DEVELOPMENT OF A FRAMEWORK FOR MANAGEMENT OF AQUATIC INVASIVE SPECIES OF CONCERN FOR YUKON:

LITERATURE REVIEW, RISK ASSESSMENT AND RECOMMENDATIONS

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Maria Leung and Al von Finster prepared the report under contract to Environment Yukon.

This report and its conclusions are not necessarily the opinion of Environment Yukon and this work does not constitute any commitment of Government of Yukon.

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Preface

Aquatic Invasive Species (AIS) are non-native aquatic species that have a detrimental impact on environments that they invade. In Canada, millions of dollars are spent each year on control alone. From experiences across the country and around the world, experts have found that strategies aimed at preventing the spread of AIS are preferable to diverting financial resources to programs aimed at managing AIS after they have established.

In Yukon, we have the opportunity to prevent the spread of additional AIS and to focus on prevention rather than management. Resources can be directed towards education, prevention, detection, and rapid response. To inform such programs and to tailor them for maximum effectiveness, it is important to understand the characteristics of the aquatic invasive species that pose the largest threat.

In 2011, Environment Yukon hired contractors Maria Leung and Al von Finster to investigate those AIS that pose the greatest risk to Yukon's environment and economy, based on objective criteria. They developed the following report and recommendations for the prevention, detection, and management of 16 AIS. Environment Yukon wishes to make this information widely available. Although this report is not necessarily the opinion of Environment Yukon and does not constitute any commitments by Environment Yukon, work is underway to implement several recommendations.

Following the completion of this report, new evidence has suggested that didymo is native to southern Canada. Since it is unclear whether this species is invasive in Yukon, Environment Yukon has begun sampling for didymo, in an effort to learn more about its distribution and to collect genetic samples to learn the origin of this species. Work on didmyo in Yukon is ongoing.

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Table of Contents

List of Tables

Introduction

The increasing presence of Aquatic Invasive Species (AIS) in Canada is causing the displacement of native flora and fauna, damaging infrastructure, and costing Canadians millions of dollars annually to control. Policies to control AIS (which can be diverse species of algae, plants, and fish) have largely been reactive rather than proactive, and focused on species rather than vectors (Strayer 2009). Strategies aimed at preventing the spread of AIS are preferable to diverting financial resources to programs aimed at managing AIS after they have established.

In Yukon, the number of known or suspected AIS is small compared to the rest of Canada. That means the opportunity to prevent the spread of additional AIS in Yukon still exists. Up to now, there has been no plan in place to prevent, detect, monitor, or manage AIS in Yukon, and there has been no coordinated effort to increase public awareness of the implications of AIS introduction.

Knowledge about AIS in northern regions is generally quite minimal. This report begins to address some of the unknowns by first reviewing literature on 16 species that have already established, or could establish, in Yukon (see Appendix 1); then ranking the relative risks of those select AIS; and finally, offering recommendations on the prevention and management of 6 AIS that are of comparatively highest risk—both ecologically and economically—to Yukon.

Risk Assessment of AIS to Yukon

To determine the AIS of greatest concern in Yukon, a ranking scheme was developed by modifying relevant criteria from other invasive species assessments (e.g., Alberta Alien Species Risk Assessment Tool) and adding other pertinent criteria (Appendix 2). The scheme was kept simple to avoid over-extrapolation of limited data on AIS, both potential and realized, within Yukon; and for clarity about how the score and subsequent ranking were determined for each species. The drawback to this simplicity is that some subjective judgement remains due to lack of explicit definitions of relative terminology. For example, terms like high, moderate, and low were seldom defined by numerical ranges as in more detailed and objective assessments (e.g., Jordan et al. 2010). To mitigate subjectivity, the 16 AIS were assessed simultaneously such that subjective assessments were made relative to other species.

The 26 criteria chosen to determine the relative risk of the 16 AIS fit into 4 categories: 1) likelihood of introduction; 2) likelihood of persistence; 3) ecological consequences; and 4) economic and social consequences. Only criteria that had potential for distinguishing the 16 AIS were included.

Questions within each category were weighted evenly except for 2: question 3 places more emphasis on pathways in Yukon that are more likely to facilitate spread of AIS; for example, boats, fishing, and recreational equipment pose a much larger risk than the live-fish-food market; and question 10 is given less weight because organisms capable of cloning tend to be prolific, but are not always more prolific than organisms that must reproduce sexually. The numeric responses to each question or criterion were tallied so that each category received a score for each species.

At the next step, each of the 4 categories was also given equal weight by adjusting their scores out of 25. Each species was then given a cumulative score out of 100, by adding the scores (out of 25) for each category.

On its own, the cumulative score for each individual AIS is rather meaningless; the significance is found in comparing the scores of the 16 AIS (Table 1). From this list, we chose 6 AIS to focus on, keeping in mind that we needed enough variety to assure adequate representation of each invasion pathway and management course of action: didymo, zebra mussels, New Zealand mud snail, waterweed, Eurasian watermilfoil, and whirling disease. The first 5 represent the top 5 scores (i.e., ranked 1 to 5), and the sixth, whirling disease, is the seventh highest ranked. We chose not to use the sixth top ranked AIS, Viral Hemorrhagic Septicemia Virus, because its status as an invasive species is debatable.

Discussion and expertise are required to properly use this ranking scheme as some judgement (i.e., intuitive guesswork) is required. For example, suspected pathways were rated above “nil” for species that are likely to travel with other organisms, such as when plants or small invertebrates travel with cultivated fish. The criteria in the “economic and social impacts” section were particularly difficult to objectify. Some of these also magnified a single issue. For example, AIS causing unsightly dead fish affects questions 23, 24, and 26.

Recommendations for the Prevention, Detection, and Management of AIS in Yukon

In this section, the major pathways of introduction, consequences of invasion, methods of detection, and possible management actions are outlined separately for each of the 6 AIS of highest concern to Yukon: didymo, zebra mussels, New Zealand mud snail, waterweed, Eurasian watermilfoil, and whirling disease. The recommended public education component to prevent AIS introduction is more or less the same for the 6 AIS. So to avoid repetition, these recommendations are presented collectively for all 6 species.

It is important to realize that eradication of any of the following species is unlikely should a population become established in an open system in Yukon. Eradication may be possible in closed systems (i.e., no outlet), but at significant expense and at the cost of disrupting other ecosystem components. Tactics to slow the rate of invasion within Yukon exist, however, and will be described. Tactics to control some species in areas where they could have a large impact will also be described.

Table 1. The relative risk of 16 AIS to Yukon, based on relative scores assigned in 26 risk assessment criteria, grouped into 4 categories.

Species	Risk Rank	Total	Likelihood of Invasion	Likelihood of Persistence	Ecological Consequences	Economic and Social Consequences
Points		100	25	25	25	25
Didymo	1	61.36	16.57	22.92	7.81	14.06
Zebra Mussels	2	59.14	11.75	14.58	12.50	20.31
New Zealand Mud Snail	3	57.51	14.76	17.36	12.89	12.50
Waterweed	4	57.25	14.46	20.14	10.16	12.50
Eurasian Watermilfoil	5	56.70	13.55	17.36	13.28	12.50
Viral Hemorrhagic Septicemia Virus	6	54.35	14.16	20.14	3.91	16.15
Whirling Disease	7	54.28	16.87	17.36	3.91	16.15
Fanwort	8	52.60	15.36	14.58	10.16	12.50
Spiny Water Flea	9	49.63	12.05	20.14	13.28	4.17
Goldfish	10	45.23	14.16	11.81	12.50	6.77
Rainbow Trout	11	44.12	12.35	12.50	14.06	5.21
Arctic Char	12	43.23	10.24	15.28	14.06	3.65
Threespine Stickleback	13	39.75	15.36	15.28	7.03	2.08
Silver Carp	14	39.47	7.53	9.03	12.50	10.42
Northern Snakehead	15	37.17	7.53	11.81	10.55	7.29
Rusty Crayfish	16	35.15	10.24	9.03	10.16	5.73

A major consideration in the development and application of eradication and control measures will be working within existing legal, social, and administrative structures. Satisfying legal and administrative requirements may require significant staff resources and may not be achievable in a timely manner. These challenges may be addressed even before an invasion, by the development of a strategy, Memoranda of Understanding, or similar instrument by the Government of Yukon in collaboration with other governments, in order to facilitate rapid response to a reported and confirmed invasion.

Didymo

Primary pathways of introduction in Yukon

Didymo (*Didymosphenia geminata*) is already found in Yukon and spreads with water movement as motile cells colonize new substrates. Any equipment or animals immersed in water where didymo is present are capable of carrying didymo to a new location. This includes boats, fishing gear, float planes, pet dogs, and waterfowl. Completely drying equipment kills didymo cells, but the porous material used in felt-soled waders can retain moisture for many days and is thus capable of harbouring didymo cells for extended periods. It is these felt-soled waders that have been most implicated in the spread of didymo in other jurisdictions.

The likelihood of didymo establishing could be high where fishing and float plane docking occur frequently and/or take place near lake outlets where water flow and quality is suitable to didymo growth.

Ecological and socio-economic consequences of invasion

Didymo is often found at very low densities; it is only considered invasive when it reaches high densities and becomes unsightly—a phenomenon known as a bloom. During a bloom, the extensive thick mats of didymo covering river and lake beds give the impression of polluted waters and reduce the aesthetic quality of the landscape. This reduced aesthetic value potentially impacts the tourism and guide outfitting industries, especially if this is reported in the sports fishing press and on the internet. Didymo mats also lessen the recreational and cultural value of affected waters, potentially discouraging users from appreciating and engaging in activities on the river or lake. If the negative effects become political, and human and operational resources are diverted to managing what is unmanageable, the situation will compromise the ability of Fish and Wildlife branch staff to conduct other programs.

Didymo blooms create noticeable ecological changes to the environment. By colonizing large surface areas, didymo prevents other macroalgae from growing on the substrate. It may compromise spawning habitat for those fish species whose substrate for depositing eggs is altered (Blanco and Ector 2009). The structural complexity created by didymo colonies alters the aquatic invertebrate community, making habitat more suitable to particular groups and less so for others. Increases in chironomids and decreases in mayflies have been reported elsewhere. The consequences to higher trophic levels, such as fish, are not well understood (Kilroy et al. 2009).

Detection

A clear idea of where didymo already occurs in Yukon is needed so that reported occurrences can be assessed as new or not relative to this baseline. A simple and inexpensive sampling kit with instructions—i.e., who collected, when collected, where collected (name of creek, GPS coordinates)—could be designed and distributed to various agencies, including Government of Yukon biologists, federal Department of Fisheries & Oceans staff, First Nations' lands & resources staff, Parks Canada, Yukon Youth Conservation Corps (Y2C2), Yukon Fish and Game Association, recreational users, fishing guides/operators, and other interested participants. The Yukon Fish and Game Association or the Yukon Invasive Species Council could apply to the Yukon Fish and Wildlife Enhancement Trust for funding to purchase the kit components and to analyze the samples collected. The Challenge program could assist with the assembly of kits. Staff and students at Yukon College, where facilities for conducting water analysis already exist, could analyze the water samples.

Reconnaissance information gathered from the samples would provide a picture of the present distribution of didymo to Environment Yukon and the public.

A model for predicting didymo blooms could be developed from more detailed analysis of environmental data and by monitoring sites to track the course of blooms. High density didymo may follow the same pattern as blooms observed in Vancouver Island streams in the 1990s; they subsided after 6 to 8 years.

New Zealand has the most aggressive program for controlling the spread of didymo and is the origin of much of the information disseminated in jurisdictions relatively closer to Yukon, such as eastern Canada. A website operated by Biosecurity New Zealand (New Zealand Government 2011) includes a protocol for analyzing water samples, detailed procedures for cleaning equipment, models for predicting potential spread, and documents containing methods and results of projects aimed at determining the impact of didymo on invertebrates and fish, as well as economic consequences of invasion.

Management

Systematic eradication of didymo has not been attempted and is not considered feasible because didymo is a microscopic organism that is likely too well-established to eradicate by the time a bloom is observed and authorities notified. If didymo is not widely distributed in Yukon, then it would be feasible to invest in education to prevent its spread. This includes cleaning and drying equipment used in water, disinfecting felt-soled waders and other porous equipment, restricting movement of pet dogs, and avoiding the disposal of algae down drains. If didymo is widespread, then public concerns need to be assuaged by giving them the opportunity to understand the implications of its presence.

While the current distribution in Yukon is not known, it is advisable to err on the side of caution and suggest that applications for land tenure for hunting, fishing, and canoe drop-off camps be discouraged near lake outlets to reduce the propagule pressure. Although didymo is reported in lakes, it seems to do best in clear, moving water such as lake and reservoir outlets, or in the rivers downstream.

New Zealand provides an example of how one jurisdiction is attempting to slow the spread of didymo. Under the New Zealand Biosecurity Act 1993, knowingly spreading didymo can result in penalties of 5 years imprisonment and/or a $100,000 fine. Felt-soled footwear is banned and non-use is a condition of holding a fishing license. All used fishing gear entering the country suspected of not being completely dry is treated. Quarantine officers identify passengers with potential risk items. Likewise, within the country, freshwater equipment has to be properly cleaned before moving from the South Island to the North Island. In parts of the country, anglers are required to have an approved didymo cleaning kit and must obtain a Clean Gear Certificate by using an approved cleaning station within 48 hours prior to fishing.

In certain areas, watercraft use is prohibited or limited to kayaks. Other users, such as hunters, are required to use disinfected boots, socks, and other clothing in designated areas.

The cumulative cost of maintaining these programs has not been calculated. The long-term effectiveness of the programs remains to be seen.

Zebra mussels

<u>Pathways of introduction in Yukon</u>

Zebra mussels and the closely related quagga mussels (*Dreissena* spp.) colonize boats that are moored long enough for their establishment. One case of 3 boats travelling from eastern Canada with attached zebra mussels has been reported in Yukon (Yukon Government files).

Even if boats are not stationary long enough for zebra mussels to colonize, boat hulls, motors, boat trailers, and associated equipment can carry and spread them. Power boats with the most residual water in cooling, drive train, or bilge components are particularly prone to transporting aquatic organisms. The inside chamber of channel steel used to construct trailers, and the stern and bow of inverted canoes and kayaks, can also retain water. Both the juvenile and adult stages of the mussel can also spread from macrophytes entangled on equipment such as motors, trailers, and fishing nets.

Once introduced into a water system, the free-floating larval stage, known as planktonic veligers, disperse by water movement and can spread into new locations.

Ecological and socio-economic consequences of invasion

Damage to infrastructure, including dams, docks, and water systems, as a result of blocked pipes can occur, however, economic impacts in Yukon would be minor compared to eastern Canada where such structures are more common. Examples of structures at risk in Yukon are the hydroelectric dams along the Yukon River. The risk of damage to boats is very minor as few boats are berthed in freshwater in Yukon. Some reduction of the aesthetic value of Yukon landscape can be expected if zebra mussels colonize boat launches and other frequently visited places.

The presence of zebra mussels in Yukon could shift energy from a pelagic to a benthic food web. They may out-compete native species for phytoplankton and suspended inorganic matter. Elsewhere, they have displaced native molluscs, especially mussels from the family Unionidae. This taxonomic family is, however, not well represented in Yukon.

Detection

Boat launches are likely sites of early invasion. Zebra mussels are distinct from native molluscs and often large enough to be visible; this allows them to be detected early enough for eradication. Signage at boat launches is a critical component of identifying and reporting the presence of zebra mussels. Other agencies associated with water use should be trained to recognize and report the organism.

Management

Once detected, the number of individual mussels and the extent of their distribution need to be rapidly assessed in order to take action. If there are a small number of individuals and the extent of distribution is small, real-time non-biocide eradication is recommended. Removal by SCUBA divers might be possible if zebra mussels are caught in the early stages of introduction and in a closed system. The cost of such treatment is prohibitive without volunteers. For example, an estimated 6,700 people hours, including 959 dives, were required over several years to remove zebra mussels at Lake George, New York (Wimbush et al 2009). However, eradication was not achieved as new colonies have since been identified. Investing in prevention by education and stopping spread by early detection is considered much more feasible than investing in measures to slow the rate of spread. However, if there are large numbers of individuals and the extent of the distribution is wide, control of further distribution is recommended. Actions could include closing lakes to recreational and commercial fishing and closing boat launches to slow the rate of invasion. Enforcing complete closure of water bodies in Yukon is not likely a viable option. If control is undertaken, ongoing monitoring for zebra mussel presence is essential for evaluating the effectiveness of the control measures. Costs of such management practices for Yukon have not been calculated, in part as the means of control must meet legal requirements for consultation (e.g., stakeholders and First Nations) and should conform to societal expectations. Imposition of measures that will negatively affect access to land, water, and resources, yet will fail anyway, must be carefully considered.

New Zealand mud snail

Pathways of introduction in Yukon

The most likely source of New Zealand mud snail (*Potamopyrgus antipodarum*) spread into Yukon is from boating and fishing equipment including nets, waders, and boots. The mud snail has a solid operculum that helps it resist lethal desiccation for several weeks if kept in cool, moist conditions. This resilience allows for long distance human-assisted travel. Fish cultivated in facilities where they are able to ingest mud snails are potentially a source of introduction.

