interacts with drift particles in water column, ingested	Intertidal	High
Group 5	Sinking Oil	Fresh	Larval[1] Stages (June to September)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure on substrate Ingestion through substrate collected with pedal foot Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
		Weathered (Little to no weathering effects)	Larval[1] Stages (June to September)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure on substrate Ingestion through substrate collected with pedal foot Interacts with drift particles in water column, ingested (High energy)	Intertidal	High

1. Larval stages are inclusive of all life phases within the water column (spawn, spatting and settling stages)
2. Adult stages are generalized to include the sessile or low mobile juvenile and matured life stages for the select mollusc

Appendix Table 6. Pathways of effects; Pacific littleneck (*Leukoma staminea*) and oil in marine environments in coastal British Columbia.

Oil Type			Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 1	Group 1A	Gasoline	Fresh	Larval[1] Stages (April to October)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	High
			Weathered (Evaporates completely within 24 hours)	Larval[1] Stages (April to October)	-	-	Nil
				Adult[2] Stages	-	-	Nil
	Group 1B	Marine Diesel	Fresh	Larval[1] Stages (April to October)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	High
			Weathered (up to 50% Evaporated within 5 days; aquatic toxicity decreases)	Larval[1] Stages (April to October)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	High

Appendix Table 6. (continued).

Oil Type		Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 2	Light Crude Oil	Fresh	Larval[1] Stages (April to October)	Potential exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	High
		Weathered (Some evaporation occurs, ~10%; dispersion is limited)	Larval[1] Stages (April to October)	Potential exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	High
Group 3	Engine/Hydraulic Oil Medium Crude Oil Heavy Crude Oil Dilbit Oil	Fresh	Larval[1] Stages (April to October)	Potential exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	High
		Weathered (Little to no evaporation; stable emulsification; sinking if sedimentation occurs dependent on ocean conditions)	Larval[1] Stages (April to October)	Potential exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	High

Appendix Table 6. (continued).

Oil Type		Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 4	Bunker C Oil	Fresh	Larval[1] Stages (April to October)	Potential exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	High
		Weathered (Little to no evaporation; very little to no dispersion or emulsification)	Larval[1] Stages (April to October)	Potential exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure on substrate Interacts with drift particles in water column, ingested	Intertidal/Shallow subtidal	High
Group 5	Sinking Oil	Fresh	Larval[1] Stages (April to October)	Exposure throughout water column	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure on substrate Interacts with drift particles in water column, ingested	Intertidal/Shallow subtidal	High
		Weathered (Little to no weathering effects)	Larval[1] Stages (April to October)	Exposure throughout water column	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure on substrate Interacts with drift particles in water column, ingested	Intertidal/Shallow subtidal	High

1. Larval stages are inclusive of all life phases within the water column (spawn, spatting and settling stages)
2. Adult stages are generalized to include the sessile or low mobile juvenile and matured life stages for the select mollusc

Appendix Table 7. Pathways of effects; butter clam (*Saxidomus gigantea*) and oil in marine environments in coastal British Columbia.

Oil Type			Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 1	Group 1A	Gasoline	Fresh	Larval[1] Stages (April to October)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides	Low Intertidal – Shallow Subtidal	High
			Weathered (Evaporates completely within 24 hours)	Larval[1] Stages (April to October)	-	-	Nil
				Adult[2] Stages	-	-	Nil
	Group 1B	Marine Diesel	Fresh	Larval[1] Stages (April to October)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Low Intertidal – Shallow Subtidal	High
			Weathered (up to 50% Evaporated within 5 days; aquatic toxicity decreases)	Larval[1] Stages (April to October)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Low Intertidal – Shallow Subtidal	High

Appendix Table 7. (continued).

Oil Type		Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 2	Light Crude Oil	Fresh	Larval[1] Stages (April to October)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Low Intertidal – Shallow Subtidal	High
		Weathered (Some evaporation occurs, ~10%; dispersion is limited)	Larval[1] Stages (April to October)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Low Intertidal – Shallow Subtidal	High
Group 3	Engine/Hydraulic Oil Medium Crude Oil Heavy Crude Oil Dilbit Oil	Fresh	Larval[1] Stages (April to October)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Low Intertidal – Shallow Subtidal	High
		Weathered (Little to no evaporation; stable emulsification; sinking if sedimentation occurs dependent on ocean conditions)	Larval[1] Stages (April to October)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Low Intertidal – Shallow Subtidal	High

Appendix Table 7. (continued).

