Bering Sea Marine Invasive Species Assessment

Alaska Center for Conservation Science

Scientific Name: *Salmo salar*

Common Name *Atlantic salmon*

Phylum	Chordata
Class	Actinopterygii
Order	Salmoniformes
Family	Salmonidae

Final Rank 49.25

Data Deficiency: 0.00

Species Occurrence by Ecoregion

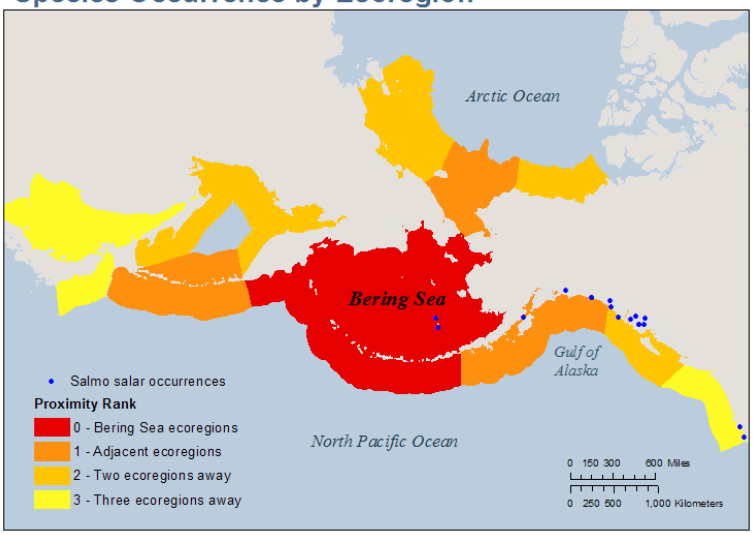

Figure 1. Occurrence records for non-native species, and their geographic proximity to the Bering Sea. Ecoregions are based on the classification system by Spalding et al. (2007). Occurrence record data source(s): NEMESIS and NAS databases.

Category Scores and Data Deficiencies

Category	Score	Total Possible	Data Deficient Points
Distribution and Habitat:	16.25	30	0
Anthropogenic Influence:	7.25	10	0
Biological Characteristics:	18.75	30	0
Impacts:	7	30	0
Totals:	49.25	100.00	0.00

General Biological Information

Tolerances and Thresholds

Minimum Temperature (°C)	-0.7	Minimum Salinity (ppt)	0
Maximum Temperature (°C)	27.8	Maximum Salinity (ppt)	35.3
Minimum Reproductive Temperature (°C)	7.2	Minimum Reproductive Salinity (ppt)	0
Maximum Reproductive Temperature (°C)	10	Maximum Reproductive Salinity (ppt)	0

Additional Notes

Atlantic salmon are anadromous fish native to the North Atlantic Ocean. Introductions in Alaska are largely the result of escaped individuals from fish farms in B.C. and Washington. Several significant escape events have been noted; for example, in August 2017, >145 000 fish escaped from a net pen on Cypress Island, WA. Atlantic salmon require freshwater to spawn. A thorough risk assessment for this species must therefore consider compatibility with freshwater as well as marine conditions. However, in keeping with the scope of this project (i.e. the Bering Sea ecosystem), we assess this species' impacts and establishment potential only with respect to its marine life phase.

Reviewed by Peter Westley, Assistant Professor, College of Fisheries and Ocean Sciences, UAF, Fairbanks AK

Review Date: 9/6/2017

1. Distribution and Habitat

1.1 Survival requirements - Water temperature

Choice: B — Moderate overlap – A moderate area (≥25%) of the Bering Sea has temperatures suitable for year-round survival

Score: 2.5 of 3.75

High uncertainty? ☑

Ranking Rationale:
Temperatures required for year-round survival occur in a moderate area (≥25%) of the Bering Sea. We ranked this question with "High Uncertainty" to indicate disagreements in model estimates.

Background Information:
The optimal temperature range for survival is 4°C to 12°C (NAS; USGS 2016). The lower lethal temperature limit is -0.7°C, upper limit is 27.8°C (Bigelow 1963).

