The distribution of freshwater mussels (Unionoida: Unionidae) and non-pulmonate snails (Heterostropha: Valvatidae) in Alaska

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Executive summary

Freshwater mussels (Unionoida: Unionidae) and non-pulmonate snails (Heterostropha: Valvatidae) play important roles in freshwater ecosystems, providing food and habitat for other aquatic organisms, and contributing to high water quality. They are also among the most sensitive taxa to water pollution. As a result, the U.S. Environmental Protection Agency (USEPA) recently revised its ammonia water quality criteria, basing most of its values on the tolerance of mollusks, rather than salmonids. These revised thresholds serve as recommendations, but states can derive alternative water quality criteria based on state or site characteristics.

We conducted an exhaustive search for occurrence records of these taxa groups, collecting more than 400 records. To our knowledge, this dataset is now the most comprehensive source for unionid mussels and non-pulmonate snail occurrences in Alaska. Both groups are widely distributed throughout the state of Alaska. Specimens have been collected in lakes and streams of various sizes and substrate types, and in both remote and urban waterbodies. Although occurrence records cannot be used to infer true absences, they do expose important gaps in our knowledge of the distribution of these species. For one, *Valvata spp.* snails were heavily collected in the Arctic and Southcentral regions, but there are no records of these species in the Southeast. In contrast, the distribution of most unionid species appears to be restricted to the Southeast region. Only *Anodonta beringiana* seems widespread, although the northern extent of its range is uncertain. Most of the occurrence records we compiled were from specimens that had been opportunistically collected. We can use these data to build

species distribution models and explore relative habitat suitability; however, we cannot use these data to infer true absences. Our ability to accurately model the distribution of these species is also limited by a lack of suitable environmental covariates.

Recalculating the USEPA ammonia criteria at a regional scale is not recommended because the data show that both unionid mussels and non-pulmonate snails are distributed throughout the state. However, field surveys can be designed to determine presence-absence of these surveys in specific waterbodies. Modeling using current data can also be done to further knowledge on species biology in areas of the State where data and environmental variables are suitable. We provide recommendations to this effect in the final section of our report. Because ammonia toxicity decreases with decreasing temperature and pH, ADEC may also want to consider site-specific criteria for waterbodies that are acidic (pH ≤ 7) or have water temperatures below 20°C. Analyses of stream temperature data in southcentral Alaska suggest that many streams never reach 20°C; site-specific criteria may therefore be appropriate.

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Introduction

Alaska is home to over 3 000 000 lakes and more than 700 000 miles of rivers and streams (ADEC 2013). These waterbodies provide 75% of the water for industry, agriculture, and public use, and 50% of the water for domestic use (ADEC 2013). The vast majority of Alaska’s waterbodies are pristine; however, increases in human population and industrial activities may degrade water quality and contribute to water pollution. One of the most common pollutants in freshwater systems is ammonia (inorganic nitrogen). Ammonia is heavily used as a fertilizer, and in industry for refining oil, synthesizing chemicals, and treating wastewater. High levels of ammonia are of particular concern to scientists and to resource managers because it is directly toxic to aquatic life, and can lead to freshwater acidification and eutrophication (Camargo and Alonso 2006).

Freshwater mussels and non-pulmonate snails are two of the most sensitive taxa to ammonia pollution (Augspurger et al. 2003; USEPA 2013). Even moderate concentrations have been shown to reduce growth and increase mortality in juveniles (Mummert et al. 2003; Newton et al. 2003). Mollusks play very important roles in freshwater ecosystems. They are prey for several taxa such as birds, fish, and crustaceans, and their shells provide habitat and refuge for other invertebrates (Gutiérrez et al. 2003; Lopes-Lima et al. 2014). Through their feeding activities, these species contribute to water quality by cleaning the water column of particles and by controlling algal growth (Brönmark 1989; Vaughn and Hakenkamp 2001; Johnson et al.

2013). They are also of special conservation concern because they are some of the most threatened taxa in North America (Johnson et al. 2013; Haag and Williams 2014).

The sensitivity of these species has prompted the USEPA to develop new guidelines for acceptable concentrations of acute and chronic ammonia in freshwater (USEPA 2013). The USEPA has allowed states and tribes to revise these guidelines if necessary. For example, higher levels of ammonia may be defensible in areas where freshwater mollusks or salmonids are absent. The objectives of this report were: 1) conduct a literature review to identify the current distribution of freshwater mussels and non-pulmonate snails in Alaska, 2) summarize statistical methods for distribution modeling, and 3) provide recommendations for future work. Since these species are poorly studied throughout their range, compiling a record of species' presence will further our knowledge of the northern distribution of these freshwater mollusks in North America.

Distribution of freshwater mollusks in Alaska

Methods

We compiled occurrence records of freshwater mussels and non-pulmonate snails by querying online databases, conducting literature searches, and contacting museums, conservation organizations, and individuals (Appendix A; Appendix B). Identification keys and previous surveys suggested the presence of two genera of unionid mussels (*Anodonta* and *Margaritifera*) and one genus of non-pulmonate snails

(*Valvata*) (Rinella and Bogan 2011; Rinella and Bogan 2010; Rinella et al. 2005; Smith et al. 2005). Primary literature searches were conducted in February 2017 in Google Scholar, Web of Science, and Zoological Records using the search terms Alaska and Unionid*, Valvat*, *Anodonta*, or *Margaritifera*. The same search terms were applied when querying databases and museum collections.

We began our search for grey literature by looking through reports and surveys by the Alaska Center for Conservation Science (formerly known as the Alaska Natural Heritage Program). Through professional experience, we were also aware of other surveys conducted in Alaska by other agencies (Appendix B). Additional searches were conducted online by consulting agency websites (Appendix A) and in-person at the UAA/APU Consortium Library. Because very few surveys are specific to mollusks, we broadened our search to include macroinvertebrate and water quality surveys, and sorted through these to extract records of unionid mussels or *Valvata spp.* snails. Lastly, we furthered our search by contacting colleagues, experts, museum collections, and malacological organizations (Appendix A). In our e-mails, we included a list of sources we had already consulted, and asked for additional suggestions, which gave us an idea of when we were nearing the end of our search.

We compiled all the occurrence records in a spreadsheet (Appendix C). We excluded records that could not be geo-referenced. If a record was missing geographic coordinates, but listed the place of collection (usually the name of a waterbody), we used Google Earth to approximate the coordinates. We verified the accuracy of all coordinates in ArcGIS (ESRI 2014) by overlaying data points on a map of Alaska. We used a simplified, ecoregional classification scheme to describe the distribution of mollusks in the State (Nowacki et al. 2001; Appendix D).

Results & discussion

We obtained 206 occurrence records of unionid mussels and 213 records of non-pulmonate snails. We identified three species of non-pulmonate snails (*Valvata lewisi*, *V. mergella* and *V. sincera*), and four species of unionid mussels (*Anodonta beringiana*, *A. kennerlyi*, *A. oregonensis*, and *Margaritifera falcata*). Collectively, these mollusks were distributed throughout the state of Alaska (Fig. 1; Fig. 2), and were reported from a variety of waterbodies including small ponds and creeks, large lakes, and high-order streams and rivers. In lakes and rivers, unionids are part of the benthic community, while non-pulmonate snails have been found in all types of waterbodies in habitats ranging from submerged aquatic vegetation to gravels and cobbles in streambeds. Specimens were reported from remote areas in the Arctic, in national parks and refuges, and in urban waterbodies in Fairbanks, Anchorage, and Juneau.

Distribution of unionid mussels

Three of the four unionid species that occur in Alaska are largely restricted to the Southeast: *A. kennerlyi, A. oregonensis,* and *M. falcata* (Fig. 1). Smith et al. (2005) collected *A. kennerlyi* across southeast Alaska, and as far north as Juneau (58.4°N); their findings extend the northern range of this species, which was previously thought to be southern British Columbia (Nedeau et al. 2009). There is one possible record of *A.*

kennerlyi in Yakutak (59.5°N), but the identification of this specimen needs to be confirmed. Similarly, there is only one record of *M. falcata* from Southcentral Alaska[1], more than 1000 km away from the closest record (Fig. 1). Here, too, the identification of this specimen was listed as uncertain.

A. beringiana is the only unionid species that is widespread throughout Alaska (Fig. 1). It has been collected from the Southeast to the Arctic, and as far west as Unalaska Island. A recent survey by Smith et al. (2005) collected specimens as far north as 64°N, and there are several older records (pre-1975) along the Yukon River. This species has also been reported in Kivalina Lagoon near Kotzebue, and along the Colville River, but no specimens have been collected there in the past twenty years. Whether this species occurs even further north is uncertain. Unionids were not found in probabilistic surveys of streams and lakes on the Arctic coastal plain conducted by the ADEC and ACCS in 2013 and 2015 (Appendix B).