New Zealand mud snails are known to survive gut passage of salmonids. Such fish may be transported between aquaculture facilities or found at food markets where they can be vectors for mud snails through stocking programs or disposal of entrails into water systems. Although of less probability in Yukon, dispersal is possible from the aquatic ornamental plant trade. Mud snails can easily escape detection on plants.

Once established in a water system, the mud snail disperses locally by water movement, its own locomotion, and assisted travel in guts of vertebrates or mud attached to birds. Both Arctic grayling and round whitefish migrate upstream into headwater tributaries in summer, potentially carrying mud snails with them.

Ecological and socio-economic consequences of invasion

The mud snail could out-compete native macro-invertebrates and potentially decrease the prey base for salmonids in Yukon, in turn affecting the various fisheries—commercial, recreational, and Aboriginal. At high densities, the mud snail noticeably alters the food web by consuming and assimilating more of the nutrients, particularly carbon, than other invertebrates. It is an inferior food type as it resists digestion and can survive gut passage in salmonids; it cannot substitute for native invertebrate prey.

Detection

Environment Yukon could regularly screen for the organism at aquaculture facilities, and actively provide training to agencies associated with water use to recognize and report the organism. This organism can easily be confused with native snails and, depending on the life stage, may escape detection before it grows to full size (6 to 7 mm).

Management

Eradication is possible in contained aquaculture facilities using chemical disinfectants (e.g., hydrogen peroxide, Oplinger and Wagner 2009), but otherwise will not be feasible as the snail will likely be well-established in a watershed by the time it is detected. Rapid response would assess the extent of the invasion in public waters using benthic samples. Immediate closure of boat launches to invaded sites will reduce motorized watercraft access, and slow the rate of spread. Aboriginal rights need to be respected in actions that can change access to waters and fisheries. To address spread by non-motorized watercraft and other equipment, public communications that highlight the risks of invasion and spread, and that outline appropriate actions to prevent further introductions, should be quickly and widely disseminated. This can include placement of labels detailing decontamination procedures on watercraft and other equipment at high risk of spreading the organism.

Watercraft, both motorized and non-motorized, are regularly transported by motor vehicles on the highways between Yukon and marine ports in Haines and Skagway, Alaska. The mud snail can tolerate salinity, so it is possible that it could survive in the freshwater lens or ground water springs in harbours. A plan should be prepared in anticipation for if and when the mud snail is identified in these areas. This plan could include requesting the Canadian Border Services Agency to distribute pamphlets to all vehicles towing or carrying a boat when entering Canada. Implementing a bio-security strategy similar to New Zealand's could be effective in assuring that watercraft and equipment posing a risk of introducing AIS are properly cleaned prior to entry into Canada. However, the costs of such a measure would be very high.

Waterweed

<u>Primary pathways of introduction in the Yukon</u>

The introduction of waterweed (*Elodea* spp.) into the Yukon is as likely to come from the nursery trade and lab kits as it is from watercraft, fishing gear and other equipment used in water. Waterweed can be shipped into Yukon from aquatic plant suppliers or businesses selling scientific equipment. Disposal of waterweed directly into open water or indirectly via drains and toilets can result in its unwanted introduction. The most recent introduction of waterweed north of 60˚ is thought to be from discarded aquaria contents or commercial lab kits. Since the plant is found across the lower latitudes of Canada, boats and related equipment traveling by road from the south and west can also be vectors of introduction for waterweed to Yukon waters.

Once established in an area, further dispersal is by means of water currents, animals, float planes, boats and other equipment used in contaminated water. Only fragments of the plants are required for the species to disperse into new locations.

<u>Ecological and Socio-economic consequences of invasion</u>

With its strong ability to assimilate nutrients from water and shade out other vegetation, waterweed can displace native plants, cause eutrophication and slow water velocity, thereby changing the composition of the plant and animal community. Habitat quality for particular fish, amphibians and invertebrates would then be reduced. For example, the spawning habitat for salmon would be compromised with reduced water velocity, lowered dissolved oxygen and overgrowth of vegetation in gravel beds.

The economic loss caused by a proliferation of waterweed could include the increased cost of maintaining infrastructure. Waterweed has obstructed waterways and intake pipes at hydropower plants elsewhere.

Revenue from fishing and tourism may also be reduced as people avoid the risk of clogging their boat motors. Additionally, the degraded aesthetic value of the landscape may attract fewer users.

Detection

Members of agencies associated with water use could be trained to recognize and report the plant. Help could be solicited from the general public by increasing awareness through media such as signage at boat launches. Providing training and/or educational materials or signage at plant nurseries and aquarium/pet stores in Yukon could help ensure that the people who are more likely to encounter the plant will recognize it.

Management

Once established, waterweeds are very difficult to eradicate, even in a closed system, as propagation is from small plant fragments. Rapid response would assess the extent of the invasion by first taking samples at access points and along the shoreline downwind and downstream. Immediate closure of boat launches to invaded sites would reduce motorized watercraft access and slow the spread between water bodies. To address spread by non-motorized watercraft and other equipment, communications that express concern for its occurrence and suggest appropriate action to prevent further introductions should be quickly disseminated. Aboriginal rights need to be respected in actions that can change access to lakes and rivers.

Following up with the neighbouring Alaskan program will help decide whether similar action would be feasible in Yukon. Eradication of waterweed in 2 lakes in Alaska is being done using the application of herbicide. Their options ranged from $225/acre with use of diquat to $750/acre with use of fluridone which is the more selective, less toxic option. Control measures used elsewhere, especially in Europe, include the draining and drying of water bodies, introduction of sterile herbivorous fish, manual harvesting, and use of materials to shade waterweed. Draining water bodies and employing herbivorous fish have limited practicality in Yukon considering the risk to endemic species and survival of grass carp in a cold climate. Manual harvesting and use of shading materials have the potential of controlling waterweed in small areas of Yukon.

Eurasian watermilfoil

Primary pathways of introduction in Yukon

The main source of Eurasian watermilfoil (*Myriophyllum spicatum*) dispersal to new locations is by fragments caught on boats, boat trailers, fishing gear, and other similar equipment. Reproduction is predominately by vegetative means in North America. New plants form from auxiliary buds detached from root crowns, fragments sloughed from stems, or pieces broken by motors or through other mechanical means.

Eurasian watermilfoil has been and may still be available in the aquaria and nursery trades. Disposal of plants into water systems from either source is another means of introduction. As well, this plant may be present in aquaculture and live food environments, but these sources are of a minor risk in Yukon.

Ecological and socio-economic consequences of invasion

If high densities are reached in Yukon, Eurasian watermilfoil could displace native macrophytes and associated invertebrates. This could result in reduced native plant forage for waterfowl and degraded habitat for larger native fish such as pike. Its profuse growth would also accelerate eutrophication. Hybridization with native northern watermilfoil (*M. sibiricum*) has been documented elsewhere but is probably of minor risk in Yukon where climatic conditions required for flowering and seed germination are dubious and reproduction would be mainly by vegetative means.

Eurasian watermilfoil has the potential of reducing the aesthetic and recreational value of Yukon by making waters look polluted; clogging boat motors; and curtailing boating, fishing, and swimming opportunities. However, such impacts may not have a significant impact in Yukon waterways because access in warmer, calm, shallow water in Yukon is already difficult in many areas due to existing aquatic vegetation.

Detection

Environment Yukon could actively provide training to agencies associated with water use to recognize and report the plant. Help can be solicited from the public at large using signage at boat launches. There are 2 milfoil species endemic to Yukon, *M. sibiricum* and *M. verticillatum*. Distinguishing Eurasian watermilfoil from these can be difficult to the untrained eye.

Management

Eradication will not be feasible due to the plant's ability to propagate from small pieces that easily escape detection and due to the risk to native vegetation if eradication were attempted.

Rapid response would assess the extent of the invasion by first taking samples at access points and along the shoreline downwind of prevailing winds (Prather et al. 2003). Immediate closure of boat launches at invaded sites would then reduce motorized watercraft access and slow the spread between lakes.

To address spreading by non-motorized watercraft and other equipment, public communications that highlight the risk of invasion and spread, and outline appropriate actions to prevent further introductions should be quickly disseminated. Aboriginal rights need to be respected in actions that can change access to lakes.

Once established, Eurasian watermilfoil control is possible for small areas by submerging a benthic barrier for short periods (< 1 year) every 2 to 3 years, by the application of herbicides (e.g., triclopyr, bispyribac-sodium), or by the more expensive option of mechanical removal. Mechanical removal is favoured by those concerned with the introduction foreign material and chemicals into the aquatic environment. Specific costs for the use of benthic barriers and herbicides were not given in the studies (Boylen et al. 1996; Getsinger et al. 1997). Mechanical removal was the primary method employed in the Okanagan (British Columbia) where removal cost over $10 million between 1972 and 2001 (Wilson et al. 2007). These control methods did not completely remove Eurasian watermilfoil, but did allow native vegetation to recover temporarily.

Whirling disease

<u>Primary pathways of introduction in Yukon</u>

The most widely reported method of transfer is between aquaculture facilities cultivating trout. It has been identified in a rainbow trout hatchery in Alaska. Subsequent spread of whirling disease (which is caused by the parasite *Myxobolus cerebralis*) into open water occurs directly from aquaculture facilities that discharge to surface waters or by infected fish released into water bodies as part of stocking programs.

Myxospores, the diapause hardy stage of the parasite, occurs in sediment and can be carried in infected boating, fishing, or recreational equipment, especially porous materials such as felt-soled waders.

Disposal of fish or fish parts, including commercially frozen imported bait fish, into the water system also poses a small human-mediated pathway in Yukon. Myxospores can survive gut passage, so can be spread by any animal—wild or domestic—that consumes infected food.

<u>Ecological and socio-economic consequences of invasion</u>

This parasite causes whirling disease in rainbow trout and can infect other salmonids, although susceptibility varies with species and population. For example, chinook salmon are moderately susceptible and Arctic grayling appear to be resistant to the parasite (Vincent 2001). The disease can severely reduce populations of affected fish thereby reducing recreational or commercial fishing opportunities.

Its presence in Yukon would likely give aquaculture facilities negative publicity, reduce consumer confidence, and hamper sales and use of their products.

<u>Detection</u>

Routine screening at hatcheries is advised to detect the parasite. Individual fish can be asymptomatic, but still spread the parasite.

Early detection in public waters is unlikely as the organism is cryptic and confirmation of its presence would likely be from symptomatic fish after an invasion has established. Nevertheless, a program to actively provide training to agencies associated with water use is recommended so that staff can recognize the symptoms of whirling disease and properly preserve infected fish. Samples should be sent to a specialized lab qualified to identify the parasite. Otherwise, there will likely be numerous misidentifications due to confusion with scoliosis and other skeletal deformations.

Management

Following detection at an aquaculture facility, all infected fish need to be destroyed and facilities need to be thoroughly decontaminated. Hydrogen peroxide is among the most cost-effective disinfectants available for this task.

Eradication in public waters will not be feasible as myxospores can be viable and undetected in sediments for years and can survive passage through the guts of fish and birds. The rate of spread could be curtailed by public communications that highlight the risks of invasion and spread, and that outline appropriate action to prevent further introductions. Appropriate actions include the proper cleaning of equipment, as outlined under the "Prevention of Introduction" section. Cost of such outreach material has not been calculated.

Prevention of Introduction

The activities and procedures designed to limit AIS introduction and target audiences are similar for all 6 AIS presented here (Table 2). There is also considerable overlap in the membership of each target audience; for example, many fishers also use watercrafts. Overall, the groups that pose the highest risk for introduction of AIS should be the primary targets for public education and outreach. These groups are people who fish and people who operate motorized watercraft. Non-motorized watercrafts pose a smaller risk, even though they are more numerous and access a greater number of waterbodies.

Although significant in their potential to spread AIS, the aquaculture, aquaria, live-food, and ornamental plant trades are lower priority targets for educational programs because their numbers are few in Yukon.

The recommended education and outreach initiatives and best practices guidelines need not be limited to the 6 identified AIS. We encourage the inclusion of other AIS of risk to Yukon in strategies to inform target audiences and the general public (e.g., information disseminated on the potential spread of AIS by felt-soled waders could include chytrid fungus that impacts local frog species, as well as didymo and whirling disease).

Table 2. Summary of recommended education and public outreach initiatives and best practices guidelines for deterring the introduction of AIS, by identified target audiences. The letters reference the item on the "best practices" list and the numbers reference the item on the "public outreach and education" list.

Target Audiences	Didymo	New Zealand Mud Snail	Zebra Mussels	Eurasian Watermilfoil & Waterweed	Whirling Disease
Non-resident fishers	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i,j,k 1,2,3,4,5
Resident fishers	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i,j,k 1,2,3,4,5
Fishing guide-outfitters	a,b,c,d,i 1,2,3,4,5,6,7	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i,j,k 1,2,3,4,5
Float plane operators	a,b,c,d,i 1,2,3,4,5,6,7	a,b,c,d,i 1,2,3,4,5,	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i, 1,2,3,4,5
Commercial canoe, kayak, raft operators	a,b,c,d,i 1,2,3,4,5,6,7	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i, 1,2,3,4,5
Non-commercial canoe, kayak, raft operators	a,b,c,d,i 1,2,3,4,5,6,7	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i, 1,2,3,4,5
Importers of used watercraft	a,b,c,d,i 3	a,b,c,d,i 3	a,b,c,d,i 3	a,b,c,d,i 3	a,b,c,d,i 3
Resident motorized watercraft users	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i, 1,2,3,4,5
Non-resident motorized watercraft users	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i, 1,2,3,4,5
Duck hunters	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i 1,2,3,4,5	a,b,c,d,i 1,2,3,4,5
Field technicians in public and private sectors	a,b,c,d,i 1,2,3,6,7	a,b,c,d,i 1,2,3,6,7	a,b,c,d,i 1,2,3,6,7	a,b,c,d,i 1,2,3,6,7	a,b,c,d,i 1,2,3,6,7
Aquaculturalists		g,k 4,8			g,h,i,j,k 4,8
Aquarium trade & Live-food market		e,f,k 3,4		e,f,k 3,4	
Ornamental plant trade		e,f 3,4		e,f 3,4	

Best practices:

a. Drain water, bilge, and bait containers before leaving. Rinse and clean off all visible debris from equipment that has been in water at the site of departure from the water body.

b. Clean and dry all boats, trailers, and equipment thoroughly. Aquicides are available and may be used to clean equipment, particularly where boats have bilges/enclosed spaces under floorboards. Also clean and dry pets.The National Geographic Area Coordination Center website provides a list of aquicides and guidance on their effectiveness on specific AIS (National Geographic Area Coordination Center 2009). Note that some materials such as rubber do not tolerate treatment by bleach. Dispose of disinfectants in a legal and appropriate manner.

c. Discourage use of felt-soled waders and provide a list of alternative footwear options with similar traction. Some invasive organisms survive well in the prolonged moist environment provided by the felt soles.

d. Disinfect felt-soled waders, boots, and any other porous material used in water. Effective treatments for most organisms are: 40 minutes in hot water above 45 ^{o}C; drying of equipment for at least another 48 hours; freezing footwear below -20 ^{o}C for one week (MDDP-MRNF 2007); or immersion in 0.3% alkyl dimethyl benzyl ammonium chloride for 10 minutes (Schisler et al. 2008). For treatment of whirling disease, freezing or chemical immersion is recommended (Hedrick et al. 2008) because myxospores are resilient to temperatures up to 60 ^{o}C (Gates et al. 2008). Proper disposal of chemical disinfectants into ground or sanitary sewers away from fish-bearing waters is required.

e. Do not dump aquarium contents into ponds, lakes, rivers, swamps, or other wild places.

f. Dispose of aquarium plants and substrate in garbage instead of drain or toilet. Water from sewage can enter watersheds without adequate treatment to kill all invasive organisms.

g. Use ground water instead of surface water at aquaculture facilities.

h. Make the environment inhospitable to the host worm by avoiding use of mud bottoms in aquaculture facilities.

i. Report suspected sightings of AIS or ill-looking fish to Environment Yukon.

j. Discourage use of imported commercially-frozen bait fish.

k. Do not release or transfer fish in the wild. It is illegal to move fish or any aquatic organism from one body of water to another. Use only dead bait when fishing. It is illegal to use live bait in Yukon.