Sources:
NAS database, USGS 2017 Bigelow 1963

1.2 Survival requirements - Water salinity

Choice: A — Considerable overlap – A large area (>75%) of the Bering Sea has salinities suitable for year-round survival

Score: 3.75 of 3.75

Ranking Rationale:
Salinities required for year-round survival occur over a large (>75%) area of the Bering Sea.

Background Information:
Freshwater is required for reproduction and very young individuals. Adaptability to seawater typically increases during parr-smolt transformation, though large parr (> 120 mm) can tolerate salinities up to 31 ppt (Farmer et al. 1978; Danie et al. 1984). Post-smolts in the Norwegian Sea were caught at salinities between 34 and 35.3 ppt (Holm et al. 2000).

Sources:
Holm et al. 2000 NAS database, USGS 2017 Danie et al. 1984 Farmer et al. 1978

1.3 Establishment requirements - Water temperature

Choice: D — No overlap – Temperatures required for reproduction do not exist in the Bering Sea

Score: 0 of 3.75

Ranking Rationale:
Atlantic salmon require freshwater to spawn.

Background Information:
Requires freshwater for spawning and juvenile life stages (NAS; USGS 2017).

Sources:
NAS database, USGS 2017

1.4 Establishment requirements - Water salinity

Choice: D — No overlap – Salinities required for reproduction do not exist in the Bering Sea

Score: 0 of 3.75

Ranking Rationale:
Atlantic salmon require freshwater to spawn.

Background Information:
Requires freshwater for spawning and juvenile life stages (NAS; USGS 2017).

Sources:
NAS database, USGS 2017

1.5 Local ecoregional distribution

Choice: A — Present in the Bering Sea

Score: 5 of 5

Ranking Rationale:
Occasionally observed in the Bering Sea.

Background Information:
Individuals have been documented primarily in southeast Alaska, but have also been caught in the Gulf of Alaska and in the Bering Sea (Wing et al. 1992, Brodeur and Busby 1998, Gross 1998). The first recorded instance of S. salar in the Bering Sea was in September 1997, when an individual was captured in a bottom trawl south of the Pribilof Islands (Brodeur and Busby 1998).

Sources:
NAS database, USGS 2017 Brodeur and Busby 1998 Gross 1998 Wing et al. 1992

1.6 Global ecoregional distribution

Choice: A — In many ecoregions globally

Score: 5 of 5

Ranking Rationale:
Wide global distribution.

Background Information:
Found in both polar and temperate waters, on both the Eastern and Western coasts of North America, and in Europe's Atlantic Ocean (as far south as Portugal). Has been introduced in Argentina, Australia, Chile, and New Zealand (WCMC 1996). Despite these extensive introduction efforts, there are no self-sustaining anadromous populations of Atlantic salmon outside the species' native range, and only a few self-sustaining landlocked populations (Thorstad et al. 2011).

Sources:
WCMC 1996 Thorstad et al. 2011

1.7 Current distribution trends

Choice: D — Not well established outside of native range

Score: 0 of 5

Ranking Rationale:
Capable of long-distance dispersal, but dispersals and introduction efforts have not resulted in established populations.

Background Information:
Atlantic Salmon have been introduced worldwide and are capable of long-distance dispersal of 1500 km or more (Hansen and Youngson 2010). However, despite extensive introduction efforts, there are no self-sustaining anadromous populations of Atlantic salmon outside the species' native range, and only a few self-sustaining landlocked populations (Thorstad et al. 2011).

Sources:
Hansen and Youngson 2010 Thorstad et al. 2011

Section Total - Scored Points:	16.25
Section Total - Possible Points:	30
Section Total -Data Deficient Points:	0

2. Anthropogenic Transportation and Establishment

2.1 Transport requirements: relies on use of shipping lanes (hull fouling, ballast water), fisheries, recreation, mariculture, etc. for transport

Choice: A

Has been observed using anthropogenic vectors for transport and transports independent of any anthropogenic vector once introduced

Score: 4 of 4

Ranking Rationale:
Intentionally moved for aquaculture or recreational purposes. Can disperse naturally after initial introduction.

Background Information:
Anthropogenic transportation is restricted to intentional introductions. Once introduced, S. salar can undergo long distance dispersal without human assistance (NAS, USGS 2017).