Oil Type		Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 4	Bunker C Oil	Fresh	Larval[1] Stages (April to October)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Low Intertidal – Shallow Subtidal	High
		Weathered (Little to no evaporation; very little to no dispersion or emulsification)	Larval[1] Stages (April to October)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure on substrate Interacts with drift particles in water column, ingested	Low Intertidal – Shallow Subtidal	High
Group 5	Sinking Oil	Fresh	Larval[1] Stages (April to October)	Exposure within water column	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure on substrate Interacts with drift particles in water column, ingested	Low Intertidal – Shallow Subtidal	High
		Weathered (Little to no weathering effects)	Larval[1] Stages (April to October)	Exposure within water column	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure on substrate Interacts with drift particles in water column, ingested	Low Intertidal – Shallow Subtidal	High

1. Larval stages are inclusive of all life phases within the water column (spawn, spatting and settling stages)
2. Adult stages are generalized to include the sessile or low mobile juvenile and matured life stages for the select mollusc

Appendix Table 8. Pathways of effects; razor clam (*Siliqua patula*) and oil in marine environments in coastal British Columbia.

Oil Type			Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 1	Group 1A	Gasoline	Fresh	Larval[1] Stages (June to August)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides	Low Intertidal – Shallow Subtidal	High
			Weathered (Evaporates completely within 24 hours)	Larval[1] Stages (June to August)	-	-	Nil
				Adult[2] Stages	-	-	Nil
	Group 1B	Marine Diesel	Fresh	Larval[1] Stages (June to August)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Low Intertidal – Shallow Subtidal	High
			Weathered (up to 50% Evaporated within 5 days; aquatic toxicity decreases)	Larval[1] Stages (June to August)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Low Intertidal – Shallow Subtidal	High

Appendix Table 8. (continued).

Oil Type		Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 2	Light Crude Oil	Fresh	Larval[1] Stages (June to August)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Low Intertidal – Shallow Subtidal	High
		Weathered (Some evaporation occurs, ~10%; dispersion is limited)	Larval[1] Stages (June to August)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Low Intertidal – Shallow Subtidal	High
Group 3	Engine/Hydraulic Oil Medium Crude Oil Heavy Crude Oil Dilbit Oil	Fresh	Larval[1] Stages (June to August)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Low Intertidal – Shallow Subtidal	High
		Weathered (Little to no evaporation; stable emulsification; sinking if sedimentation occurs dependent on ocean conditions)	Larval[1] Stages (June to August)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Low Intertidal – Shallow Subtidal	High

Appendix Table 8. (continued).

Oil Type		Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 4	Bunker C Oil	Fresh	Larval[1] Stages (June to August)	Potential exposure at upper reach of water column	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides (intertidal) Interacts with drift particles in water column, ingested (High energy)	Intertidal/Subtidal	High
		Weathered (Little to no evaporation; very little to no dispersion or emulsification)	Larval[1] Stages (June to August)	Potential exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure on substrate Interacts with drift particles in water column, ingested (High energy)	Intertidal/Subtidal	High
Group 5	Sinking Oil	Fresh	Larval[1] Stages (June to August)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure on substrate Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	High
		Weathered (Little to no weathering effects)	Larval[1] Stages (June to August)	Potential exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure on substrate Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	High

1. Larval stages are inclusive of all life phases within the water column (spawn, spatting and settling stages)
2. Adult stages are generalized to include the sessile or low mobile juvenile and matured life stages for the select mollusc

Appendix Table 9. Pathways of effects; varnish clam (*Nuttallia obscurata*) and oil in marine environments in coastal British Columbia.

Oil Type			Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 1	Group 1A	Gasoline	Fresh	Larval[1] Stages (May to September)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides (intertidal) Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
			Weathered (Evaporates completely within 24 hours)	Larval[1] Stages (May to September)	-	-	Nil
				Adult[2] Stages	-	-	Nil
	Group 1B	Marine Diesel	Fresh	Larval[1] Stages (May to September)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides (intertidal) Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
			Weathered (up to 50% Evaporated within 5 days; aquatic toxicity decreases)	Larval[1] Stages (May to September)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides (intertidal) Interacts with drift particles in water column, ingested (High energy)	Intertidal	High

Appendix Table 9. (continued).

