

Coinfección por genogrupos LF-89 y EM-90 de *Piscirickettsia salmonis*: implicaciones para la vigilancia y el control de la piscirickettsiosis

M. Rozas-Serri^{1,*}, A. Peña¹, I. Gardner², E. Peñaloza¹, L. Maldonado¹, A. Muñoz¹, F. Mardones³, R. Ildefonso¹, C. Senn¹ y F. Aranis¹

¹ Pathovet Labs SpA, Puerto Montt, Chile

² Department of Health Management, Atlantic Veterinary College, University of Prince Edward Island, Charlottetown, Prince Edward Island, Canada

³ Escuela de Medicina Veterinaria, Facultad de Agronomía e Ingeniería Forestal, Facultad de Ciencias Biológicas, Facultad de Medicina, Pontificia Universidad Católica de Chile, Santiago, Chile

*marco.rozas@pathovet.cl



Fryer, J.L.; Lannan, C.N.; Giovannoni, S.J.; Wood, N.D. *Piscirickettsia salmonis* gen. nov., sp. nov., the causative agent of an epizootic disease in salmonid fishes. *Int. J. Syst. Bacteriol.* 1992, 42, 120–126.

Rozas, M.; Enriquez, R. Piscirickettsiosis and *Piscirickettsia salmonis* in fish: A review. *J. Fish Dis.* 2014, 37, 163–188.

Bohle, H.; Henríquez, P.; Grothusen, H.; Navas, E.; Sandoval, A.; Bustamante, F.; Bustos, P.; Mancilla, M. Comparative Genome Analysis of Two Isolates of the Fish Pathogen *Piscirickettsia salmonis* from Different Hosts Reveals Major Differences in Virulence-Associated Secretion Systems. *Genome Announc.* 2014, 2, e01219-14.

Bravo, C.; Martínez, V. Whole-genome comparative analysis of the pathogen *Piscirickettsia salmonis*. *Vet. Microbiol.* 2016, 196, 36–43.

Isla, A.; Saldarriaga-Cordoba, M.; Fuentes, D.E.; Albornoz, R.; Haussmann, D.; Mancilla-Schulz, J.; Martínez, A.; Figueroa, J.; Avendaño-Herrera, R.; Yáñez, A. Multilocus sequence typing detects new *Piscirickettsia salmonis* hybrid genogroup in Chilean fish farms: Evidence for genetic diversity and population structure. *J. Fish Dis.* 2019, 42, 721–737.

Mandakovic, D.; Glasner, B.; Maldonado, J.; Aravena, P.; Gonzalez, M.; Cambiazo, V.; Pulgar, R. Genomic-Based Restriction Enzyme Selection for Specific Detection of *Piscirickettsia salmonis* by 16S rDNA PCR-RFLP. *Front. Microbiol.* 2016, 7, 643.

Nourdin-Galindo, G.; Sanchez, P.; Molina, C.F.; Espinoza-Rojas, D.A.; Oliver, C.; Ruiz, P.; Vargas-Chacoff, L.; Cárcamo, J.G.; Figueroa, J.E.; Mancilla, M.; et al. Comparative Pan-Genome Analysis of *Piscirickettsia salmonis* Reveals Genomic Divergences within Genogroups. *Front. Cell. Infect. Microbiol.* 2017, 7, 459

Otterlei, A.; Brevik, O.J.; Jensen, D.; Duesund, H.; Sommerset, I.; Frost, P.; Mendoza, J.; McKenzie, P.; Nylund, A.; Apablaza, P. Phenotypic and genetic characterization of *Piscirickettsia salmonis* from Chilean and Canadian salmonids. *BMC Vet. Res.* 2016, 12, 55.

Aravena, P.; Pulgar, R.; Ortiz-Severin, J.; Maza, F.; Gaete, A.; Martínez, S.; Serón, E.; González, M.; Cambiazo, V. PCR-RFLP Detection and Genogroup Identification of *Piscirickettsia salmonis* in Field Samples. *Pathogens* 2020, 9, 358.

Isla, A.; Martínez-Hernandez, J.E.; Levipan, H.A.; Haussmann, D.; Figueroa, J.; Rauch, M.C.; Maracaja-Coutinho, V.; Yáñez, A. Development of a Multiplex PCR Assay for Genotyping the Fish Pathogen *Piscirickettsia salmonis* Through Comparative Genomics. *Front. Microbiol.* 2021, 12, 673216.

Saavedra, J.; Hernandez, N.; Osses, A.; Castillo, A.; Cancino, A.; Grothusen, H.; Navas, E.; Henriquez, P.; Bohle, H.; Bustamante, F.; et al. Prevalence, geographic distribution and phenotypic differences of *Piscirickettsia salmonis* EM-90-like isolates. *J. Fish Dis.* 2017, 40, 1055–1063.