Public Outreach and Education:

1. Post information on government websites, for example:
    - Yukon government fishing and tourism-related boating web pages
2. Approach non-governmental organizations to post information on their websites, for example:
    - Yukon Canoe and Kayak Club
    - Yukon Fish and Game Association
    - Yukon Fish and Wildlife Management Board
    - Ducks Unlimited
    - Yukon Conservation Society
3. Distribute information bulletins or pamphlets to a variety of organizations and locations, for example:
    - Visitor centres in Yukon and in gateway communities such as Dease Lake and Fort Nelson
    - Yukon Canoe and Kayak Club
    - Gas stations in Watson Lake area, including Highway 37 corners
    - Entrances to Yukon territorial parks and provincial parks in northern British Columbia
    - Stores that sell fishing and boating equipment, aquaria supplies and aquatic plants, or live aquatic food
    - Locations selling fishing and hunting licenses, displayed adjacent to the Yukon Fishing and Hunting Regulations booklet (and/or as in insert in the booklet)
    - Boat operator accredited training courses held in a classroom setting at Yukon College or community. It might be possible to convince the instructor to have information available even though it is not part of the curriculum. This can be in the form of a pamphlet or a sticker for boats, with instructions to clean watercraft to minimize spread of AIS.
    - Ducks Unlimited
4. Submit and solicit articles in newspapers, newsletters, and websites, for example:
    - Yukon News' "Your Yukon" column
    - Yukon Fish and Game Association's Outdoor Edge bimonthly magazine
5. Place signage at boat launches
    - These should be visually appealing, with simple, clear messages
6. Seek and solicit opportunities to give presentations, for example
    - When land/water managers of Federal, Territorial, Municipal, and First Nation governments are meeting for other reasons
    - Yukon Science Institute lecture series
    - Annual general meetings of relevant environmental

   - non-governmental organizations
   - MacBride Museum lecture series
   - Biodiversity Working Group forum
7. Solicit collaboration to develop a code of practice to deter further introductions. The code of practice could be a condition of authorizations that environmental consultants require such as the "License to Collect Fish for Scientific, Educational or Public Display Purposes" issued under the federal Fisheries (General) Regulations. It could also be adopted by government agencies.
8. Train territorial, federal, and First Nation government personnel to recognize and monitor aquatic invasive species. Include less populated communities. Provide equipment, such as sampling kits, as needed. Information from such an initiative should be centralized into a database to track surveillance effort and occurrences of AIS. A critical component is quality assurance / quality control especially if the information is placed on a public website.

Although not particularly aimed at any of the audiences strongly associated with likely pathways of AIS introduction, children and youth can also be trained to be vigilant about AIS by including an AIS unit in environmental education programs such as Salmon in the Classroom and the Yukon Youth Conservation Corps.

Depending on the policies governing the use of road signs, it may be possible to use road signs to inform highway travellers, such as those crossing into Canada from Haines or Skagway, of potential AIS carried on boating and fishing equipment.

A study of angler awareness of AIS found that sources of AIS education were newspapers, television, signage at water access points, inspection and education programs delivered at boat landings, brochures, and fact sheets (Lindgren 2006).

Conclusions and Next Steps

The threat of AIS to Yukon is real. Habitat attributes suitable for many AIS exist in Yukon waters and some models' potential distribution include Yukon in the potential range of AIS (e.g., northern snakehead; Cudmore and Mandrak 2006). The cold temperatures at northerly latitudes may partly explain why some AIS found elsewhere have yet to establish in Yukon, but the remoteness of Yukon from source populations of AIS is an equally significant reason. As the distribution of AIS moves further north, and as climate change potentially warms waters, the risk of AIS establishing populations in Yukon increases. Three priorities are suggested as starting points for the protection of Yukon from AIS. These are: education, systematic surveillance for AIS, and development of protocols on how to respond to initial detection of a variety of potential AIS in Yukon.

With respect to education, a strategy needs to be implemented to increase public awareness of AIS and the potential ecologically and economically damage they can cause. The primary message to the public should be to stop equipment from being a potential vector by keeping it clean and free of any potential AIS.

Another message is to properly dispose of potential AIS (e.g., aquarium fish, ornamental aquatic plants) or items potentially harbouring AIS (e.g., frozen bait fish). Development and maintenance of signage, web content, pamphlets, and other communications products are also advised. Education, or outreach, should extend actively to agency staff and others involved with use or regulation of aquatic systems, as they travel widely and will have access to isolated areas and could provide a measure of surveillance.

Systematic surveillance will be essential to identify invasions at likely locations. This may curtail the spread of specific AIS in Yukon. Developing a program of surveillance whereby access points to public waters are monitored would increase the chances of detecting AIS early in its introduction to Yukon. Sites should include boat ramps, docks, and landing sites for motorized and non-motorized watercraft and float planes. To detect the variety of possible AIS, a range of sampling techniques appropriate for finding many different kinds of AIS is required (e.g., benthic and water samples). The monitoring should be conducted by staff with suitable qualifications. If limited to road-accessible areas, and not requiring diving, a crew of 2 people employed from May to September inclusive could suffice. Employment could have a 30 to 50% field component, with the remaining time divided between laboratory and office.

Systematic surveillance should extend to aquaculture facilities and stocking programs, as these have historically been one of the sources of AIS introductions. Screening programs at aquaculture facilities should specifically focus on AIS such as whirling disease, *Saprolegnia ferax*, and Viral Hemorrhagic Septicemia Virus.

The third priority is the development of protocols for rapid response. Except in rare cases where AIS were detected early and found in small, closed systems, eradication has not been successful. Managers are largely aware of this and focus programs on controlling further spread of the organisms and mitigating the damage (e.g., cleaning zebra mussels from water intake pipes) rather than trying to eradicate AIS. Management strategies and analyses on the cost and long-term effectiveness of control measures are not readily available for many AIS. Dealing with AIS in Yukon also presents some additional considerations like obligations under land claims agreements. Developing collaborative management strategies with First Nations before the need to respond arises, would allow rapid response to new instances of AIS in Yukon.

As a closing comment, the field of aquatic invasive species is dynamic in North America. New invasive species are identified regularly. Connections to AIS specialists in neighbouring jurisdictions should be actively maintained by Environment Yukon staff to identify emerging threats and to track the progress of existing AIS.

APPENDIX 1 OVERVIEW OF AIS: LIKELIHOOD AND CONSEQUENCES OF YUKON INVASION

This section presents an overview of invasion likelihood and consequences for 16 of the many potential AIS posing a risk to Yukon. These species were chosen to represent a variety of life histories, pathways of introduction, and management challenges. The literature review is intended to be an overview of each chosen species, and not an exhaustive account of what is available. A great deal of information, including whole books and conference proceedings, has been written about some of the better known AIS. In general, however, information on the cost and effectiveness of eradication and control is limited. As well, the economic costs of invasion have not been calculated for many AIS and monetary values, if available, tend to be rough estimates that are specific to sites or regions.

For each species, the following topics are reviewed:

(1) likelihood of invasion:
- *a.* the life history
- *b.* the origin and history of invasion and spread
- *c.* the habitat requirements
- *d.* the pathways of introduction

(2) the consequences of invasion:
- *a.* ecological consequences
- *b.* economic consequences
- *c.* possibility and cost of eradication
- *d.* possibility and cost of control

1. Arctic Char (*Salvelinus alpinus*)

Phylum: Chordata
Class: Actinopterygii
Order: Salmoniformes
Family: Salmonidae

Likelihood of Invasion

Overview of Life History

- considered the northernmost freshwater fish in the world
- both anadromous and non-anadromous types exist; regardless, all spawn and overwinter in freshwater
- anadromous populations are only in the northern part of the species range, including Arctic Canada
- weight at maturity ranges from 3 to 12 kg; length of small morphs at maturity estimated at 7 cm, while typical non-anadromous morphs

mature at 20 to 40 cm, and anadromous types are 30 to 70 cm at maturity
- age of maturity is variable; generally by 6 years, but may be several years younger
- larger females tend to have more eggs; upwards of 9,200 eggs in females from Labrador
- generalist, feeding on zooplankton, pelagic fish, epibenthos, and, in some cases, smaller members of its own species (Klemetson et al. 2003)
- spawns in either spring or fall for non-anadromous populations; anadromous populations only spawn in fall
- redd construction in gravel/pebble substrate in water depths <10 m; eggs are buried beneath the surface for protection during incubation
- incubation time for eggs varies considerably, with values ranging from 64 to 180 accumulated thermal units (equivalent to degree days) depending on the stock (Johnson 1980)
- Arctic char, Dolly Varden, and bull trout form a species complex that has been the subject of genetic and evolutionary studies; the Dolly Varden west of the Mackenzie River were previously identified as Arctic char; aside from 2 isolated populations of lake-dwelling Arctic char in the Yukon North Slope, the current distribution of Arctic char in Canada is believed to be east of the Mackenzie River (Reist and Sawatzky 2008)

Origin and History of Invasion and Spread
- circumpolar distribution and 5 phylogeographic lineages (Atlantic, Arctic, Bering, Siberian, and Acadian)
- introduced in parts of Europe as early as medieval times (Klemetson et al. 2003)
- in Yukon, Arctic char is present in Porter Creek (Whitehorse), and local anglers have caught char in the Yukon Electrical Company Limited Hydro # 2 headpond (Yukon Government data)

Habitat Requirements (physical and chemical) in comparison to availability in Yukon
- inhabits streams, lakes, near-marine habitats
- oligotrophic to ultra-oligotrophic, cold water, and depauperate fish community typify lake habitat
- can actively feed just below ice
- uses all depths and habitats of lakes; regarded as a generalist, but may confine itself to particular habitats to segregate itself from other species (Klemetson et al. 2003)
- optimal growth at 10 ^{o}C to 16 ^{o}C, but withstands sub-zero saline water (Johnson 1980)
- optimal incubation temperature for eggs from Canada is 3.5 ^{o}C (Koops and Tallman 2004)
- environmental conditions required for rearing Arctic char are detailed in Johnston (2002)

Pathways of Introduction

- intentional stocking of lakes
- escapes from aquaculture facilities (Environment Yukon 2010)
- unintentional introductions have occurred in McIntyre Creek (an open system near Whitehorse) and Porter Creek (a closed system near Whitehorse). There was also an undocumented release in the Takhini River several years ago.

Consequences of Invasion

Ecological Consequences of Invasion

- slight potential that Arctic char may breed with lake trout to produce hybrids (Wilson and Bernatchez 1998)
- Arctic char populations are unlikely to persist in lakes with populations of lake trout (Wilson 1997, Wilson and Bernatchez 1998)
- reduces abundance of prey species including zooplankton, aquatic invertebrates, larval stages of dragonflies, caddisflies, and stoneflies
- juveniles may provide alternate prey source for resident lake trout (Swanson 2007)
- escaped cultured fish may also introduce diseases into native fish

Economic Consequences of Invasion

- valued sports fish (Environment Yukon 2010)
- uses the same small-stream habitats as rearing and overwintering juvenile chinook salmon. There is no documentation of interaction, but competition for food is likely, although juvenile chinook would probably prevail. With larger Arctic char, predation on juvenile chinook is possible (Al von Finster, personal observation)

Possibility and Cost of Eradication

- information gap

Possibility and Cost of Control

- information gap

2. Didymo (*Didymosphenia geminata*)

Also known as rock snot

Phylum: Heterokontophyta
Class: Bacillariophyceae
Order: Cymbellales
Family: Gomphonematacaea

Likelihood of Invasion

Overview of Life History

- benthic diatom
- individual motile cells are the source of colonies, but it is unclear as to whether a colony develops from a single motile cell, or an aggregation of them
- attach to solid surfaces with polysaccharide stalks extruded from individual cells, and together form hemispherical colonies
- stalks divide to form an interwoven structure
- numerous colonies growing together can form extensive mats reputedly as thick as 20 cm (Whitton et al. 2009)
- interwoven structure persists after most didymo cells die, and are colonized by other diatom species (Spaulding and Elwell 2007)
- mucilage is described for colonies in North America, thus the name "rock snot"; mucilage is not always associated with didymo colonies elsewhere
- although sexual reproduction is not necessary for the spread of this organism, it does occur: auxospores are formed by 2 cells pairing within a mucilage tube prior to sexual reproduction (Whitton et al. 2009)

Origin and History of Invasion and Spread

- circumboreal distribution and is found in botanical records from the 1800s for British Columbia including Vancouver Island (Bothwell et al. 2009)
- in the fossil record for Alaska (Pite et al. 2009)
- the first documented didymo blooms in North America occurred on the Heber River and lower Gold River of Vancouver Island in 1989 (Bothwell et al. 2009)
- by 1994, didymo blooms were documented for 13 watersheds on Vancouver Island and blooms have since appeared in other parts of North America and the world, most notably New Zealand and Chile (Bothwell et al. 2009, Whitton et al. 2009); both countries have introduced salmonids supporting world class fisheries
- didymo blooms on Vancouver Island declined 6 to 8 years after they were first seen
- a consistent pattern between bloom occurrence and water chemistry or hydrological characteristics could not be found for Vancouver Island; it was then suspected that the didymo variant responsible for the blooms

differed from the endemic one (Bothwell et al. 2009). This is supported by documented morphological differences between endemic didymo from Naknek Lake in Alaska and invasive didymo from various locations (Pite et al. 2009)

- the observation that blooms always occurred where there was an active steelhead fishery or in close proximity to campgrounds suggested that people introduced this didymo variant to the affected watersheds (Bothwell et al. 2009)
- felt-soled boots came into common use in 1988, just before the first didymo bloom was reported; it is now believed that didymo is spread by people harbouring live didymo in their moisture-retaining felt-soled boots (Bothwell et al. 2009)
- the origin of the suspected variant responsible for blooms is not clear
- the potential distribution of didymo was estimated to be south of Yukon (Allison 2009), but this is probably inaccurate because they used plant hardiness zone 3 to determine the northern limit; such zoning may not be applicable to aquatic habitats, which tend to buffer against temperature extremes
- didymo has been confirmed in several locations in southern Yukon that are not necessarily connected by waterways (Environment Yukon, unpublished data)
- in Alaska, didymo is considered to be an endemic “curiosity” and not an invasive species (Center for Lakes and Reservoirs 2009)
- known in Yukon since mid-1990s or earlier (Pat Roach, biologist, personal communication)
- Barraclough (1995) identified didymo at two locations along the Yukon River near Whitehorse and Lake Laberge
- “Wolverine Project Environmental Assessment Report. Section 7: Environmental assessment findings 7.7 Benthos and periphyton -Yukon Zinc Corporation, Vancouver YZC 2005” was cited as a reference by Blanco and Ector (2009) as having information on didymo in Yukon, but the actual sampling data was not found in the version available at the Energy, Mines and Resources library.

Habitat Requirements (physical and chemical) in comparison to availability in Yukon

- prefers stable rocky substrates where there is water movement either in the form of water current or wave action
- intolerant of high suspended sediment or bed-load movement
- grows well in streams subject to natural or human flow regulation; extreme floods inhibit growth
- rocky substrates of rough texture and harbouring an existing periphyton community are more easily colonized (Flöder and Kilroy 2009, Bergey et al. 2010)

- high light; pH above neutral, tolerates pH 7–9 (Spaulding and Elwell 2007)
- overall phosphorous (P) concentration is low enough for organic P to be an important P source; for example, P release from organic-rich soils is favourable (Miller et al. 2009; Whitton et al. 2009)
- prefers high nitrogen to phosphorous (N:P) ratio (Whitton et al. 2009)
- thought to inhabit cold water, but grows well in warmer temperatures (20 ^{o}C)
- the presence of hydroelectric dams that moderate the discharge of water is a good predictor of didymo density (Kirkwood et al. 2009), although such structures are limited in Yukon
- Kumar et al. (2009) developed a habitat model to predict distribution of didymo in western US in relatively cool sites and at high elevations with a high base-flow index using climatic, topographical, hydrological, and other environmental variables
- the glaciated area of Yukon has numerous lake outlets and reaches downstream that could, or do, provide excellent habitat for didymo
- A working hypothesis: didymo will be found downstream of every lake with an early spring polyna large enough to be used as staging area by migrating waterfowl. Most of these lakes will be at low altitude and the rivers/streams draining from them will be at an even lower altitude. High altitude lakes, smaller lakes, and the streams draining from them should, or may, be free of didymo. Headwaters of tributaries are probably free of didymo, although lower reaches may have didymo due to spread by piscivorous birds and mammals.

