THREAT ASSESSMENT FOR ATLANTIC MUD-PIDDOCK (*BARNEA TRUNCATA*), CANADIAN POPULATION

Context

The Atlantic Mud-piddock (*Barnea truncata*), assessed as Threatened (COSEWIC 2009), was added to Schedule 1 of the *Species at Risk Act* (SARA) on May 3, 2017 (GoC 2017). Consequently, it is required that a proposed recovery strategy be posted on the Species at Risk Public Registry within two years of listing (SARA, s. 42[1]).

For aquatic species, SARA recovery strategies require the inclusion of a threat assessment, based on Fisheries and Oceans Canada's (DFO's) Guidance on Assessing Threats, Ecological Risk and Ecological Impacts for Species at Risk (DFO 2014). Threat assessments inform species listing recommendations, recovery strategies, and action plans (DFO 2014). Information on threats is needed to plan and prioritize recovery measures for the species, and to inform the regulatory and management decisions made by DFO, regarding human activities that interact with the species. Threat assessments are normally completed as part of the Recovery Potential Assessment (RPA) for the species[1]. In the Atlantic Mud-piddock RPA, threats were described briefly (DFO 2010); however, a threat assessment table was not completed. Since that time, new threat assessment guidance has become available (DFO 2014).

This report identifies the Threat Risks (see Table 2 for definition of "Threat Risk") for the Atlantic Mud-piddock where it occurs in Atlantic Canadian waters. Since the species has no conservation status in other parts of its global distribution, there are no comparable risk assessments published for a comparison of threats in Atlantic Canada.

This Science Response Report results from the Science Response Process of February 16, 2018, of the Threat Assessment for Atlantic Mud-piddock (*Barnea truncata*).

Background

Range

The Atlantic Mud-piddock has a global range that is described as "amphi-Atlantic", being found along the Atlantic Ocean margins. In the eastern Atlantic, it is found from 15˚N to 34˚S latitude, with no reports north of Senegal (von Cosel, pers. comm). In the western Atlantic, it has been recorded from 24˚S to 45.4˚N, including a recent report of its occurrence in Argentina (Fiori et al. 2012), through southeastern Brazil (west of San Paulo), then sporadically through Guyana, Columbia, the Yucatan, Gulf of Mexico and north through to southern Maine, with a disjunct population in the Minas Basin and Cobequid Bay of the Bay of Fundy, collectively referred to as the Minas Basin when discussing the entire population.

[1] DFO. Draft. Guidance for the Completion of Recovery Potential Assessments (RPA) for Aquatic Species at Risk, unpublished manuscript

It has not been recorded on any oceanic islands in the Atlantic Ocean (Avila 2000) or any island within the Gulf of Mexico or Caribbean Sea, with the exception of a single report from Puerto Rico (Warmke and Abbott 1961).

The Canadian population, restricted to the Minas Basin in the upper Bay of Fundy (Figure 1), is disjunct from the nearest occurrence in southern Maine (COSEWIC 2009). This separation, coupled with the prevailing counter-clockwise circulation within the Gulf of Maine (GoMA 2017), makes natural recruitment into the population, or potential rescue effect[2], unlikely.

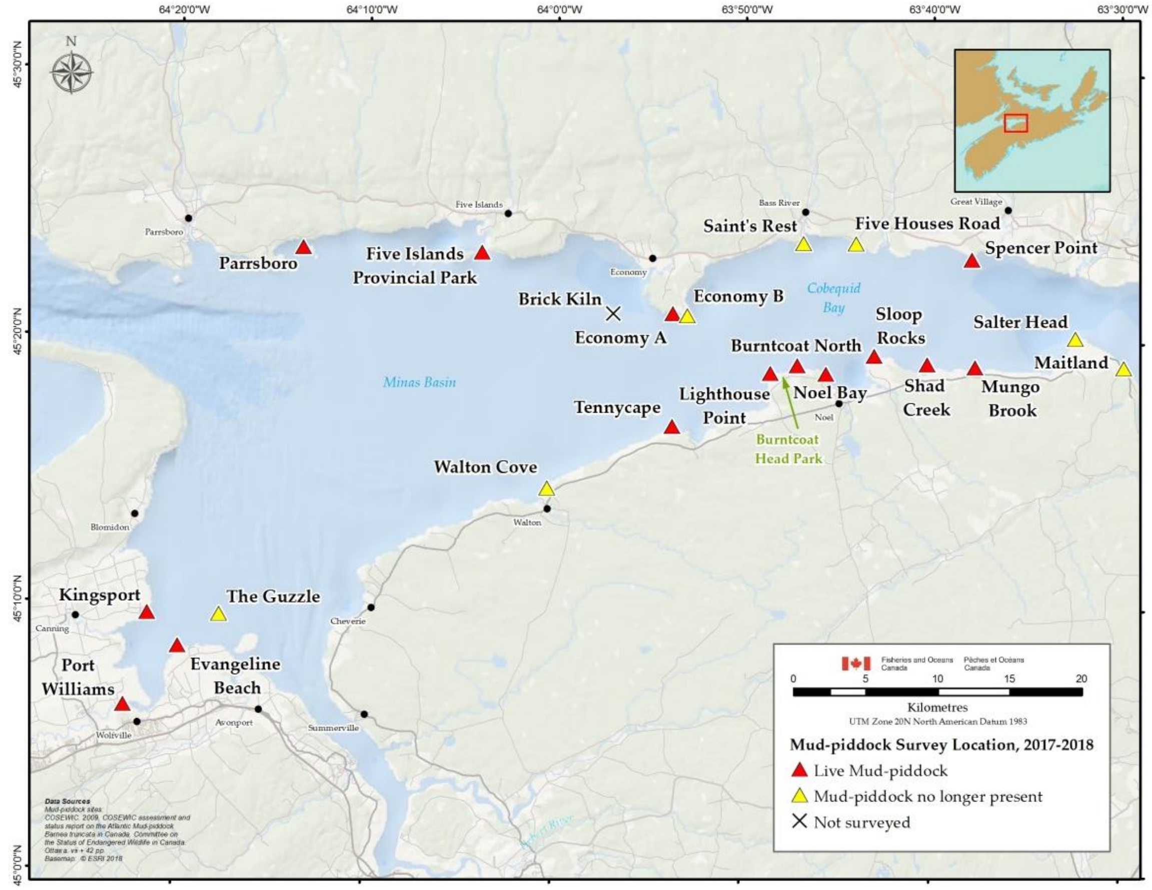

Figure 1. Distribution of the Atlantic Mud-piddock in Canada based on 2017-2018 field surveys. Core sites are found from Burntcoat Head to Mungo Brook (contains approximately 90% of the population).

The use of a unique substrate, a Triassic-age red-mudstone facies (COSEWIC 2009), differentiates the Canadian population of the Atlantic Mud-piddock from occurrences throughout the rest of its range, where it is found in peats and muds in estuarine (and riverine) habitats (von Cosel, pers. comm.). It is restricted to the mudstone substrate in its Canadian range, in part due to its inability to bore (post-settlement) in firmer substrates or persist in more ephemeral, soft, saltmarsh substrates.

[2] COSEWIC Rescue Effect is defined as “Immigration of gametes or individuals that have a high probability of reproducing successfully, such that extirpation or decline of a wildlife species can be mitigated. If the potential for rescue is high, the risk of extirpation may be reduced.”

Biology

The life stages [Chanley 1965 (in part) and COSEWIC 2009] of Atlantic Mud-piddock are:

a. Eggs (in water column)
b. Trocophore larval stage (in water column)
c. Shelled veliger larva (in water column)
d. Adult - post metamorphosis (benthic)

While all life-history stages (eggs to settled adult) of Atlantic Mud-piddock are vulnerable, the adult stage is most vulnerable to the threats assessed in this document. Adults reside in a mudstone burrow and are not able to move or relocate in response to changes in sedimentary or other environmental regimes near their burrow. The restricted substrate use and lack of mobility of individuals in these sub-populations make them vulnerable to sediment redistribution (including increased rates and volumes of deposition).