Distribution of non-pulmonate snails

Non-pulmonate snails are widely distributed throughout Alaska (Fig. 2), with occurrences as far west as Atka and St. Matthew Islands. Unlike unionid mussels, most occurrence records were in Southcentral and in the Arctic. *Valvata spp.* were present in 23 of 26 Arctic streams (88%) and in 6 of 32 Arctic lakes (16%) surveyed by ADEC and ACCS in 2013 and 2015 using a probabilistic sampling design (Appendix B). Holmquist (1975) collected *Valvata helicoidea* (= *sincera*) from 66 lakes and ponds in northern

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[1] Deshka River, Matanuska-Susitna Valley, from Xerces database.

Alaska and northwestern Canada (Appendix E). The abundance of lakes in the Arctic may explain the high numbers of *Valvata spp.* specimens that have been collected there (E.J. Johannes, *pers*. *comm.*). Interestingly, we did not find any records of non-pulmonate snails in Southeast Alaska (Fig. 2). ADEC and ACCS will be conducting a probabilistic survey of lakes in Southeast Alaska in summer 2017. This survey will help to inform the distribution of these taxa in this region of the state.

What factors influence mollusk distribution and abundance?

At a broad geographic scale, water temperature may limit species' distribution at northern latitudes (Haag 2012). For example, invasive zebra mussels (*Dreissena polymorpha*) can survive at water temperatures of 0°C, but require water temperatures ≥ 10°C for growth and reproduction (Feng and Papeş 2017). Although the physiological requirements of Alaskan species are unknown, species that have not been detected in northern Alaska (e.g., *M. falcata*, *A. oregonensis*, and *A. kennerlyi*) may be restricted by water temperature to the Southeast region. The current distribution of mollusks may also be affected by past events such as glaciation and local extinctions (Haag 2012; Hovingh 2016). The most recent glaciation period, known as the Wisconsin glaciation, took place ~70 000 to 10 000 years ago (Frye et al. 1968). During this period, the Brooks Range and all of southern Alaska (up to the Alaska Range) were covered in ice, which would have prevented mollusks from living in those regions (Kaufman and Manley 2004; Milner et al. 1997). Recolonization after this glaciation period came either from Siberia or from ice-free regions in North America (Milner et al. 1997). *A. beringiana*, the northernmost *Anodonta* species in Alaska, is more closely related to

Asian species than to North American mussels (Chong et al. 2008), which supports the idea of recolonization via the Bering land bridge. In contrast, occurrence records of *Margaritifera falcata* are largely restricted to the Southeast (Fig. 1). Even though this species is closely related to an Asian species (Huff et al. 2004), it, unlike *A. beringiana*, may have colonized Alaska from the south (E.J. Johannes, *pers*. *comm.*). The Southeast region, which has over 1000 islands and spans more than 300 miles, is likely a major barrier to species with limited dispersal abilities such as mollusks. *Valvata* snails appear to be entirely absent from the Southeast, even though they have been extensively collected in other regions of the state, suggesting a potential dispersal barrier from the mainland to the Alexander Archipelago.

At local scales, the distribution of mollusks is influenced by the biotic and abiotic characteristics of individual waterbodies. Several abiotic factors are believed to influence the distribution of freshwater mollusks, including flow velocity, substrate size, and water chemistry (Haag 2012; Hegeman 2012). Mollusks are usually rare or absent in soft waters, waters with low pH, low levels of dissolved oxygen, or potassium concentrations above 4-7 ppm (Holmquist 1975; Haag 2012). On this point, Holmquist (1975) was surprised to collect *Valvata sincera* in Heart Lake (68.9°N, 151.3°W), which has low specific conductance and soft water. As benthic organisms[1], mollusks also require stable substrates (Nedeau et al. 2009; Haag 2012). Unstable substrates, such as those that are prone to erosion, or those found in waterbodies with high flows and/or steep gradients, may transport mollusks violently downstream, inflicting mortality and

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[1] Living on or in the bottom of a waterbody

affecting recruitment rates (Howard and Cuffey 2006; Haag 2012). High turbidity may interfere with filter feeding and host-parasite interactions between fish and mussel larvae (Brim Box et al. 2006). Finally, because of their calcareous shells, mollusks need waterbodies with sufficient concentrations of calcium and bicarbonate (Haag 2012).

Biotic interactions also affect the distribution and density of mollusks. A study by Hershey (1990) found that *Valvata lewisi* snails in an Arctic lake system were limited by competition with a larger snail, *Lymnaea elodes*. For unionid mussels, which have a parasitic larval stage, distribution and dispersal depend on the distribution and diversity of their fish host species (Watters 1992). *Anodonta* larvae are considered host generalists (Hegeman 2012); in Alaska, they have been found in three-spine stickleback, Chinook salmon, and sockeye salmon (Cope 1959). The larvae of *M. falcata*, meanwhile, are commonly considered specialists of coldwater salmonids (Hovingh 2004; Hegeman 2012). Invasive species are also known to affect populations of unionid mussels. In the Great Lakes ecosystem of eastern North America, mortality of unionid mussels was linked to fouling by zebra (*Dreissena polymorpha*) and quagga mussels (*Dreissena bugensis*) (Ricciardi et al. 1995). Dreissenid mussels have been discovered as far west as Montana and California (USGS 2017). No dreissenid mussels were found in Alaska during a recent 2012 survey (Bogan and Rinella 2013). Two non-native freshwater snails are of concern in the State: the big-ear radix (*Radix auricularia*) and the New Zealand mudsnail (*Potamopyrgus antipodarum*). *R. auricularia* has been reported in ponds and lakes in Fairbanks and on the Kenai Peninsula. The New Zealand mudsnail has not been found in Alaska, but it is widespread in California, Washington, and Oregon, and has spread as far north as British Columbia (DFO 2011;

Benson et al. 2017). Until now, there are no known impacts of *R. auricularia* (Kipp et al. 2017). Effects of *P. antipodarum* are still largely unknown, and appear to be context-dependent. In some cases, high densities of *P. antipodarum* have been linked to low populations of native macroinvertabrates, including snails (Kerans et al. 2005; Strzelec 2005). In contrast, other studies have found no or even positive effects of *P. antipodarum* on native snails (Schreiber et al. 2002; Sardiña et al. 2015).

Implications for site-specific water quality criteria

The occurrence records we compiled indicate that freshwater mussels and non-pulmonate snails are broadly distributed across the state. Recalculating USEPA's ammonia criteria therefore seems unjustified at the regional scale, but site-specific criteria may also be justified for waterbodies that are cold or acidic. Ammonia toxicity generally decreases at low temperatures and pH values, and criterion values are adjusted to reflect these relationships (USEPA 2013). At temperatures below 15.7°C, USEPA regulations for acute criterion are based on salmonids, because salmonids are more sensitive to ammonia than unionid mussels at cold water temperatures. Nevertheless, the acute criterion is less stringent at lower temperatures, increasing from 17 mg TAN/L at 20°C to 24 mg TAN/L at 15°C (Appendix F). In the Cook Inlet region of southcentral Alaska, analyses of 5 years of stream temperature data revealed that only 12 of 48 salmon streams reached temperatures above 20°C, and 17 streams never reached temperatures above 18°C (Mauger et al. 2016). These results suggest that revising the USEPA ammonia criterion values may be warranted for many waterbodies whose temperatures are consistently below 20°C.

Species distribution modeling

Species distribution models (SDMs) are used to predict species' ranges across a variety of spatial scales (e.g. across North America, across the state of Alaska, or within a watershed). SDMs are statistical models that use information on species occurrence and on environmental variables to predict where species might occur in areas where we have information on environmental variables, but not on the species themselves (Pearce and Boyce 2006). Depending on the data available, SDMs can provide a measure of occurrence probability (the probability that a species is absent in a certain area) or a relative measure of habitat suitability, which can tell us where a species is most likely to be found. We provide a list of recommended modeling methods that can be used with the different data types along with benefits and limitations in this section, and in Figure 3 and Table 1. All recommended modeling methods can be implemented using available packages in the free statistical software, R.