Sources:
NAS database, USGS 2017

2.2 Establishment requirements: relies on marine infrastructure, (e.g. harbors, ports) to establish

Choice: C

Uses anthropogenic disturbance/infrastructure to establish; never observed establishing in undisturbed areas

Score: 1.25 of 4

Ranking Rationale:
Although populations have been introduced worldwide for aquaculture and recreation, very few have become self-sustaining.

Background Information:
Once Atlantic salmon escape from their mariculture infrastructure, they can disperse to and survive in pristine, natural areas (Gross 1998). Natural spawning has been observed among 'escaped' Atlantic salmon in British Columbia (Volpe et al. 2000); however, this species rarely establishes self-sustaining populations outside of its native range (Thorstad et al. 2011).

Sources:
Gross 1998 Volpe et al. 2000 Thorstad et al. 2011

2.3 Is this species currently or potentially farmed or otherwise intentionally cultivated?

Choice: A

Yes

Score: 2 of 2

Ranking Rationale:
Atlantic salmon is one of the most important commercially farmed fin fish in the world. It has also been intentionally introduced for sportfishing.

Background Information:
Atlantic Salmon have a long history of being stocked and farmed in areas outside of their historic range. Salmon mariculture is practiced in many parts of the world including the UK, Ireland, Faroe Island, Canada, USA, Chile, Australia, New Zealand, France and Spain (reviewed in FAO 2017b). In 2014, worldwide production of farmed Atlantic salmon was estimated at 2.3 million tonnes (FAO 2017b).

Sources:
FAO 2017b

Section Total - Scored Points:	7.25
Section Total - Possible Points:	10
Section Total -Data Deficient Points:	0

3. Biological Characteristics

3.1 Dietary specialization

Choice: A

Generalist at all life stages and/or foods are readily available in the study area

Score: 5 of 5

Ranking Rationale:
Generalist at all life stages.

Background Information:
Young salmon feed on aquatic and terrestrial insects. Adults feed on crustaceans and other fish. At the population level, Atlantic Salmon are considered as generalist feeders, even though individuals may specialize on only a few food items (Jorgensen et al. 2000).

Sources:
Jorgensen et al. 2000

3.2 Habitat specialization and water tolerances

Does the species use a variety of habitats or tolerate a wide range of temperatures, salinity regimes, dissolved oxygen levels, calcium concentrations, hydrodynamics, pollution, etc?

Choice: B

Requires specialized habitat for some life stages (e.g., reproduction)

Score: 3.25 of 5

Ranking Rationale:
Requires freshwater for spawning and juvenile development.

Background Information:
Atlantic Salmon are anadromous and require freshwater for spawning and during the juvenile life stage (Thorpe 1994; NAS, USGS 2016).

Sources:
NAS database, USGS 2017 Thorpe 1994

3.3 Desiccation tolerance

Choice: C

Little to no tolerance (<1 day) of desiccation during its life cycle

Score: 1.75 of 5

Ranking Rationale:
Atlantic salmon cannot survive out of water for extended periods of time.

Background Information:
S. salar is a ray-finned fish that requires water for respiration.

Sources:
Randall 1970

3.4 Likelihood of success for reproductive strategy

i. Asexual or hermaphroditic ii. High fecundity (e.g. >10,000 eggs/kg) iii. Low parental investment and/or external fertilization iv. Short generation time

Choice: **B**

Moderate – Exhibits one or two of the above characteristics

Score: **3.25** **of** **5**

Ranking Rationale:

Exhibit low parental investment and external fertilization. However, reproduction is sexual, fecundity is low, and they do not have a short generation time.

Background Information:

Life span is 4 - 6 years, half in freshwater, half in a marine environment (NOAA 2016). Females produce 1,500 to 1,800 eggs/kg and are capable of spawning more than once during their life time. There is no parental investment after eggs have been covered and nesting is complete.

Sources:

NOAA 2016

3.5 Likelihood of long-distance dispersal or movements

Consider dispersal by more than one method and/or numerous opportunities for long or short distance dispersal e.g. broadcast, float, swim, carried in currents; vs. sessile or sink.

Choice: **A**

Disperses long (>10 km) distances

Score: **2.5** **of** **2.5**

Ranking Rationale:

Capable of long-distance movements.