Status

Atlantic Mud-piddock in Canada was assessed as Threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2009. The reason provided for the designation was as follows:

"*This intertidal marine bivalve species is restricted to a single population in the Minas Basin, Nova Scotia. Although this species is adapted to boring into hard clay and soft rock, in Canada, it is entirely dependent on a single geological formation, the red–mudstone facies within the basin. The total available habitat for this species is < 0.6 km². This species settles on and bores into the mudstone, and once settled, is immobile. Any changes in deposition of sediments can smother individuals or cover entire areas of habitat. Disturbances that change the sediment depositional regime are considered the main threat. Most serious is the increased frequency and severity of storms, due to climate change, which have the potential to rapidly bury habitat and smother individuals. It is expected that erosion from rising sea levels (storm surges) and increased rainfall (floods), would also contribute to habitat loss by sediment deposition. Proposed development in the basin could also alter or add to sediment deposition.*" (COSEWIC 2009)

Threats

DFO (2014) defines a threat as:

> "Any human activity or process that has caused, is causing, or may cause harm, death, or behavioural changes to a wildlife species at risk, or the destruction, degradation, and/or impairment of its habitat, to the extent that population-level effects occur. A human activity may exacerbate a natural process."

The RPA (DFO 2010) provides information on sources of harm and mortality to the Atlantic Mud-piddock in Atlantic Canadian waters (Table 1). The sedentary, adult (boring), life-phase of the Atlantic Mud-Piddock is highly susceptible to smothering by sediments through either natural processes or activities affecting circulation/energy regimes within the habitat. Their immobility at this stage also makes them potentially vulnerable to a threat not previously identified in either COSEWIC (2009) or DFO (2010); specifically, recreation and adventure sport activities.

Table 1. Potential Threats and Impacts to Atlantic Mud-piddock, as described in the Recovery Potential Assessment (DFO 2010).

Potential Anthropogenic Threats	**Potential Biophysical or Chemical Changes**	**Potential Impact on Atlantic Mud-piddock**
Climate change	• Storm events could cause serious disruption to sediments in shallow estuarine ecosystems • Change in temperature regimes • Changes to the movement of ice in mid to late winter • Rising sea level • Increased rain could increase the frequency of floods substantially altering the flow in rivers	• Storms – smothering of Mud-piddock habitat • Temperature – greater oscillation of temperatures around annual means or decreased winter temperatures could harm the population • Ice – habitat could be destroyed due to substantive ice scour and the collapse of protective cap-rock[3] under the weight of ice after water retreat at low tide • Rising sea level – likely to destroy habitat due to an increase in shore erosion and beach migration • Rainfall – a greater amount of sediment could be carried from the rivers into the Basin resulting in smothering of Mud-piddock habitat
Construction or alteration of shoreline or water-crossing structures (e.g., aboideaus, dams, causeways wharves, boat slips)	• Modification of currents • Destruction of fish habitat • Smothering of habitat via sedimentation	• Changes in currents could result in the alteration of nearby intertidal fish habitat due to the movement of sediment, erosion, etc. (possibly critical alteration of substantial areas of habitat which could include Mud-piddock habitat) • Activities associated with shoreline structures could result in the destruction of Mud-piddock habitat
Exploratory or extraction activities in nearby rivers	• Disturbance of sediments (e.g., resuspension and migration of sediments)	• Smothering of Mud-piddock habitat
Non-point source pollution, i.e. agricultural and urban runoff form the Annapolis Valley and the Shubenacadie drainage basins	• Degradation of water quality due to mitigation of soil, animal waste, pesticides, etc. into the water	• Adverse health effects on Mud-piddock related to degraded water quality
Developments with potential to impact the estuary – turbines	• Alteration of tidal regimes	• Unknown
Developments with potential to impact the estuary – underground natural gas storage project with associated release of brine into the Shubenacadie River	• Increase in the salinity level of the water over a two year period	• Unknown, likely no measurable impact in the Minas Basin due to the dilution of the brine
Bulk movement of petroleum by sea throughout the Gulf of Maine and Bay of Fundy to four seaports with oil refineries in Maine and New Brunswick	• Accidental oil spill – oil could enter the Basin from the lower reaches of the Fundy Basin	• Could cause significant impacts in intertidal habitats and pose considerable problems in cleanup

[3] Also known as capstone.

Impacts to Date

Within Canadian habitats, there are no specific documented mortalities of Atlantic Mud-piddock related to the identified anthropogenic threats in this assessment. This is due to the absence of historical data and little direct field monitoring, until recent investigations (COSEWIC 2009). Observed changes to sub-populations in the last 10 years (A. Hebda, pers. observ, Clark et al. unpublished manuscript[4]) suggest that sedimentation is the principal threat to Mud-piddock. The recent losses of sub-populations are not directly attributable to human activity but are attributed to shifting sand that has covered these populations.

Analysis and Response

Methods

DFO Guidance on Conducting a Threats Assessment

The species-level threat assessment described in DFO (2014) guidance is not applied here because occurrence of Atlantic Mud-piddock in Canada is restricted to a single population (in the Minas Basin); therefore, only the population-level threat assessment is applied.

This threat assessment follows DFO (2014) guidance to the extent possible in the context of limited data and information on the Atlantic Mud-piddock within Atlantic Canadian waters. The DFO (2014) guidance for assessing threats provides quantitative definitions for characterizing threats (e.g. Likelihood of Occurrence, Level of Impact, and Threat Extent) that require abundance estimates; however, abundance estimates within Canada are not available. As a result, application of DFO (2014) guidance was followed with modifications as described below.

Description of Threats and Relationship to Threats Identified in the RPA

This assessment includes a total of eight threats, seven of which were identified in the RPA (DFO 2010, Table 1) and have been modified for this assessment as described below. Recreational and adventure sport activities is a new threat included in this threat assessment.

The first seven threats are discussed in detail in COSEWIC (2009), Hebda (2010) and DFO (2010).

Increase in the frequency and intensity of storm events, as well as sea level changes related to climate change, may significantly affect the Atlantic Mud-piddock population in Canada. Although the threat assessment guidance (DFO 2014) suggests that climate change not be characterized within the threat assessment, it was identified as a threat by COSEWIC (COSEWIC 2009) and DFO (2010) and is, therefore, characterized in this document. The availability of Atlantic Mud-piddock habitat is the limiting factor for population persistence in the Minas Basin. The impacts of natural processes on the persistence of sub-populations in the Minas Basin system can be significant with regard to the short and long-term occupancy at identified sites.

The changes in sedimentation patterns associated with changes in the frequency and intensity of events such as storm surges, coastal erosion resulting from sea-level rise, and rafting regimes of ice in later winter and early spring could result in a loss of localized sub-populations. Increases in sediment loading in the Minas Basin, related to sea level changes, have been documented since 1964 (Wilson 2016). Sea level rise modeling (James et al. 2014) suggests

[4] Clark, C.M., Hebda, A., Jones, G., Butler, S., and Pardy, G. In prep. Identification of Atlantic Mud-piddock Habitat in Canadian Waters. DFO Can. Tech. Rep. Fish. Aquat. Sci.

this may be a significant factor in the area. The threat of climate change is characterized in Table 3 and in the Rationalization for Threat Characterization section of this document.

For this analysis, “construction or alteration of shoreline or water-crossing structures” (Table 1) has been broadened and renamed “Alteration of Shoreline or Water Control Structures”. This includes construction activities and also captures recently approved initiatives to remove and realign dikes with re-establishment of saltmarsh habitat in the upper Cobequid Bay (Salmon River Estuary), and includes water control structures, in addition to water crossings. Harbour/waterway dredging is also included in this category.

Evaluation of exploratory or extraction activities focuses on mining of sediments in the Shubenacadie estuary, as well as Cobequid Bay. Mineral exploration of leases, covering approximately 102 square kilometers of the lower Shubenacadie River and estuary, was proposed and would have involved dredging sediments and extracting titanium from them. The residual sediments would then be re-deposited in the estuary. Although this particular proposal is not active, that could change in the future and similar activities may be proposed.