Quantifying occurrence probabilities requires presence-absence data (Elith et al. 2006). Two groups of statistical methods are commonly used to model species distributions using presence-absence data: regression-based and machine learning techniques (Table 1). Regression-based techniques include generalized linear models (GLMs) and generalized additive models (GAMs). GLMs can model different response distributions (e.g. binomial for presence-absence data or Poisson for count data), while GAMs can allow for complex, non-linear relationships between species and their environment. The benefits of regression techniques include: the ability to model count data with many zeros (as in the case of rare species), an explicit understanding of effect sizes, and extensions to mixed models, which account for nested sampling designs common to ecology (e.g. subplots within a stream reach). There have also been recent developments to account for spatial autocorrelations that allow modeling of sampling data that violate the independence assumption (Isaak et al. 2010, Frieden et al. 2014, https://www.fs.fed.us/rm/boise/AWAE/projects/SpatialStreamNetworks.shtml).

The second major group of methods for presence-absence data encompasses machine learning techniques. Machine learning techniques can handle non-linearities and interactions between environmental predictors, and don’t require a priori knowledge of the relationship between environmental predictors and species distributions. They have been shown to have high prediction accuracy, but are less intuitive than regression techniques (Cutler et al. 2007, Knudby et al. 2010). We therefore provide a short description of two recommended methods here (Table 1). Random forest is a machine learning method that combines predictions from a large set (e.g. 500) of classification trees (Cutler et al. 2007). Each tree is based on a bootstrap sample (sampling with replacement) of ~63% of the original observations. This sample is then used to predict species occurrence for the remaining observations. Support vector machines (SVM) define an optimal hyperplane based on explanatory variables to identify a species’ ecological niche (Drake et al. 2006). SVM models do not require that observations are independent, but do assume that they reasonably represent the range of environments preferred by the species.

Presence-only data, which is what most of our dataset is comprised of, can be used to model species distributions using either presence-only or presence-absence techniques (Fig. 3). Recommended presence-only modeling techniques include one-class support vector machines and Poisson point process models (PPM; Table 1).

PPMs are similar to regression models, except that they model the spatial location of presence points, rather than a random variable (e.g. presence-absence or count data). The spatial locations and number of presence points are used to predict “intensity”, a measure of relative abundance that represents the number of presence points per unit area (Renner et al. 2015).

To use presence-absence models with a presence-only dataset, pseudo-absences must be generated to create a full presence-absence dataset (hereafter called presence-background data, PB; Table 1). A species distribution modeled using presence-background data can only be interpreted as habitat suitability. It cannot tell us about occurrence probability because the background data are not true absences (Franklin 2009). Pseudo-absences can be generated either randomly or by using stratification. Guidance on the best methods for creating pseudo-absences depend on the modeling technique (see Table 1 in Barbet-Massin et al. 2012). For regression techniques, a large number (e.g. 10 000) of randomly selected pseudo-absences are recommended. For random forests or other classifiers, an equal number of pseudo-absences as presences is recommended, and pseudo-absences should be randomly selected using spatial or environmental stratification.

Table 1. Recommended species distribution modeling methods.

Data Type[1]	Model Types	Model Variations	Pros	Cons	References
PA or PB	Generalized linear model (GLM)	Poisson, logistic, or negative binomial, generalized linear mixed model (GLMM)	Can model different distributions, non-linear effects, spatial auto-correlation, random effects (GLMM); easy to interpret	Must meet model assumptions, may not predict as well as other model types	
PA	Generalized additive model (GAM)	Generalized additive mixed model (GAMM)	Can model complex non-linear effects and random effects (GAMM)	Must meet model assumptions, may not predict as well as other model types, effect sizes not as easy to interpret	
PA	Machine learning	Random forest	Allows for interactions and non-linearities, good for prediction	Not as easily interpretable	Cutler et al. 2007
PA, PB, or PO	Machine learning	Support vector machine (SVM)	Good for prediction, works with presence-only data, no independence assumption	Not as easily interpretable	Drake et al. 2006
PO	Generalized linear model	Poisson point process	Works with presence-only data, can model spatial dependencies	Must meet model assumptions, more recent, software options are more complex	Renner et a. 2015

1 Data types include presence-absence (PA), presence-background (PB), and presence-only (PO). See text for details.

Limitations

We have summarized some of the limitations to species distribution modeling that should be considered before pursuing watershed or regional models for Alaska.

1. Presence-absence data are required to build a distribution model of occurrence probability. Data from random survey designs are preferred in order to draw inference across the sampled population. Our current probabilistic datasets only represent a small subset of ecosystems in Alaska (e.g. wadeable streams in the Lime Hills ecoregion of the Nushagak and Kvichak watersheds). There are very few probabilistic surveys that have been conducted in the State for benthic macroinvertebrates as they are extremely costly to implement (see Appendix B).
2. True absences are difficult to ascertain because detection probabilities are typically not known and surveys are based on one sampling event in time. A study by Reid (2016) found that intensive sampling (two repeat 4½ hour surveys) is required to achieve high detection probabilities; however, detection probabilities for unionids vary by species and across habitats (Wisniewski et al. 2013, Pandolfo et al. 2016, Reid 2016) and are not known for species found in Alaska. The AMAP survey methods used by ADEC and ACCS were designed for detecting benthic macroinvertebrates rather than mussels; as a result, these data are unsuitable for determining true absences.
3. Environmental covariates for stream and lakes are entirely absent or very limited in Alaska. The best spatial dataset of streams and lakes across the State is the USGS National Hydrography Dataset (NHD). The NHD is currently being revised to meet high-resolution national standards using newly acquired digital elevation datasets. The integration of high-resolution stream networks with elevation data will allow for creation

of environmental variables that can be used for aquatic species distribution modeling, but this ability is currently limited to regions in the State where the NHD has been updated (http://akhydro.uaa.alaska.edu/update-status/). Additionally, environmental covariates that *directly* impact habitat suitability (e.g. stream temperature or discharge) will require additional data and modeling. Accurate stream temperature models in the Lower 48 are possible due to a high density of continuous stream temperature data. For example, Isaak et al. (2010) used 518 sites in one basin only slightly larger than the Talkeetna River watershed to explain 93% of the variation in mean stream temperatures. To put our data limitations in context, a recent query of continuous stream temperature sites across the entire Mat-Su Basin, which is approximately 10 times the size of the Talkeetna River watershed, returned only 80 sites.

4. Distribution model performance may be very low for Alaska. Modelling exercises using site-specific habitat data for mussels in northeastern Oregon had low to moderate predictive power (Hegeman 2012), suggesting that the factors influencing mollusk distribution are still not fully understood. The distribution of habitat generalists such as *Anodonta* sp. may also be harder to model than habitat specialists that have specific habitat requirements or narrow environmental tolerances (Elith et al. 2006). The lack of suitable environmental covariates in Alaska (point #3, above) is an additional and important challenge that will likely limit model performance.

Recommendations for future work

1. Conduct a pilot study to establish survey methods required to achieve high detection probabilities for individual species. Previous studies indicate that detection

probabilities are highly variable across species and habitats (Wisniewski et al. 2013, Pandolfo et al. 2016). ACCS has extensive experience in sampling benthic macroinvertebrate communities and in taxonomic identification. Methods deployed could include qualitative, semi-quantitative, and/or quantitative methods outlined in the Technical Support Document (USEPA 2013b) or those recommended by Smith (2006) for detecting rare freshwater mussels. It is important to note that proving true absences is difficult even when no specimens have been found. Following an intensive surveying effort in a 7.5 mile stretch of Utah's Jordan River in which they did not find any unionid mussels, researchers nevertheless admitted that, "concluding true absence of target mollusks is not possible without examining the entire substrate of the Jordan River" (Richards 2014).

2. Use data from existing probabilistic surveys to understand habitat preferences of *Valvata* spp. ACCS could use statistical models to explore water chemistry and physical habitat variables as possible predictors of *Valvata* spp. presence in each study region sampled. These results could be used to prioritize collection of environmental data for future distribution modeling efforts. We recommend building models at the genus level because freshwater mollusks are difficult to identify and not all specimens in our database have been verified by taxonomic experts (Nedeau et al. 2009). Note that unionid mussels were not found in any of the existing probabilistic aquatic surveys across the State, precluding our ability to build presence-absence models for this taxonomic group.

3. Create a distribution model using presence datasets and environmental data for the State. Presence-only methods such as PPM or SVM could be used to model

species habitat suitability using gridded climatic, topographic, hydrologic, and anthropogenic variables. This method has been applied to model the distribution of *Elodea sp.* in Alaska (Luizza et al. 2016), and elsewhere for fishes (Markovic et al. 2012). This type of model could provide insights into regions of the State with limited habitat suitability for unionids and non-pulmonate snails given the newly created presence dataset included in this report.