Pathways of Introduction

- contaminated equipment, particularly infected felt-soled boots or waders, spread didymo from one location to another (Bothwell et al. 2009)
- animals, including pet dogs, are also capable of transferring didymo (Allison 2009)

Consequences of Invasion

Ecological Consequences of Invasion

- forms extensive, thick, and occasionally mucilaginous mats that prevent some other macroalgae from growing
- the high percentage of polysaccharide content of the mats is not as palatable or nutritious as other forms of algae, which have higher lipid and protein contents (Blanco and Ector 2009)
- didymo creates microhabitat for particular organisms and is associated with an increase in some aquatic invertebrates and a decrease in others. Gillis and Chalifour (2010) found that the proportion of chironimids increased in the presence of didymo; similarly, James et al. (2010) found

an increase in dipterans and a decrease in mayflies, stoneflies, and caddisflies were associated with didymo; Kilroy et al. (2009) found increased densities of oligochaetes, cladocerans, nematodes as well as chironimids; the effects of these shifts on higher trophic levels, such as fish, are not well understood.
- one study showed that the change in macroinvertebrate assemblage was similar to that of polluted waters (Anonymous 2005 in Blanco and Ector 2009)
- in severe infestations, macrophytes disappeared and fish numbers declined (Blanco and Ector 2009)
- decline of blue-ribbon brown trout is associated with didymo bloom in Rapid Creek, South Dakota (Bothwell et al. 2009)
- may reduce exchange rates of ground water and surface water (Bickel and Closs 2008)

Economic Consequences of Invasion

- clogs intakes and pipes at hydro power and irrigation canals
- may affect recreational income by making rivers look heavily polluted so reducing their aesthetic quality
- economic losses in New Zealand are estimated at $57 million to $285 million over 8 years; this includes impacts on eel fisheries, tourism, water supply, and biodiversity values (Spaulding and Elwell 2007)

Possibility and Cost of Eradication

- not well developed; current focus of management is to avoid introductions of didymo
- very little possibility of eradication due to low detectability at onset of introduction

Possibility and Cost of Control

- very little possibility of control where it has already established; management is focused on curtailing spread
- methods suggested to control didymo include the use of Organic Interceptor®, certain enzymes, chelated copper, and sodium chloride. The effectiveness of these substances is not known (Blanco and Ector 2009) and effects on other organisms may be severe
- a technique for early detection based on didymo at low levels has been developed; this technique detects the presence of genetic material from didymo in samples (Cary et al. 2007, Duncan et al. 2007, Hicks et al. 2007)
- guidelines for disinfecting equipment are available from the Quebec government (MDDP-MRNF Scientific Advisory Committee on *Didymosphenia geminata* 2007). Advice includes throwing clumps of algae in the garbage rather than the drain, soaking items in hot water and disinfectants, drying or freezing equipment, and washing pets or

restricting their movement to sites of possible contamination for 48 hours.
- a public information sheet is available from Parks Canada.
- Kilroy et al. (2008) developed a didymo habitat suitability rating for New Zealand rivers that takes light, pH, temperature, and hydrological and substrate stability into consideration

3. Zebra Mussels (*Dreissena polymorpha*)

Dreissena polymorpha (zebra mussels) with mention of closely related invasive *Dreissena bugensis* (quagga mussel)

Phylum: Mollusc
Class: Bivalvia
Order: Veneroida
Family: Dreissenidae

<u>Likelihood of Invasion</u>

Overview of Life History

- zebra mussels are dioecious and fertilization occurs externally (Ram et al. 1996)
- sexual maturity reached in first year, usually at 8 to 10 mm in shell length
- high fecundity found in females, ranging from 30,000 to 1,610,000 eggs/female in one year
- gametogenesis begins in fall and continues through winter
- rapid growth of oocytes and spermatozoa in spring
- in the Great Lakes region, eggs grow through the trochophore, D-shape, velichoncha, pediveliger, then plantigrade larval stages between late May and mid-August (Mackie and Schloesser 1996)
- planktonic veliger larvae passively disperse
- before attaining adult form, mortality is estimated between 70% and 99% (Mackie and Schloesser 1996)
- adults attach themselves to substrate with byssal threads; substrate is usually a hard surface
- lifespan in North America is 1.5 to 2 years
- maximum size is 2.5 to 3.0 cm
- temperature affects timing of reproduction and growth rate
- highly gregarious, with densities as high as 800,000/m^2 (Ram et al. 1996)
- filter feeding by cilia in the mantle cavity, stomach, and midgut
- consumes algae; selection for particles of 15–40 µm
- considered a freshwater inhabitant, but tolerates brackish water
- not found below a depth of 40 m

Origin and History of Invasion and Spread

- endemic to freshwater in Europe (Ram and McMahon 1996)
- probable source into North America was the Black Sea region of the Ukraine at the extreme southern portion of their European range (McMahon 1996)
- likely introduced into North America by release of larvae from ship ballast water into Lake St. Clair near Detroit, Michigan in 1986 (Herbert et al. 1989 cited in Ram and McMahon 1996); then it dispersed into the lower Great Lakes and freshwater portion of the St. Lawrence River and continued eastward through the Erie Canal, into the Hudson River, and overland into the upper Susquehanna River and Illinois River into the Mississippi River
- moved up tributaries of the Mississippi River and into inland water bodies
- zebra mussels and quagga mussels have recently crossed the 100th meridian (Mackie 2010), an event once thought to be of low probability (Brossenbroek et al. 2007)

Habitat Requirements (physical and chemical) in comparison to availability in Yukon

- Infestation determined by physical and chemical parameters of water (Table 1.A)
- impoundments and other human-altered aquatic environments were found to have more favourable conditions for colonization than more natural environments (Johnson et al. 2008, Zaiko et al. 2007)
- lakes with significant amounts of limestone in their drainage basin are at the highest risk, and lakes in acidic (i.e., granite) rocks have the lowest risk. Many of Yukon's lakes northwest of the coastal batholith drain lands with significant amounts of limestone. These include all of the vehicle-accessible southern lakes, with the possible exception of Kusawa Lake in southwest Yukon.

Table 1.A. Physical and chemical parameters affecting dreissenid mussel infestation (from Mackie 2010)

Parameter	No Infestation	Little	Moderate	High
Calcium mg/L	<10	<16	16–24	≥24
Alkalinity mg $CaCO_3$/L	<35	35–45	45–89	>90
Total Hardness mg CaCO3/L	<40	40–44	45–90	≥90
pH	<7.2	7.2–7.5	7.5–8.0 or 8.7-9.0	8.0–8.6
Mean Summer Temperature °C	<18	18–20 or >28	20–22 or 25–28	22–24
Dissolved Oxygen mg/L (% saturation)	<6 (25%)	6–7 (25%–50%)	7–8 (50%–75%)	≥8 (>75%)
Conductivity µS/cm	<30	<30–37	37–84	≥85
Salinity mg/L (ppt)	>10	8–10 (<0.01)	5–10 (0.005-0.01)	<5 (<0.005)
Secchi depth m	<0.1	0.1–0.2 or >2.5	0.2–0.4	0.4–2.5
Chlorophyll a µ/L	<2.5 or >25	2.0–2.5 or 20–25	8–20	2.5–8
Total phosphorous µg/L	<5 or >35	5–10 or 30–35	15–30	10–15
Total Nitrogen µg/L	<200	200–250	250–300	300–500

Pathways of Introduction

- ship ballast water, bait buckets, bilges, or boat engines with larvae (Johnson et al. 2001)
- adult stages attached by proteinaceous byssal threads to boats, barge hulls, nets, buoys, or floating debris can disperse along waterways or overland (Ram and McMahon 1996)
- adult and juvenile mussels primarily transported on macrophytes entangled on boat trailers, and secondarily on boat anchors (Johnson et al. 2001)
- planktonic veliger larval stage disperses passively in water current
- proximity of water bodies connected by streams to source infestations is correlated to the probability of infestation (Bobeldyk et al. 2005)
- risk of establishment is dependent on the conditions in the receiving environment (invasibility) and the ability of the invasive species to reach the receiving environment (propagule pressure) (Leung and Mandrak 2007); propagule pressure is higher where the mussels are abundant (Ricciardi 2003) and where boat launches exist

Consequences of Invasion

Ecological Consequences of Invasion

- infests unionids, causing unionids to starve or become dislodged from the substratum

- also colonizes snails (Schloesser et al. 1996)
- reduction of phytoplankton and suspended inorganic matter, resulting in increased water clarity and a shift in energy from pelagic to benthic food chain (MacIsaac et al. 1992, Zhu et al. 2006)
- high rate of soluble reactive phosphate resulting in higher abundance of nuisance algae (e.g., Cladophora) and higher abundance and toxicity of cyanobacteria *Microcystis* (Turner 2010, Knoll et al. 2008)
- may cause decline in *Diporeia* spp. by out-competing them for food; decline in *Diporeia* implicated in decline of its predator, lake whitefish (*Coregonus clupeaformis*) (Dobiesc et al. 2005)
- creates habitat that protects invertebrates from fish predation (Sousa et al. 2009)
- potentially exacerbates eutrophication (Bruesewitz et al. 2008, Strayer 2009)
- zebra mussels accumulate contaminants, which then become concentrated in their predators, particularly waterfowl (MacIsaac 1996)

Economic Consequences of Invasion

- zebra mussels form dense aggregates on hard surfaces such as pilings, bridges, docks, and watercraft, and on human-made raw water systems where they occlude or block flow in large diameter pipes; such colonizing is called "biofouling"
- impacts power stations, potable water treatment plants, and industrial facilities (Ram and McMahon 1996)
- impacts sports fisheries
- the economic cost of zebra mussels in the Great Lakes was estimated at $4 billion in the first decade of invasion (Strayer 2009)
- economic loss for an invasion into the Columbia Basin is estimated at $1.94 million annually (Independent Economic Analysis Board 2010)

Possibility and Cost of Eradication

- early detection and eradication by SCUBA divers at Lake George, New York required approximately 6,700 people hours, including 959 dive hours; community volunteers made this possible, otherwise the costs would have been prohibitive (Wimbush et al. 2009)
- no prospects of eradicating in open waters (Strayer 2009)

Possibility and Cost of Control

- little or no prospects of control in open waters (Strayer 2009)
- treatment on human-made structures includes the use of oxidants, flocculants, heat, dewatering, mechanical removal, and pipe coating resistant to colonization
- estimated cost to mitigate a hypothetical zebra mussel infestation at 14 hydroelectric projects along the Columbia River was over $23 million in 2005, excluding annual operating costs (Philips et al. 2005)

- Hickey (2010) reports that, for Lake Mead National Recreation Area, Nevada, concentrated human access in particular areas where dreissenid mussels had been introduced exacerbated the spread of the mussels; she suggests that zoning buffers around undisturbed areas would help prevent introduction of dreissenid mussels

Notes on Quagga Mussels

- can reproduce at lower temperatures (<8 ^{o}C) than zebra mussels, but has lower tolerance of high temperatures showing rapid mortality at 30 ^{o}C (Mills et al. 1996)
- found at lower depths (>40 m) than zebra mussels (Mackie and Schloesser 1996) and more tolerant of lower oxygen conditions (<25%) (Karatayev et al. 1998)
- attachment to soft substrates (e.g., soft profundal sediments) with low hydrodynamic activity as well as firm inshore substrates
- less resistance to desiccation than zebra mussel, and less likely to survive overland transport (Ricciardi et al. 1995)
- has displaced the zebra mussel at sites in Lake Ontario and Lake Erie, the northern portion of their eastern distribution in North America (Orlova et al. 2005)

4. Eurasian Watermilfoil (*Myriophyllum spicatum*)

Also known as spiked watermilfoil

Phylum: Tracheophyta
Class: Magnoliopsida
Order: Haloragales
Family: Haloragaceae

<u>Likelihood of Invasion</u>

Overview of Life History

- Eurasian watermilfoil is a submergent plant, rooting in waters up to 10 m deep
- when stems reach the water surface, shoots near the surface branch out profusely forming a canopy, and lower leaves and branches slough off
- the main mode of colonizing new sites is by vegetative reproduction; new plants can form from auxiliary buds that easily detach from the root crown in late winter, from fragments released from stems in summer, or from pieces broken off plants by wave action, boat motors, or other mechanical means (Aiken et al. 1979)
- the spent flowering spikes of Eurasian watermilfoil lie parallel to the water as seeds mature
- conditions required to germinate seeds are unclear; if seeds are viable, they can remain dormant for as long as 7 years (Aiken et al. 1979)

- plants typically die back in winter, especially in cooler climates, but retain root crowns that are ready to grow as soon as temperatures rise
- grows quickly in spring with increased light and temperature
- uptake of nutrients such as phosphorus is with roots and leaves (Nichols and Shaw 1986)
- explanations for observed die-offs include insect predation or phytopathogens (Nichols and Shaw 1986)

Origin and History of Invasion and Spread

- introduced in Chesapeake Bay area in late 1800s, possibly from ballast
- in 1930s, approximately 80,000 ha were covered by Eurasian watermilfoil
- introduced into Tennessee in 1953 by a resort owner and by 1969 had reached a coverage of 10,000 ha; continued spread in United States thereafter
- early records of Eurasian watermilfoil in Canada consist of several sites along the St. Lawrence Seaway and a park on Lake Erie in the 1960s
- in the 1970s it was recognized as a nuisance, occurring at locations in Quebec, southern British Columbia, and in the Kawartha Lakes in southern Ontario (Aiken et al. 1979)
- it is now widespread across North America, including locations in British Columbia

Habitat Requirements (physical and chemical) in comparison to availability in Yukon

- plants establish in water 2 to 3 m deep and spread to shallower or deeper sites (Boylen et al. 1996, Madsen 1999)
- can grow in deeper water if light penetration is good (i.e., clear water)
- grows well in eutrophic lakes; also found in oligotrophic lakes (Boylen et al. 1996)
- pH at sites ranges from 5.4 to 10
- thrives in salinity up to 10 parts per thousand (Aiken et al. 1979)
- abundance is positively correlated with agricultural intensity in watersheds of the Laurentian Great Lakes (Trebitz and Taylor 2007)
- tolerates wave action, but grows better in sheltered waters
- minimum nitrogen is .75% and minimum phosphorus is .07%
- thrives best on fine sediments with 10% to 25% organic matter (Nichols and Shaw 1986)
- once in Yukon, it may only proliferate in still, shallow, warm waters that generally occur at low elevations, but it may persist in other Yukon waters at low density

Pathways of Introduction

- boats and associated equipment harbouring pieces of Eurasian watermilfoil are the vectors of introduction
- the aquaria and aquatic nursery trade is implicated in some long distance dispersals (Nichols and Shaw 1986)

Consequences of Invasion

Ecological Consequences of Invasion

- shades out other water plants, resulting in the disappearance or severe reduction of many native species (Boylen et al. 1999)
- potentially reduces plant food preferred by waterfowl
- alters temperature profiles in lakes by increasing water temperatures as much as 10 ^{o}C (Aiken et al. 1979)
- may create good habitat for larvae of mosquitoes, chironomids, and other invertebrates
- provides cover for small fish which could lead to overpopulation of these species or to populations skewed to dwarfed fish (Nichols and Shaw 1986)
- may alter and reduce invertebrate abundance and diversity by displacing native macrophytes (Keast 1984)
- may accelerate eutrophication
- may limit larger fish by creating a refuge for prey species (Horsch and Lewis 2009) or may enhance invertebrate prey base for fish and waterfowl (Nichols and Shaw 1986)
- hybridizes with the native northern watermilfoil, *Myriophyllum sibiricum* (Roley and Newman 2006)
- can mobilize nutrients from lake bottom sediments into the water column by sloughing off leaves (Nichols and Shaw 1986)

Economic Consequences of Invasion

- clogs industrial and potable water supply systems
- curtails recreational activities such boating, swimming, and fishing
- reduces water flow
- adds costs to beach maintenance (Aiken et al. 1979)
- reduces property values along affected lakes (Horsh and Lewis 2009)

Possibility and Cost of Eradication

- difficult to eradicate without dire consequences to associated native vegetation (Horsch and Lewis 2009)

Possibility and Cost of Control

- between 1961 and 1977, Tennessee Valley Authority spent $4 million to control Eurasian watermilfoil (Aiken et al. 1979)
- control can be achieved by physically removing the plants every 2 to 3 years

- submerging a benthic barrier onto Eurasian watermilfoil for 1 or 2 years thwarts its growth for a short period (< 1 year) after the barrier is removed (Boylen et al. 1996)
- application of the herbicide triclopyr reduced Eurasian watermilfoil for 3 years during which non-target native species became more abundant; this can be effective along shores, in coves, and regulated rivers (Getsinger et al. 1997)
- Bispyribac-sodium is an herbicide that inhibits acetolactate synthesis in Eurasian watermilfoil, but some weed species have become resistant to this herbicide (Richardson 2008)
- control by milfoil weevils has the potential to reduce watermilfoil infestations if high densities of the insect can be maintained; however, predation on the weevil by fish limits its population size (Newman 2004)
- cost of control in the Okanagan between 1972 and 1990 was $6 million, and more than $4 million between 1990 and 2001; primary removal was by mechanical means (Wilson et al. 2007)
- in Yukon, control would need to be limited to small, high use areas to reduce costs

5. Fanwort (*Cabomba caroliniana*)

Also known as cabomba, Carolina water-shield, purple fanwort, fish grass, and Washington grass

Phylum: Magnoliophyta
Class: Magnoliopsida
Order: Nymphaeles
Family: Cabombaceae

Likelihood of Invasion

Overview of Life History

- submergent plant that grows quickly to the surface early in the growing season
- multiple stems grow from a root mass, and fan shaped leaves grow along the length of the stem
- any fragment having a node and a pair of leaves is capable of becoming a mature plant
- overwinters vegetatively
- viable seeds have not been found to overwinter in Canada
- flowering period depends on climate; peak flowering in southern Ontario occurred August and September
- mainly pollinated by flying insects
- mature fruits fall into the substrate and germinate in some regions of the plant’s range
- seeds from Ontario and New Jersey were not viable

- absorbs nutrients through shoots, leaves, and stems, efficiently using dissolved phosphorus and nitrogen
- roots are not very deep
- can be free-floating in deep water (Wilson et al. 2007)