In the 2010 RPA, the effect of tidal turbines focused on the alteration of tidal regimes and potential changes in sediment in the Minas Basin. Small-scale tidal development is not expected to have a measurable effect on tidal regimes in the Minas Basin. Far-field effects, from large-scale tidal power development, are identified as a potential threat in COSEWIC (2009). Modelling and field investigations have shown the potential for substantive changes in sediment load and deposition associated with this development within the Minas and Cobequid Bay system (Mulligan et al. 2013; Wu et al. 2015; Ashall et al. 2016).

This analysis considers only large-scale tidal power that has the potential to alter tidal regime sufficiently to result in changes in sedimentation at locations where Atlantic Mud-piddock occur. Experimental small-scale tidal turbine deployments, in this portion of the Bay of Fundy, have been underway since 2009, but monitoring of environmental effects has been restricted to those associated with the small (pilot-scale) site and units. To date, only a single turbine has been deployed at a time, so there have been no specific studies of incremental or cumulative effects of smaller scale developments. In addition, deployment of these experimental turbines has not been continuous, so longer term data related to those deployments are not available.

This analysis does not include additional considerations or modifications to the non-point source pollution and natural gas storage threats described in the RPA.

Bulk movement of petroleum by sea throughout the Gulf of Maine and Bay of Fundy has been expanded to include spills of petroleum material from other shipping activities, where substantive volumes of vessel propulsion fuels (e.g. bunker C) may also be carried. Consequently, it is not just restricted to the bulk movement of raw petroleum materials or derivatives. Other materials, such as diesel, have not been assessed.

Recreational and adventure sport activities were not considered in DFO (2010), COSEWIC (2009), or Hebda (2010). This threat category includes relatively low intensity activities such as guided walks through Mud-piddock habitat, public runs on the ocean floor, which could have several dozen to several hundred runners in the area of Mud-piddock habitat (2 sites – Burntcoat Head (Hants County) and Five Islands Provincial Park (Colchester County)), potentially high intensity activities involving competitive mountain biking near Mud-piddock habitat, and the use of motorized vehicles, such as All-terrain Vehicles (ATVs). These high-intensity events are at the extreme end of the continuum of public use of intertidal habitats for tourism purposes.

The final list of threats assessed in this document is:

1. Climate Change
2. Alteration of Shoreline or Water Control Structures
3. Exploration or Extraction Activities in the Minas Basin and Nearby Rivers
4. Large-scale Tidal Turbines
5. Underground Gas Storage Project
6. Other Sources of Pollution, Including Non-point Source Pollution, i.e., agricultural and urban runoff
7. Release of Petroleum Products in the Gulf of Maine and Bay of Fundy
8. Recreation and Adventure Sport Activities

Assessment of Threats

For each threat, several elements are examined, as defined in DFO (2014): Likelihood of Occurrence, Level of Impact, Causal Certainty, Population Threat Risk, Threat Occurrence, Threat Frequency, and Threat Extent. Each element is characterized using the definitions provided in DFO (2014) to the extent possible. Detailed methods and interpretations of DFO guidance (DFO 2014), for the purpose of this assessment, are provided in Table 2.

Two factors need to be considered while reviewing these threats.

First, there is no actual or estimated population size for the Atlantic Mud-piddock, nor is there a ready way in which to determine population size at this time. For sites where the Mud-piddock occupies habitat under protective “cap-rock” structures, occupation may extend in excess of 30 cm from the visible (undercut) surfaces, so accurate counts (or even densities) are not possible without the destruction of the overlaying (and protective) structures; however, there is some information on the extent of occupancy. Therefore, in examining threats, the elements defined in DFO (2014) that characterize the threat by effect on the trajectory of the populations are somewhat problematic. This is noted in the specific threat categories.

The second factor relates to the distribution of the species in Canadian waters. The Mud-piddock is restricted to the intertidal habitat, primarily around the mid-tidal zone. This area has the highest global tidal fluctuations on record (Parker et al. 2007), with water depths varying from less than 10 cm up to 16 meters in a single tidal cycle. The average maximum depth at most occupied sites is anticipated to range between 8-9 m (A. Hebda, pers. observ.). At such sites, low current regimes may only be present at high slack and low slack (tide pool) periods.

The precautionary approach was applied when characterizing threat elements for which limited or inconclusive information was available, or in cases of uncertainty. In these situations, higher characterizations were selected. For example, Threat Extent for Spills from bulk petroleum movement in Gulf of Maine and Bay of Fundy was characterized as extensive based on predictive modelling in Owens (1977).

The rationales for the assignment of each characterization for Likelihood of Occurrence, Level of Impact, Causal Certainty, Threat Occurrence, Threat Frequency, and Threat Extent are detailed in the Results sub-section, “Rationalization for Threat Characterization”. Threat Risk does not require a rationale, as it is based on a formula in DFO (2014) that considers Likelihood of Occurrence and Level of Impact (see Table 2).

Most of the threats in this assessment are anticipatory, rather than current or historical, and, therefore, there is uncertainty in characterizing the risk of many of these threats for Atlantic

Mud-piddock. Responses of similar species (e.g., other bivalves) to these threats in other jurisdictions can help characterize some threats to Atlantic Mud-piddock in the Minas Basin. However, these threats are likely to have implications for Mud-piddock distribution, abundance, and persistence within Canadian waters.

Table 2. Methodology for Atlantic Mud-piddock Threat Assessment based on the DFO Guidance on Assessing Threats, Ecological Risk, and Ecological Impacts for Species at Risk (DFO 2014).

Threat Evaluation Criteria	**Methods**
Likelihood of Occurrence	*DFO 2014 Definition*: "The likelihood of occurrence: the probability of a specific threat occurring over 10 years or 3 generations, whichever is shorter." Categories: unknown, remote, unlikely, likely to occur (likely), known or very likely to occur (known) For the Atlantic Mud-piddock, the shorter period is 10 years. The 2009 COSEWIC report estimated a generation time of 4-5 years (COSEWIC 2009). Likelihood of Occurrence was determined based on evidence of threat occurrence as noted in COSEWIC (2009).
Level of Impact	*DFO 2014 Definition*: "Level of impact: the magnitude of the impact caused by a given threat, and the level to which it affects the survival or recovery of the population." Categories: unknown, low, medium, high, extreme There is no population estimate for the species or for the portion of the global population using Canadian waters. Therefore, a quantitative assessment of effects on population (as per DFO 2014) cannot be made using the population criteria. In Canada, there is no estimate of anthropogenic mortality. Qualitative evaluation has been done at extant sites with evaluation of presence/absence of current occupation in exposed habitats (pool bottoms, edges of undercuts under cap-rocks, etc). Consequently, gross evaluation of presence is possible; changes in occupancy can be noted as increases, decreases, or no change in apparent areas of occurrence at each site. Many of these threats are emerging, and impacts have not been assessed. It is therefore challenging to assess the potential level of impact, and so many are listed as unknown. Throughout this assessment, the precautionary approach is used to evaluate the threat evaluation criteria. For example, while the specific sites that may be impacted by the increased storm frequency and intensity associated with climate change is unknown, given their restricted distribution the potential impact from these events is considered high as per the precautionary approach.
Causal Certainty	*DFO 2014 Definition*: "Causal certainty: the strength of evidence linking the threat to the survival and recovery of the population." Categories: very low, low, medium, high, very high