4. Investigate the possibility of distribution modeling for the Southeast region after the ADEC AMAP studies are complete for lakes (2017) and streams (2018-19). Recommend that the ADEC AMAP program focus on the Southcentral region after the Southeast region is complete. Both regions have updated hydrography data that could be used to generate environmental covariates for modeling. In the Mat-Su Basin, The Nature Conservancy contracted Netmap to create reach scale habitat variables. Possibly, other efforts have occurred or are underway to create environmental covariates using the new stream networks.

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References

ADEC. (2013). Alaska's Final 2012 Integrated Water Quality Monitoring and Assessment Report. Alaska Department of Environmental Conservation, Juneau, AK

Augspurger T, Keller AE, Black MC, et al. (2003). Water quality guidance for protection of freshwater mussels (Unionidae) from ammonia exposure. Environmental Toxicology and Chemistry 22(11):2569–2575. doi: 10.1897/02-339

Barbet-Massin M, Jiguet F, Albert CH, and Thuiller W. (2012). Selecting pseudo-absences for species distribution models: How, where and how many? Methods in Ecology and Evolution 3:327–338.

Benson AJ, Kipp RM, Larson J, and Fusaro A. (2017). *Potamopyrgus antipodarum*. USGS Nonindigenous Aquatic Species Database, Gainesville, FL. https://nas.er.usgs.gov/queries/factsheet.aspx?SpeciesID=1008 Revision Date: 6/26/2014

Bogan D and Rinella D. (2013). Early detection of Zebra and Quagga mussels in Alaska. Prepared for Alaska Department of Fish and Game. Alaska Natural Heritage Program, University of Alaska Anchorage.

Brabets TP, Ourso RT. (2006). Water quality, physical habitat, and biology of the Kijik River Basin, Lake Clark National Park and Preserve, Alaska, 2004-2005. U.S. Geological Survey, Scientific Investigations Report 2006-5123.

Brim Box J, Howard J, Wolf D, et al. (2006). Freshwater mussels (Bivalvia: Unionoida) of the Umatilla and Middle Fork John Day Rivers in Eastern Oregon. Northwest Science 80(2):95–107.

Brönmark C. (1989). Interactions between epiphytes, macrophytes and freshwater snails: A review. Journal of Molluscan Studies 55(2):299–311. doi: 10.1093/mollus/55.2.299

Camargo JA and Alonso Á. (2006). Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: A global assessment. Environment International 32(6):831–849. doi: 10.1016/j.envint.2006.05.002

Chong JP, Brim Box JC, Howard JK, et al. (2008). Three deeply divided lineages of the freshwater mussel genus Anodonta in western North America. Conservation Genetics 9(5):1303–1309. doi: 10.1007/s10592-007-9485-x

Cope OB. (1959). New parasite records from stickleback and salmon in an Alaska stream. Transactions of the American Microscopical Society 78(2):157–162. doi: 10.2307/3224024

Cutler D, Edwards TJ, Beard K, et al. (2007). Random forests for classification in ecology. Ecology 88:2783–2792.

DFO. (2011). Science advice from the risk assessment of New Zealand mud snail (*Potamopyrgus antipodarum*) in Canada. DFO Canadian Science Advisory Secretariat Science Advisory Report 2010/065.

Dillon RT. (2000). The ecology of freshwater molluscs. Cambridge University Press, Cambridge

Drake JM, Randin C, Guisan A. (2006). Modelling ecological niches with support vector machines. Journal of Applied Ecology 43(3):424–432. doi: 10.1111/j.1365-2664.2006.01141.x

Elith J, H. Graham C, P. Anderson R, et al. (2006). Novel methods improve prediction of species' distributions from occurrence data. Ecography 29(2):129–151. doi: 10.1111/j.2006.0906-7590.04596.x

ESRI. (2014). ArcGIS 10.3 for Desktop.

Feng X and Papeş M. (2017). Physiological limits in an ecological niche modeling framework: a case study of water temperature and salinity constraints of freshwater bivalves invasive in USA. Ecological Modelling 34648–57. doi: 10.1016/j.ecolmodel.2016.11.008

Franklin, J. (2009). Mapping species distribution: spatial inference and prediction. Cambridge University Press, Cambridge, UK.

Frieden JC, Peterson EE, Webb JA, and Negus PM. (2014). Improving the predictive power of spatial statistical models of stream macroinvertebrates using weighted autocovariance functions. Environmental Modelling and Software 60:320–330.

Frye JC, Willman HB, Rubin M, and RF Black. (1968). Definition of Wisconsinan Stage. U.S. Geological Survey Bulletin 1274-E pp E1-E22.

Gutiérrez JL, Jones CG, Strayer DL, et al. (2003). Mollusks as ecosystem engineers: the role of shell production in aquatic habitats. Oikos 101(1):79–90. doi: 10.1034/j.1600-0706.2003.12322.x

Haag WR. (2012). North American freshwater mussels: natural history, ecology, and conservation. Cambridge University Press, Cambridge, UK.

Haag WR and Williams JD. (2014). Biodiversity on the brink: An assessment of conservation strategies for North American freshwater mussels. Hydrobiologia 735(1):45–60. doi: 10.1007/s10750-013-1524-7.

Hegeman EE. (2012). Modeling freshwater mussel distribution in relation to biotic and abiotic habitat variables in the Middle Fork John Day River, Oregon. MSc thesis, Utah State University.

Hershey AE. (1990). Snail populations in arctic lakes: Competition mediated by predation? Oecologia 82: 26-32.

Holmquist C. (1975). Lakes of northern Alaska and nordwestern Canada and their invertebrate fauna. Zoologische Jahrbücher Abteilung für Systematik, Ökologie und Geographie der Tiere 102(3):333–484.

Hovingh P. (2016). A natural history study of leech (Annelida: Clitellata: Hirudinida) distributions in western North America north of Mexico. Peter Hovingh, Sandy, UT.

Hovingh P. (2004). Intermountain freshwater mollusks, USA (Margaritifera, Anodonta, Gonidea, Valvata, Ferrissia): geography, conservation, and fish management implications. Monographs of the Western North American Naturalist 2(1):109–135. doi: 10.3398/1545-0228-2.1.109

Howard JK, Cuffey KM. (2006). Factors controlling the age structure of Margaritifera falcata in 2 northern California streams. Journal of North American Benthological Society 25(3):677–690.

Huff SW, Campbell DC, Gustafson DL, et al. (2004). Investigations into the phylogenetic relationships of the threatened freshwater pearl-mussels (Bivalvia, Unionoidea, Margaritiferidae) based on molecular data: implications for their taxonomy and biogeography. Journal of Molluscan Studies 70(4):379–388. doi: 10.1093/mollus/70.4.379

Isaak D, Luce C and Rieman B. (2010). Effects of climate change and wildfire on stream temperatures and salmonid thermal habitat in a mountain river network. Ecological Applications 20:1350–1371.

Johnson PD, Bogan AE, Brown KM, et al. (2013). Conservation Status of Freshwater Gastropods of Canada and the United States. Fisheries 38(6):247–282. doi: 10.1080/03632415.2013.785396

Kaufman DS, Manley WF. (2004). Pleistocene maximum and Late Wisconsin glacier extents across Alaska, USA. In: Ehlers J, Gibbard PL (eds). Quaternary Glaciations: Extent and Chronology Part II: North America. Elsevier, Amsterdam, pp 9-27.

Kendall NW, Rich HB, Jensen LR, et al. (2010). Climate effects on inter-annual variation in growth of the freshwater mussel (Anodonta beringiana) in an Alaskan lake. Freshwater Biology 552339–2346. doi: 10.1111/j.1365-2427.2010.02447.x

Kerans BL, Dybdahl MF, Gangloff MM, et al. (2005). *Potamopyrgus antipodarum*: distribution, density, and effects on native macroinvertebrate assemblages in the Greater Yellowstone Ecosystem. Journal of The North American Benthological Society 24(1):123–138.

Kipp, RM, Benson, AJ, Larson J, and Fusaro A. (2017). *Radix auricularia*. USGS Nonindigenous Aquatic Species Database, Gainesville, FL. https://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=1012 Revision Date: 6/26/2014

Knudby A, Brenning A, and LeDrew E. (2010). New approaches to modelling fish–habitat relationships. Ecological Modelling 221:503–511.