Oil Type		Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 2	Light Crude Oil	Fresh	Larval[1] Stages (May to September)	Potential exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides (intertidal) Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
		Weathered (Some evaporation occurs, ~10%; dispersion is limited)	Larval[1] Stages (May to September)	Potential exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides (intertidal) Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
Group 3	Engine/Hydraulic Oil Medium Crude Oil Heavy Crude Oil Dilbit Oil	Fresh	Larval[1] Stages (May to September)	Potential exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides (intertidal) Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
		Weathered (Little to no evaporation; stable emulsification; sinking if sedimentation occurs dependent on ocean conditions)	Larval[1] Stages (May to September)	Potential exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides (intertidal) Interacts with drift particles in water column, ingested (High energy)	Intertidal	High

Appendix Table 9. (continued).

Oil Type		Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 4	Bunker C Oil	Fresh	Larval[1] Stages (May to September)	Potential exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides (intertidal) Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
		Weathered (Little to no evaporation; very little to no dispersion or emulsification)	Larval[1] Stages (May to September)	Exposure throughout water column	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure on substrate Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
Group 5	Sinking Oil	Fresh	Larval[1] Stages (May to September)	Exposure throughout water column	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure on substrate Interacts with drift particles in water column, ingested	Intertidal	High
		Weathered (Little to no weathering effects)	Larval[1] Stages (May to September)	Exposure throughout water column	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure on substrate Interacts with drift particles in water column, ingested	Intertidal	High

1. Larval stages are inclusive of all life phases within the water column (spawn, spatting and settling stages)
2. Adult stages are generalized to include the sessile or low mobile juvenile and matured life stages for the select mollusc

Appendix Table 10. Pathways of effects; Nuttall cockle (*Clinocardium nuttallii*) and oil in marine environments in coastal British Columbia.

Oil Type			Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 1	Group 1A	Gasoline	Fresh	Larval[1] Stages (April to November, spike from July to September)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides (intertidal) Interacts with drift particles in water column, ingested (High energy)	Intertidal/Subtidal	High
			Weathered (Evaporates completely within 24 hours)	Larval[1] Stages (April to November, spike from July to September)	-	-	Nil
				Adult[2] Stages	-	-	Nil
	Group 1B	Marine Diesel	Fresh	Larval[1] Stages (April to November, spike from July to September)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides (intertidal) Interacts with drift particles in water column, ingested (High energy)	Intertidal/Subtidal	High
			Weathered (up to 50% Evaporated within 5 days; aquatic toxicity decreases)	Larval[1] Stages (April to November, spike from July to September)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides (intertidal) Interacts with drift particles in water column, ingested (High energy)	Intertidal/Subtidal	High

Appendix Table 10. (continued).

Oil Type		Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 2	Light Crude Oil	Fresh	Larval[1] Stages (April to November, spike from July to September)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides (intertidal) Interacts with drift particles in water column, ingested (High energy)	Intertidal/Subtidal	High
		Weathered (Some evaporation occurs, ~10%; dispersion is limited)	Larval[1] Stages (April to November, spike from July to September)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides (intertidal) Interacts with drift particles in water column, ingested (High energy)	Intertidal/Subtidal	High
Group 3	Engine/Hydraulic Oil Medium Crude Oil Heavy Crude Oil Dilbit Oil	Fresh	Larval[1] Stages (April to November, spike from July to September)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides (intertidal) Interacts with drift particles in water column, ingested (High energy)	Intertidal/Subtidal	High
		Weathered (Little to no evaporation; stable emulsification; sinking if sedimentation occurs dependent on ocean conditions)	Larval[1] Stages (April to November, spike from July to September)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides (intertidal) Interacts with drift particles in water column, ingested (High energy)	Intertidal/Subtidal	High

Appendix Table 10. (continued).