Threat Evaluation Criteria	Methods
	For this assessment, each category is defined by the amount of evidence linking the threat to population decline or jeopardy to the species' survival or recovery. Evidence can be scientific, traditional ecological knowledge, or local knowledge. Very low - no studies on Mud-piddock, and no or limited studies on similar species Low - no studies on Mud-piddock, but studies on similar species Medium - few studies on Mud-piddock, or multiple studies on similar species High - modelling/predictions specific for threats and impacts to Mud-piddock Very high - impacts are documented and occurring now or occurred in the past; modelling studies have been validated
Threat Risk	*DFO 2014 Definition*: "Threat risk: the product of likelihood and level of impact as determined using a risk matrix approach." Categories: low, medium, high, unknown There is a standard formula provided in DFO 2014 to determine Threat Risk.
Threat Occurrence	*DFO 2014 Definition*: "Threat occurrence: refers to the timing of the occurrence of the threat, and describes whether a threat is *historic*al, *current* and/or *anticipatory*." Categories: historical, current, anticipatory These are defined as population-level Threat Occurrences.
Threat Frequency	*DFO 2014 Definition*: "Threat frequency: the temporal extent of the threat over the next 10 years or three generations, whichever is shorter." Categories: single, recurrent, and continuous In the absence of population or historical population trend data, expert opinion is used to assess the frequency of threats, considering uncertainty around timing and occurrence of specific events, over 10 years, which is shorter than 3 generations (generation time is estimated at 4-5 years; COSEWIC 2009). As with other threat evaluation criteria, threat frequency is characterized using a precautionary approach. For example, stochastic events such as major storm events, storm surges and changes in episodic erosional events, could be characterized as "single" events at present but could become more frequent and therefore "recurrent" in the future. Recurrent is applied to this threat as a precautionary approach. Due to the tidal cycle in the Bay of Fundy, threats that may be experienced by individuals as "recurring" were characterized as "continuous" as per the precautionary approach. For example, tidal turbine development is currently experimental with only two deployments since 2009, making the threat frequency recurrent. Turbines have been operational only for short periods after deployment, and therefore operation has also been recurrent. Operation of tidal turbines could be characterized as

Threat Evaluation Criteria	Methods
	“continuous” if experimental scale turbines are successful and/or lead to large scale development. Although this is uncertain at present, assuming that the turbines are “continuously” operating takes a precautionary approach.
Threat Extent	*DFO 2014 Definition*: “Threat extent: the proportion of the population affected by the threat.” Categories: restricted, narrow, broad, extensive Although there are no population/abundance estimates for the Atlantic Mud-piddock in Canadian waters, the distribution is restricted to a very limited geographic zone as defined by restricted substrate availability. Within that zone, the whole Canadian population would be subject to certain threats (e.g. climate change) although some threats may be localized and affect sub-populations at specific locations in the Minas Basin (e.g., recreational and adventure sport activities). For purposes of this assessment, this category is assessed in relation to the proportion of the occupied sites potentially affected by the threat, with consideration of the scope or extent of occupation of specific sites. There is little apparent consistency in the extent of occupancy among the locations, nor any (historical) data for changes in level of occupancy with time, except at “core” sites such as those spanning from Burntcoat Head to Mungo Brook, which contain approximately 90% of the population and appear to have a relatively stable population. For this assessment, the threat extent categories are interpreted as follows: Restricted: 1-25% of sites (1-3 sites) Narrow: 25-50% of sites (4-6 sites), or 1 of the “core” sites (not Burntcoat) Broad: 50-75% of peripheral sites (7-9 sites), or >50% of core sites (3 sites between Burntcoat Head and Mungo Brook) or Burntcoat Extensive:75-100% of sites (9-13 sites)

Results

The threat assessment summary is presented in Table 3 with a detailed rationale for each characterization provided in the Rational for Threat Characterization section.

Observed Impact

The Minas Basin is a dynamic environment with changes observed during the last two Mud-piddock surveys (2007-2008 and 2017-2018). For example, there is evidence that the extent of occupation at Saint’s Rest decreased in the period from 1948-2009 (COSEWIC 2009), and the sub-population became extirpated between 2009 and 2018 (A. Hebda, pers. observ., Clark et al. unpublished manuscript[4]). There is evidence that some historically occupied areas (i.e. previously populated areas between Sloop Rocks and Shad Creek, and an area to the west of the current Five Islands site) were previously covered by sand/cobbles and have since been uncovered, as indicated by the presence of old boreholes. The former site has been re-covered with sediment since 2009 (A Hebda, pers. observ.). Currently, there is colonization at Salter Head and Kingsport; however, there are extensive empty burrows at these sites, which indicates previous colonization and population loss. At these two sites, there is little evidence of extant mudstone, so the loss could be related to erosion of these soft habitats. Refer to COSEWIC 2009 or DFO 2010 for specific mapping (see Rationalization for Threat Characterization section for rationale).

It is estimated that approximately 90% of the population is associated with the headlands from Burntcoat Head, east to Mungo Brook (referred to as the “core” sites). The most significant sub-population within the core sites is associated with the western headlands and intertidal zone of Burntcoat Head. With the exception of small secure sub-populations at Port Williams and Spencer Point, the remaining sites are very small sub-populations, represented by very few individuals. Those sites are probably more reflective of the presence of suitable substrate for settlement during the reproductive period but do not reflect stable physical conditions allowing for larger-scale occupation or even persistence. The loss of the Burntcoat to Mungo Brook sub-populations would, in all likelihood, have a very significant effect on the persistence of the species in Canadian waters (Clark et al. unpublished manuscript[4]).

Due to the lack of abundance estimates or historical data, the causal certainty for each threat is considered very low to medium. Recent observations have noted local-scale impact of recreation and adventure sport activities, which caused the shearing off of soft red mudstone sediment on the edge of a tidal pool that slumped very close to an area of current occupancy, as evidenced by presence of siphons (A. Hebda, pers. observ. 2017). This could have caused smothering, had the sediment slumped onto the Mud-piddock burrows.

Table 3. Threat assessment summary for Atlantic Mud-piddock in Canadian waters based on DFO 2014 guidance.

Threat	Geographic Scale	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Climate Change	Minas Basin/Cobequid Bay	Known	High	Low	High	Current	Continuous	Extensive
Alteration of Shoreline or Water Control Structures	Cobequid Bay (with no consideration for potential far-field effects)	Likely	Low	Very Low	Low	Anticipatory	Recurrent	Narrow
Exploration or Extraction Activities in Minas Basin and Nearby Rivers	Minas Basin/Cobequid Bay	Unlikely	Unknown	Low	Unknown	Anticipatory	Continuous	Restricted
Large Scale Turbines	Minas Basin	Unlikely	Unknown	Medium	Unknown	Anticipatory	Continuous	Broad
Underground Gas Storage Project	Minas Basin	Very Likely	Low	Very Low	Low	Anticipatory	Continuous	Restricted
Other Sources of Pollution, Including Non-point Source Pollution	Minas Basin/Cobequid Bay	Remote	Unknown	Low	Unknown	Anticipatory	Single	Narrow
Release of Petroleum Products in Gulf of Maine and Bay of Fundy	Minas Basin/Cobequid Bay	Remote	Extreme	Medium	Low	Anticipatory	Recurrent	Extensive
Recreation and Adventure Sport Activities	Minas Basin/Cobequid Bay	Known	Low	Medium	Low	Current	Recurrent	Restricted

Rationalization for Threat Characterization

This section presents the rationale for characterizing each threat for the population of Atlantic Mud-piddock found in Atlantic Canada. Note that rationales are not provided for the Threat Risk, as explained in the Methods section and in Table 1.

Climate Change

Likelihood of Occurrence: **KNOWN**
• As noted in COSEWIC (2009), climate change enhancement of local natural processes may be a significant driver in the persistence or loss of local populations of Atlantic Mud-piddock. It should be noted that the degree of the natural variations in larger-scale movement and distribution of sediments is poorly documented in the Minas Basin. • Historical data concerning sediment discharge within the Basin suggest substantive change over a 113-year period (Knight 1977). Such natural variation may account for apparent changes in some of these populations during that period. Shorter-term changes in sub-populations are noted in COSEWIC (2009) and in this report (section Impacts to Date).
Level of Impact: **HIGH**
• Sea level rise, which has been associated with increases in rates of coastal erosion, results in greater sediment loading in the estuary. This is associated with a decrease in Basin volume (in spite of sea level increase) due to coastal erosion (Wilson 2016). As the intertidal zone shifts with sea-level rise, Mud-piddock in the lower intertidal zone could be lost, as the species is not known to exist subtidally in the Minas Basin. A shift could also result in settlement on new areas of red mudstone that are currently in the high intertidal zone. • An increase in ice panning on cap-rock, as well as otherwise unprotected habitats, could increase the scouring rate of protective cap-rock and/or soft substrates. This form of physical disturbance may have played a significant role in the loss of some sub-populations in the past (A. Hebda, pers. observ.) and could occur in the future; however, the resulting loss of habitat can expose new surfaces for settlement and colonization. • Impacts of ocean acidification are known for other bivalve species; however, potential impacts on Mud-piddock are currently unknown. • The current body of knowledge concerning increase in storm frequency and intensity in the Northwest Atlantic is changing, with a suite of studies building on the understanding of such large scale geo-spatial events (Eichler et al. 2013, Rapaport et al. 2017, GFDL 2018). • There has been a loss of small sub-populations at Five Houses Road, with ingress of fine sediments and changes in movement of coarser materials at Saints Rest (A. Hebda, pers. observ., Clark et al. unpublished manuscript[4]). This may not have a significant detrimental effect on the population as a whole, but, may in part, explain why all exposures of apparently suitable substrate may not be able to support sustainable populations outside of core locations.
Causal Certainty: **LOW**
• Climate change impacts are being experienced by other species elsewhere. There are no studies on Mud-piddock but studies on other bivalve species. • Field observations of losses of sub-populations from storm events indicate that Mud-piddock are susceptible to such events, which are known to be increasing with climate change.
Threat Occurrence: **CURRENT**
• Effects of climate change are currently being observed, including increased storm frequency and/or intensity.