Background Information:

Adults are capable of moving large distances (1500 km; Hansen and Youngson 2010).

Sources:

Hansen and Youngson 2010

3.6 Likelihood of dispersal or movement events during multiple life stages

i. Can disperse at more than one life stage and/or highly mobile ii. Larval viability window is long (days v. hours) iii. Different modes of dispersal are achieved at different life stages (e.g. unintentional spread of eggs, migration of adults)

Choice: **B**

Moderate – Exhibits one of the above characteristics

Score: **1.75** **of** **2.5**

Ranking Rationale:

Although larval viability is long, dispersal only occurs with the adult lifestage. Individuals show high natal site fidelity.

Background Information:

Dispersal events occur only at smolt and post-smolt life stages. Younger life stages remain in the freshwater body in which they were born until they are ready to migrate to sea. Anadramous populations tend to return to the same freshwater site year after year (NOAA 2016).

Sources:

NOAA 2016

3.7 Vulnerability to predators

Choice: **D**

Multiple predators present in the Bering Sea or neighboring regions

Score: **1.25** **of** **5**

Ranking Rationale:

Several taxa including birds, fishes, and marine mammals prey upon Atlantic Salmon.

Background Information:

Atlantic Salmon are predated upon by birds (Montevecchi et al. 2002), fish (Hvidsten and Lund 1988), and marine mammals (Carss et al. 1990).

Sources:

Montevecchi et al. 2009 Hvidsten and Lund 1988 Carss et al. 1990

Section Total - Scored Points:	18.75
Section Total - Possible Points:	30
Section Total -Data Deficient Points:	0

4. Ecological and Socioeconomic Impacts

4.1 Impact on community composition

Choice: C

Limited – Single trophic level; may cause decline but not extirpation

Score: 0.75 of 2.5

Ranking Rationale:
May compete with native salmon species.

Background Information:
Farmed Atlantic salmon may compete with native salmon populations for resources such as habitat, mating partners and prey. Farmed Atlantic salmon can have significant and negative impacts on wild Atlantic salmon (e.g. Fleming and Einum 1997; Fleming et al. 2000; McGinnity et al. 2003; reviewed in Glover et al. 2017), but their impacts on Pacific salmon appear limited (Naylor et al. 2005; Nielsen et al. 2013).

Sources:
Naylor et al. 2005 Fleming and Einum 1997 Fleming et al. 2000 McGinnity et al. 2003 Nielsen et al. 2013 Glover et al. 2017

4.2 Impact on habitat for other species

Choice: D

No impact

Score: 0 of 2.5

Ranking Rationale:
No impacts have been reported. Given its ecology, we do not expect Atlantic Salmon to impact habitat in the Bering Sea.

Background Information:
No information found.

Sources:
None listed

4.3 Impact on ecosystem function and processes

Choice: D

No impact

Score: 0 of 2.5

Ranking Rationale:
No impacts have been reported.

Background Information:
No information found.

Sources:
None listed

4.4 Impact on high-value, rare, or sensitive species and/or communities

Choice: C

Limited – Has limited potential to cause degradation of one more species or communities, with limited impact and/or within a very limited region

Score: 0.75 **of** 2.5

Ranking Rationale:
May have limited impact on Pacific salmon populations.

Background Information:
Competition may occur between Atlantic and Pacific salmon populations for resources such as habitat, mating partners and prey. Atlantic salmon may also inter-breed and introduce disease into natural salmon populations. However, the likelihood of these scenarios appears low (Naylor et al. 2005), and historical evidence suggests that Pacific salmon may have a compeittive advantage over Atlantic salmon in high-latitude ecosystems (Nielsen et al. 2013).

Sources:
Naylor et al. 2005 Nielsen et al. 2013

4.5 Introduction of diseases, parasites, or travelers

What level of impact could the species' associated diseases, parasites, or travelers have on other species in the assessment area? Is it a host and/or vector for recognized pests or pathogens, particularly other nonnative organisms?)

Choice: A

High – Is known to spread multiple organisms and/or is expected to have severe impacts and/or will impact the entire region

Score: 2.5 **of** 2.5

Ranking Rationale:
Can spread numerous bacteria, viruses and disease with moderate impacts to native salmonids.