Lopes-Lima M, Teixeira A, Froufe E, et al. (2014). Biology and conservation of freshwater bivalves: past, present and future perspectives. Hydrobiologia 7351–13. doi: 10.1007/s10750-014-1902-9

Luizza MW, Evangelista PH, Jarnevich CS, et al. (2016). Integrating subsistence practice and species distribution modeling: assessing invasive Elodea's potential impact on Native Alaskan subsistence of Chinook salmon and whitefish. Environmental Management 58(1):144–163. doi: 10.1007/s00267-016-0692-4

Markovic D, Freyhof J, Wolter C, et al. (2012). Where are all the fish: potential of biogeographical maps to project current and future distribution patterns of freshwater species. PLoS ONE 7(7):e40530. doi: 10.1371/journal.pone.0040530

Milner AM, Irons JG, Oswood MW. (1997). The Alaskan landscape: an introduction for limnologists. In: Milner AM, Oswood MW (eds). Freshwaters of Alaska: ecological syntheses. Springer-Verlag, New York City, pp 1–44.

Mauger S, Shaftel R, Leppi JC, et al. (2016). Summer temperature regimes in southcentral Alaska streams: watershed drivers of variation and potential implications for Pacific salmon. Canadian Journal of Fisheries and Aquatic Sciences 715:1–14. doi: 10.1139/cjfas-2016-0076

Mummert AK, Neves RJ, Newcomb TJ, et al. (2003). Sensitivity of juvenile freshwater mussels (*Lampsilis fasciola*, *Villosa iris*) to total and un-ionized ammonia. Environmental Toxicology and Chemistry 22(11):2545–2553.

Nedeau EJ, Smith AK, Stone J, et al. (2009). Freshwater mussels of the Pacific Northwest.

Newton TJ, Allran JW, O'Donnell JA, et al. (2003). Effects of ammonia on juvenile unionid mussels (Lampsilis cardium) in laboratory sediment toxicity tests. Environmental Toxicology and Chemistry 22(11):2554. doi: 10.1897/02-342

Nowacki G, Spencer P, Fleming M, et al. (2001). Ecoregions of Alaska: 2001. U.S. Geological Survey Open-File Report 02-297 (map).

Ourso RT. 2001. Effects of urbanization on benthic macroinvertebrate communitites in streams, Anchorage, Alaska. US Geological Survey Water Resources Investigations Report 01-4278.

Pandolfo TJ, Kwak TJ, Cope WG, et al. (2016). Species traits and catchment-scale habitat factors influence the occurrence of freshwater mussel populations and assemblages. Freshwater Biology 61:1671–1684.

Reid SM. (2016). Search effort and imperfect detection: Influence on timed-search mussel (Bivalvia: Unionidae) surveys in Canadian rivers. Knowledge and Management of Aquatic Ecosystems:17.

Renner IW, Elith J, Baddeley A, et al. (2015). Point process models for presence-only analysis. Methods in Ecology and Evolution 6:366–379.

Ricciardi A, Whoriskey FG, Rasmussen JB. (1995). Predicting the intensity and impact of *Dreissena* infestation on native unionid bivalves from *Dreissena* field density. Canadian Journal of Fisheries and Aquatic Sciences 1461:1449–1461. doi: 10.1139/f95-140

Richards, DC. (2014). Freshwater mollusk survey, Jordan River, UT. Part 1: Unionid mussels and non-pulmonate snails. Report prepared for Central Valley Water Reclamation Facility and Central Davis Sewer District, UT. Available from: https://deq.utah.gov/ProgramsServices/programs/water/wqmanagement/standards/docs/2015/03Mar/3_Jordan_River_Mollusk_Survey_Final_Report_2.3.pdf

Rinella D, and Bogan D. (2011). Testing Alaska's macroinvertebrate- and diatom-based stream condition indices in select urbanized streams. Report prepared for Alaska Department of Environmental Conservation. Environment and Natural Resources Institute, University of Alaska Anchorage.

Rinella D, and Bogan D. (2010). Ecological condition of lakes in the Cook Inlet Basin, Alaska. Prepared for Alaska Department of Environmental Conservation. Environment and Natural Resources Institute, University of Alaska Anchorage.

Rinella D, Bogan D, Dasher D. (2008). Ecological condition of wadeable streams in the Tanana River basin, interior Alaska. Report for the US Environmental Protection Agency. Environment and Natural Resources Institute, University of Alaska Anchorage.

Rinella D, Bogan, D, Kishaba K, et al. (2005). Development of a macroinvertebrate biological bssessment index for Alexander Archipelago streams – final report prepared for Alaska Department of Environmental Conservation. Environment and Natural Resources Institute, University of Alaska Anchorage.

Sardiña P, Beringer J, Roche D, et al. (2015). Temperature influences species interactions between a native and a globally invasive freshwater snail. Freshwater Science 34(3):933–941. doi: 10.1086/681639

Schreiber ESG, Lake PS, Quinn GP. (2002). Facilitation of native stream fauna by an invading species? Experimental investigations of the interaction of the snail, *Potamopyrgus antipodarum* (Hydrobiidae) with native benthic fauna. Biological Invasions 4(3):317–325. doi: 10.1023/A:1020925022843

Sikes DS, Bogan D, Bickford C, et al. (2016). Non-marine invertebrates of the St. Matthew Islands, Bering Sea, Alaska. Newsletter of the Alaska Entomological Society, 9(1):11-20.

Smith SC, Foster N, and Gotthardt T. (2005). The distribution of the freshwater mussels Anodonta spp. and Margaritifera falcata in Alaska. Alaska Natural Heritage Program, University of Alaska Anchorage.

Smith, DR. (2006). Survey designs for detecting rare freshwater mussels. Journal of the North American Benthological Society 25(3): 701-711.

Strzelec M. (2005). Impact of the introduced *Potamopyrgus antipodarum* (Gastropods) on the snail fauna in post–industrial ponds in Poland. Biologia 60(2):159–163.

USEPA. (2013). Aquatic life ambient water quality criteria for ammonia - freshwater. EPA-822-R-13-001, U.S. Environmental Protection Agency, Office of Water, Washington, DC

USEPA. (2013b). Technical support document for conducting and reviewing freshwater mussel occurrence surveys for the development of site-specific water quality criteria for ammonia. EPA-800-R-13-003. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

USGS. (2017). Zebra and quagga mussel sightings distribution. Retrieved from: https://nas.er.usgs.gov/UserImages/current_zm_quag_map.jpg

Urban MC. (2006). Road facilitation of trematode infections in snails of Northern Alaska. Conservation Biology, 20(4):1143-1149.

Vaughn CC, Hakenkamp CC. (2001). The functional role of burrowing bivalves in freshwater ecosystems. Freshwater Biology 46(11):1431–1446. doi: 10.1046/j.1365-2427.2001.00771.x

Watters TG. (1992). Unionids, fishes, and the species-area curve. Journal of Biogeography 19(5):481–490.

Williams JD, Warren ML, Cummings KS, et al. (1993). Conservation status of freshwater mussels of the United States and Canada. Fisheries 18(9):6–22.

Wisniewski JM, Rankin NM, Weiler DA, et al. (2013). Occupancy and detection of benthic macroinvertebrates: a case study of unionids in the lower Flint River, Georgia, USA. Freshwater Science 32:1122–1135.

Figure 1 Occurrence records of freshwater mussels (Unionoida) in Alaska. Three of the four species are largely restricted to the Southeast region, while *Anodonta beringiana* appears to be more widespread.