Oil Type		Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 4	Bunker C Oil	Fresh	Larval[1] Stages (April to November, spike from July to September)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides (intertidal) Interacts with drift particles in water column, ingested (High energy)	Intertidal/Subtidal	High
		Weathered (Little to no evaporation; very little to no dispersion or emulsification)	Larval[1] Stages (April to November, spike from July to September)	Exposure throughout water column	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure after sinking Interacts with drift particles in water column, ingested	Intertidal/Subtidal	High
Group 5	Sinking Oil	Fresh	Larval[1] Stages (April to November, spike from July to September)	Exposure within water column	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure after sinking Interacts with drift particles in water column, ingested	Intertidal/Subtidal	High
		Weathered (Little to no weathering effects)	Larval[1] Stages (April to November, spike from July to September)	Exposure within water column	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure after sinking Interacts with drift particles in water column, ingested	Intertidal/Subtidal	High

1. Larval stages are inclusive of all life phases within the water column (spawn, spatting and settling stages)
2. Adult stages are generalized to include the sessile or low mobile juvenile and matured life stages for the select mollusc

Appendix Table 11. Pathways of effects; softshell (*Mya arenaria*) and oil in marine environments in coastal British Columbia.

Oil Type			Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 1	Group 1A	Gasoline	Fresh	Larval[1] Stages (May to September; peak in June and July)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
			Weathered (Evaporates completely within 24 hours)	Larval[1] Stages (May to September; peak in June and July)	-	-	Nil
				Adult[2] Stages	-	-	Nil
	Group 1B	Marine Diesel	Fresh	Larval[1] Stages (May to September; peak in June and July)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
			Weathered (up to 50% Evaporated within 5 days; aquatic toxicity decreases)	Larval[1] Stages (May to September; peak in June and July)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal	High

Appendix Table 11. (continued).

Oil Type		Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 2	Light Crude Oil	Fresh	Larval[1] Stages (May to September; peak in June and July)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
		Weathered (Some evaporation occurs, ~10%; dispersion is limited)	Larval[1] Stages (May to September; peak in June and July)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
Group 3	Engine/Hydraulic Oil Medium Crude Oil Heavy Crude Oil Dilbit Oil	Fresh	Larval[1] Stages (May to September; peak in June and July)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
		Weathered (Little to no evaporation; stable emulsification; sinking if sedimentation occurs dependent on ocean conditions)	Larval[1] Stages (May to September; peak in June and July)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal	High

Appendix Table 11. (continued).

Oil Type		Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 4	Bunker C Oil	Fresh	Larval[1] Stages (May to September; peak in June and July)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
		Weathered (Little to no evaporation; very little to no dispersion or emulsification)	Larval[1] Stages (May to September; peak in June and July)	Exposure throughout water column	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure after sinking Interacts with drift particles in water column, ingested	Intertidal	High
Group 5	Sinking Oil	Fresh	Larval[1] Stages (May to September; peak in June and July)	Exposure within water column	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure after sinking Interacts with drift particles in water column, ingested	Intertidal	High
		Weathered (Little to no weathering effects)	Larval[1] Stages (May to September; peak in June and July)	Exposure within water column	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure after sinking Interacts with drift particles in water column, ingested	Intertidal	High

1. Larval stages are inclusive of all life phases within the water column (spawn, spatting and settling stages)
2. Adult stages are generalized to include the sessile or low mobile juvenile and matured life stages for the select mollusc

Appendix Table 12. Pathways of effects; California mussel (*Mytilus californianus*) and oil in marine environments in coastal British Columbia.

Oil Type			Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 1	Group 1A	Gasoline	Fresh	Larval[1] Stages (Year-round, spikes in spring and fall)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	High
			Weathered (Evaporates completely within 24 hours)	Larval[1] Stages (Year-round, spikes in spring and fall)	-	-	Nil
				Adult[2] Stages	-	-	Nil
	Group 1B	Marine Diesel	Fresh	Larval[1] Stages (Year-round, spikes in spring and fall)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	High
			Weathered (up to 50% Evaporated within 5 days; aquatic toxicity decreases)	Larval[1] Stages (Year-round, spikes in spring and fall)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	High

Appendix Table 12. (continued).