Rozas-Serri, M.; Ildefonso, R.; Pena, A.; Enriquez, R.; Barrientos, S.; Maldonado, L. Comparative pathogenesis of piscirickettsiosis in Atlantic salmon (*Salmo salar* L.) post-smolt experimentally challenged with LF-89-like and EM-90-like *Piscirickettsia salmonis* isolates. *J. Fish Dis.* 2017, 40, 1451–1472. [Google Scholar] [CrossRef]

Rozas-Serri, M.; Pena, A.; Arriagada, G.; Enriquez, R.; Maldonado, L. Comparison of gene expression in post-smolt Atlantic salmon challenged by LF-89-like and EM-90-like *Piscirickettsia salmonis* isolates reveals differences in the immune response associated with pathogenicity. *J. Fish Dis.* 2018a, 41, 539–552.

Rozas-Serri, M.; Pena, A.; Maldonado, L. Transcriptomic profiles of post-smolt Atlantic salmon challenged with *Piscirickettsia salmonis* reveal a strategy to evade the adaptive immune response and modify cell-autonomous immunity. *Dev. Comp. Immunol.* 2018b, 81, 348–362.

Rozas-Serri, M.; Pena, A.; Maldonado, L. Gene expression associated with immune response in Atlantic salmon head-kidney vaccinated with inactivated whole-cell bacterin of *Piscirickettsia salmonis* and pathogenic isolates. *Fish Shellfish. Immunol.* 2019, 93, 789–795.

Figueroa, C.; Bustos, P.; Torrealba, D.; Dixon, B.; Soto, C.; Conejeros, P.; Gallardo, J.A. Coinfection takes its toll: Sea lice override the protective effects of vaccination against a bacterial pathogen in Atlantic salmon. *Sci. Rep.* 2017, 7, 17817.

Figueroa, C.; Veloso, P.; Espin, L.; Dixon, B.; Torrealba, D.; Elalfy, I.S.; Afonso, J.M.; Soto, C.; Conejeros, P.; Gallardo, J.A. Host genetic variation explains reduced protection of commercial vaccines against *Piscirickettsia salmonis* in Atlantic salmon. *Sci. Rep.* 2020, 10, 18252.

Happold, J.; Sadler, R.; Meyer, A.; Hillman, A.; Cowled, B.; Mackenzie, C.; Lagno, A.L.G.; Cameron, A. Effectiveness of vaccination for the control of salmonid rickettsial septicaemia in commercial salmon and trout farms in Chile. *Aquaculture* 2020, 520, 734968

Jakob, E.; Stryhn, H.; Yu, J.; Medina, M.H.; Rees, E.E.; Sanchez, J.; St-Hilaire, S. Epidemiology of Piscirickettsiosis on selected Atlantic salmon (*Salmo salar*) and rainbow trout (*Oncorhynchus mykiss*) salt water aquaculture farms in Chile. *Aquaculture* 2014, 433, 288–294.

- Vargas, D.; Vallejos-Vidal, E.; Reyes-Cerpa, S.; Oyarzun-Arrau, A.; Acuna-Castillo, C.; Imarai, M.; Reyes-López, F.; Sandino, A. The Analysis of Live-Attenuated Piscirickettsia salmonis Vaccine Reveals the Short-Term Upregulation of Innate and Adaptive Immune Genes in Atlantic Salmon (*Salmo salar*): An In Situ Open-Sea Cages Study. *Microorganisms* 2021, 9, 703.
- Karatas, S.; Mikalsen, J.; Steinum, T.M.; Taksdal, T.; Bordevik, M.; Colquhoun, D.J. Real time PCR detection of *Piscirickettsia salmonis* from formalin-fixed paraffin-embedded tissues. *J. Fish Dis.* 2008, 31, 747–753.
- Delphino, M.; Mardones, F.O.; Neumann Heise, J.; Gallardo, A.; Jimenez, D.; Pena, A.; Rozas-Serri, M.; Gardner, I.A. Cost-effectiveness of longitudinal surveillance for *Piscirickettsia salmonis* using qPCR in Atlantic salmon farms (*Salmo salar*) in Chile. *J. Fish Dis.* 2021, 44, 315–326.
- Laurin, E.; Gardner, I.A.; Pena, A.; Rozas-Serri, M.; Gayosa, J.; Neumann Heise, J.; Mardones, F.O. Bayesian estimation of diagnostic sensitivity and specificity of a qPCR and a bacteriological culture method for *Piscirickettsia salmonis* in farmed Atlantic salmon (*Salmo salar L.*) in Chile. *J. Fish Dis.* 2020, 43, 1167–1175.
- Gaete-Carrasco, A.; Rosenfeld, C.; Gallardo, A. Análisis epidemiológico del programa de vigilancia activa de *Piscirickettsia salmonis* del Servicio Nacional de Pesca y Acuicultura de Chile. *Rev. Sci. Tech.* 2019, 38, 823–849.
- Rees, E.E.; Ibarra, R.; Medina, M.; Sanchez, J.; Jakob, E.; Vanderstichel, R.; St-Hilaire, S. Transmission of *Piscirickettsia salmonis* among saltwater salmonid farms in Chile. *Aquaculture* 2014, 428–429, 189–194.
- Happold, J.; