North American Journal of Fisheries Management

ISSN: 0275-5947 (Print) 1548-8675 (Online) Journal homepage: http://www.tandfonline.com/loi/ujfm20

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To cite this article: Nicholas B. D. Phelps, Meggan E. Craft, Dominic Travis, Katharine Pelican & Sagar M. Goyal (2014) Risk-Based Management of Viral Hemorrhagic Septicemia Virus in Minnesota, North American Journal of Fisheries Management, 34:2, 373-379, DOI: 10.1080/02755947.2014.880766

To link to this article: http://dx.doi.org/10.1080/02755947.2014.880766

Published online: 01 Apr 2014.

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North American Journal of Fisheries Management 34:373–379, 2014
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ISSN: 0275-5947 print / 1548-8675 online
DOI: 10.1080/02755947.2014.880766

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MANAGEMENT BRIEF

Risk-Based Management of Viral Hemorrhagic Septicemia Virus in Minnesota

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Abstract
Viral hemorrhagic septicemia virus (VHSV; strain VHSV-IVb) is an emergent and serious disease of fish in the Great Lakes region of North America. In addition to the numerous large-scale mortality events in wild fish, the emergence of VHSV has resulted in a major regulatory response to protect both farm-raised and wild fish populations. However, characterizing and mitigating risk factors for the continued transmission of VHSV is a difficult task. A semiquantitative risk assessment model was used to focus VHSV management efforts in Minnesota. The risk of VHSV introduction into major watersheds in Minnesota was directly correlated to their proximity to Lake Superior, the only VHSV-positive body of water in the state. Although the current regulations are uniform across Minnesota, the risk varied for specific locations within the watersheds. For example, the introduction of game fish for stock enhancement (a common fisheries management practice) is a significant factor in determining the risk of VHSV introduction into public waters, as is the movement of baitfish. In this analysis, aquaculture facilities with strict biosecurity programs and frequent health inspections received the lowest risk scores and were largely considered as protective or at low risk for VHSV introduction. These results suggest that the current management strategy, based on political boundaries, should be reevaluated. We recommend the creation of a risk-based management strategy based upon the identification of higher-risk watersheds and specific bodies of water, thus allowing managers to efficiently target surveillance and response activities in Minnesota.

Viral hemorrhagic septicemia (VHS) is a highly contagious viral disease that causes high morbidity and mortality in a wide range of marine, brackish, and freshwater fish species (USDA 2008a; Kim and Faisal 2011). The disease is caused by the viral hemorrhagic septicemia virus (VHSV), which belongs to the genus *Novirhabdovirus* within the family Rhabdoviridae. Due to its significant effect on farmed and wild fish populations, VHSV is listed by the World Organization for Animal Health as a reportable pathogen (OIE 2012). In 2005, a new strain of VHSV (VHSV-IVb) was identified in the Great Lakes (Elsayed et al. 2006; Lumsden et al. 2007). This novel strain spread rapidly through the region, resulting in numerous mass mortality events in wild fish throughout the eastern Great Lakes and inland lakes of Michigan, New York, and Wisconsin (Kim and Faisal 2011; Thompson et al. 2011). Although a large mortality event has not been reported in Lake Superior, the virus has been isolated from Cisco *Coregonus artedi* near the Apostle Islands (Faisal et al. 2012). The rapid spread of VHSV-IVb in the Great Lakes region has consequently heightened

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Received July 22, 2013; accepted November 27, 2013

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concerns about the transmission of this virus to naive populations in Minnesota.

Assessing the risk of introducing VHSV into Minnesota has been an area of management focus; however, this has been complicated by a number of factors both intrinsic and extrinsic to the virus. Intrinsically this has been difficult due to the complex interactions between the virus, host, and environment and due to the increasing viral diversity of VHSV in the Great Lakes (Kim and Faisal 2010; Thompson et al. 2011; Cornwell et al. 2012; Goodwin et al. 2012). Introduction concerns are also complicated due to extrinsic factors such as the extent of the virus's current geographic range, the interconnectedness of the Great Lakes watersheds via physical hydrologic connection and large-scale shipping, the commerce-driven movement of fish across borders and watersheds, the present complex regulatory framework, and the presence of potentially asymptomatic carriers (Goodwin et al. 2004; Bain et al. 2010; Kim and Faisal 2011; Faisal et al. 2012). While the extent of the possible introduction routes are not fully understood, knowledge is rapidly expanding (VHSV Expert Panel and Working Group 2010). Regardless, monitoring or regulating all risk factors for the introduction of VHSV is not a feasible task. Interventions, such as movement restrictions and increased diagnostic testing, are costly and time consuming and can easily prohibit business activity and recreational enjoyment. Management agencies tasked with protecting public-trust resources face difficult decisions between the trade-offs of limited budgets, feasibility, and potentially devastating consequences of VHSV introduction. Therefore, a targeted risk-based management strategy has been advocated as an ideal solution and as the most feasible and cost-effective approach to manage VHSV (Gustafson et al. 2010; Thrush et al. 2011).

The implementation of a risk assessment model to inform the creation of a risk-based surveillance and monitoring plan can have wide-reaching benefits for aquatic animal health (Stephen 2001; Stark et al. 2006; Oidtmann et al. 2011; Peeler and Taylor 2011; Thrush et al. 2011). For VHSV, the allocation of limited funds can be directed to watersheds or individual waters identified as being at a comparably "higher risk" for introduction. Strategies may include additional surveillance testing, regulatory action, increased educational effort, or other intervening management actions. In addition, the identification of risk, along with active surveillance, can identify areas free of disease where the regulatory burden could potentially be relaxed or, at a minimum, reevaluated (Gustafson et al. 2010). For example, an aquaculture facility participating in a voluntary or required certification program with several years of VHSV-negative certifications and a strict biosecurity program could be subjected to lower regulatory requirements (i.e., less frequent inspections) than baitfish harvested from the wild where the disease status is unknown. This, in turn, could be expected to change the behavior of producers and management agencies (Oidtmann et al. 2011)

While VHSV-IVb was first isolated from Lake Superior in 2009, no inland waters of Minnesota have been identified as VHSV positive, despite active surveillance and regulatory testing of hundreds of high-risk locations (e.g., aquaculture facilities and hatcheries with VHSV-susceptible species, wild baitfish harvest, popular recreation waters) since 2008 (Phelps et al. 2012; N. B. D. Phelps, unpublished). However, Minnesota regulations remain some of the most burdensome to public and private aquaculture production in regards to VHSV, requiring costly and time-consuming annual inter- and intrastate inspections of all susceptible species prior to movement regardless of location in the state and previous health history (USDA 2008b; Minnesota Statutes 2012, Section 17.4991, Subdivision 3). These regulations, combined with increasingly limited funds to manage the disease, have created the need for current policies to be reexamined. Risk-based management would help to identify high-risk populations where interventions could then be focused.

Identifying VHSV risk factors is a time-consuming task in itself, involving decades of research and expert opinion. The present case study used the risk factors identified by the VHSV Expert Panel and Working Group (2010). Based on expert opinion, their assessment identified and quantified nine of the most likely VHSV exposure routes and their associated likelihood ratios (as summarized in Table 1). The likelihood ratio for each factor represents the potential for VHSV introduction to occur, whereby values greater than 1 indicate a positive likelihood of occurrence and values less than 1 indicate the factor is to some degree protective (VHSV Expert Panel and Working Group 2010). While by no means a complete list, the factors were considered the highest-ranked actual or perceived risks to facilitate the spread of VHSV in the Great Lakes region. This case study examines the risk of VHSV introduction for watersheds in Minnesota, as well as specific wild and farmed populations, to inform the state's long-term management strategy. This approach could serve as a model for a broader VHSV management strategy throughout the Great Lakes region.

METHODS

Identifying locations at risk of VHSV introduction.—The goal of this study was to evaluate the introduction risk of VHSV to a variety of locations representing Minnesota's diverse and interconnected environment and activities. The first location type examined was watersheds within the state of Minnesota. There are 12 four-digit hydrologic unit code (HUC-4) watersheds in Minnesota (0401, 0701, 0702, 0703, 0704, 0706, 0708, 0710, 0902, 0903, 1017, 1023; USGS 2013). Since these areas are large and are comprised of diverse aquatic populations, the characteristics for each watershed were generalized based on the dominant factors of wild fish populations in the watershed. For example, the use of live bait and stock enhancement are commonplace throughout Minnesota and, thus, considered to occur in each watershed regardless of isolated management or behavior activities. However, proximity to a risk factor (i.e., a VHSV-positive body of water) was based on the nearest location within the watershed. Characteristics included factors associated with the potential for introduction of VHSV, such as

TABLE 1. Viral hemorrhagic septicemia virus (VHSV; strain VHSV-IVb) introduction risk factors and associated likelihood ratios, as determined by the VHSV Expert Panel and Working Group (2010). Likelihood ratios greater than 1 suggest the response category is a likely risk for VHSV introduction, values equal to 1 suggest the risk is neutral, and values less than 1 suggest the response category is protected.

Risk factor	Response category	Likelihood ratio
Hydrologic connectivity to VHSV-positive body of water	Connected, with fish movement	3.16
	Downstream, no fish movement	1.41
	Upstream, no fish movement	0.71
	No connection	0.32
Linear distance to VHSV-positive body of water	<100 km	2.50
	100–500 km	1.00
	>500 km	0.39
Known-susceptible species	Yes, with known congregation areas	2.00
	Yes, but no known congregation areas	1.22
	No	0.24
Conducive water temperatures	Yes, cool to cold water	1.50
	No	0.47
Fomite exposure	Yes, shared traffic or wastes	2.24
	Yes, but limited by education or regulation	1.00
	No	0.39
Live-fish transfer, bait	Yes, without testing	2.65
	Yes, with testing	1.00
	No, transfers prevented	0.34
Live-fish transfer, culture or stock	Yes, without testing	2.45
	Yes, with testing	1.00
	No, transfers prevented	0.39
Frozen-fish transfer	Yes, without testing	2.45
	Yes, with testing	1.00
	No, transfers prevented	0.58
Regulatory framework	Sufficient	0.80
	Insufficient	1.34

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fish introductions and geographic proximity to positive bodies of water. To visually demonstrate the risk of VHSV introduction to Minnesota watersheds, a GIS-based heat map was created using R (Version 2.15.1; R Development Core Team 2012).

The second location type examined was specific sites of 10 different wild and farmed fish populations distributed across Minnesota. The locations were selected to represent the diversity of locations and activities in Minnesota watersheds. Data were collected from on-site inspections and manager surveys, as well as the Minnesota Lake Finder database (MDNR 2013). Five wild fish populations identified by the Minnesota Department of Natural Resources, based on recreational use and perceived VHSV risk, were evaluated: Big Stone Lake (Big Stone County), Lake Minnetonka (Hennepin County), Lake Pepin (Goodhue County), Leech Lake (Cass County), and the St. Louis River (St. Louis County). Two public bodies of water frequently used for wild baitfish harvest were evaluated: Battle Lake (Otter Tail County) and Lake of the Woods (Lake of the Woods County). Three aquaculture facilities raising both VHSV-susceptible and nonsusceptible fish species were also examined; the precise locations of the aquaculture facilities are confidential.

Identifying risk factors for VHSV introduction.—The semi-quantitative risk factors for the introduction of VHSV were based on those established by the VHSV Expert Panel and Working Group (2010). These factors were identified based on the experience of participants as experts in the field. Briefly, the expert panel was asked to individually identify the top 10 potential watershed-level risk factors that would likely be associated with a new introduction of VHSV-IVb in the United States. The resulting list of factors ($n = 28$) were scored (1–10) and narrowed down to the nine top risk factors. These were further evaluated and were assigned response categories (i.e., high, medium, low) and associated likelihood ratios (LRs). For example, close proximity to a VHSV-positive body of water was identified as a major risk factor. Thus, locations further than 500 km were at lower risk (LR = 0.39) than bodies of water within 100 km (LR = 2.50). To reduce asymmetrical bias (score of 10 was the maximum), the median of the square root transformation of each LR was used for this study (VHSV Expert Panel and Working Group 2010; summarized in Table 1).

Risk assessment model.—For each location, the likelihood of VHSV introduction, also known as the risk score (RS), was determined. This was calculated by evaluating each risk factor for a given location and selecting the associated LR. The product of the multiplied LR for a given location provides the RS for potential VHSV-IVb introduction. Values greater than 1 suggest the potential for VHSV introduction is likely, while values less than 1 suggest the location is less likely or even protective. An LR or RS equal to 1 indicates the introduction risk is neutral (VHSV Expert Panel and Working Group 2010). For purposes of this case study, we have arbitrarily assigned RS values greater than 5 to be "high risk," 2–5 to be "moderate risk," 0.8–2 to be "low risk," 0.3–0.8 to be "minimal risk," and values less than 0.3 to be "protective."

A map was generated using R to overlay the watershed introduction risk with the locations of previous VHSV surveillance testing from 2010 to 2011. These previous surveillance sites included the majority of private aquaculture production and wild baitfish harvest in Minnesota (Phelps et al. 2012).

RESULTS

Risk scores for all 12 HUC-4 watersheds in Minnesota were calculated, with scores ranging from 0.30 to 18.96 (Figure 1). Linear distance and hydrologic connectivity to a VHSV-positive body of water were the only significant risk factors for introduction of VHSV into the watershed. All other risk factors were equivalent across watersheds. An overlay of the watershed RSs with the VHSV survey sites from 2010 to 2011 shows the majority of aquaculture facilities and wild baitfish harvest are in watersheds with minimal risk (RS = 0.77) of VHSV introduction, while most of the remaining locations are in watersheds with low risk (RS = 1.92; Figure 2).

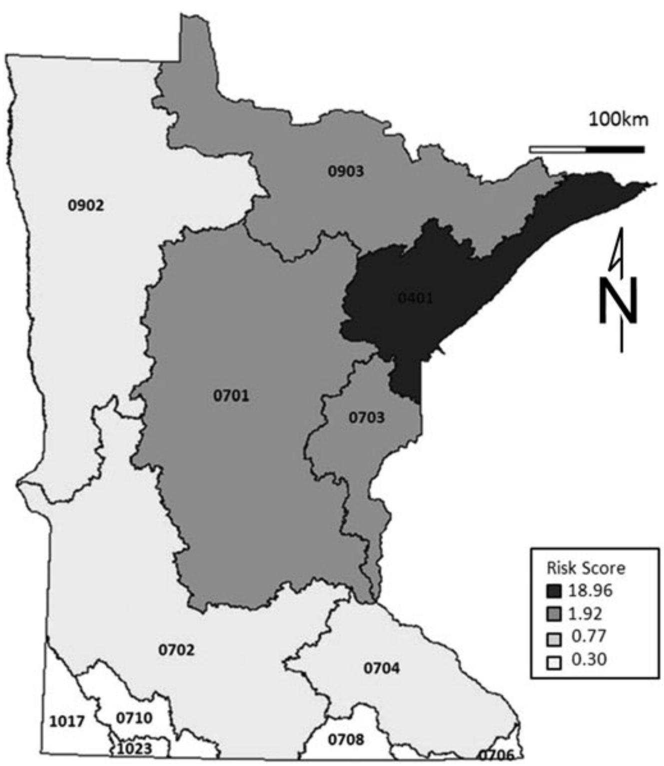

FIGURE 1. Map of the risk of VHSV introduction into Minnesota watersheds. Numbers within the watersheds identify the watersheds based on four-digit hydrologic unit codes. The darker the shading, the higher the risk of VHSV introduction.

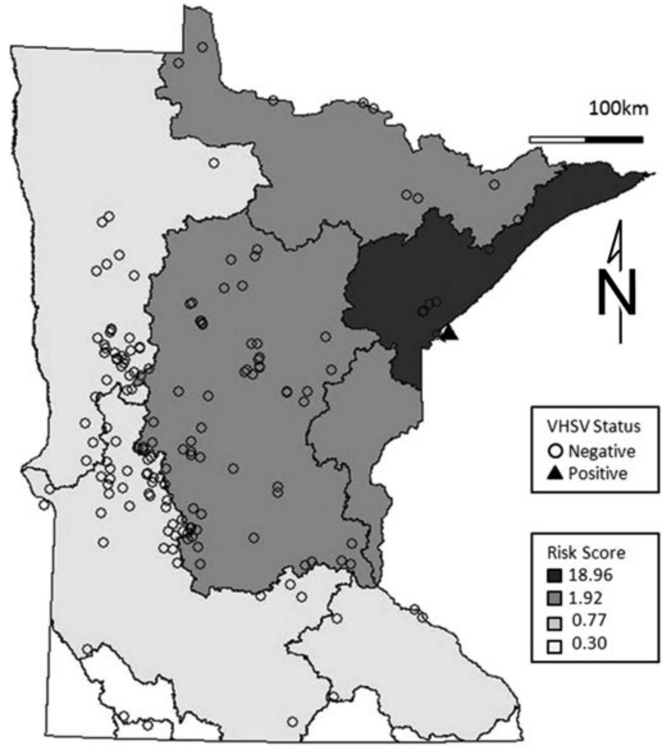

FIGURE 2. Map of the risk of VHSV introduction to Minnesota watersheds showing the locations of aquaculture and wild baitfish activity as circles. Open circles indicate a VHSV-negative health inspection from 2010 to 2011. The filled triangle on Lake Superior indicates the only VHSV-positive body of water in Minnesota. The darker the shading in the watershed, the higher the risk of VHSV introduction.

The RSs for specific sites varied from their associated watershed RS (Table 2). In addition to linear distance and hydrologic connectivity to a VHSV-positive body of water, the transfer of fish for stocking or culture, the control of fomite exposure, and the use of bait influenced the risk of VHSV introduction. The RS for five public bodies of water ranged from 0.30 to 16.56. The RS for the two bodies of water frequently used for wild baitfish harvest were 0.30 and 0.77. The three private aquaculture production facilities were considered the most protected of the sites evaluated, with RSs ranging from 0.00 to 0.17.

DISCUSSION

In Minnesota, the current management strategy considers VHSV introduction risk equal across the state, regardless of unique location characteristics, control measures, or disease-free history. In this case study, we estimated the risk level for introduction of VHSV in Minnesota watersheds and at specific

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TABLE 2. Viral hemorrhagic septicemia virus introduction risk scores (RSs) for specific locations in Minnesota. The likelihood ratio (as determined by Table 1) of VHSV introduction for each risk factor is given and these values were multiplied to determine the RS for each site. Locations include five public bodies of water, two public bodies of water frequently used for wild baitfish harvest ("Bait"), and three aquaculture farms ("Culture").