Oil Type		Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 2	Light Crude Oil	Fresh	Larval[1] Stages (Year-round, spikes in spring and fall)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	High
		Weathered (Some evaporation occurs, ~10%; dispersion is limited)	Larval[1] Stages (Year-round, spikes in spring and fall)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	High
Group 3	Engine/Hydraulic Oil Medium Crude Oil Heavy Crude Oil Dilbit Oil	Fresh	Larval[1] Stages (Year-round, spikes in spring and fall)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	High
		Weathered (Little to no evaporation; stable emulsification; sinking if sedimentation occurs dependent on ocean conditions)	Larval[1] Stages (Year-round, spikes in spring and fall)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	High

Appendix Table 12. (continued).

Oil Type		Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 4	Bunker C Oil	Fresh	Larval[1] Stages (Year-round, spikes in spring and fall)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	High
		Weathered (Little to no evaporation; very little to no dispersion or emulsification)	Larval[1] Stages (Year-round, spikes in spring and fall)	Exposure throughout water column	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure after sinking Interacts with drift particles in water column, ingested	Intertidal/Shallow subtidal	High
Group 5	Sinking Oil	Fresh	Larval[1] Stages (Year-round, spikes in spring and fall)	Exposure within water column	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure after sinking Interacts with drift particles in water column, ingested	Intertidal/Shallow subtidal	High
		Weathered (Little to no weathering effects)	Larval[1] Stages (Year-round, spikes in spring and fall)	Exposure within water column	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure after sinking Interacts with drift particles in water column, ingested	Intertidal/Shallow subtidal	High

1. Larval stages are inclusive of all life phases within the water column (spawn, spatting and settling stages)
2. Adult stages are generalized to include the sessile or low mobile juvenile and matured life stages for the select mollusc

Appendix Table 13. Pathways of effects; bay mussels (*Mytilus trossulus, M. edulis* and *M. galloprovincialis*) and oil in marine environments in coastal British Columbia.

Oil Type			Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 1	Group 1A	Gasoline	Fresh	Larval[1] Stages (May to September)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
			Weathered (Evaporates completely within 24 hours)	Larval[1] Stages (May to September)	-	-	Nil
				Adult[2] Stages	-	-	Nil
	Group 1B	Marine Diesel	Fresh	Larval[1] Stages (May to September)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
			Weathered (up to 50% Evaporated within 5 days; aquatic toxicity decreases)	Larval[1] Stages (May to September)	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal	High

Appendix Table 13. (continued).

Oil Type		Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 2	Light Crude Oil	Fresh	Larval[1] Stages (May to September)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
		Weathered (Some evaporation occurs, ~10%; dispersion is limited)	Larval[1] Stages (May to September)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
Group 3	Engine/Hydraulic Oil Medium Crude Oil Heavy Crude Oil Dilbit Oil	Fresh	Larval[1] Stages (May to September)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
		Weathered (Little to no evaporation; stable emulsification; sinking if sedimentation occurs dependent on ocean conditions)	Larval[1] Stages (May to September)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal	High

Appendix Table 13. (continued).

Oil Type		Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 4	Bunker C Oil	Fresh	Larval[1] Stages (May to September)	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal	High
		Weathered (Little to no evaporation; very little to no dispersion or emulsification)	Larval[1] Stages (May to September)	Exposure throughout water column	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested	Intertidal	High
Group 5	Sinking Oil	Fresh	Larval[1] Stages (May to September)	Exposure within water column	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure after sinking Interacts with drift particles in water column, ingested	Intertidal	High
		Weathered (Little to no weathering effects)	Larval[1] Stages (May to September)	Exposure within water column	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure after sinking Interacts with drift particles in water column, ingested	Intertidal	High

1. Larval stages are inclusive of all life phases within the water column (spawn, spatting and settling stages)
2. Adult stages are generalized to include the sessile or low mobile juvenile and matured life stages for the select mollusc

Appendix Table 14. Pathways of effects; fat and Pacific gapers (*Tresus capax* and *T. nuttallii*) and oil in marine environments in coastal British Columbia.