Threat Frequency: **CONTINUOUS**
• While storms may occur periodically, impacts of sea level rise and ocean acidification (for example) would be continuous. • Climate change and sea level rise are continuous, while storm events occur episodically.
Threat Extent: **EXTENSIVE**
• Could potentially impact any and all sub-populations. • Impacts are unknown but are expected to be broadly distributed affecting multiple sub-populations within the Basin. Impacts may be different for each sub-population.

Alteration of Shoreline or Water Control Structures

Likelihood of Occurrence: **LIKELY**
• Planning is underway for dike removal and some dikeland re-alignment in the upper end of Cobequid Bay (Salmon River) with potential channel re-alignment resulting and creation of 22 hectares of saltmarsh in the Onslow area (Bowron and van Proosdij 2017a[5], Bowron and van Proosdij 2017b[6]). • Recent proposals through the Nova Scotia Departments of Transportation and Infrastructure Renewal, and Agriculture, for improvements to the hydrological conditions on a portion of the NS067 Onslow North River Dike System are moving forward. • Some potential exists for construction of new wharves. • Expansion of the Windsor causeway is under review. • Given the number of anticipated projects that may require some shoreline alteration, this threat is assessed as likely.
Level of Impact: **LOW**
• Changes in the outflow pattern (position of channel) of the Salmon River have been recorded by Knight (1977). The cause of these changes and how they have affected the sub-populations along the north shore of Cobequid Bay are not clear. However, one sub-population, Spencer Point, is within 25 km of the proposed area of dike removal and may be impacted by further changes in the Salmon River channel. • If the NS067 Onslow North River Dike System project proceeds, the net result could be a channel re-alignment of the lower reaches of the Salmon and North rivers, with potential changes in the energetic regimes (and concurrent sediment transport and deposition) in the upper Cobequid Bay. There is no data regarding the effect of such a dike removal and re-alignment on downstream sediment regimes. • Since each new project would require some form of regulatory review, the opportunity exists to include mitigation measures to reduce the risk of these projects to Mud-piddock; therefore, the level of impact is expected to be low.
Causal Certainty: **VERY LOW**
• There is no regional data on the effects of sedimentation from dike removal on the Atlantic Mud-piddock or other similar species; therefore, causal certainty is assessed as low.
Threat Occurrence**: ANTICIPITORY**
• Based on the recorded changes noted in Knight (1977), it is predicted that there may be an impact on the position of the Salmon River channel in the Eastern end of Cobequid Bay; at this point, it is not possible to determine what such a change would be or its magnitude.

[5] Bowron, G.J., and van Proosdij, D. 2017a. Managed Re-alignment & Restoration of the Truro-Onslow Marsh (NS067) – DRAFT discussion paper #1, prepared for the Nova Scotia Department of Transportation and Infrastructure Renewal & Department of Agriculture, CBWES Inc, March 2017, 31 pages.

[6] Bowron, G.J., and van Proosdij, D. 2017b. Managed Re-alignment & Restoration of the Truro-Onslow Marsh (NS067) – DRAFT discussion paper #2, prepared for the Nova Scotia Department of Transportation and Infrastructure Renewal & Department of Agriculture, CBWES Inc, May 2017, 10 pages.

- As mentioned above, dikeland re-alignment in the upper end of Cobequid Bay (Salmon River) is proposed but has not yet occurred.

Threat Frequency: **RECURRENT**

- If the developments documented by Bowron and van Proosdij (2017a[5],b[6]) proceed, this would be a single event, although the duration of the impact is uncertain (length of time for re-stabilization of the channels). The effect may be masked by other activities affecting sediment movement and redistribution within the Minas Basin.
- Given that other shoreline-altering projects are also expected to occur within the Minas Basin (e.g., wharf construction could occur at any time), this threat frequency is assessed as recurrent.

Threat Extent: **NARROW**

- The specific extent of such a change is difficult to predict since far-field effects of single developments in the Minas Basin (such as the impact of the construction of the Windsor Causeway) are difficult to predict (Graham Daborn, pers. comm.).
- None of the currently proposed projects are expected to affect the core sites, so the threat extent is assessed as narrow.

Exploration or Extraction Activities in the Minas Basin and Nearby Rivers

- Disturbance of sediments (e.g., resuspension and migration of sediments).

Likelihood of Occurrence: **UNLIKELY**

- A drilling and pilot-scale dredging/boring project was undertaken, with samples collected in the Shubenacadie River from the Gosse Bridge (45º15’01.45”N, 63º27’14.20”W), north to the discharge into Cobequid Bay at Black Rock (45º19’00.51”N, 63º29’06.03”W) and in the sand deposits with discharge into the Bay (NSDNR 2001). These samples were related to potential titanium extraction from the estuarine sediments proposed to occur in 1997-2002 (Titanium Corporation 2005). This project is not currently active and no activity has taken place since bulk sampling and drill samples were collected in 2001 and 2002, respectively.
- There have been no new proposals since this time.

Level of Impact: **UNKNOWN**

- In the RPA, the potential impact on Mud-piddock from extraction activities was described as smothering of habitat and may also include introduction of heavy metals and other potential toxins.
- No monitoring was undertaken at the time of coring/drilling or dredging to document the extent of change or movement of sediments.
- There are no Mud-piddock sites at the locations noted above where samples were collected.
- Given there is no information available on the potential far-field effects from the proposed titanium extraction project and the effects associated with other extraction activities are unknown at this time, the level of impact cannot be assessed.

Causal Certainty: **LOW**

- There are no published data on the specific (physical) nature of the materials (sediments) to be dredged and re-deposited post metal extraction. Consequently, it is difficult to ascertain the potential movement of such sediments within the Bay.
- Although there are no lab studies on the effects of heavy-metals on Mud-piddock, either from the point of view of toxicity or bioaccumulation, there is an extensive literature base on other bi-valve species, primarily those with commercial harvesting potential (see Azizi et al. (2018) for a current review using *Mytilus* spp as the model species).
- Potential effects on other species have been noted. Bradford et al. (2015) note this activity (and related aggregate extraction) may pose a threat to Striped Bass habitat.

- In the absence of data (sieve and pipette analyses), the causal certainty is assessed here as low.

Threat Occurrence: **ANTICIPATORY**

- There has been no submission of a project proposal to DFO.

Threat Frequency: **CONTINUOUS**

- The previously proposed project identified a potential processing rate of 3,600 tonnes per hour with a reserve of sand of 331 million tonnes, and it was calculated that approximately 1.94% of that mass would be heavy metals. If the development activity reported in the media is accurate (Cox 2017), with an expected life-cycle of the project of 10 years, the frequency is assessed as continuous.

Threat Extent: **RESTRICTED**

- No modeling of impact or extent of episodic release of dredged sediments has been undertaken.
- May impact populations adjacent to the operation. Given the location of the previously proposed project, which is not close to Burntcoat, the extent of the impact of this activity is assessed as restricted.

Large-scale Tidal Turbines

- Turbines at a scale sufficient to cause changes in sedimentation that would impact Atlantic Mud-piddock habitat.