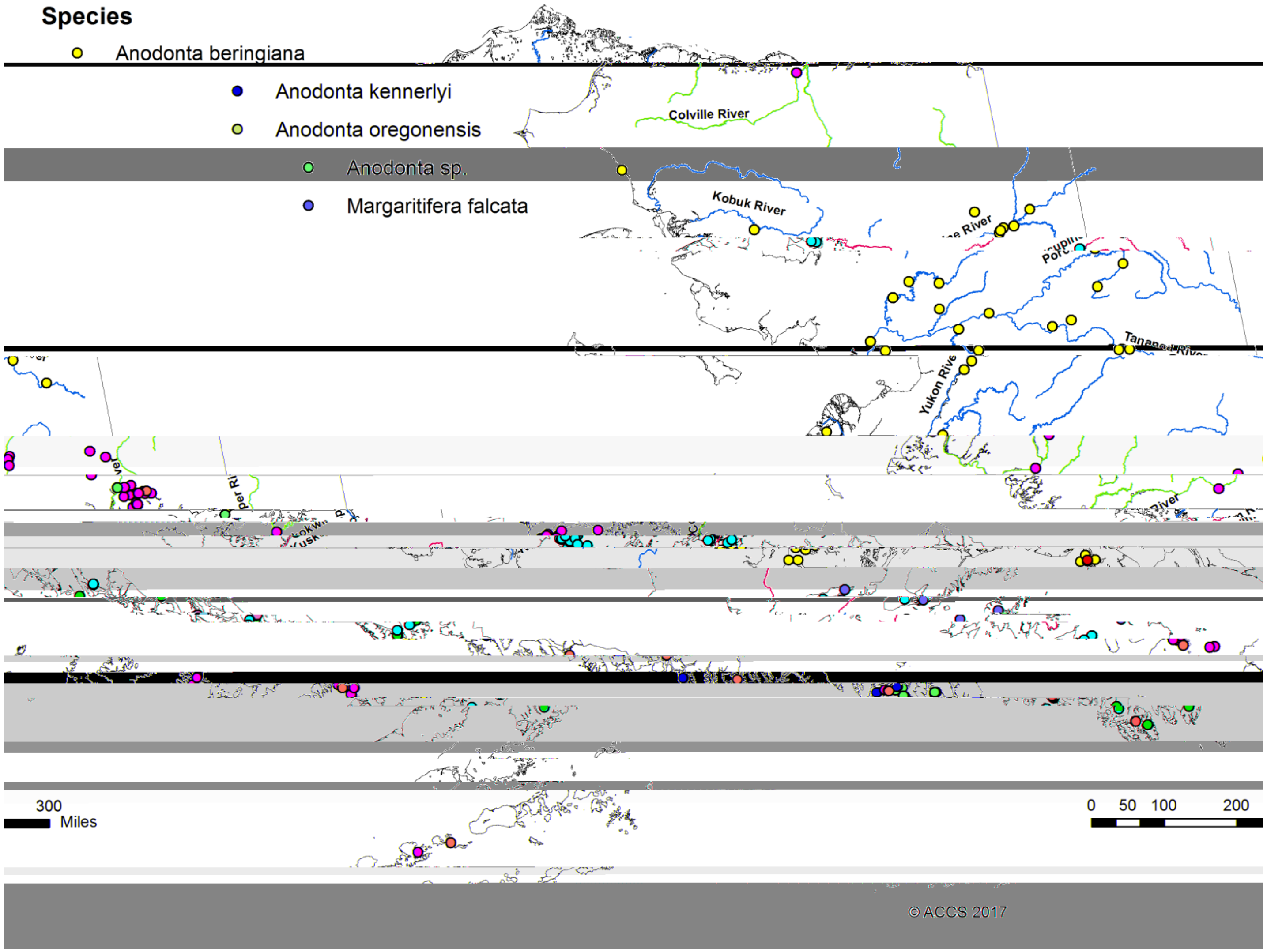


Figure 2 Occurrence records of non-pulmonate snails (Heterostropha: Valvatidae) in Alaska. Non-pulmonate snails appear to be broadly distributed in Alaska; however, no specimens have been collected in Southeast.

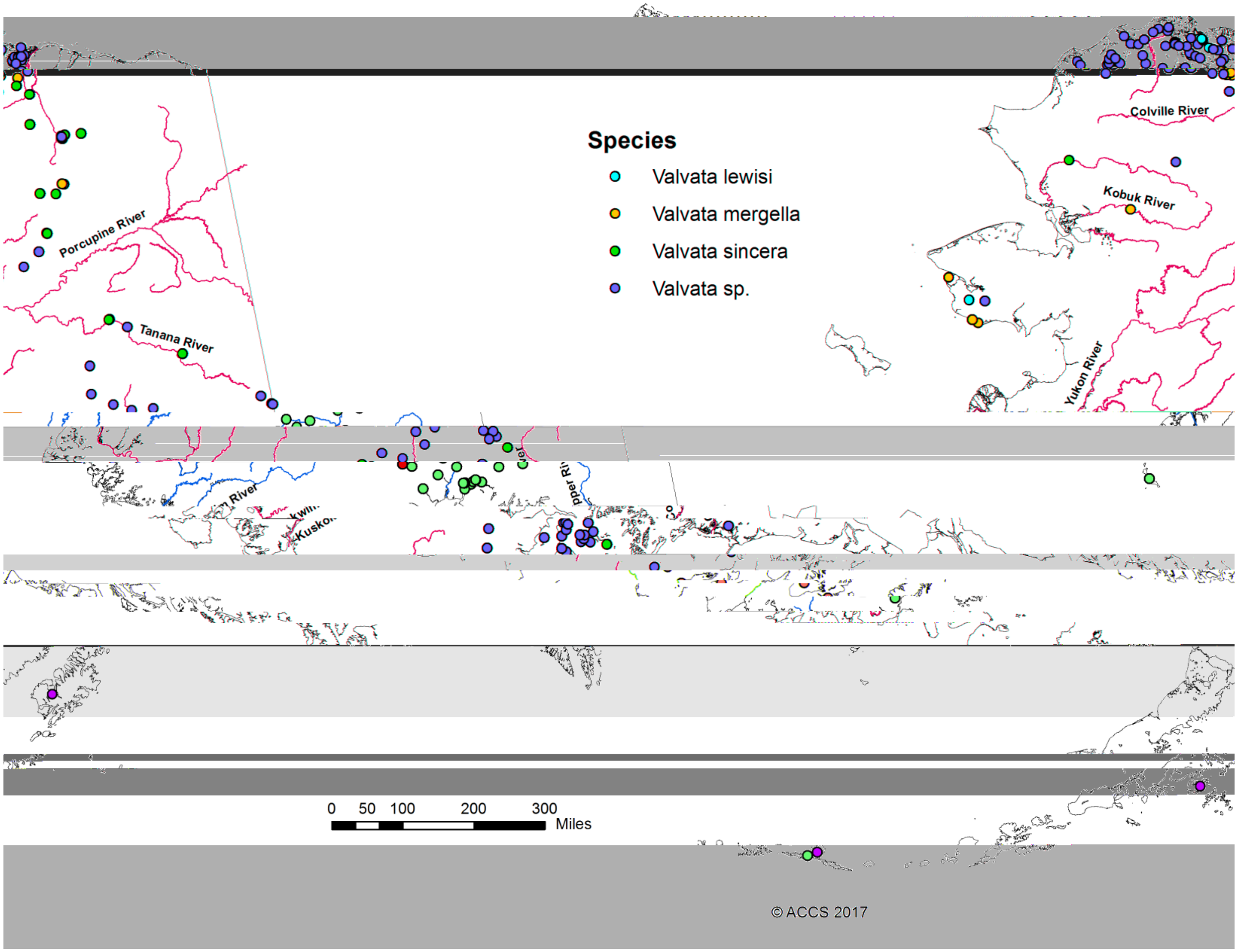
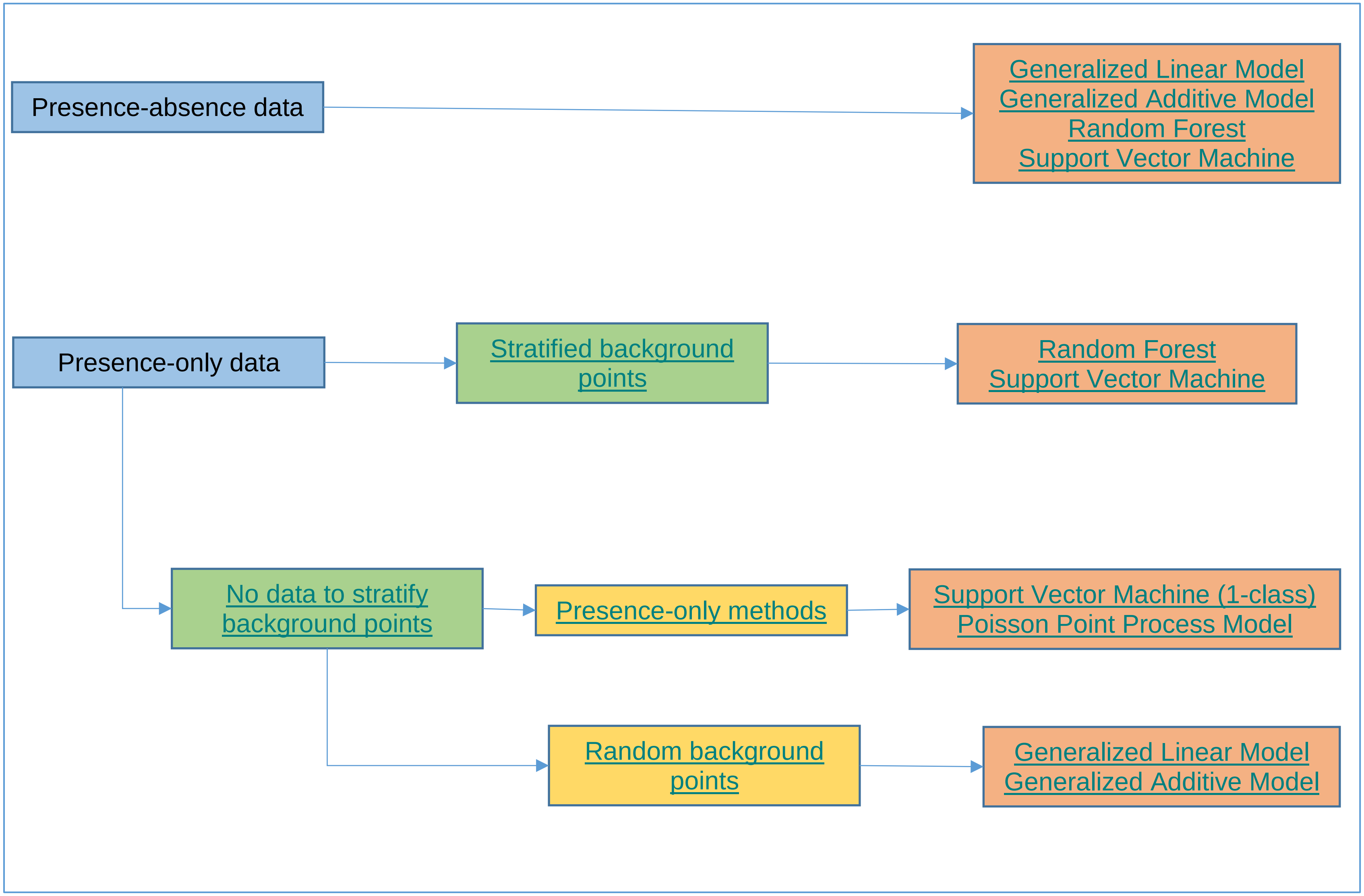