Background Information:
Farmed Atlantic salmon can transmit several bacteria, viruses or parasites including furunculosis, sea lice, infectious salmon anemia virus (ISA), and piscine reovirus (PRV) (Johnsen and Jensen 1994; Naylor et al. 2005; Phillips 2005; Marty et al. 2010). PRV has recently been correlated with instances of heart and skeletal muscle inflammation (HSMI) in farmed Atlantic salmon in British Columbia (Di Cicco et al. 2017).

Sources:
Naylor et al. 2005 Johnsen and Jensen 1994 Phillips 2005 Marty et al. 2010 Di Cicco et al. 2017

4.6 Level of genetic impact on native species

Can this invasive species hybridize with native species?

Choice: C

Limited – Has limited potential to cause genetic changes in one or more species, with limited impact and/or within a very limited region

Score: 0.75 **of** 2.5

High uncertainty? ☑

Ranking Rationale:
Limited potential to interbreed with native Pacific salmon. Discrepancies exist regarding impacts.

Background Information:
It is very difficult, even under optimal laboratory conditions, to cross-breed between Pacific and Atlantic salmon and produce viable offspring (reviewed in WDFW 2016). Even if this event were to occur in the wild, the offspring would be functionally sterile and incapable of reproduction. However, some literature suggests that cross-breeding of farmed and native salmon species has occurred in spawning areas; the extent to which this interbreeding affects long-term fitness and productivity is uncertain (reviewed in Naylor 2005).

Sources:
Naylor et al. 2005 WDFW 2016

4.7 Infrastructure

Choice: D — No impact

Score: 0 of 3

Ranking Rationale:
No impacts have been reported. Given its ecology, we do not expect Atlantic Salmon to impact infrastructure in the Bering Sea.

Background Information:
No information found.

Sources:
None listed

4.8 Commercial fisheries and aquaculture

Choice: C — Limited – Has limited potential to cause degradation to fisheries and aquaculture, and/or is restricted to a limited region

Score: 0.75 of 3

Ranking Rationale:
May have limited impact on Pacific salmon.

Background Information:
Farmed Atlantic salmon can have significant and negative impacts on wild Atlantic salmon (e.g. Fleming and Einum 1997; Fleming et al. 2000; McGinnity et al. 2003; reviewed in Glover et al. 2017), but impacts on Pacific salmon (e.g. competition, hybridization, parasite transmission) appear limited (Naylor et al. 2005; Nielsen et al. 2013; WDFW 2016).

Sources:
WDFW 2016 Naylor et al. 2005 Nielsen et al. 2013 Fleming and Einum 1997 Fleming et al. 2000 McGinnity et al. 2003 Glover et al. 2017

4.9 Subsistence

Choice: C — Limited – Has limited potential to cause degradation to subsistence resources, with limited impact and/or within a very limited region

Score: 0.75 of 3

Ranking Rationale:
May have limited impact on local salmon populations.

Background Information:
Farmed Atlantic salmon can have significant and negative impacts on wild Atlantic salmon (e.g. Fleming and Einum 1997; Fleming et al. 2000; McGinnity et al. 2003; reviewed in Glover et al. 2017), but impacts on Pacific salmon appear limited (Naylor et al. 2005; Nielsen et al. 2013; WDFW 2016).

Sources:
WDFW 2016 Fleming and Einum 1997 Fleming et al. 2000 McGinnity et al. 2003 Glover et al. 2017 Naylor et al. 2005 Nielsen et al. 2013

4.101 Recreation

Choice: C

Limited – Has limited potential to cause degradation to recreation opportunities, with limited impact and/or within a very limited region

Score: 0.75 **of** 3

Ranking Rationale:

Atlantic Salmon has limited potential to degrade local salmonid populations (WDFW 2016).

Background Information:

Farmed Atlantic salmon can have significant and negative impacts on wild Atlantic salmon (e.g. Fleming and Einum 1997; Fleming et al. 2000; McGinnity et al. 2003; reviewed in Glover et al. 2017), but impacts on Pacific salmon appear limited (Naylor et al. 2005; Nielsen et al. 2013; WDFW 2016).