Origin and History of Invasion and Spread

- native to southern Brazil, Uruguay, Paraguay, and northeastern Argentina
- likely naturalized in the southeastern United States several centuries ago
- main source for North American aquaria trade is Marcos River, Texas
- first well-substantiated account of fanwort naturalized in Canada occurred in 1991 in North River near Peterborough, Ontario
- documented in at least 31 American states including the New England states and the west coast; some of the northward expansion may have been by motor boats harbouring stem fragments
- it has also been introduced in Asia, Europe, and Australia either by discarding or deliberate planting into waterways (Wilson et al. 2007; Zhang et al.2003)

Habitat Requirements (physical and chemical) in comparison to availability in Yukon

- may prefer organic-rich sediments
- occurs in a wide range of depths (.2 to 1.8 m) in the littoral zone (Lyon and Eastman 2006)
- optimal temperature range is 13 ^{o}C to 27 ^{o}C, but tolerates sub-zero temperatures
- primarily found in loose, silty substrates, but also found on cobble, sand, and rock ledges
- usually in water < 3 m, but does occur to depths of 10 m
- optimum pH range for growth is 4 to 6
- grows well in nutrient-rich water but growth is inhibited by high calcium levels (Wilson et al. 2007)
- Jacobs and MacIsaac (2009) used an environmental niche model to predict lakes in Ontario with the greatest invasive risk based on the variables pH, temperature, calcium, conductivity, phosphorus, oxygen, alkalinity, ammonia, and nitrate
- some Yukon waters are probably too alkaline for fanwort to proliferate

Pathways of Introduction

- fanwort is a popular plant sold for aquariums and garden ponds
- introduction occurs directly by cultivating or discarding the plant into lakes or rivers
- may be introduced indirectly through the sink or toilet if the sewage is inadequately treated and released into watersheds (Cohen et al. 2007)
- it may spread via boats and other equipment (Wilson et al. 2007)

Consequences of Invasion

Ecological Consequences of Invasion

- associated with reduced species richness of aquatic plants (Lyon and Eastman 2006)
- shades out native plant species
- dieback at end of growing season may deplete oxygen in water
- can provide cover for fish and invertebrates, but also alters fish habitat (Wilson et al. 2007)

Economic Consequences of Invasion

- clogs waterways, impedes flow, obstructs navigation
- reduces property values along infested lakes
- reduced income from fishing and tourism
- limits outdoor recreation and aesthetic value of lakes (Wilson et al. 2007)

Possibility and Cost of Eradication

- not considered cost-effective (Wilson et al. 2007)

Possibility and Cost of Control

- small infestations can be controlled by manually removing plants
- operation of diver-operated suction dredges has minimal environmental impact but is slow, treating approximately 100 m^2 per person-day; labour cost would be high
- caution is required during removal by mechanical means, particularly when using harvesters and similar equipment, as fragments readily root
- temporary benthic barriers have been effective at controlling fanwort in small areas
- in reservoirs, drawdown of the water level to desiccate plants and hydrosoil can be effective
- sterile triploid grass carp have been used to control fanwort in Florida, but are less effective in cold water and consume native species as well as invasive species
- control by herbicides is inconclusive (Wilson et al. 2007)
- introductions could be prevented by implementing policies that require accurate identification of aquarium and nursery species, and through public education on the invasive species (Keller and Lodge 2007)

6. Goldfish (*Carassius auratus*)

Phylum: Chordata
Class: Actinopterygii
Order: Cypriniformes
Family: Cyprinidae

Likelihood of Invasion

Overview of Life History

- a freshwater fish in the carp family developed from either the Prussian carp, silver Prussian (or Gibel) carp, (*Carassius gibelio*), or the Crucian carp (*Carassius carassius*)
- goldfish hybridize with common carp (*Cyprinus carpio*); feral populations represent a complex of morphologically and taxonomically diverse forms (Nico and Schofield 2010)
- adult goldfish are generally from 15 to 20 cm total length and weigh from 100 to 300 g (Nico and Schofield 2010); larger goldfish may be carp-goldfish hybrids
- age to sexual maturity may be as little as 225 days at water temperatures 20 ^{o}C to 30 ^{o}C with a mean fecundity at first spawning of 4,699 ova (Ortega-Salas and Reyes-Bustamante 2006)
- In Lake Trasimeno, central Italy, a feral goldfish population was comprised of 8 age-classes with a female: male sex ratio of 19:1. Males and 7.55% of females spawned after their first winter, and the remainder of the females after their second winter. Spawning extended from March to June. Fecundity ranged from 286 to 219,104 eggs/female, with absolute fecundity, relative fecundity, and egg diameter increasing with specimen size (Lorenzoni et al. 2010).
- in small ponds in England, sexual maturity was more rapid (mean 1.7 years vs. mean 2.1 years) and at shorter standard lengths (50–64 mm vs. 139.2 mm) than an Italian population (Tarkan et al. 2010)
- several spawning events occur during the overall spawning period (Chen 1928), and this attribute may be increased after translocation or disturbance (Copp et al. 2005)
- goldfish in the mid-Columbia River spawned at temperatures from 10 ^{o}C to 16 ^{o}C (Hatfield and Pollard 2009)
- spawning generally takes place in warm shallows and is associated with submerged vegetation
- fertilized eggs are 1.2 to 1.5 mm in diameter, adhesive, and hatch at 3 to 4 days at 18.5 ^{o}C to 29.5 ^{o}C (Scott and Crossman 1973)
- maximum ages of captive goldfish in excess of 40 years old have been reported in the popular press (BBC News 1999)
- diet is opportunistic and omnivorous (Scott and Crossman 1973)

Origin and History of Invasion and Spread

- first domesticated in China in about 960 CE (Scott and Crossman 1973)
- introduced into Europe in the 1600s as an ornamental fish (Crivelli 1995, Copp et al. 2005, Ribeiro and Collares-Pereira 2009, Musil et al. 2010), and later introduced to Australia (Morgan et al. 2004), New Zealand (Rowe 2007), and parts of Asia (Jang et al. 2002)
- introduced to North America in the early 1600s as intentional releases (Nico and Schofield 2010)

- present in every state of the US except Alaska (Nico and Schofield 2010)
- in western and central Canada, present in British Columbia (Hatfield and Pollard 2009); in Alberta, as a lacustrine stock (Scott and Crossman 1973) and as a riverine/fluvial stock (Kari Hamilton, biologist, personal communication); in Manitoba and in interior waters of Ontario (Lui et al. 2008) including all of the Great Lakes (O'Connor et al. 2008)
- in Yukon, present in the effluent pond from the Takhini Hot Springs

Habitat Requirements (physical and chemical) in comparison to availability in Yukon

- typical habitat includes the quiet backwaters of streams and pools, especially those with submerged aquatic vegetation
- tolerant of high turbidity levels, temperature fluctuations, low levels of dissolved oxygen, and pH levels between 4.5 and 10.5, with a preference for levels between 5.5 and 7.0 (Nico and Schofield 2010)
- can survive water temperatures between 0 °C and 41 °C (Carlander 1969, Nico and Schofield 2010)
- more tolerant of aquatic pollution than most native North American fish (Nico and Schofield 2010)
- habitats in Yukon are available

Pathways of Introduction

- goldfish won as prizes at summer fairs, then released
- intentional introductions originating from nurseries or the aquarium trade, particularly close to roads (Copp et al. 2005)
- tend to remain close to their original release sites (Hatfield and Pollard 2009)
- as a live bait fish; in the United States, individual states have jurisdiction for baitfish; most states do not allow live goldfish to be used, but some do
- live goldfish use for bait has been banned in Canada

<u>Consequences of Invasion</u>

Ecological Consequences of Invasion

- grazes and uproots aquatic vegetation, freeing nutrients sequestered in sediments and aquatic plants (Richardson et al. 1995)
- increases growth and potential photosynthesis of cyanobacteria that have passed through goldfish guts (Kolmakov and Gladyshev 2003)
- the cumulative effect is an increase in turbidity and a decrease in rooted aquatic vegetation (Crivelli 1995, Richardson et al. 1995, Rowe 2007)
- may predate on the eggs and larvae of amphibians (Monello and Wright 2001) and other fish (Nico and Schofield 2010)

Economic Consequences of Invasion

- information gap

Possibility and Cost of Eradication

- eradication appears feasible only where both the environment and the source of re-introduction can be controlled
- goldfish were successfully extirpated from cooling ponds at the Clear Air Force Station in Alaska in 1980
- Goldfish were either eradicated or reduced to a very low level in the effluent pond of the Takhini Hot Springs near Whitehorse in 1994. The eradication was administratively challenging, in part as it was the first project of its kind in Yukon. Rotenone was applied to the ponds. Financial expenditures on the project exceeded $4,000 in 1995 dollars (Government of Yukon files). The total cost of the project, including all Government of Yukon and Government of Canada staff time and legal fees, was far greater. The goldfish have apparently re-established a population in the pond (Nathan Millar, biologist, Environment Yukon, personal communication).
- Goldfish were either eradicated or reduced to a very low level in 2 small ponds near Hamilton, Ontario in 2009 by the Hamilton Conservation Authority. The eradication was administratively challenging. A consultant was hired, and rotenone was applied. The cost of conducting the project was around $8,000. The total cost of the project, including Hamilton Conservation Authority, Government of Ontario, and Government of Canada time was somewhat higher. The ponds were not monitored in 2010, and it is likely that the goldfish population is either recovering from those not destroyed in 2009 or from subsequent illegal releases (Shari Faulkenham, personal communication).
- the American Fisheries Society's fish management chemicals subcommittee has no success stories regarding eradication or control of goldfish by rotenone (American Fisheries Society 2010)

Possibility and Cost of Control

- restriction or prohibition of goldfish as fairground prizes has been enforced in some places (Copp et al. 2005); such regulations have been created to improve animal welfare (i.e., of the goldfish), not to deter introduction of non-native species.
- control of goldfish introduction is subject to section 55 of the federal Canadian Fishery (General) Regulations, which prohibits the release of any live fish to fish habitat. Enforcing this regulation to the point of ensuring compliance would be prohibitively expensive.
- control of established populations is similar to eradication, and would depend on site-specific circumstances. If the population is a monoculture, rotenone can effectively reduce the population.

7. New Zealand Mud Snail (*Potamopyrgus antipodarum*)

Phylum: Mollusc
Class: Gastropoda
Order: Mesogastropoda
Family: Hydrobiidae

<u>Likelihood of Invasion</u>

Overview of Life History

- an aquatic snail
- reaches 6 to 7 mm in invaded regions, but grows to 12 mm in New Zealand (Alonso and Castro-Diez 2008)
- has a solid operculum, which helps it to resist digestion in the gastrointestinal tract of fish and lethal desiccation for several weeks if kept in cool, moist conditions (Bersine et al. 2008)
- populations in invaded regions consist entirely of females
- in New Zealand, it reproduces sexually and asexually
- in invaded areas, reproduces asexually via parthenogenesis (Morley 2008)
- reaches sexual maturity at 3 to 3.5 mm
- one to 6 generations per year
- females are ovoviviparous, brooding their offspring to the "crawl away" developmental stage in a brood pouch
- average 230 juveniles per adult per year
- feeds on periphyton, macrophytes, and detritus
- buries itself in sediment during dry or cold periods (Alonso and Castro-Diez 2008)
- can reach densities of 500,000 per m^2 in rivers (Levri et al. 2008)
- can live past one year (Montana State University [no date])

Origin and History of Invasion and Spread

- indigenous to New Zealand
- believed to have spread into Europe from ballast (Morley 2008)
- first occurred in the United Kingdom in 1859, Australia in 1892, and recently in Japan
- documented in Middle Snake River, Idaho in 1987, and thought to have escaped from a fish farm; this clone has been traced back to Australia (Levri et al. 2008)
- introductions into Lake Ontario and St. Lawrence River by 1991, and Columbia River by 1997, are probably from ballast water (Alonso and Castro-Diez 2008)
- one sample from the Great Lakes matches one of the clones from Europe, but it is possible that the Great Lakes have experienced multiple introductions (Levri et al. 2008)
- spread to multiple sites in Lake Erie by 2006, and in Lake Superior by 2003

- spread has continued within watersheds
- recently found at Port Alberni, British Columbia, the most northerly location in western North America (Montana State University [no date])
- thought to have spread inland from brackish water to freshwater habitats (Morley 2008)

Habitat Requirements (physical and chemical) in comparison to availability in Yukon

- tolerates salinities up to 16‰
- found in freshwater habitats, with preference for running water (Morley 2008)
- requires calcium
- limited by conductivity; most prevalent at conductivity > 200 $\mu S \cdot cm^{-1}$ (Herbst et al. 2008)
- substrata ranges from clay, fine sand, mud, and macrophytes
- tolerates 0 ^{o}C to 28 ^{o}C, with highest growth rate around 18 ^{o}C
- early colonizer, faring well in disturbed sites (Alonso and Castro-Diez 2008)
- tolerates eutrophic and oligotrophic conditions
- found between 4 and 45 m depths in the Great Lakes, but does persist in shallower waters elsewhere (Levri et al. 2008)
- more common in streams with variable flows than in streams with more stable flows, likely due to its ability to colonize disturbed sites (Schreiber et al. 2003)
- potential range, as predicted by a model based on an invaded range in Australia, spans the breadth of the lower states and southern Canada (Loo et al. 2007)
- potential habitats exist in Yukon but some areas are limited by low-conductivity (Environment Yukon data)

Pathways of Introduction

- through ballast water of commercial ships
- transport of aquaculture products and aquatic ornamental plants
- can travel in water pipes, within mud attached to bills or legs of birds, or inside guts of birds and fish
- spreads upstream and downstream within waterways by own means of movement or assisted by currents
- recreational boats and associated equipment including nets, waders, and boots (Alonso and Castro-Diez 2008)
- can be introduced from lake or river stocking of reared salmonids that have fed on the snails, as the snails can survive in the gut (Bruce and Moffit 2010)

Consequences of Invasion

Ecological Consequences of Invasion

- a vector for trematode parasites, so can either be an alternate host for trematodes in adapted locations, or can introduce trematodes from its New Zealand origin (Morley 2008)
- can increase nitrogen fixation and increase the proportion of nitrogen-fixing diatoms in a stream (Arango et al. 2009)
- can limit growth of native snails (Riley et al. 2008)
- can alter food web by assimilating the largest fraction of carbon available to invertebrate production and dominating the invertebrate community (Hall et al. 2006), but not always (Cross et al. 2010)
- potentially out-competes macroinvertebrates (i.e., larval mayflies, caddisflies, stoneflies) for food, potentially decreasing the prey base for salmon (Sanderson et al. 2009)
- according to one study on trout, the snails are nutritionally inferior food compared to native invertebrates (Vinson et al. 2006 cited in Bersine et al. 2008)

Economic Consequences of Invasion

- information gap

Possibility and Cost of Eradication

- information gap

Possibility and Cost of Control

- primary control is to deter the spread to new areas
- immersion of equipment, such as boots, in disinfectants with quaternary ammonium compound for 10 minutes kills the mud snails (Schisler et al. 2008)
- concentrations of most disinfectants required to kill snails in trout hatcheries would also be detrimental to fish and eggs; dilute Pine-Sol might be an exception (Oplinger and Wagner 2009)
- hydrogen peroxide is the most cost-effective household disinfectant for cleaning hatchery equipment, at an estimated USD $0.024 per litre (Oplinger and Wagner 2009)
- freezing and proper drying of equipment has also been suggested (Levi et al. 2008)

8. Northern Snakehead (*Channa argus*)

Phylum: Chordata
Class: Actinopterygii
Order: Perciformes
Family: Channidae

Likelihood of Invasion

Overview of Life History

- freshwater fish
- the most cold tolerant of the snakehead species
- obligate air-breather, with capacity to survive out of water for up to 4 days if kept moist
- overland migration possible but limited (Cudmore and Mandrak 2006)
- spawning spanned April to September in Potomac River, Maryland (Odenkirk and Owen 2007), but has been found to be shorter elsewhere; may have multiple spawning in a year
- builds cylindrical nests up to 1 m wide with pieces of macrophytes in shallow aquatic vegetation
- 1,300 to 1,500 pelagic, non-adhesive, buoyant eggs per spawn
- maturity at 2 years at about 30 cm in length
- can grow to 1.8 m and 6.8 kg (Cudmore and Mandrak 2006)
- initially, fry feed on zooplankton, then change to small crustaceans and insects
- adults mainly prey on fish (Afraro et al. 2009)
- can reach 15 years of age
- larvae school for weeks prior to dispersal, then disperse up to 35 km (Jiao et al. 2009)