Figure 3 Flowchart for selecting a species distribution model, depending on the type of data available.



Appendix A List of sources that we consulted for occurrence records of freshwater mussels (Unionoida) and non-pulmonate snails (Heterostropha: Valvatidae) in Alaska.

Type	**Project name (Affiliation)**	**Notes (contact person)**
Database	ARCTOS (University of Alaska Fairbanks)	Queries museum catalogs
Database	BISON (USGS)	
Database	EDAS (EPA)	
Database	Freshwater Bivalve Database (Ohio State University)	
Database	iNaturalist (California Academy of Sciences)	Citizen science data
Database	iDigBio (University of Florida, Florida State University, Florida Museum of Natural History)	
Database	NatureServe Explorer (NatureServe)	Scale of occurrence is too large
Database	North American Mussel Atlas (Freshwater Mollusk Conservation Society)	Atlas not yet available (John Harris)
Database	NPSpecies (National Park Service)	No results found
Database	Red List of Threatened Species (IUCN)	Scale of occurrence is too large
Database	Western Freshwater Mussel Database (The Xerces Society)	Emilie Blevins and Celeste Mazzacano
Literature search	Consortium library (University of Alaska Anchorage/Alaska Pacific University)	
Literature search	Natural Resource Data Series Reports (National Park Service)	Sorted through all potentially relevant reports for Alaska
Literature search	Web of Science (Thomson Reuters)	Requires subscription
Literature search	Zoological Records (Thomson Reuters)	Requires subscription
Museum	Department of Invertebrate Zoology and Geology (California Academy of Sciences)	
Museum	Natural History Museum of Utah	Christy Bills and Peter Hovingh
Museum	North Carolina Museum of Natural Sciences	
Museum	Peggy Notebaert Nature Museum	No specimens in Alaska (Erica Krimmel)
Museum	Royal BC Museum	Heidi Gartner
Museum	Smithsonian National Museum of Natural History	
Museum	Swedish Museum of Natural History	Records of *Valvata* species (by C. Holmquist) not geo-referenced (Anna Persson and Anders

		Warén)
Private collection	Steve Welty collection (Deixis Consultants)	Collection not digitized (Ed Johannes)
Personal communication	Alaska Department of Fish & Game	Parker Bradley
Personal communication	NRF Taxonomic Services	Nora Foster
Personal communication	Utah State University/Bureau of Land Management	Scott Miller

Appendix B List of surveys and studies in Alaska that reported unionid mussels and/or non-pulmonate snails. The number of sites sampled is listed only for probabilistic surveys. Surveys were either conducted in-house by the Alaska Center of Conservation Science, or were obtained by contacting colleagues and by conducting a literature search. None of the surveys focused specifically on unionid mussels or non-pulmonate snails; rather, collections of these species were part of larger macroinvertebrate or invasive species surveys.

Probabilistic surveys

Citation	**Location**	**Survey year**	**Species**	**Sites present**	**Total sites**
ADEC and ACCS 2015	Bristol Bay	2015	*Valvata sp.*	3	30
Rinella et al. 2008	Tanana River basin streams	2004-2005	*Valvata sp.*	2	50
Rinella and Bogan 2010	Cook Inlet lakes	2008	*Valvata sp.*	28	45
ADEC and ACCS 2013	Arctic lakes	2013	*Valvata mergella*	6	38
ADEC and ACCS 2015	Arctic streams	2015	*Valvata sp.*	23	26

Non-probabilistic surveys

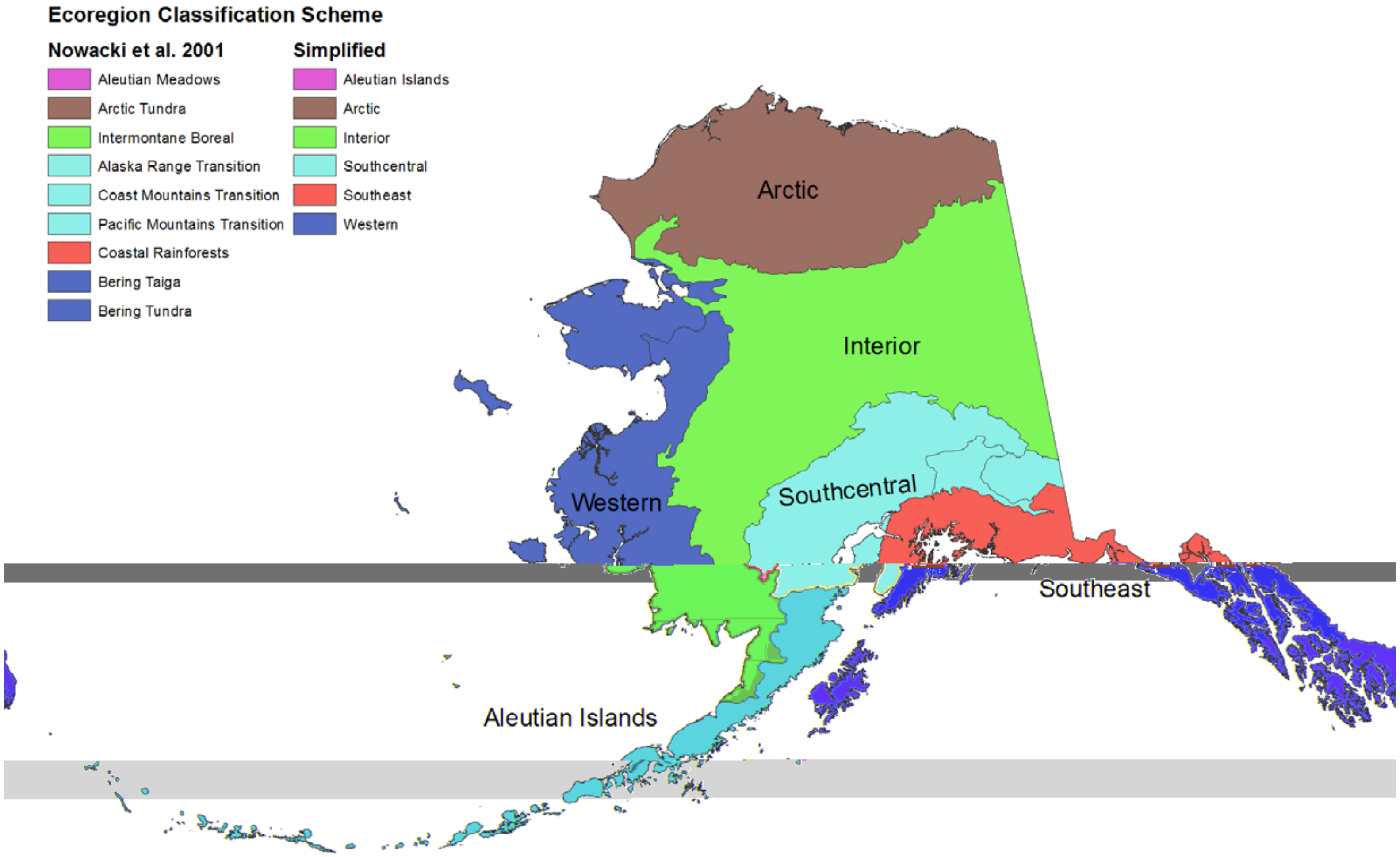
Citation	**Location**	**Survey year**	**Species**	**Sites present**	**Total sites**
Bogan and Rinella 2013	Southcentral and Interior lakes	2012	*Anodonta* sp.	—	—
Brabets and Ourso 2006	Kijik River	2004-2005	*Valvata sp.*	—	—
Holmquist 1975	Northern Alaska and Canada	1964-1975	*Valvata helicoidea (=sincera)*	—	—
Moulton et al. 2007	Teshekpuk Lake	2004	*Valvata lewisi*	—	—
Ourso 2001	Anchorage	1999	*Valvata sp.*	—	—
Sikes et al. 2016	St. Matthew Islands	2012	*Valvata sp.*	—	—
Smith et al. 2005	Statewide	2004	*Anodonta sp.*	—	—

