Hanging on by a byssal thread,
The Asian Green Mussel, *Arcuatula senhousia* (Benson in Cantor, 1842) in British Columbia, Canada and Washington State, U.S.A.

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The Asian Green Mussel, *Arcuatula senhousia*, native to the NW Pacific (Siberia-Japan-Korea-China), has successfully spread worldwide (Carlton 1979; Crooks 2002). It has a number of common names including the Green Bag-mussel, Green Mussel, Asian Date Mussel and Senhouse's Mussel. *A. senhousia* is a highly adaptive species, and is able to tolerate low salinities. It is a small mussel, coloured olive and brown with green patches and radial lines and has zig-zag markings, distinguishing it from native mussels (Fig. 1). It has a shell length to 35 mm and a short life span of approximately 2 years. It is typically found in mud-gravel sediments in the intertidal zone to 20 m (Coan et. al. 2000). The Asian Green Mussel has persisted for almost 100 years, circa 1924 to 2020, in the Salish Sea of B.C. and Washington.

Etymology: *Arcuatula senhousia*, was first found in China, and was described in 1842 by William Benson. It is believed he named it after Sir Humphrey Fleming Senhouse, a British naval officer who died in Hong Kong in 1841 during the infamous Opium War between Britain and China (Watson 2019).

Asian green mussels *Arcuatula senhousia* in B.C. (1971-2018)

A review of collections determined that the earliest record for BC was collected by Elsie Marshall of Washington, from Portage Inlet, Victoria, B.C. in May, 1971 (G.Holm, pers. comm.). A sample was given to George Holm and a second sample was deposited at the Burke museum (M. Frey, pers. comm.). This is earlier than Robert Forsyth's collection of *Musculista senhousia* (now *Arcuatula senhousia*) in B.C., from the Nikomekl estuary, in 1991 (Forsyth 1993; Cohen 2011). I believe, however, that the Asian mussel may have been long established at several sites in B.C., just overlooked because of its small size.

The next records of *A. senhousia* in B.C. were from intertidal clam surveys at Goldstream estuary Finlayson Arm, near Victoria in 1994, and at Savary Island (northern record) in April, 1995 (Merilees and Gillespie 1995). The Asian mussels in Finlayson Arm and at Savary Island were detected because they were attached to the shells of Manila clams, *Ruditapes philipinarum*, being collected as part of intertidal clam surveys. Merilees and Gillespie (1995) note that had the mussels not been attached to the larger clams, they would have likely been overlooked. Subsequently, *A. senhousia* has been found at additional locations in southern British Columbia (**Table 1**). In the Salish Sea, they have been found at multiple sites (**Table 1**) in Ladysmith Harbour, Nanoose Bay, Departure Bay and in Portage Inlet in Victoria (Y. Carolsfeld, pers. comm.).

Figure 1. Ladysmith Harbour, single specimens in mud-gravel; gravel bound in the byssal mat; intertidal.May, 2014. Rick Harbo image.

The mussels have also been found on the outer, west coast of Vancouver Island, surviving in protected waters of Pipestem Inlet (2007) and Hismit Inlet (Tahsis Inlet) (**Table 1**). It is not known if these were transported during aquaculture activities or if the larvae travelled up the west coast of Vancouver Island. Other invasive bivalves (e.g. manila clams, *Ruditapes philippinarum* and Varnish clams, *Nuttallia obscurata*) that originated in inside waters have travelled to the outer coast of Vancouver Island and as far south as Oregon .

Dead shells of *A. senhousia* are often found on surface sediments and live specimens are collected by digging and screening. Live mussels found in B.C. to date have been single individuals, buried with byssal threads attached to gravel (**Figure 1**). In other locations, Washington (J. Kocian, pers. comm.; **Figure 2, 3**) and California (Crooks 2002), mussel mats can reach densities of 5,000 to 10,000 and more, mussels per square meter.

On 2014-05-29, as part of a Fisheries and Oceans Canada (DFO) diversity study, live specimens of *A. senhousia* were collected at Ladysmith Harbour, B.C. and sequenced (CAPBS424-17 **-** *Arcuatula senhousia* COI-5P:661; Leg. R. Harbo MIB2769). The sequences are posted on BOLD, http://www.boldsystems.org/index.php/Public_RecordView?processid=CAPBS424-17

New sampling techniques for environmental DNA found in water samples in 2016, revealed *A. senhousia* in Departure Bay, Nanaimo, B.C. (Westfall et al. 2020).

Asian green mussels *Arcuatula senhousia* in Washington (1924-2020)

In Washington, Asian green mussels, *A. senhousia*, have been found in northern Puget Sound (Samish Bay; Whidbey Island), the length of Hood Canal, and southern Puget Sound (Oyster Bay; Shelton) (**Table 2**).