Origin and History of Invasion and Spread

- native to parts of Asia: Amur River basin, Sungari River, Tungushka River, Yangtze River, and Korea (Courtenay and Williams 2004 cited in Cudmure and Mandrak 2006)
- introduced into parts of China, Europe, and parts of Asia in 1900s; mode of introduction is only known for some locations
- introduction into Japan from Korea in 1923 was intentional and used to establish a recreational fishery
- introduction in Kazakhstan and Turkmenistan was accidental in 1961 when it was shipped with other fish species
- in the United States, northern snakehead was first found in California in 1977, then in Florida in 2000 (Cudmore and Mandrak 2006)
- adult snakehead from a live-fish market were introduced into a retention pond in Maryland; they reproduced and were discovered in 2002 and have since been eradicated (Lazur et al. 2006)
- since 2002, it has also been documented in the Potomac River in Maryland and Virginia; a pond in Philadelphia, Pennsylvania; Burnham Harbour, Lake Michigan; and in a New York City park (Cudmore and Mandrak 2006).
- genetic work on northern snakehead in the Potomac River indicate that there have been multiple introductions; individuals were not always closely related (Orrell and Weigt 2005)
- it has not been found in natural waters in Canada

Habitat Requirements (physical and chemical) in comparison to availability in Yukon

- found in lakes and slow moving waters, usually close to shore with vegetated or muddy substrate
- mean annual air temperature in native range ranges from -7 ^{o}C to 18 ^{o}C
- potential of reaching 60 degrees latitude in Canada (Cudmore and Mandrak 2006)
- habitats in Yukon are available

Pathways of Introduction

- possible introductions resulting from deliberate release by animal rights activists or for ceremonial/prayer purposes, or accidental release from live-food-fish fisheries
- found at live-food fish markets in Vancouver (e.g., Chinatown); importing live snakeheads into British Columbia is legal and occurs via the Vancouver International Airport, Vancouver marine and rail terminals, and the Pacific Highway (Cudmore and Mandrak 2006)

Consequences of Invasion

Ecological Consequences of Invasion

- potentially detrimental to native fish populations because of the voracious predatory feeding habits and ability to out-compete other fish for food resources (Afraro et al. 2009)
- of 17 food items identified in northern snakehead from the Potomac River, 15 were fish (Odenkirk and Owens 2007)

Economic Consequences of Invasion

- information gap

Possibility and Cost of Eradication

- possible to eradicate from closed water system, such as a retention pond in Maryland, using Rotenone, but treatment also killed the native fish (Lazur et al. 2006); the cost of the eradication was estimated at $110,000 for the 1.8 ha pond (Global Invasive Species Programme 2010)
- details of the eradication plan for northern snakehead at a watershed in New York are available on the New York government website (New York Government 2008)

Possibility and Cost of Control

- possibility of control is better if timed prior to spawning or juvenile dispersal (Jiao et al. 2009)

9. Threespine Stickleback (*Gasterosteus aculeatus*)

Phylum: Chordata
Class: Actinopterygii
Order: Gasterosteiformes
Family: Gasterosteidae

<u>Likelihood of Invasion</u>

Overview of Life History

- small fish with 3 sharp dorsal spines, typically 35 to 55 mm in length
- Holarctic species complex comprising marine, freshwater, and anadromous forms (Lucek et al. 2010)
- subject of numerous studies on speciation, including benthic-limnetic pairs, lentic-lotic pairs, and anadromous–non-anadromous pairs living in parapatry or sympatry (COSEWIC 2006)
- feeds on aquatic invertebrates and zooplankton
- matures at one year or older
- males develop brightly coloured orange or red belly during breeding period in April to June (Hammerson et al. 2010)
- males construct nests or plant materials in shallow areas, and lure females to spawn
- males then guard and fan eggs to provide them with oxygen for 7 to 10 days until they hatch; males continue guarding juveniles for a few days (COSEWIC 2006)
- females typically lay a few hundred eggs in several nests over several days
- several reproductive cycles over one year or several years (Hammerson et al. 2010)
- maximum lifespan is about 3.5 years
- seems prone to various parasites, some of which reach maturity in fish-eating birds (Scott and Crossman 1973), or are passed on to other fish species (e.g., coho salmon, Meehan 1964)

Origin and History of Invasion and Spread

- native range includes coastal water of Eurasia, Iceland, eastern Asia, and North America
- introduced populations found in Switzerland (Lucek et al. 2010) originated elsewhere in Europe
- introduced population found in Japan in 1983, from a source within the country (Mori and Takamura 2004)
- also introduced in Austria, Czech Republic, Hungary, Iran, Italy, Slovenia, and parts of the United States
- first found in Lake Huron and Lake Superior in 1980s, probably introduced by bait bucket or ships' ballasts; native to Lake Ontario
- found in tributaries of Lake Huron and Lake Michigan in 1984 (Stedman and Bowen 1985)

- introduced populations in Alaska, California, Massachusetts, Illinois, Michigan, Minnesota, Oregon, and Wisconsin, predominantly from use as bait by anglers (US Geological Survey 2009)
- intentionally introduced into new areas in British Columbia from populations within the province, by a fish hobbyist from Quebec (Crossman 1991)
- unauthorized introduction into Hasse Lake, Alberta prior to 1980s (Nelson and Harris 1987)
- unintentionally introduced into 2 pothole lakes in Yukon in 1970s; they were likely released with trout fry used to stock lakes for recreational fishing (Government of Yukon 2010, Crossman 1991)

Habitat Requirements (physical and chemical) in comparison to availability in Yukon

- typically in marginal vegetation of streams over sand and muddy substrates, weedy pools, backwaters (Hammerson et al. 2010)
- require a stable riparian vegetation zone
- macrophyte beds in littoral zone for feeding and shelter (Hatfield 2008)

Pathways of Introduction

- contamination of aquaculture stocks
- sticklebacks used as live bait in recreational fishing
- ballast (Crossman 1991)
- release of aquarium fish (numerous sources on the internet discuss sticklebacks as aquarium fauna)

Consequences of Invasion

Ecological Consequences of Invasion

- found to hybridize with unarmoured stickleback species in California
- preys on eggs of other species (US Geological Survey 2009)
- may provide additional forage for large salmonids (Stedman and Bowen 1985)
- native populations are found in coexistence with other fish species, including cutthroat trout, rainbow trout, coho salmon, Dolly Varden, and prickly sculpin (COSEWIC 2006)
- threespine sticklebacks are known to be intermediate hosts for parasites, or vectors of infection, to piscivorous birds and fish (Meehan 1964)

Economic Consequences of Invasion

- information gap

Possibility and Cost of Eradication

- information gap

Possibility and Cost of Control

- information gap

10. Rainbow Trout (*Oncorhynchus mykiss*)

Phylum: Chordata
Class: Actinopterygii
Order: Salmoniformes
Family: Salmonidae

<u>Likelihood of Invasion</u>

Overview of Life History

- in native range, rainbow trout spawns in spring, and fry emerge from April to June
- up to 1,000 eggs are laid in each redd, which is dug in gravel in stream riffles; females cover eggs by displacing gravel on the upstream edge of the redd
- females deposit eggs in multiple redds; average fecundity is 3,250 eggs per female
- development of eggs to hatching is positively correlated to water temperature, ranging from 4 to 7 weeks
- fry emerge from redds in mid-June to mid-August
- reproductive maturity generally reached at 3 to 5 years, with males usually maturing earlier
- size at maturity varies greatly, from 15 to 40 cm; anadromous forms are larger
- repeated spawning does occur, but prevalence varies widely among populations
- maximum lifespan is about 9 years
- lake dwellers migrate to spawning streams; stream forms tend not to migrate
- anadromous (i.e., steelheads) and freshwater forms exist
- feeds on invertebrates, plankton, snails, and leeches, and is not considered very selective in food choice (Morrow 1980)
- introduced populations in Japan spawn in late winter, and fry emerge in mid-spring (Kitanishi et al. 2010); such plasticity in timing is common for rainbow trout

Origin and History of Invasion and Spread

- native to the Pacific coast of North America and the Kamchatka Peninsula of Russia, where both anadromous and non-anadromous stocks are present
- has been introduced to eastern North America and in 87 countries but not all introductions result in invasions; the ones that did include introductions to Australia in late 1800s, to the Andes mountains of Venezuela and Chile in early 1900s, and to Hokkaido Island, Japan in 1920 (Fausch 2001)
- one of the most common non-native vertebrates in streams in non-Pacific drainages of the western United States (Lomnicky et al. 2007)

- anadromous form has developed from introduced stocks in the upper St. Lawrence River, enabling colonization into new areas that require migration through saline water (Thibault et al. 2010)
- intentionally introduced for recreational fishing in Northwest Territories and all provinces of Canada (Crossman 1991)
- in Yukon, stocking is believed to have started during World War II and has continued since; releases have been documented since about 1957
- rainbow trout entered the Yukon River from plantings in Jackson (Louise) Lake in the 1950s; since then, they have established spawning populations in lower McIntyre Creek, the Yukon River, and Croucher Creek (Walker et al. 1973, Moodie et al. 2000, Bradford et al. 2001)
- in Yukon, rainbow trout (or rainbow/cutthroat hybrids) have developed a spawning population in the McLean Creek watershed where they are the sole species (Walker et al. 1973)

Habitat Requirements (physical and chemical) in comparison to availability in Yukon

- moderate and stable flow regime during fry emergence (Fausch 2001, Inoue et al. 2009); flow rate is function of stream gradient (Kitanishi et al. 2010)
- spawning at water temperatures between 5.5 ^{o}C and 17 ^{o}C, with most spawning occurring between 10 ^{o}C and 13 ^{o}C
- survival of eggs dependent on water velocity through redd, and the amount of dissolved oxygen
- upper lethal temperature is 24 ^{o}C (Morrow 1980)
- habitat appears available and abundant in Yukon, but most attempts to develop spawning populations where other fish species are present have generally failed (Al von Finster, personal observation)

Pathways of Introduction

- introductions from stocking programs intended to enhance recreational fishing
- escapes from hatcheries (Kitanishi et al. 2010)
- watershed capture by hydroelectric projects, such as the Yukon Electric Company's diversion of Fish Creek and Jackson (Louise) Lake to McIntyre Creek

<u>Consequences of Invasion</u>

Ecological Consequences of Invasion

- threat of genomic extinction of native cutthroat trout with which it hybridizes, with differing degrees of introgression depending on habitat and distance upstream from site of introduced rainbow trout (Fausch 2001, Boyer et al. 2008); greater hybridization found at lower-elevation, warmer parts of the Upper Oldman River watershed of Alberta (Rasmussen et al. 2010)

- hybrids have been observed to have better foraging success and grow better than cutthroat trout in cohabitation experiments (Seiler and Keeley 2009)
- introduced hatchery-reared rainbow trout interbreed with native rainbow trout (Krueger and May 1991)
- reduced survivorship of amphibians such as western toads due to the pathogen *Saprolegnia ferax* carried by hatchery trout (Kiesecker et al. 2001)
- implicated in the decline of amphibians, either by competing and reducing food sources or by predation (Hirner and Cox 2007, Vredenburg and Wake 2004); predation enhanced by inability of some amphibians to recognize the new predator (Gall and Mathis 2010)
- alter behaviour of prey; mayflies increased activity at night in the presence of rainbow trout (Simon and Townsend 2003)
- reduces abundance of native salmonids by competing for food and space (Krueger and May 1991, Baxter et al. 2010)
- the protozoan causing whirling disease, *Myxobolus cerebralis*, is transmissible to other fish from rainbow trout
- reduces abundance and biomass of invertebrates; can facilitate increase in periphyton and retard leaf-litter decay by consuming periphyton grazers (Nystrom et al. 2001, Buria et al. 2010)
- reduction of invertebrate food available to other predators, including gray-crowned rosy finches that feed on emerging mayflies (Epanchin et al. 2010)

Economic Consequences of Invasion

- rainbow trout are a highly valued sports fish, contributing $400 million to the British Columbia economy in 2000 (Hirner and Cox 2007)

Possibility and Cost of Eradication

- chemical treatment of streams has successfully removed introduced trout, along with all fish in the treated area; costs are “substantial” (Krueger and May 1991)
- rotenone successfully eradicated rainbow trout in a section of stream in southeastern Australia that was then recolonized with native fish
- 3 years of gill netting eradicated rainbow trout in a subalpine lake in California (Sato et al. 2010)

Possibility and Cost of Control

- interference and competition with other salmonid species can be mitigated by increasing structural complexity of streams (Hasegawa and Maekawa 2008)
- barrier construction has prevented movement from downstream areas (Krueger and May 1991)
- an effective barrier has been constructed with a stream-gauging weir reinforced with heavy steel grill (Sato et al. 2010)

- natural barriers, such as water falls, are associated with reduced hybridization with cutthroat trout (Rasmussen et al. 2010)

11. Rusty Crayfish (*Orconectes rusticus*)

Phylum: Arthropoda (Subphylum: Crustacea)
Class: Malacostraca
Order: Decapoda
Class: Camparidae

<u>Likelihood of Invasion</u>

Overview of Life History

- freshwater crustacean with a pair of large chilipeds
- reaches 11 cm in length; adult males are larger than females
- mating season is usually in fall during September and October, but breeding in spring also occurs
- when bred, females construct horizontal burrows in the banks near water line
- up to 200 eggs are carried by females
- young hatch in spring and remain with their mothers until early summer; by then they have undergone 3 moults
- sexual maturity may occur in the year of hatch, but is usually delayed until the following spring
- males moult into breeding form in middle to late summer, and into non-breeding form in spring
- omnivore, feeds on zoobenthic and algal organisms and aquatic plants (Philips 2010)
- capable of moving 200 m in 2 days (Bobeldyk and Lamberti 2008)
- dominance behaviour exhibited by larger individuals can result in exclusion of smaller individuals from food resources (Ogle and Kret 2008)
- lifespan of 3 to 4 years (Aquatic Invasive Species Partnership [no date])
- reaches densities of $60/m^2$ or more (Hein et al. 2006)

Origin and History of Invasion and Spread

- native to the Ohio River Basin
- now occurs from New Mexico to Maine
- first found in Canada in Lake-of-the-Woods, Ontario in 1963, and has since reached the Kawartha Lakes Region
- thought to have reached Thunder Bay in the Lake Superior watershed by way of coastal Lake Superior in Minnesota
- has recently been expanding down the Winnipeg River into Manitoba (Philips 2010)
- found in a popular sports fishing lake in Manitoba, with highest densities near a boat ramp; the crayfish has populated the lake but has not spread

to adjacent lakes (Wendy Ralley, water quality specialist, Government of Manitoba, personal communication)

Habitat Requirements (physical and chemical) in comparison to availability in Yukon

- tolerates 0 ^{o}C to 39 ^{o}C, with preference for 20 ^{o}C to 25 ^{o}C
- prefers well-oxygenated water
- not tolerant of low pH (< 6.1), particularly juvenile stages
- prefers complex habitats, for example, areas with rocks or fractured concrete substrate (Philips 2010); not common in sand and muck substrates (Hein et al. 2007, Maezo et al. 2010)
- may be depth limited; found in littoral zones up to 12 m deep (Bobeldyk and Lamberti 2008)
- appears to favour sites of lower water velocity (Bobeldyk and Lamberti 2008)
- cobble, log, and macrophyte habitats provide shelter from predators (Hein et al. 2007)
- occurs in lakes with calcium levels greater than 2.5 mg/L (Keller et al. 2008)
- appears that potential habitats exist in Yukon

Pathways of Introduction

- live bait discarded or used by anglers has likely introduced the rusty crayfish into new watersheds; once established, it spreads along connecting waterways (Kilian et al. 2010, Philips 2010)
- aquaculture, pet trade (Peters and Lodge 2010)
- may have been introduced to control macrophytes (Hein et al. 2007)
- natural dispersal may not be rapid because rusty crayfish do not have a pelagic larval stage (Vander Zanden et al. 2004)

<u>Consequences of Invasion</u>

Ecological Consequences of Invasion

- capable of eliminating macrophyte beds, reducing habitat for macroinvertebrates and altering fish habitat
- destruction of macrophytes less likely due to consumption than to the search for higher protein foods such as invertebrates (Philips 2010)
- associated with decreased abundance of snails, dragonflies/damselflies, caddisflies, amphipods, mayflies, and dipterans (Klocker and Strayer 2004, McCarthy et al. 2006)
- displaces native crayfish (Kilian et al. 2010), possibly by dominating protective habitat of rock strewn areas of lake beds (Snyder and Evans 2006)
- indirectly reduces fish abundance by consuming detritus and benthic invertebrates that would otherwise be available to fish (Bobeldyk and Lamberti 2010)

- may indirectly promote periphyton growth by consumer snails that graze on periphyton (Johnson et al. 2009)
- known to interbreed with other crayfishes (Snyder and Evans 2006)
- long-term (i.e., 15 years) reduction of macrophytes by rusty crayfish appears to reduce seed bank in sediment and limit the ability of macrophytes to regrow in an area (Rosenthal et al. 2006)

Economic Consequences of Invasion
- estimated loss of $1.5 million annually due to reduced sports fishing revenues for Vilas County, Wisconsin (Keller et al. 2008)
- bathers have stopped using areas where risk of being pinched by crayfish can be realized (O'Connor et al. 2008)

Possibility and Cost of Eradication
- information gap

Possibility and Cost of Control
- consistent policies banning rusty crayfish in aquaculture, pet trade, and among anglers and bait dealers have been recommended (Peters and Lodge 2010)
- estimate cost of $210,000 annually to pay personnel at boat-launching ramps has been suggested to deter further introduction of rusty crayfish into lakes in Villas County, Wisconsin (Keller et al. 2008)
- reduction of crayfish achieved over 3 years by restricting angling of crayfish predators (i.e., bass) and by trapping crayfish (Hein et al. 2006)