Likelihood of Occurrence: **UNLIKELY**

- Demonstration-scale deployment of tidal turbines in the Minas Channel has been initiated, with a single turbine installed at the test site on two occasions (2009 and 2016). The Cape Sharp Tidal turbine that was deployed in 2016 has a generating capacity (nameplate capacity) of 2 megawatts (MW) (M. Baker, pers. comm.). This is not sufficient to alter the tidal regime and increase sedimentation.
- As part of a broader energy strategy, the Province of Nova Scotia has announced the tabling of Bill 29, the *Marine Renewable-Energy Act* (Nova Scotia Legislature 2017a), which would facilitate the broader scale deployment of test turbines (up to a total of 10 MW) outside the FORCE lease area. FORCE has a cap of 22 MW. This amount of energy extraction would not be sufficient to increase sedimentation and cause impacts to Mud-piddock.
- Predictions indicate potentially 300 MW of energy could be produced from tidal generation after 2020, including the Annapolis River facility that produces 20 MW of power (Province of Nova Scotia 2012), but this is unlikely to occur in the next 10 years.
- It is unlikely that the scale of tidal turbines installed in the Minas Passage will reach the extent that it will impact sedimentation in the Minas Basin in the next 10 years.

Level of Impact: **UNKNOWN**

- The Marine Renewable Energy Strategy (Province of Nova Scotia 2012) noted the potential of 2400 MW generating potential, which would result in a 5% decrease of flow of water through the Minas Passage and approximately a 30% loss of the kinetic resources of the Bay of Fundy (NRCAN 2017). The degree of suspension of sediment in the water column reflects the energetic regime of that water column. Reduced mixing due to energy decrease will result in a lower ability of particles to remain in suspension. In addition, resulting reduction in current near the water bottom interface may result in changes in the extent of deposition. This level of development is not expected to occur in the next 10 years (see above).
- Wu et al. (2015) note that a 500 MW generating potential would result in a 1.5% decrease in flow through the Minas Channel. It is not clear what effect such a decrease may have on sedimentation rates. Indications are there will be increased sedimentation in the Southern Bight.
- Ashall et al. (2016) model and document potential effects on suspended sediments and sedimentation rates with decreases in flow and current circulation patterns in the Minas

Basin. Results of the two model scenarios, low (770 MW, 16 turbine regions) and high (5,600 MW, 41 turbine regions) tidal power extraction cases, indicate that each scenario would cause a 5.6% and 37% decrease in suspended sediment concentrations in the Minas Basin, which could affect physical and biological processes particularly on the fine-grained intertidal areas around the macrotidal basin. Based on this modelling, 7 (Kingsport, Evangeline Beach, Noel Bay, Parrsboro, Economy Point, Spencer Point and Five Islands) of the current identified sites of occupancy for Mud-piddock would be effected. These sites have been listed in order of decreasing likelihood to experience effects, based on field work of extant sites where the presence of fine-grained sediments has been noted. Since the distribution of the Mud-piddock is either within this zone or adjacent to current areas of fine particulate deposition, it is inferred that fine sediment deposition would increase, potentially resulting in the loss of some of the current sites of occupancy. Affected sites are identified through personal observation (A. Hebda) and deposited materials and substrate identified, in part, in Knight (1977). Specific sites that could be lost as a result of sedimentation are Parrsboro and Economy Point in the north, and Kingsport and Evangeline in the south, where a qualitative increase in fine particulates was noted in the intervening period between the field work conducted in 2007-2008 and 2018. Previous survey data (COSEWIC 2009) and current work suggest that these sites continue to remain minor population sites with relatively low densities and limited distributions. Sites such as Port Williams (Starrs Point), Burntcoat Head, and Mungo Brook are in areas of higher tidal current regimes and to date do not appear to be impacted.

- A high level of uncertainty leads to an assessment of unknown.

Causal Certainty: **MEDIUM**

- The Mud-piddock is constrained in how it can respond to changes in sedimentation. Once it settles and starts boring, the body shifts slowly downwards as boring continues. The only part of the body that remains at the surface of the substrate is the terminal part of the siphons. There is only limited ability of the siphons to extend beyond the substrate surface since they also increase in diameter at points more proximal to the main body. Consequently, it is not able to extend the siphons much beyond the initial substrate surface (maximum observed – 0.5 cm, A. Hebda, pers. observ.), Therefore, any sedimentation events that would exceed this deposition depth would result in smothering of the individuals.
- The changes in cohesive (mud) suspended sediment concentrations from the addition of a tidal power extraction turbine array could lead to a potentially major environmental impact in the Minas Basin (Ashall et al. 2016). The modeling presented in Wu et al. (2015) suggests further changes possible, both in near and far fields. They note differences in predicted sediment deposition, depending on area within the Minas Basin with more coarse sediment being deposited in the Southern Bight (Avon River Estuary) compared to the central area of the Minas Basin. These potential changes in sediment movement are not resolved in the context of the increased erosional rates noted by Wilson (2016).
- Changes in resulting sedimentation patterns, especially distal from the turbine (arrays) would result in more substantive accumulation in sediments (Ashall et al. 2016), potentially magnifying the impact of naturally occurring changes as noted, historically by Knight (1977).
- Evidence exists that sedimentation can impact Mud-piddock, with coarse sediments more of a threat than fine sediments.

Threat Occurrence: **ANTICIPATORY**

- Small-scale tidal arrays have been tested but have not reached the scale necessary to alter tidal regimes or increase sedimentation on Mud-piddock habitat.

Threat Frequency: **CONTINUOUS**
• A large-scale array would be expected to be in continuous operation. Break down of individual turbines may occur; however, the threat is assessed as continuous as per the precautionary approach.
Threat Extent: **BROAD**
• Based on the very limited available information, a large-scale tidal array in continuous operation would be expected to impact seven sites, but not Burtncoat.

Underground Gas Storage Project

Likelihood of Occurrence: **VERY LIKEY**
• Industrial approval for the operation of the brine dispersal facility was granted in 2016 (Nova Scotia Environment 2016).
Level of Impact: **LOW**
• Modeling of the dispersal of the brine plume from the dispersal facility (MARTEC 2007) does not clearly outline the potential for changes in salinity regimes within Cobequid Bay, although restrictions were applied to other discharge factors including suspended particulate matter, pH, and total hydrocarbons (Nova Scotia Environment 2016). Due to uncertainties, additional restrictions were recommended on timing of discharge to avoid sensitive periods for other species (DFO 2016). • There have been no lab studies on the impact of salinity changes on Mud-piddock; however, they can be found in a wide range of salinity environments from 5-30 parts per thousand (ppt) but are more likely found in salinities of 14-30 ppt (COSEWIC 2009). Mud-piddock have been characterized as living in "mid and higher salinity regions of Chesapeake Bay" (Lippson and Lippson 2006). Salinity tolerance of Mud-piddock larvae is unknown, although Chanley (1965) maintained larval forms in a laboratory setting in a salinity range of 26-33 ppt. • If the salinity range resulting from this project is within natural salinity range of Mud-piddock, the impact is expected to be low. The salinity tolerance of Mud-piddock is broad, depending on the location and the stage of the tide. It has been found in estuarine habitats with salinites as low as 10 ppt (potentially much lower in rivulet habitats post major rainstorm events). Parker et al. (2007) note mid-summer salinities of 29.3 ppt at Burntcoat Head. If these current salinities were to change outside the current range, the level of impact may also change.
Causal Certainty: VERY LOW
• Specific modeling is not available, although changes in salinity and suspended particulate matter may be within the ranges the species normally encounters in this habitat. The impact on the whole Minas Basin population would be restricted (see Threat Extent, below); therefore, effects on species survival and recovery (DFO 2014) would be limited. • Impacts on larvae and other life-history stages are unknown.
Threat Occurrence: ANTICIPITORY
• Industrial approval for the operation of the brine release facility has been granted (Nova Scotia Environment 2016); the construction start date is unknown.
Threat Frequency: CONTINUOUS
• The brine dispersal facility would be operating continuously (brine release on falling tides) with the exception of spawning/migratory periods for fish species (DFO 2016) until the completion of the gas storage caverns.
Threat Extent: RESTRICTED
• With movement of either a plume or enhanced brine levels from the Shubenacadie River into the estuary (Cobequid Bay), potential effects will decrease with distance from point of discharge. Based on circulation models (Greenberg 1983, Wu et al. 2015), Spencer Point, the most easterly site (to the east of the Shubenacadie River outflow), is the only site that may be effected.