The Asian green mussel was first collected in Samish Bay, Washington, on beds of Japanese oysters in 1924 (Kincaid 1947. It was named as *Modiolus senhausi* (misspelling) and reported as "abundant" in the summer of 1924 in Japanese oyster (*Crassostrea gigas*) beds in the Samish Bay, northern Puget Sound, Washington (Kincaid 1947), but it probably did not establish at that time (Cohen 2011). Kincaid 1949 found at least one "*Volsella senhausi*" specimen in several boxes of oyster seed from Kumamoto, Southern Japan, to be planted in Willapa Bay.

There are museum lots of *A. senhousia* from Hood Canal, Washington at the LACM and RBCM (Table 2). Similar to BC, individual mussels have been detected in Manila clam surveys in Hood Canal (2016, 2017 M. Duthier, pers. comm.; 2020 J. Ruesink, pers. comm.). There are historic records for Oyster Bay and recent discoveries at Whidbey Island (2013-2020) in tidal pools that were found to have high density mats of *A. senhousia* and individuals attached to algae and wood debris (Jan Kocian, pers. comm.; **Figures 2,3,4**).

Figure 2. High density mussel mat, *A. senhousia*. Whidbey Island, WA, tidal pools. Nov. 22, 2020. Jan Kocian image.

Siphon show characteristics of *Arcuatula senhousia*

The siphon shows of live *A. senhousia* are unique and can be used to identify the mussels in the field (**Figure 4)**. The larger incurrent siphon is broad and has well spaced, short white papillae on the rim. The smaller, oval excurrent siphon does not have papillae. The siphons may be clear (more so in juveniles?) to rusty red with numerous white patches. The siphons can be completely retracted into the shells (**Figure 1**).

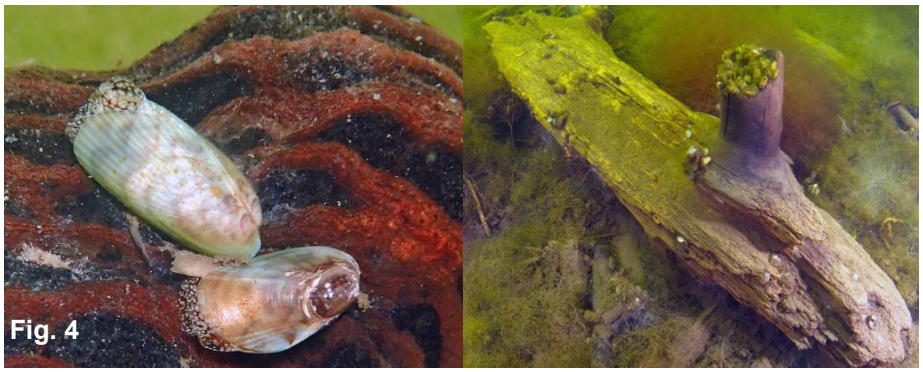

Figure 3. Mussels on surface, attached to algae, Whidbey I., WA. June 29, 2019. Jan Kocian image.
Figure 4. Mussels on surface, attached to wood debris. Whidbey I., WA. June 29, 2019. Jan Kocian image.

Introduction and Reproduction

Initial introductions in Washington were from oyster aquaculture activities. Oyster seed movements from Japan ceased by the 1970's (Bourne 1979). Introductions at many locations may not have resulted in populations that are sustainable (Cohen 2011). The early new record of 1971, suggests that introductions in BC may also have been from oyster aquaculture activities. Some introductions in B.C. and Washington may have also been a result of mussel larvae spread from discharges of ships ballast waters (Carlton 1992).

This mussel has separate sexes, with males and females spawning at the same time. Spawning time is likely late spring in our waters. Individual *A. senhousia* continue to be found in the intertidal zone but high-density mussel mats, a source of the mussels, have not been identified in BC and only at one location in WA.

It is not known how *A. senhousia* is able to reproduce and sustain the populations. The widespread populations may originate from subtidal populations and high density mussel mats, yet to be identified.

Fish and shorebirds are significant predators on the introduced mussel, *A. senhousia* (Crooks 2002).


Fig. 5

Fig. 5. Comparative size of Asian green mussel and Blue mussel, *Mytilus trossulus*. - **Fig. 6**. Ponds at Whidbey Island. Jan Kocian Image.