12. Silver Carp (*Hypophthalmichthys molitrix*)

Phylum: Chordata
Class: Actinopterygii
Order: Cypriniformes
Family: Cyprinidae

Likelihood of Invasion
Overview of Life History
- freshwater fish in the carp family
- reaches 1.3 m and can weigh more than 35 kg
- fingerlings adapt to low oxygen conditions by temporarily developing hypertrophy of lower lip to increase intake of the surface-water layer
- mature at 2 to 3 years in subtropical/tropical regions, and 4 to 6 years in temperate regions (Schofield et al. 2005)
- matured earlier and grew quicker in middle Mississippi River than in native range in Asia, with maturity at 2 years and mean length at age exceeding the Asian values by up to 26%, but this may decrease as the silver carp becomes more established (Williamson and Garvey 2005)

- lives up to 20 years
- estimates of fecundity vary from 265,000 to 2,000,000 eggs per female, with larger females generally having more eggs
- spawns at 17 °C to 26.5 °C, with peak activity at 21 °C to 26 °C
- spawns in rivers with water turbulence and higher water temperatures; these conditions stimulate spawning and are necessary for development of eggs; eggs are semi-buoyant and carried by currents until they hatch (Schofield et al. 2005)
- movement of adults stimulated by increasing water flow, as in spring floods (DeGrandchamp et al. 2008)
- females resorb eggs if conditions for spawning are poor, such as drought or low water flow (DeGrandchamp et al. 2007)
- larvae mainly feed on zooplankton
- adults typically swim in upper layer of water, feeding on phytoplankton, zooplankton, and detritus; gill rakers are used to sieve plankton from the water (Schofield et al. 2005, Smith 1989); particular types of plankton are consumed more heavily than others (Radke and Kahl 2002)
- travels up to 64 km per day (Cooke and Hill 2010; this citation also documents daily energy requirements)

Origin and History of Invasion and Spread

- native to large lowland rivers, reservoirs, canals, and lakes of eastern Asia, from southern Russia and North Korea to southern China, and from coastal waters inland (Mandrak and Cudmore 2004)
- introduced to the United States in 1973 to control plankton blooms in Arkansas, then raised in government and private aquaculture facilities
- first found in natural waters of Arkansas, Louisiana, and Kentucky in 1980; these were probably escapees originating from fish hatcheries (Freeze and Henderson 1982 cited in Williamson and Garvey 2005)
- discovered in Missouri River in 1982, and in Mississippi River in southern Illinois in 1983 (Williamson and Garvey 2005)
- has become the most abundant species in parts of the Mississippi River basin (Rach et al. 2009)
- La Grange Reach, Illinois River reported that silver carp comprised 51% of the fish collection in 2008 and could be a source population for expansion into the Laurentian Great Lakes

Habitat Requirements (physical and chemical) in comparison to availability in Yukon

- tolerates water temperatures from 0 °C to 40 °C (Schofield et al. 2005)
- mean annual air temperature in native range spans from -6 °C to 24 °C
- potential to reach 65 degrees latitude (Mandrak and Cudmore 2004)
- reported pH tolerance generally between 7 and 9.5
- tolerates salinity up to 4 ppt, and higher for larvae in brackish water of the Caspian Sea

- water velocity of .33 to .90 m/s and temperature of 19.2 °C to 29 °C reported for spawning habitat (Schofield et al. 2005)
- by examining water hardness in waterways where silver carp have established in the United States, researchers suggest that eggs may not survive in soft water (Whittier and Aitkin 2008), but laboratory evidence for this is inconclusive (Rach et al. 2009)
- seems like habitat is available in Yukon, but may be limited by thermal requirements for spawning; the temperature of rivers in Yukon rises above 17 °C but usually not for long periods of time

Pathways of Introduction

- escapees from aquaculture
- introduction from live-food-fish market
- intentional release as prayer fish or as a "rescue" by animal rights activists
- possible dispersal into Canada from the Mississippi River Basin where it has already established itself (Mandrak and Cudmore 2004)

Consequences of Invasion

Ecological Consequences of Invasion

- feeds heavily on phytoplankton and zooplankton, and competes with young of most native fish species and all stages of native planktivorous species (Kolar et al. 2005)
- presence of silver carp correlated with reduced body condition of native planktivorous fish species in Illinois River (Irons et al. 2007)
- where diet overlaps with native species and plankton productivity is limiting, growth and abundance of native species could be compromised (Sampson et al. 2009)
- can introduce Asian tapeworm and the virus *Rhabdovirus carpio* to native populations
- can alter plankton community by selectively consuming or differentially digesting particular species; pinnate diatoms and euglenoid algae can survive through the 5 to 7 m gut of silver carp (Pongrukham et al. 2010)

Economic Consequences of Invasion

- fouls and destroys commercial fishing nets
- can leap out of the water and seriously injure boaters (Rach et al. 2009)
- competes with commercially valuable fish by competing for the same food (Spataru and Gophen 1985)

Possibility and Cost of Eradication

- information gap

Possibility and Cost of Control

- an electrified barrier, or bubble and sound barriers, may prevent further dispersal, with particular vigilance during spring floods when dispersal behaviour is highest (DeGrandchamp et al. 2008)
- behavioural barriers (e.g., strobe lights) or physical barriers (e.g., floating curtains) and waterways engineering may prove effective
- rotenone and antimycin can be administered at levels within guidelines to kill silver carp (Rach et al. 2009)

13. Spiny Water Flea (*Bythotrephes longimanus*)

Phylum: Arthropoda
Class: Branchiopoda
Order: Onychopoda
Family: Cercopagida

<u>Likelihood of Invasion</u>

Overview of Life History

- large-bodied, carnivorous zooplankton
- ability to detect prey increases with light intensity (Pangle and Peacor 2009)
- adults are up to 1 cm long, with a stiff caudal spine accounting for 80% of its length
- the caudal spine protects it from small, predatory fishes
- reproduction is primarily by parthenogenesis in spring and summer during which populations are dominated by females
- males are typically produced in fall, and sexual reproduction results in diapausing eggs, which are the usual overwintering stage (Branstrator et al. 2006, Yan et al. 2001)
- females carry eggs in a brood sac in which they develop into embryos and are nourished by bodily fluid (Straile and Hälbich 2000)
- reproduction and population growth is positively related to temperature; at 20 ^{o}C, maturity time is about 11 days (Drake et al. 2006)
- initial high population growth rates in spring achieved by large clutch sizes (> 7) of small neonates; then females raise smaller clutches (approximately 2 to 3) and larger neonates in response to the growing mouth size of their main predator—juvenile, gape-limited fish (Straile and Hälbich 2000)

Origin and History of Invasion and Spread

- native to Asia and northern Europe (Dumitru et al. 2001)
- first found in Lake Ontario in 1982, probably introduced from ballast water of cargo ships from the Baltic sea
- by 1989, it had spread to all the Great Lakes and had begun to spread inland

- it is spreading rapidly across the Canadian Shield, and is documented in over 130 lakes in Ontario, Michigan, Minnesota, and Ohio (Weisz and Yan 2010)
- a survey in 2004 failed to find spiny water flea in 2 lakes in Minnesota where it had been detected in 1990, suggesting a range compression, although it did expand its range to other lakes (Branstrator et al. 2006)

Habitat Requirements (physical and chemical) in comparison to availability in Yukon

- deep, clear, and less productive lakes
- a combination of relatively high Secchi depth, high maximum lake depth, high lake surface area, and low chlorophyll concentration were used to predict range expansion in the Great Lakes (MacIsaac et al. 2000); Branstrator et al. (2006) suggested modifying the model to accommodate the use of low light refuges in the water column
- appears that potential habitats occur in Yukon

Pathways of Introduction

- primarily spread by humans (Weisz and Yan 2010), including use of contaminated equipment such as anchor mud, bilge water, bait buckets
- fish, birds, mammals, wind, and surface water might be vectors but need further examination (Branstrator et al. 2006)
- assisted travel in connecting waterways, including hulls of boats and digestive tracts of fish (Weisz and Yan 2010)

Consequences of Invasion

Ecological Consequences of Invasion

- disrupts pelagic food web structure (Branstrator et al. 2006)
- alters abundance of various zooplankton species; small copepod prey numbers reduced and larger cladocerans increased following invasion in one lake (Dumitru et al. 2001); abundance of one rotifer species increased, likely because the spiny water flea reduced the abundance of the rotifer species' competitors and predators (Hovius et al. 2007)
- implicated in population reductions of native cladocerans and overall decline in species richness and abundance of crustaceans and other zooplankton; predation on native fauna is the primary mechanism explaining this pattern (Barbiero and Tuchman 2004, Boudreau and Yan 2003, Strecker et al. 2006, Wahlstrom and Westman 1999, Yan et al. 2002)
- energy required to avoid the spiny water flea shown to reduce population growth of native invertebrates (Pangle and Peacor 2006, Pangle et al. 2007)
- out-competes native predaceous cladoceran (e.g., *Leptodora kindtii*) for food resources (Branstrator 2005, Weiscz and Yan 2010a)

- potentially reduces availability of zooplankton to native invertebrate predators (Foster and Sprules 2009) and particular fish species such as cisco (Strecker and Arnott 2008)
- may redirect feeding pressure of native invertebrates such as *Mysis relicta* that have been found to feed on spiny water flea in invaded waters (Nordin et al. 2008)

Economic Consequences of Invasion
- fouls recreational equipment (Branstrator et al. 2006)
- information gap

Possibility and Cost of Eradication
- information gap

Possibility and Cost of Control
- invaded waters that have large likelihood of infecting nearby waters (i.e., via heavy human use) should be the focus of management efforts to curtail the spread of spiny water flea (Muirhead and MacIsaac 2005)
- abundances may be controlled by fish predation in inland lakes (Vander Zanden et al. 2004)

14. Viral Hemorrhagic Septicemia Virus (VHSV)

Note: It is debatable whether VHSV should be considered an AIS; genotype IVa is widely considered endemic to the Pacific Coast of Canada and the US. Genotype IVb is much more devastating, as is genotype I. The mutation of genotype IVa into a more harmful form is as much a concern as the introduction of more serious genotypes.

Phylum: Viruses
Class: Single-stranded, Negative-sense, RNA viruses
Order: Monongegavirales
Family: Rhabdoviridae

<u>Likelihood of Invasion</u>
Overview of Life History
- VHSV is in a group of viruses that have a high mutation rate and are known to acclimate to new host species
- 5 genotypes occur worldwide; genotype IV occurs in Canada and United States (Kaufman 2010), with genotype I well-known to devastate trout in European fish farms (Neukirch 1984)
- presumed to have originated in the marine waters of the North Pacific or North Atlantic
- genotype IVa can cause significant mortality in some marine species, including Pacific herring, Pacific hake, and walleye pollock in Alaska; and

sardine in the mid-coast of British Columbia (Meyers et al. 1999, Marty et al. 1998)
- other marine hosts include surf smelt, mackerel, and Pacific cod (Hendrick et al. 2003, Meyers et al.1992)
- also found in eulachon and threespine stickleback (Kent et al. 1998)
- genotype IVa is of low virulence to Pacific salmonids
- remains viable in frozen tissue such as frozen bait fish
- genotype IVb is a freshwater pathogen, capable of infecting about 28 freshwater fish species and causing massive mortalities is some species (e.g., muskellunge)
- VHSV can remain viable in water for several days
- virus is found in urine, sperm, and ovarian fluid excreted by infected fish
- causes breakdown of the epithelium lining of blood vessels and systemic organ necrosis caused by viral septicemia
- infected individuals show clinical signs in 7 days, and mortality occurs shortly after
- survivors are believed to be lifelong carriers
- susceptibility of individuals in part due to other stressors on the immune system, including other pathogens, water quality, and survival pressure (Kaufman 2010)

Origin and History of Invasion and Spread

- genotype IVa was first found in 1988 in chinook salmon returning to a hatchery on Orcas Island, Washington (Amos et al. 1998)
- it occurs along the Pacific Coast from Alaska to central California
- in 2001, found in asymptomatic Pacific eulachon in a tributary of the Columbia River basin, and in symptomatic surf smelt from the mid-coast
- found in Atlantic salmon raised in a pen near the north end of Vancouver Island
- genotype IVb has been in Lake St. Claire since 2001 or earlier
- genotype IVb is found in all the Great Lakes and as far west as Wisconsin and Illinois (Kaufman 2010)

Habitat Requirements (physical and chemical) in comparison to availability in Yukon

- requires host to survive long term
- can survive in water for several days; it is inactivated by drying and by sustained temperatures above 20 ºC (Amos et al. 1998)

Pathways of Introduction

- frozen bait fish used for angling or feed in aquaculture
- fish contract virus by ingesting infected material or by close contact with infected individuals
- boats and fishing gear
- can move along waterways connected to infected area (Kaufman 2010)

- commercially frozen bait fish is widely available and used in Yukon for lake fisheries

Consequences of Invasion

Ecological Consequences of Invasion

- VHSV genotype IVb causes mass mortality of fish and cascading effects throughout food web (Kaufman 2010)
- fish affected with VHSV genotype IVb are both native (e.g., burbot) and non-native species such as round gobies (Groocock et al. 2007)

Economic Consequences of Invasion

- reduces income from the fishing industry (Kaufman 2010)
- treatment to prevent spread of VHSV by the destruction of eggs and fish, or reduction of fish stocking and fishing opportunities (Amos et al. 1998)

Possibility and Cost of Eradication

- in an effort to rid VHSV from fish hatcheries in Washington State and prevent its spread, infected facilities were sanitized with lime, chlorine, iodophor, and all potentially infected fish and eggs were destroyed (Amos et al. 1998)
- additionally, a fish barrier was installed to capture and destroy fish migrating downriver, and a 5 year quarantine was imposed upstream of one of the hatcheries in case a reservoir for the virus occurred there; this has now been relaxed to one year in the US
- VHSV continued to be detected after these efforts and was then reclassified from an exotic to an endemic (Amos et al. 1998)

Possibility and Cost of Control

- techniques such as DNA probes have improved efficiency of detecting and distinguishing VHSV genotypes (Batts et al. 1993)
- potential control through enforcement of regulations, and by examining fish before transfer
- potential control through rigorous enforcement of regulations that deter introduction of potentially infected fish (Kaufman 2010)
- prohibit use of unpasteurized marine fish as feed (Amos et al. 1998)
- a vaccine to protect fish in aquaculture facilities against pathogens like VHSV has been developed; likely feasible, but method of inoculation and legalities have to be worked out (Lorenzen and LaPatra 2005)

15. Whirling Disease (caused by the parasite *Myxobolus cerebralis*)

Phylum: Myxozoa
Class: Myxosporea
Order: Bivalvulida

Family: Myxobolidae

Likelihood of Invasion

Overview of Life History

- a microscopic parasite requiring 2 hosts to complete its life cycle
- myxospores are ingested by the aquatic oligochaete worm *Tubifex tubifex* as it burrows through sediment; the parasite undergoes sexual reproduction and structural transformation in the worm's intestine and is released in its triactinomyxon stage; the buoyant triactinomyxon spore attaches to the salmonid host where its sporoplasm enters the epidermis, spreads through the central nervous system, and ultimately to the cartilaginous tissue where it forms lesions; here, it grows through presporogonic development and then through sporogony which results in myxospores which are released when the fish dies
- an infected worm releases at least 3,000 triactinomyxons over a 3 month period (Hedrick et al. 1998)
- the development time in the oligochaete worm takes 3 months at 15 ^{o}C and is not detrimental to the host
- the development in the salmonid takes 8 months, with pansporoblasts forming at 4 months (Aquatic Nuisance Species Research Program 2003)
- the characteristic tail chasing behaviour of infected fish is thought to be caused by damage to the brainstem and spinal cord
- infections are more devastating to young fish than to older fish; older fish have less cartilage and more ossified bones (Hedrick et al. 1998)
- not all genetic lineages of *T. tubifex* are suitable hosts to whirling disease (Hallett et al. 2009); one of 4 lineages of the worm species found in southcentral Alaska is demonstrably susceptible to *M. cerebralis* infection (Arsan et al. 2007b)
- *T. tubifex* can live for 3 years (Bartholmew et al. 2007)
- myxospores can survive temperatures from -20 ^{o}C to 60 ^{o}C and persist in sediment for many years while retaining infectivity (Gates et al. 2008)
- some degree or resistance has developed among wild rainbow trout (Miller and Vincent 2008, Granath and Vincent 2010)

Origin and History of Invasion and Spread

- endemic to brown trout of central Europe and southeastern Asia; these brown trout do not show clinical signs of whirling disease
- in 1898, whirling disease was first observed in farmed rainbow trout introduced to Germany from the United States, and has since been documented in other European countries, New Zealand, and South Africa (Hedrick et al. 1998, Granath and Vincent 2010)
- thought to have entered the US in 1956 from a shipment of infected brown trout brought over from Denmark (Arsan et al. 2007a; Granath and Vincent 2010)
- reported in 26 countries and many of the US states, either in hatcheries or in wild populations