Other Sources of Pollution, Including Non-point Source Pollution

- Agriculture and urban runoff at levels that might be expected to impact Mud-piddock, including a pulse event at higher than usual concentrations.

Likelihood of Occurrence: **REMOTE**
• The watershed and surrounding land area adjacent to the Minas Basin is approximately 8,715 km^2, with a population of approximately 180,000 people, sparsely distributed around the basin, with 3 concentrations at Kings County, Shubenacadie River (East Hants corridor), and Salmon River (Truro) (Parker et al. 2007). • There is no documented effect of either urban or agricultural run-off on these waters, although there is record of a single incident in 1986, where a fire at a pesticide and agrichemical warehouse in the Canning area (Kings County) resulted in the release of both fertilizers and pesticides into the Avon Estuary of the Minas Basin (Percy et al. 1989).
Level of Impact: **UNKNOWN**
• No impacts were recorded on any mollusc populations, although mortalities were noted on fish species, as a result of the warehouse fire and associated chemical release (Percy et al. 1989). • Studies on the impacts of non-point source pollution, agricultural, and urban run-off on Mud-piddock have not been completed. • A review of the impact of coastal infrastructure associated with urban development is presented in Bulleri and Chapman (2010). • There have been reports of changes in fish community structure as a result of increased urbanization (DFO 2010).
Causal Certainty: **LOW**
• There is only a single spill event on record (Percy et al. 1989). • Studies are limited with none specific to Mud-piddock.
Threat Occurrence: **ANTICIPATORY**
• The past event resulted in the release of some toxins into an area without Mud-piddock, and it is not known to have impacted Mud-piddock (though no monitoring was conducted). Threat occurrence is listed as anticipatory to account for the possibility of a similar event occurring in an area of Mud-piddock occurrence.
Threat Frequency: **SINGLE**
• Based on past experience, it was felt that there was a low likelihood of a similar event occurring once in the next 10 years.
Threat Extent: **NARROW**
• Based on the single event (Percy et al. 1989), the area covered by an individual event would depend on the state of the tide, but could be affected by the specific river input and the stage of the tide. Specific surveys were not carried out at the time of the incident in Canning to determine the extent of noted fish mortalities; however, the bulk of the run-off generated during the incident was contained in drainage channels and one impoundment (Percy et al. 1989). • No other, specific, potential sources of surficial watershed contamination were identified during this review, although the presence of both agricultural and urban development within the Minas Basin watershed leaves open that possibility. • While a large spill might spread to a number of different sub-populations, with tidal flushing, concentrations of potential toxic agents might be expected to be reduced fairly quickly. There is potential for localized impacts on sub-populations, so threat extent is assessed here as narrow.

Release oF Petroeum Products iN tHE GULF oF MAINE aND BAY fF FUNDY

Likelihood of Occurrence: **REMOTE**
• In general, spills of crude and refined petroleum product occur within most areas where bulk tanker traffic is present, although most are of relatively small volume and local scope, with relatively few larger incidents in Canadian waters to date (Chadid 2015), and none have been recorded in the Minas Basin. • There are only 2 records of substantive crude petroleum/fuel marine accidents in Nova Scotia Atlantic waters, the M/T Arrow in 1970, with the release of approximately 10,000 tonnes of Bunker C fuel (Transport Canada 2016), and the MV Kurdistan in 1979, with the release of approximately 7,000 tonnes of Bunker C fuel in the Cabot Strait (Vandermeulen and Buckley 1985). • According to Transport Canada (2016), approximately 82 million tonnes of various petroleum and fuel products are moved annually by ship in Atlantic Canada, which includes the Gulf of St. Lawrence. At present, the closest regular petroleum traffic transits in and out of Saint John Harbour in New Brunswick. A total of 28,101,794 tonnes of liquid cargo (primarily petroleum) were shipped through the Port of St John in 2017 (Port of Saint John 2018).
Level of Impact: **EXTREME**
• In the absence of population data, the only indicator of potential "population-scale" impact is the restricted area of habitat use within the Minas Basin/Cobequid Bay. • Intertidal deposition of such materials could significantly affect the existing populations of Atlantic Mud-piddock through smothering and toxicity. Spill materials could be spread over a very large intertidal area (Owens 1977), including Mud-piddock habitat. The intertidal area of the Minas Basin is roughly 40,000 hectares (Percy 2001). Because of the floating nature of petroleum materials and the limited mobility of most shoreline invertebrates, intertidal communities are especially vulnerable, with both bivalves and gastropods being susceptible to smothering and chemical toxicity resulting in sub-lethal to lethal effects (Suchanek 1993). • Specific information on potential lethal and sub-lethal effects of crude oil on the veligers (mobile larva stage) is presented by Vignier et al. (2016), who reported toxic effects of the released, floating oil fraction from the *Deepwater Horizon* slick as well as the dispersant used in the clean-up on planktonic larval stages of Eastern oyster, *Crassostrea virginica*. Effects were recorded on larval growth, settlement and, ultimately, survival. The theoretical presence of Mud-piddock veligers in the water column and entrained (tidal pool) water for up to 35 days based on Chanley (1965) in July-August (G. Jones, pers comm.) suggests there may be a period of added susceptibility that could impact recruitment for the given year. Suchanek (1993) does note the potential impact on gametogenesis in adults leading to lowered fitness. • Clean-up activities may also have an impact. In cold water habitats, cleanup procedures can be very disruptive both physically and chemically to intertidal substrates (Owens 1977, Deslauriers et al. 1982).
Causal Certainty: **MEDIUM**
• There is little bulk shipping traffic inside the Minas Channel, so impact of site specific incidents would be low, but the twice daily ingress of approximately three billion cubic meters of tidal water from the Bay of Fundy and upper Gulf of Maine (Parker et al. 2007) could be a significant factor in the introduction of such spilled materials from other locations into the Mud-piddock occupied areas. • Although there are no published studies regarding the potential impact of spilled petroleum materials on the Atlantic Mud-piddock, it can be assumed that effects would be similar to those on other intertidal organisms, including bivalves.
Threat Occurrence: **ANTICIPATORY**
• There are no records of any substantive spill of such materials in the Bay of Fundy, as a whole, or the Minas Basin specifically, in the literature.

Threat Frequency: **RECURRENT**
• With the permanent closure of the Fundy Gypsum operations (CBC News 2011), and corresponding suspension of quarrying/mining and shipping activities, bulk marine cargo movement within the Minas Basin is substantially lower than in the past. There are no current Environmental Registrations on file with the Nova Scotia Department of Environment for the Bay of Fundy. • With continued use of ships for movement of petroleum crude and derivatives, as well as other non-petroleum cargoes, the potential frequency of this threat is dependent on the volume of bulk and liquid cargo that is moved. Recent hearings (National Energy Board 2017) received predictions of increased levels of tanker traffic in the Bay of Fundy, if the Energy East Pipeline and Eastern Mainline Projects were to proceed, although the hearings were suspended with the withdrawal of the Pipeline applications for the Energy East Pipeline and Eastern Mainline Projects. • Although tanker incidents and spills are infrequent, they do occur within the shipping industry in Canada and cannot be ruled out in Atlantic Canadian waters, including the Bay of Fundy (Chadid 2015).
Threat Extent: **EXTENSIVE**
• Distribution of the Mud-piddock is restricted to intertidal areas of the Minas Basin (COSEWIC 2009). That, coupled with the contention by Yeo and Risk (1979) that the majority of benthic invertebrates in this system reside in the intertidal zone, could put the whole population at risk in the event of a major petroleum spill. Owens (1977) has included this type of scenario in the 1977 Bay of Fundy Coastal Environment review.

Recreation and Adventure Sport Activities

- Assessing the current level of activity, including public runs, high intensity activity involving competitive mountain biking, and the use of motorized vehicles.