Sources:

WDFW 2016 Fleming and Einum 1997 Fleming et al. 2000 McGinnity et al. 2003 Glover et al. 2017 Nielsen et al. 2013 Naylor et al. 2005

4.11 Human health and water quality

Choice: D

No impact

Score: 0 **of** 3

Ranking Rationale:

No impacts reported.

Background Information:

Atlantic Salmon require high water quality for survival (Staurnes et al. 1995) and are not reported to carry disease that would impact human health.

Sources:

Staurnes et al. 1995.

Section Total - Scored Points:	7
Section Total - Possible Points:	30
Section Total -Data Deficient Points:	0

5. Feasibility of prevention, detection and control

5.1 History of management, containment, and eradication

Choice: C — Attempted; control methods are currently in development/being studied

Score: _____ **of** _____

Ranking Rationale:
Current methods to contain Atlantic Salmon within fish farms, and reduce the incidence of sea lice, are being studied. Efforts to reduce the incidence of escaped individuals have been relatively successful, but major incidents still occur.

Background Information:
There are regulations in place in British Columbia and in Washington to prevent the escape of farmed fish and to lower incidence of disease. The number of escaped Atlantic Salmon caught in Alaska has declined (Piccolo and Orlikowska 2012), but escapes still occur. Recently (August 2017), more than 145 000 salmon escaped from a net pen on Cypress Island, WA (DNR WA 2017). Methods to control incidence of diseases and sea lice are being studied (e.g. using closed cages Nilsen et al. 2017 or lumpfish as biocontrol Powell et al. 2017).

Sources:
Piccolo and Orlikowska 2012 Nilsen et al. 2017 DNR WA 2017 Powell et al. 2017

5.2 Cost and methods of management, containment, and eradication

Choice: B — Major short-term and/or moderate long-term investment

Score: _____ **of** _____

Ranking Rationale:
No cost estimates found; however, current containment methods and commonly used methods for fish eradication likely require major short-term and/or moderate long-term investments.

Background Information:
There are strict regulations in place in British Columbia and in Washington to contain farmed fish (Piccolo and Orlikowska 2012). We have not found studies of eradication programs in areas where Atlantic Salmon have been introduced, but several methods to control or eradicate invasive fish are available, including chemical methods, physical removal (e.g., by seining or netting), or draining.

Sources:
Piccolo and Orlikowska 2012

5.3 Regulatory barriers to prevent introductions and transport

Choice: C — Regulatory oversight and/or trade restrictions

Score: _____ **of** _____

Ranking Rationale:
The transport and trade of live fish is regulated in Alaska. Finfish farming is illegal in Alaska.

Background Information:
According to the Alaska Administrative Code, "No person may transport, possess, export from the state, or release into the waters of the state, any live fish unless the person holds a fish transport permit […] and the person is in compliance with all conditions of the permit and the provisions of this chapter." Permits are issued by the Alaska Department of Fish & Game and are project- and time-specific. AAC 16.40.210 prohibits finfish farming.

Sources:
AAC 2017

5.4 Presence and frequency of monitoring programs

Choice: D

State and/or federal monitoring programs exist, and monitoring is conducted frequently

Score: _____ **of** _____

Ranking Rationale:

State monitoring programs exist.

Background Information:

The Alaska Department of Fish and Game is monitoring for escaped Atlantic salmon by sampling commercial catches, conducting snorkel surveys, and asking fishermen to report any Atlantic salmon they might catch (Senkowsky 2004, Carroll 2005).

Sources:

Senkowsky 2004 Carroll 2005

5.5 Current efforts for outreach and education

Choice: C

Educational materials are available and outreach occurs only sporadically in the Bering Sea or adjacent regions

Score: _____ **of** _____

Ranking Rationale:

Educational materials exists and occasional outreach events are held.

Background Information:

Atlantic Salmon is currently listed as an invasive species in AK and educational materials are available online (Carroll 2005; McClory and Gotthardt 2008). The Alaska Department of Fish and Game is currently monitoring Atlantic Salmon populations; part of this monitoring program involves outreach and education (Carroll 2005).

Sources:

Carroll 2005 McClory and Gotthardt 2008

Section Total - Scored Points:

Section Total - Possible Points:

Section Total -Data Deficient Points:

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Literature Cited for *Salmo salar*

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