- a low incidence of whirling disease was found in hatchery rainbow trout in Alaska (Arsan et al. 2007a)
- the host worm *T. tubifex* is not exotic to North America although some genetic lineages are found only in Europe or North America (Arsan et al. 2007b)
- *Tubifex* species have been found in Yukon, but have not been identified to the species level (Environment Canada, unpublished data)

Habitat Requirements (physical and chemical) in comparison to availability in Yukon
- optimal water temperature for parasite propagation is 10 ^{o}C to 15 ^{o}C
- worm host *T. tubifex* commonly associated with abundant organic matter, fine sediments, and low flow rate; it is tolerant of low oxygen, desiccation, and variable temperature regimes; found in environments ranging from eutrophic, nutrient rich lakes to very unproductive lakes (Arsan et al. 2007b)
- Hallett and Bartholomew (2008) demonstrated that a low flow rate of .02 cm/sec resulted in very high rates of infection, compared to a high flow rate of 2.0 cm/sec

Pathways of Introduction
- stocking infected hatchery trout into streams, rivers, and lakes
- people and wildlife capable of moving sediment, water, fish, or fish parts
- can spread from fecal material of avian piscivores; survives gut passage in great blue herons (Koel et al. 2010)
- infected boating and fishing equipment, especially porous materials such as felt-soled waders that are difficult to rinse thoroughly and easily harbour myxospores (Gates et al. 2008)

<u>Consequences of Invasion</u>
Ecological Consequences of Invasion
- with the exception of lake trout and Arctic grayling, most salmonids are susceptible to whirling disease to varying degrees; infected rainbow trout exhibit the most severe symptoms, causing severe declines in wild trout populations in the western United States (Arsan and Bartholomew 2008, Vincent 2001)

Economic Consequences of Invasion
- reduces income from recreational fishing (Koel et al. 2010)

Possibility and Cost of Eradication
- destroying infected fish in hatchery has been implemented to try and eradicate *M. cerebralis* (Koel et al. 2010)

Possibility and Cost of Control

- use of well water instead of surface water in hatcheries helps to prevent spread of *M. cerebralis*
- proper disposal of sediment from hatcheries; avoid creating suitable environment for *T. tubifex* by using alternatives (e.g., concrete) to mud bottoms of fish hatchery facilities; implementing regular cleaning schedule at aquaculture facilities (Bartholomew et al. 2007)
- complete desiccation, exposure to 40 to 480 mJ/cm^2 of UV light, or prolonged freezing below -20 ^oC kills myxospores; alkly dimethyl benzyl ammonium chloride and chlorine bleach at specific concentrations and exposure time reduces viability of myxospores (Hedrick et al. 2008)

16. Waterweed (*Elodea* spp.)

Includes *Elodea canadensis* (Canadian waterweed) and *E. nuttallii* (Nuttall's waterweed, St John's waterweed)
Phylum: Magnoliophyta
Class: Liliopsida
Order: Alismatales
Family: Hydrocharitaceae

Likelihood of Invasion

Overview of Life History

- Waterweed are perennial submergent aquatic vascular plants
- invasive waterweed are usually dioecious, but can be monoecious; in countries where it has been introduced, plants of only one sex often occur (Bowmer et al. 1995)
- plants appearing to be hybrids of *E. nuttallii* and *E. canadensis* have been found
- individual plants have a fibrous root and several flowering stems, branched at nodes
- in *E. nuttallii*, male flower buds detach and become free-floating; the flowers open and the pollen is shed as the flower blows around; the female flowers also float but remain attached to the rooted plant; one to 5 seeds are produced in each fruit (Bowmer et al. 1995)
- seeds have rarely been found; propagation and regeneration is mainly by vegetative stem fragments in spring (Barrat-Segretain et al. 2002)
- in fall, waterweed develops vegetative buds, called turions, that germinate the following spring (Vernon and Hamilton 2011)
- Waterweed disperses by water movement, animal vectors, or human activity

- *E. nuttallii* is better able to establish itself than *E. canadensis* by growing more rapidly, particularly in eutrophic conditions (Barrat-Segretain and Elger 2004; Barrat-Segretain 2005)
- *E. nuttallii* is more plastic phenotypically, at least in Europe where it assumes different growth forms in flowing water compared to still water, and deep water compared to shallow water (Thiébaut and Di Nino 2009); both exhibit morphological changes when exposed to different light intensity and temperatures (Vernon and Hamilton 2011)
- waterweed has a good ability to store phosphorous and buffer against fluctuating nutrient availability (Thiébaut 2005); this also gives the species the ability to grow quickly in spring.
- waterweed is consumed by waterfowl and crayfish, but avoided by many insect herbivores (Erhard et al. 2007)

Origin and History of Invasion and Spread

- both *E. nuttallii* and *E. canadensis* are native to North America, with distribution concentrated in the temperate regions of southern Canada and northern United States
- in western Canada, *E. nuttallii* occurs mainly in southern B.C. and has been listed as a species of concern because of its restricted distribution in the province; *E. canadensis* is more common, with the closest known records in northern BC and Alaska, all north of 59˚ latitude; northern records in BC are from Tatisno Creek area and southwest of Smith River; the oldest record from Alaska is from Eyak Lake near Cordova, south Alaska where a specimen was collected in 1982 (Klinkenberg 2013). The 2 records from northern BC need further verification (Bruce Bennett pers. comm.). Their substantiation would mean that detections of *E. canadensis* in the Liard drainage of Yukon would be records of an endemic, rather than an invasive plant.
- in 2009, both *Elodea* species were newly found at Chena Slough near Fairbanks, Alaska, far away from previously known occurrences; the discarded content of an aquarium (or aquaria) is believed to be the origin of this introduction (Alaska Department of Natural Resources 2013)
- recently, waterweed has been found in 3 lakes in Anchorage and in Stormy and Daniels Lakes on the Kenai Peninsula (Alaska Department of Natural Resources 2013)
- abroad, *E. canadensis* was introduced to the British Isles in 1836 beginning with Northern Ireland (Heikkinen et al. 2009), then largely displaced by *E. nuttallii* starting in 1939 (Barrat-Segretain et al. 2002) due to the trade in live aquarium plants; subsequent spread of both species has occurred in Europe, Asia, Africa, Australia and New Zealand
- spread continues by contamination of recreational equipment, vehicles and animals, as well as the aquaria and ornamental plant trade

Habitat Requirements (physical and chemical) in comparison to availability in Yukon

- grows in lakes, ponds, streams, ditches, shallow water along rivers (Klinkenberg 2013)
- grows in lentic and lotic environments with strong water velocity (> 0.2 m/s; Grinberga 2010)
- in central North America, *E. nuttallii* typically grows in the lower littoral zone (Thiébaut and Di Nino 2009)
- grows in water from 0.1 m to 12 m; optimum water depth is 4 m to 8 m (Nichols and Shaw 1986), but can be the dominant species in shallower water (Heikkinen et al. 2009)
- *E. canadensis* grows in peaty waters to calcareous sites (Thiébaut 2005), grows in pH of 6.5 to 10 (Josefsson 2011)
- *E. nuttallii* has not been reported in peaty waters, but grows well in nutrient-rich waters (Thiébaut 2005)
- can assimilate carbon from bicarbonate under alkaline conditions (Bowmer et al. 1995) as well as use dissolved CO_2 (Vernon and Hamilton 2011), meaning that it can readily adapt to changes in pH
- grows on substrate ranging from sand and silt to gravel (Barrat-Segretain et al. 2002; Grinberga 2010; Kuhar et al. 2010)
- conditions favouring colonization include silty substrate and a supply of iron in its reduced form (Bowmer et al. 1995)
- Nichols and Shaw (1986) suggested that sediment organic matter of 10 to 25% promotes optimal growth
- both species persist well in environments with fluctuating nutrient regimes (Thiébaut 2005) as characterized by seasonal floods
- proliferates in nutrient-rich conditions (Xie et al. 2010); plant size of *E. canadensis* is enhanced by inorganic carbon, nitrogen and phosphorous (Riis et al. 2010)
- Waterweed generally has high light requirements (Alaska Department of Natural Resources 2013), but in an experiment by Mormul et al. (2012) *E. canadensis* did grow well in unclear, brown water
- *E. canadensis* has been observed photosynthesizing and growing under ice cover and surviving inside ice (Bowmer et al. 1995; Alaska Department of Natural Resources 2013); other authors suggest that temperatures ranging from 10 to 25 ˚C characterize its habitat (Heikkinen et al. 2009)
- climate models indicate that northern dispersal and colonization of *E. canadensis* is probable (Heikkinen et al. 2009)
- suitable habitats occur in the Yukon for the growth of waterweed

Pathways of Introduction

- in Europe, the ornamental plant industry is mainly responsible for its introduction (Brunel 2009); establishment into waterways is likely from discarded aquaria contents
- in South Africa, pet stores, aquaria supplies stores, and internet businesses that sell and ship aquatic plants were identified as modes of introduction (Martin and Coetzee 2011)

- once established, further spread is by means of water currents taking plant fragments downstream, or animals/humans and boating/recreational equipment moving plant fragments between water bodies; in Alaska, spread by float planes is a concern
- in Alaska, initial modes of introduction are likely aquaria and discarded commercial lab kits; waterweed is commonly used in lab experiments as well as an ornamental plant in aquaria

Consequences of Invasion

Ecological Consequences of Invasion

- outcompetes native plants by reducing light penetration in water column, shading out other plants (Hussner 2012)
- its superior ability to assimilate nutrients and outcompete endemic species when grown on a nutrient-rich sediments (Xie et al. 2010) gives it the potential to alter and displace existing plant communities
- depletes dissolved oxygen content in water and changes hydrochemistry (Hussner 2012); the compromised water quality affects fish, amphibian and invertebrate populations
- reduces water velocity and ability of wind-induced mixing (Hussner 2012)
- under controlled lab conditions Baek (2013) demonstrated that *E. nuttallii* can outgrow and outroot *Hippuris vulgaris* which is an endemic to Alaska and Yukon

Economic Consequences of Invasion

- impedes the flow of water in supply and drainage channels; can clog up waterways, intake pipes at hydropower and industrial plants (Bowmer et al. 1995; Josefsson 2011)
- hinders boat traffic; potentially damages boats in calcium encrusted stands (Josefsson 2011)
- reduces recreational activity such as boating and fishing
- impacts native fishery, for example, reducing spawning habitat for salmon (Alaska Department of Natural Resources 2013)
- reduces aesthetics of landscape; reduces property values for landowners
- in 2009, mechanical control of waterweed in Great Britain was estimated at £16,000,000 (Oreska and Aldridge 2011)

Possibility and Cost of Eradication

- Alaska Department of Natural Resources (2013) proposes to use the pesticides diquat and/or fluridone in Stormy Lake (403 acres) and Daniels Lake (621 acres), maximum depth of 50 feet. Estimated cost ranges from $80,000 to $340,000 depending on which herbicide regime is followed. Diquat is the cheaper more toxic option, and is non-selective; fluridone is rated as having lower toxicity and selectively kills particular plant species, including waterweed, but is much costlier. The proposal suggests a possibility of eradicating waterweed over several years

- application of herbicide was proposed for the beginning of growing season when uptake by plants is higher; water turbidity is low and water volume is relatively low (Alaska Department of Natural Resources 2013)

Possibility and Cost of Control

- methods include the draining and drying of channels or water bodies, the use of herbicides (e.g., acrolein, fluridone, terbutryne), and the introduction of herbivorous fish such as grass carp, *Ctenopharyngodon idella* (Bowmer et al. 1995)
- use of grass carp is seen as risky as they may consume endemic species and it is not a native species; there is a sterile triploid strain available (Vernon and Hamilton 2011)
- *E. canadensis* is partially resistant to some herbicides (i.e., diquat), possibly because it has a protective coating of bacteria and surface plants and animals (aufwuchs, Bowmer et al. 1995)
- another difficulty with the use of herbicides is achieving sufficient concentration to penetrate dense weed beds, especially in flowing water (Bowmer et al. 1995)
- in 2013 for Alaska, diquat treatment was estimated at $225/acre and fluridone at $750/acre
- manual harvesting in north-east France aimed at reducing the abundance and density of plants resulted in short-term reduction of *E. nuttallii* (Di Nino et al. 2005)
- mechanical control for about 5,000 occurrences of waterweed in Great Britain was estimated at £16,000,000 (Oreska and Aldridge 2011)
- shading, either by surface shading materials or benthic shading materials may be effective in small areas (Centre for Aquatic Plant Management 2004, Vernon and Hamilton 2011)
- other potential options include use of invertebrate or fungal bio-controls if suitable species can be found, and nutrient management to deter establishment of waterweed (Vernon and Hamilton 2011)

APPENDIX 2 RISK ASSESSMENT FOR AQUATIC INVASIVE SPECIES IN YUKON.

Likelihood of introduction

1. **Is it in Yukon?**
    - 4 = widespread
    - 2 = uncommon
    - 0 = no documented cases
2. **Does it occur in the neighbouring jurisdictions: Alaska, NWT, BC?**
    - 4 = three jurisdictions
    - 2.5 = two jurisdictions
    - 1 = one jurisdiction
    - 0 = no
3. **What is the likelihood of the organism reaching or spreading in Yukon through the following human-mediated pathways?**

    boats/fishing/recreational equipment
    - 6 = high
    - 4 = moderate
    - 2 = low
    - 0 = nil

    aquaculture
    - 3 = high
    - 2 = moderate
    - 1 = low
    - 0 = nil

    aquarium trade / aquatic nurseries
    - 3 = high
    - 2 = moderate
    - 1 = low
    - 0 = nil

    live food market
    - 1.5 = high
    - 1 = moderate
    - 0.5 = low
    - 0 = nil
4. **What are the potential natural pathways in Yukon?**

    interconnected water
    - 4 = high
    - 2.5 = moderate
    - 1 = low
    - 0 = nil

    overland by mammals and birds
    - 4 = high
    - 2.5 = moderate
    - 1 = low
    - 0 = nil
5. **Is it cultivated or raised in Yukon**
    - 4 = yes
    - 2 = probably
    - 0 = no
6. **How easily is the organism detected along invasion pathway in Yukon?**
    - 0 = high
    - 2 = moderate
    - 4 = low
7. **Do possibilities of controlling introductions through the primary pathways currently exist for Yukon?**
    - 0 = yes
    - 4 = no

Likelihood of persistence

8. **How much suitable climate / habitat exists in Yukon for it to survive?**
    - 4 = widespread
    - 2 = moderate
    - 0 = limited
9. **How much suitable climate / habitat exists in Yukon for it to reproduce?**
    - 4 = widespread
    - 2 = moderate
    - 0 = limited
10. **Does reproduction include vegetative means or parthenogenesis ?**
    - 2 = yes
    - 0 = no
11. **Are there likely natural control agents, such as predators or competitors, in Yukon?**
    - 0 = high
    - 1 = moderate
    - 2.5 = low
    - 4 = nil
12. **Has it been successfully controlled?**
    - 0 = yes
    - 2 = partially
    - 4 = no

Ecological impacts

13. **Is the species known to compete for resources with native species?**
    - 4 = high
    - 2.5 = moderate
    - 1 = low
    - 0 = no
14. **Is it known to hybridize with native species that exist in Yukon?**
    - 4 = yes
    - 0 = no
15. **Is the species known to predate native species?**
    - 4 = high
    - 2.5 = moderate
    - 1 = low
    - 0 = nil
16. **Is the species known to be a parasite or pathogen of native species?**
    - 4 = yes
    - 0 = no
17. **Is the species known to be a host or vector for disease to native species?**
    - 4 = yes
    - 2 = maybe
    - 0 = no
18. **Is the species known to alter water chemistry?**
    - 4 = high
    - 2.5 = moderate
    - 1 = low
    - 0 = nil
19. **Is the species known to alter community structure?**
    - 4 = high
    - 2.5 = moderate
    - 1 = low
    - 0 = nil

20. Is the species known to alter community composition?

- 4 = high
- 2.5 = mod
- 1 = low
- 0 = nil

Economic and Social Impacts

21. Is the species potentially harmful to the aquaculture industry?

- 4 = high
- 2.5 = moderate
- 1 = low
- 0 = nil

22. Is the species potentially harmful to Aboriginal, commercial, or recreational fisheries?

- 4 = high
- 2.5 = moderate
- 1 = low
- 0 = nil

23. Is the species potentially harmful to the tourism industry or the aesthetic value of Yukon?

- 4 = high
- 2.5 = moderate
- 1 = low
- 0 = nil

24. Is the species potentially harmful to subsistence or recreational activities?

- 4 = high
- 2.5 = moderate
- 1 = low
- 0 = n

25. Can the species negatively impact infrastructure?

- 4 = high
- 2.5 = moderate
- 1 = low
- 0 = nil

26. Can the species impact traditional, cultural, social, or ceremonial values?

- 4 = high
- 2.5 = moderate
- 1 = low
- 0 = nil

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