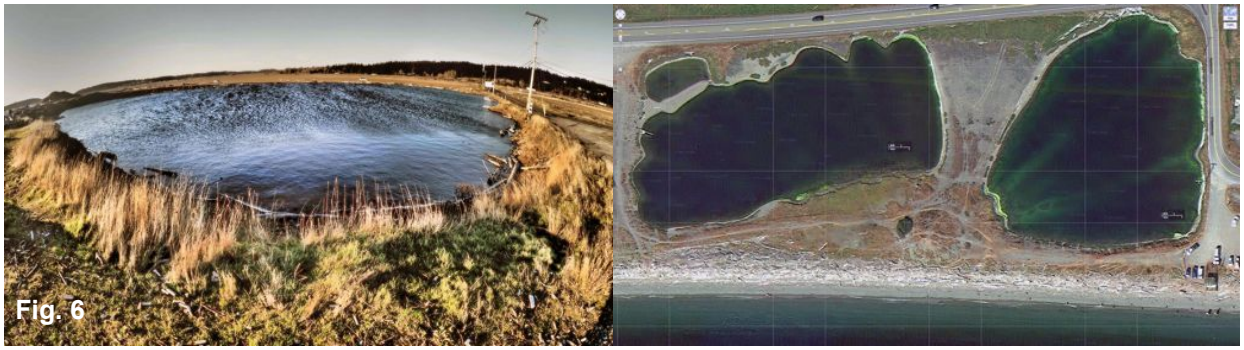
Fig. 6

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[**Note**: A search for *Arcuatula senhousia,* the Asian Date Mussel, on iNaturalist did not find any observations in BC or WA. Images from BC were then posted by R. Harbo.]

Table 1. Asian Green Mussels, *Arcuatula senhousia*, in B.C., 1971-2018.

Date	Location	Collector	Reference
1971-05	Portage Inlet, Victoria, B.C.	Elsie Marshall	G. Holm collection GH3818-5; Burke Museum 37026
1991-06-27	Nikomekl River estuary, Boundary Bay	Robert Forsyth	RBCM[1] 13-27-1
1994-08-05	Goldstream estuary, Finlayson Arm	Graham Gillespie	Clam survey; R. Harbo (RH) collection
1994-08-08	Arbutus creek estuary, Finalyson Arm	Graham Gillespie	Clam survey; RBCM 995-32-1
1995-04-21	Indian Point, Savary Island* **Northern record*	Graham Gillespie	Clam survey; RBCM 995-52-1
1996-04-25	Goldstream Estuary Finlayson Arm	Graham Gillespie	Clam survey; RH collection
1999-10-24	Departure Bay, Nanaimo	Bill Merilees	B. Merilees collection
2001-04-09	Nanoose Bay	Mike Kattilakoski	RH collection

2007-07-01	Himlet Inlet- beach below Deserted Lake, Tahsis	Gavin Hanke	RBCM 13-26-1
2007-07-03	Pipestem Inlet, just west of Hillier Island, Barkley Sound	Gavin Hanke	RBCM 13-27-1
2014-05-19	Ladysmith Harbour	Rick Harbo	RBCM014-315-1
2014-05-29	Ladysmith Harbour	Rick Harbo	BOLD[2] CAPBS424-17; MIB2769
2014-06-27	Ladysmith Harbour	Melissa Frey	RBCM 14-318-17
2016	Departure Bay, Nanaimo	Kristen Westfall	Westfall et al. 2020 (water sample)
2018-08-30	Bush Creek, Ladysmith Harbour	Rick Harbo	RBCM 18-837-1

[1]Royal BC Museum, Victoria, B.C.

[2]Barcode of Life Data Systems

Table 2. Asian Green Mussels, *Arcuatula senhousia*, in Puget Sound, Washington State, 1924-2020.

Date	Location	Collector (or Observer)	Reference
1924	Samish Bay	Trevor Kincaid	Kincaid 1947; Burke M[1] 31923
June, 1961	Oyster Bay	Eleanor Duggan	LACM 182359; Unpublished communication to G. Hanna 1963
1961	Shelton, southern Puget Sound	Lola Elford	Burke 42058
1977	Brinnon, Dosewallips Flats	James T. Carlton	Carlton, 1979
1979	Hood Canal; Lynch Cove Mudflats,	B. Wisseman	RBCM 989-540-1
Aug. 19, 2009	Oak Bay, Puget Sound	Linda Schroeder, George Holm	PNWSC[2] photos
June 29, 2013	Whidbey Island	Jan Kocian	J. Kocian, pers. comm.; photos 2013, 2019, 2020
June 2016 and June 2017	Hamma Hamma Oyster Farm, on the central-west side of Hood Canal	Megan Dethier	Megan Dethier, clam survey; Friday Harbor Labs, U of WA
Feb. 2020	Belfair, Lynch Cove, Hood Canal	Chris Jendry	Jennifer Ruesink, clam survey, U of WA; Burke Museum 58325

[1] Burke Museum, University of Washington, Seattle

[2] http://www.bily.com/pnwsc/web-content/Family-Pages/Bivalves-Mytilidae.html

[3]Royal BC Museum, Victoria, B.C.

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Figure of widespread locations (approximate) of *A. senhousia* (excluding sites on the west coast of Vancouver I.)