Ecological studies

Citation	**Location**	**Survey year**	**Species**	**Sites present**	**Total sites**
Cope 1959	Otter Creek	1947	*Anodonta beringiana*	—	—
Hershey 1990	Toolik Lake Field Station	1982	*Valvata lewisi*	—	—
Urban 2006	Fairbanks/Dalton Highway	2001	*Valvata sincera*	—	—
Kendall et al. 2010	Iliamna Lake	2007-2008	*Anodonta beringiana*	—	—

Appendix C Occurrence records for unionid mussels and non-pulmonate snails in the state of Alaska. Records were collected by querying databases, contacting museums and experts, and conducting literature searches. See Excel worksheet: *Unionid data compilation.xlsx*

Appendix D A simplified ecoregion classification scheme used to describe the regional distribution of freshwater mollusks in Alaska. This scheme is based on work by Nowacki et al. (2001).



Appendix E Charlotte Holmquist conducted extensive macroinvertebrate surveys in northern Alaska from 1964 to 1975. Her manuscript, “Lakes of Northern Alaska and Northwestern Canada and their Invertebrate Fauna”, includes a figure in which she documents the occurrence and relative density of *Valvata helicoidea* (=*sincera*) at 66 localities. The information she provides in her manuscript does not allow us to add these data points to our maps, so we have included a copy of her figure instead. Her data support the presence of *Valvata spp.* in the Arctic, and adds several occurrence records along the western Brooks Range area.

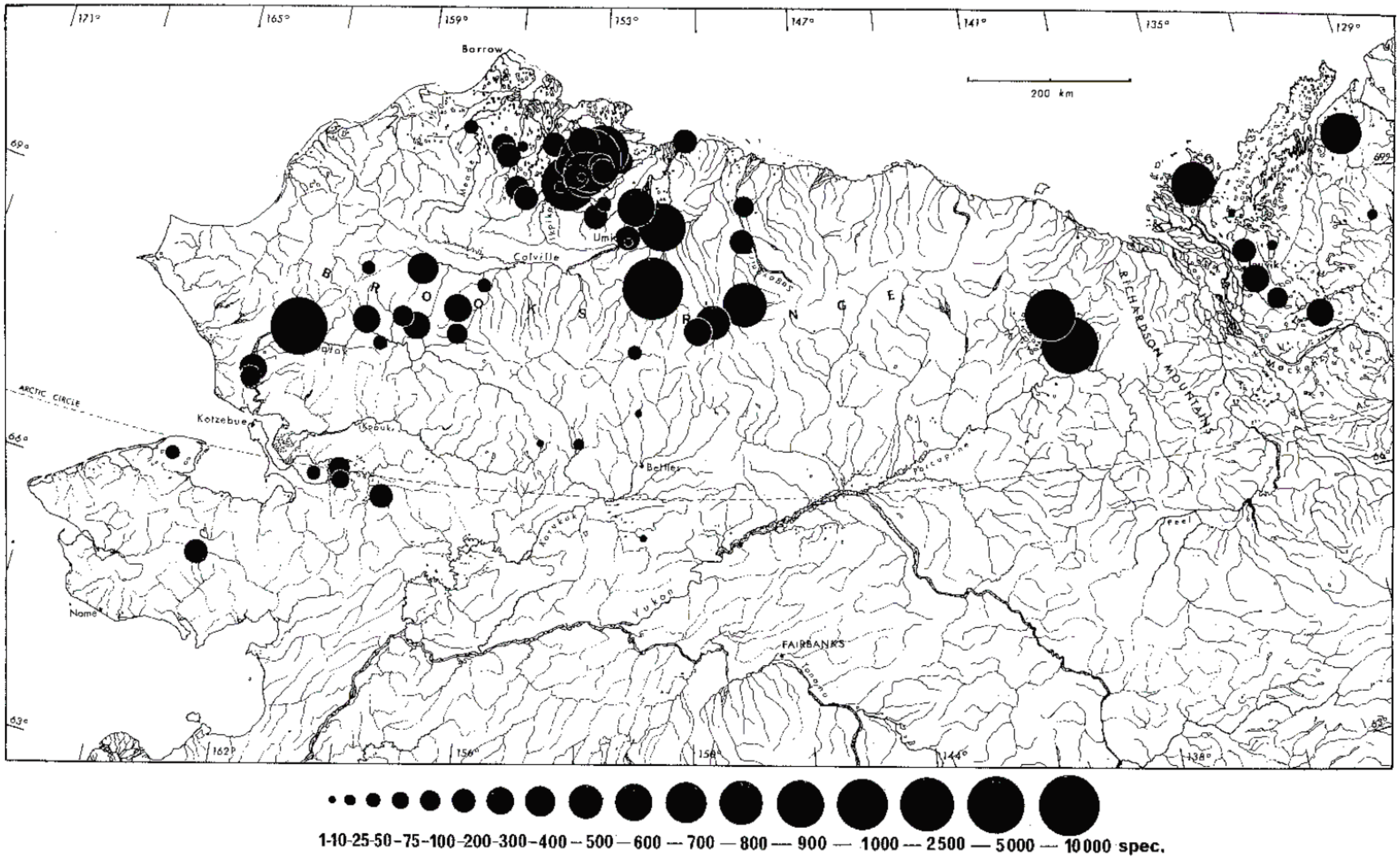
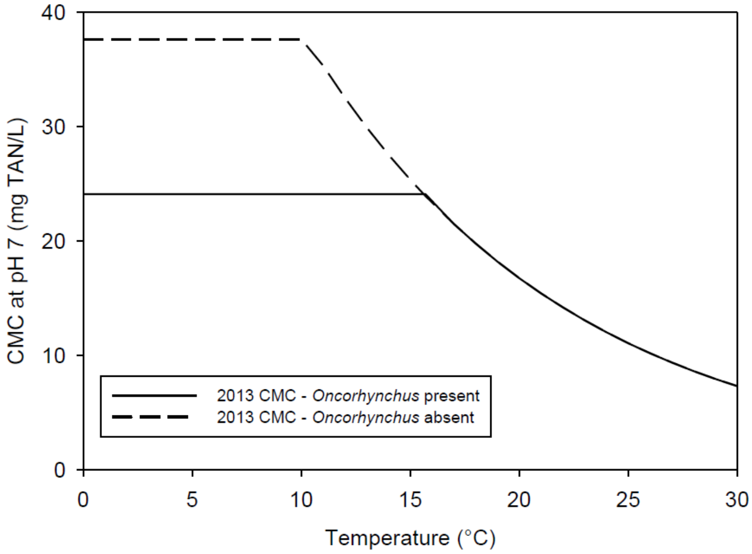


Fig. 55. Distribution of *Valvata helicoidea* as found during the survey.

Appendix F USEPA recommended maximum values for (a) acute and (b) chronic levels of ammonia in freshwater. These graphs demonstrate the relationship between ammonia toxicity, water temperature, and aquatic species. At water temperatures ≤ 15.7°C, salmonids (*Oncorhynchus sp.*) are more sensitive to ammonia than freshwater mussels. Nevertheless, recommended levels of ammonia become less stringent with decreasing water temperatures. A similar relationship exists with pH.

From: USEPA. (2013). Aquatic life ambient water quality criteria for ammonia - freshwater. EPA-822-R-13-001, U.S. Environmental Protection Agency, Washington, DC

(a) Acute criterion



(b) Chronic criterion