					Likelihood ratios for risk factors									
Site	County	Watershed (HUC-4)	Watershed RS	Classification	Hydrologic connectivity	Linear distance	Known-susceptible species	Conducive water temperatures	Fomite exposure	Live-fish transfer, bait	Live-fish transfer, culture or stock	Frozen-fish transfer	Regulatory framework	Site RS
St. Louis River	St. Louis	0401	18.96	Public	3.16	2.50	2.00	1.50	2.24	1.00	0.39	1.00	0.80	16.56
Leech Lake	Cass	0701	1.92	Public	0.32	1.00	2.00	1.50	1.00	1.00	1.00	1.00	0.80	0.77
Farm	Aitkin	0701	1.92	Culture	0.32	1.00	0.24	1.50	0.39	0.34	0.39	0.58	0.80	0.00
Big Stone	Big Stone	0702	0.77	Public	0.32	1.00	2.00	1.50	1.00	1.00	1.00	1.00	0.80	0.77
Farm	Douglas	0702	0.77	Culture	0.32	1.00	2.00	1.50	0.39	1.00	1.00	0.58	0.80	0.17
Lake Peppin	Goodhue	0704	0.77	Public	0.32	1.00	2.00	1.50	1.00	1.00	0.39	1.00	0.80	0.30
Lake Minnetonka	Hennepin	0704	1.92	Public	0.32	1.00	2.00	1.50	1.00	1.00	1.00	1.00	0.80	0.77
Battle Lake	Otter Tail	0902	0.77	Bait	0.32	1.00	2.00	1.50	1.00	1.00	1.00	1.00	0.80	0.77
Lake of the Woods	Lake of the Woods	0903	1.92	Bait	0.32	1.00	2.00	1.50	1.00	1.00	0.39	1.00	0.80	0.30
Farm	Brookings, South Dakota	1017	0.30	Culture	0.32	0.39	2.00	1.50	0.39	1.00	0.39	0.58	0.80	0.03

locations. The RS variation between watersheds was strongly associated with the proximity to Lake Superior, the only VHSV-positive body of water in Minnesota. Outside of the Lake Superior watershed, much of the state is considered as "protective" or at "low risk" for VHSV introduction. While these results may be intuitive, current management strategies at the state and federal levels are based on broad political boundaries, not on established hydrologic units. While this may be justified by jurisdictional authority, ease of public communication, or regulatory consistency, alternative strategies may be warranted.

All three aquaculture facilities evaluated had a lower RS than their associated watershed and were considered as protective. This was achieved by relatively simple management procedures, such as preventing fomite exposure from waters with an unknown VHSV status and limiting the introduction of fish into the facility. One farm located on the Minnesota–South Dakota border provides an example of where regulations could be relaxed. It was included in this case study because farms in this area provide a significant number of bait and sport fish to Minnesota and beyond. Despite the distance from Lake Superior (>500 km) and the use of containment and other biosecurity measures, this farm is currently subjected to the same regulations in Minnesota as wild baitfish operations within the Lake Superior watershed. While on-farm vigilance and regulatory compliance must remain high to prevent even the unlikely introduction of VHSV, compromises could be reached to maintain regulatory confidence while promoting production activities.

Focusing limited available resources on VHSV high-risk areas is clearly a priority in Minnesota. This work shows that the implementation of "VHSV Management Zones" based upon risks associated with watersheds, not political boundaries, may be an alternative strategy (OIE 2013). Similar zonation approaches are currently being used in Michigan (Natural Resources and Environmental Protection Act 1995) and Ontario (OMNR 2011) for the regulation of fish movement and other management activities related to VHSV. The creation of risk-based management plans for each risk category, or zone, would help managers work with stakeholders, including aquaculture facilities, recreational boating, wild baitfish harvest, and other fish-movement dependent activities, for more targeted surveillance and response. For example, the State of Minnesota could be divided into three hypothetical zones (Figure 3). Zone 1,