Likelihood of Occurrence: **KNOWN**
• Two bicycling events have occurred, one in July 2017 and the other in June 2018 in the core area of Atlantic Mud-piddock sub-populations (Burntcoat Head area). • Runs have occurred in Five Islands Provincial Park and Burntcoat in 2007 and 2015, respectively. A run is not planned at Burntcoat in 2018. • There is evidence of ATV use in the general area.
Level of Impact: **LOW**
• Localized impacts are expected, but population scale is low. However, the bicycle event occurs at Burntcoat, where most of the population occurs; therefore, higher impacts are possible if the scale of the events at Burntcoat were to increase (e.g., more bikes). • The current level of impact is considered to be low. While there is potential for increases in activity, mitigation measures are feasible in most cases. • All-terrain vehicles could pose a higher risk in the next 10 years, but there may be avoidance due to the presence of salt water. • Individuals who explore the intertidal zone on foot (e.g. visitors to Burntcoat Head Park or Five Islands Provincial Park) are not likely to have a major impact on Mud-piddock; impacts are expected to increase with an increase in individuals at the same time and place.
Causal Certainty: **MEDIUM**
• Understanding of impact is based on observations of existing activities, with evidence of damage to habitat but no evidence of impact on individuals or sub-populations. There have been no systematic experiments of these impacts with controls. • There is no evidence that these activities have affected the population abundance.
Threat Occurrence: **CURRENT**
• The biking and running events occur annually.
Threat Frequency: **RECURRENT**
• The biking and running events occur annually.

Threat Extent: **RESTRICTED**
• This threat is currently restricted to the specific footprint of the event (i.e., the course track).

Data Limitations and Uncertainties

This assessment process identified a number of data limitations that may affect the results. These include the following:

Lack of Historical Data

- There is neither a directed nor incidental harvest of the species, so historic harvesting and population data are lacking.
- Due to the relatively recent nature of specific details on the distribution and habitat use in Canadian waters, and lack of this information historically, conclusive evidence of threats having an effect on the population is lacking.

Lack of Population Estimate

- Determining the current occupancy of the identified sites is difficult. To validate occupancy, it would be necessary to visually inspect each site for evidence of occupancy (current or historic). This would require a burrow presence/absence evaluation, as well as evidence of live animals, which requires evaluation of presence of siphons (in order to differentiate occupancy between the Mud-piddock and the similar False Angel wing).
- The area under the "cap-rock" structures noted in COSEWIC (2009) is inaccessible for observation of occupancy. It is unknown how significant these habitats are as "critical" habitat. Unlike other species, veligers (larva) will move if settlement occurs on substrate that is unsuited for boring (and establishment). Using their foot, they can move from the first point of settlement/deposition, and will start burrowing once suitable texture for boring is located. Due to their "thigmotactic" habit, (orienting toward the surface of contact, regardless of gravitational orientation) Mud-piddock will bore at 90˚ to this final surface of establishment, so some burrows may be parallel to the ground, while, in some instances they may exhibit apparent negative geotropism, resulting in a complex structure of riffled substrate [see Figure 7 in Hebda (2010)]. Consequently, there is no ready method of determining occupancy in these structures.
- The significance of these protected areas may also be greater as veligers remain in the water column up to 35 days, based on culture trials (Chanley 1965). With the degree of water exchange in each of the daily tidal cycles, it is suspected that the majority of the veligers are exported out of the Minas Basin, so annual recruitment may be due to retained individuals within low-flushing areas. If so, habitats under cap-rock may be more significant when considering specific threats and or resistance to such threats.
- There is no population estimate for the Atlantic Mud-piddock in Canadian waters due to the cryptic nature of its habitat use, as well as poor mapping of the specialized substrate it occupies. This is compounded by the similarity in appearance of bore holes with another co-occurring species (the False Angel Wing, *Petricolaria pholadiformis*) upon casual evaluation, as well as similarity in siphon structure in living animals.

Lack of Information on Sedimentation Changes

- Although the principal potential threat to Mud-piddock persistence in Canadian waters appears to be changes in estuarine energy regimes affecting patterns, rates, and intensity of sedimentation, there is little understanding of how patterns of sedimentation would be affected by current and proposed energy-related developments, increasing storm intensity and frequency due to climate change, as well as climate adaptation mitigation initiatives. This is more significant in terms of far-field effects related to activities such as large-scale tidal energy projects, which are predicted to cause significant depositional changes (modelling by Ashall et al. 2016). This is confounded by natural changes in sedimentation patterns within the estuary, in a medium period of time (Knight 1977). Consequently, the assignment of values for Causal Certainty, Threat Risk, and Threat Occurrence are very subjective.

Lack of Species Specific Contaminant (organic or inorganic) Studies

- Due to the cryptic use of substrate in Canadian estuarine habitats, and the lack of biological knowledge, the Atlantic Mud-piddock are expected to be difficult to maintain in a laboratory setting through all of its life-history stages.

Recommendations to Address Data Limitations and Uncertainties

Since the Atlantic Mud-piddock is constrained to a single geological formation, fine-scale mapping of the intertidal areas of the Minas Basin for the red-mudstone facies would, at least, define potential habitat that could be examined in finer detail for evidence of settlement and occupation. Furthermore, the monitoring of suitable habitat through time could be used to detect changes in the location and number of sub-populations.

Sampling for veligers in the water column in late June/July, as well as within tidally-protected areas (low energy tide pools and under cap-rock complex), may identify significant recruitment sites or areas, allowing for comparison with sites identified as having a heightened sensitivity to sedimentary changes. Chanley (1965) spawned adult *B. truncata* from Virginia in mid-May, as well as through August and September. Preliminary work by G. Jones, in a histological study of *B. truncata,* noted that gonad size in Nova Scotia specimens increased until late June to early July, suggesting a later spawning period than most other marine molluscs (Sullivan 1948; G. Jones, pers comm.) Validation of this preliminary observation is required.

A comprehensive evaluation of the potential for sediment redistribution related to infrastructure development, which may affect current energy regimes and deposition patterns, is recommended for the Minas Basin. Examples of infrastructure development include the installation of tidal generators, modification or installation of causeway structures, or removal of existing dikes to create or re-establish saltmarshes. Current environmental reviews are restricted to the scope of specific, individual projects, and do not account for potential cumulative effects of multiple projects. This may, in part, be addressed by current legislative initiatives (Nova Scotia Legislature 2017b) and amendments to the Marine Renewable-energy Act - Bill 29 (Nova Scotia Legislature 2017a).

The understanding of far-field effects associated with infrastructure development is poor in both low energy areas, such as salt-marshes, and other areas with little active sediment deposition (areas noted to be of concern by Ashall et al. (2016)). Sediment modelling at current, as well as potential Mud-piddock sites of occupancy, could indicate the natural variation at these sites and their relative importance. This would provide some clarity concerning the “far-field” effects that may be generated during activities within the basin.

To determine the recovery potential of the Mud-piddock in Canadian waters, it is necessary to understand the genetic relationships of this population with nearby (American) populations. This would also clarify the uncertainty about the origins of the populations in the Minas Basin area, the most northerly populations in the species’ global range.

Conclusions

Within Canadian habitats, there are no specific documented mortalities of Atlantic Mud-piddock related to anthropogenic threats due to the lack of historical data and little direct field monitoring. Observed changes to sub-populations in the last 10 years suggest that sedimentation is the principal threat to Mud-piddock, with the recent losses of sub-populations attributed to shifting sand that has covered these populations.

Climate change is the threat with the highest identified risk. Addressing climate change is outside of the scope of DFO's mandate; however, it is considered the species' highest potential threat. The effects of climate change are uncertain, with potential wide-ranging effects varying from the loss of existing habitat to the creation of new habitat for Atlantic Mud-piddock settlement.

The precautionary approach is applied throughout this risk assessment, assuming the greatest potential risk to Mud-piddock for all threats. The threat risks associated with the alteration of shoreline or water control structures, underground gas storage, release of petroleum products, and recreation and adventure activities were evaluated as low. Due to uncertainties concerning the level of impact associated with exploration and extraction activities, large scale turbines, and other sources of pollution, the threat risk for these activities was evaluated as unknown.

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