Oil Type			Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 1	Group 1A	Gasoline	Fresh	Larval[1] Stages (mid-February to May (*T. capax*) (April to August (*T. nuttallii*))	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stage	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	Low (Fine sediments) Moderate (Coarse sediments) High (Non-burrowed juvenile; high tidal activity)
			Weathered (Evaporates completely within 24 hours)	Larval[1] Stages (mid-February to May (*T. capax)*) (April to August (*T. nuttallii*))	-	-	Nil
				Adult[2] Stages	-	-	Nil
	Group 1B	Marine Diesel	Fresh	Larval[1] Stages (mid-February to May (*T. capax*)) (April to August (*T. nuttallii*))	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	Low (Fine sediments) Moderate (Coarse sediments) High (Non-burrowed juvenile; high tidal activity)
			Weathered (up to 50% Evaporated within 5 days; aquatic toxicity decreases)	Larval[1] Stages (mid-February to May (*T. capax*)) (April to August (*T. nuttallii*))	Potential exposure at upper reach of water column (1-2mm) (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
				Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	Low (Fine sediments) Moderate (Coarse sediments) High (Non-burrowed juvenile; high tidal activity)

Appendix Table 14. (continued).

Oil Type		Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 2	Light Crude Oil	Fresh	Larval[1] Stages (mid-February to May (*T. capax*)) (April to August (*T. nuttallii*))	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	Low (Fine sediments) Moderate (Coarse sediments) High (Non-burrowed juvenile; high tidal activity)
		Weathered (Some evaporation occurs, ~10%; dispersion is limited)	Larval[1] Stages (mid-February to May (*T. capax*)) (April to August (*T. nuttallii*))	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	Low (Fine sediments) Moderate (Coarse sediments) High (Non-burrowed juvenile; high tidal activity)
Group 3	Engine/Hydraulic Oil Medium Crude Oil Heavy Crude Oil Dilbit Oil	Fresh	Larval[1] Stages (mid-February to May (*T. capax*)) (April to August (*T. nuttallii*))	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	Low (Fine sediments) Moderate (Coarse sediments) High (Non-burrowed juvenile; high tidal activity)
		Weathered (Little to no evaporation; stable emulsification; sinking if sedimentation occurs dependent on ocean conditions)	Larval[1] Stages (mid-February to May (*T. capax*)) (April to August (*T. nuttallii*))	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	Low (Fine sediments) Moderate (Coarse sediments) High (Non-burrowed juvenile; high tidal activity)

Appendix Table 14. (continued).

Oil Type		Age	Life Stage Affected	Pathway of Effect	Depth	Risk of Effect
Group 4	Bunker C Oil	Fresh	Larval[1] Stages (mid-February to May (*T. capax*)) (April to August (*T. nuttallii*))	Exposure at upper reach of water column (Low energy) Exposure throughout water column (Medium/high energy)	Planktonic/Intertidal	Low (Low energy) High (Medium/high energy)
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested (High energy)	Intertidal/Shallow subtidal	Low (Fine sediments) Moderate (Coarse sediments) High (Non-burrowed juvenile; high tidal activity)
		Weathered (Little to no evaporation; very little to no dispersion or emulsification)	Larval[1] Stages (mid-February to May (*T. capax*)) (April to August (*T. nuttallii*))	Exposure within water column	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure during low tides Interacts with drift particles in water column, ingested	Intertidal/Shallow subtidal	Low (Fine sediments) Moderate (Coarse sediments) High (Non-burrowed juvenile; high tidal activity)
Group 5	Sinking Oil	Fresh	Larval[1] Stages (mid-February to May (*T. capax*)) (April to August (*T. nuttallii*))	Exposure within water column	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure after sinking Interacts with drift particles in water column, ingested	Intertidal/Shallow subtidal	Low (Fine sediments) Moderate (Coarse sediments) High (Non-burrowed juvenile; high tidal activity)
		Weathered (Little to no weathering effects)	Larval[1] Stages (mid-February to May (*T. capax*)) (April to August (*T. nuttallii*))	Exposure within water column	Planktonic/Intertidal	High
			Adult[2] Stages	Exposure after sinking Interacts with drift particles in water column, ingested	Intertidal/Shallow subtidal	Low (Fine sediments) Moderate (Coarse sediments) High (Non-burrowed juvenile; high tidal activity)

1. Larval stages are inclusive of all life phases within the water column (spawn, spatting and settling stages)
2. Adult stages are generalized to include the sessile or low mobile juvenile and matured life stages for the select mollusc