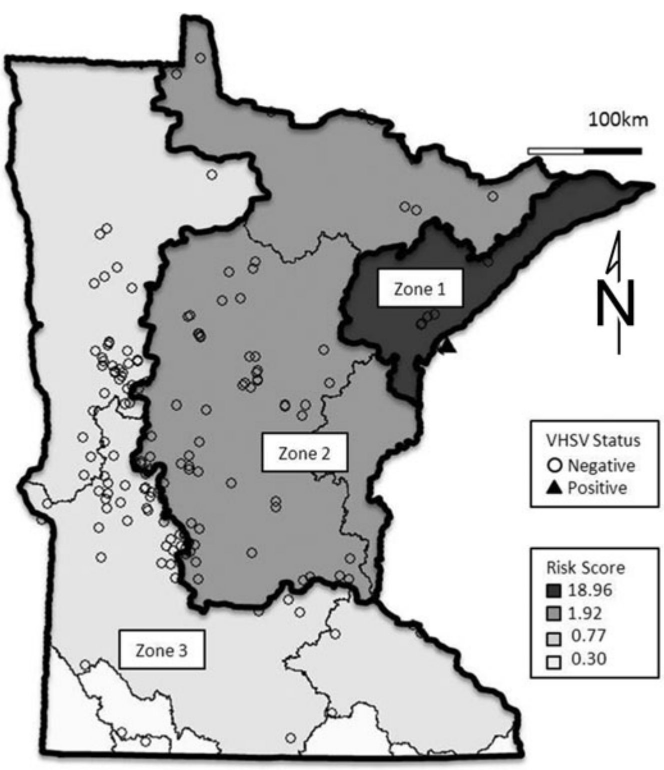

FIGURE 3. Minnesota divided into three proposed VHSV risk-based management zones.

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considered at high risk of VHSV introduction, would be subjected to current regulatory policy with increased educational outreach. Additional precautions, such as limiting the movement of fish (including both those harvested from the wild and those farm raised in high-risk waters) out of Zone 1, should be considered. Zone 2, associated with low risk, would define a probationary zone in which locations demonstrating freedom of disease and proactive biosecurity programs could gain regulatory privileges, such as fewer fish needed for testing or less frequent fish health inspections. Educational outreach to the general public should continue; however, the effort should be focused on waters with high levels of boat traffic, particularly with boats originating in Zone 1. Zone 3, considered protected from the introduction of VHSV, would benefit from this classification and immediately be subjected to fewer regulatory requirements. Much of the aquaculture industry in Minnesota is based in Zones 2 and 3 of this scenario and would, perhaps deservedly so, benefit from relaxed VHSV management regulations.

This approach would depend on a cooperative aquaculture industry and public that were willing to promote the implementation of biosecurity programs, to test to demonstrate that freedom from disease is maintained, and to comply with other regulations. In addition, outreach efforts to inform these stakeholders of the justification for and locations of watershed-based zones will be essential. This effort could be incentivized over time or, if needed, be subjected to heavy regulatory penalties to ensure continued compliance. In turn, this motivation would help to prevent the introduction and dissemination of VHSV in Minnesota.

Future iterations of this risk-management plan should include input from all stakeholder groups that may exist for each state or region to gain support and compliance and to account for risk tolerance. For example, what we arbitrarily assigned as “low risk” may in fact be “moderate risk” to others. Future iterations must also consider the risk factors and associated LRs as our understanding of VHSV improves. The VHSV Expert Panel and Working Group (2010) only evaluated the top nine most likely routes of VHSV introduction; however, state-specific risk may identify other factors, such as recreational boating, commercial fishing, or ballast water.

Based on this case study for Minnesota, we feel a risk-based management approach should be evaluated for other states throughout the Great Lakes region. Focusing the limited available resources on high-risk areas and practices is essential to managing VHSV. Thus, efforts must continue to improve our understanding of VHSV and update future risk assessment models. We believe that these findings should be used to inform current management plans to effectively and efficiently prevent the spread of VHSV.

ACKNOWLEDGMENTS

The authors thank Andy Goodwin and Paula Phelps for thoughtful review and development of this manuscript.

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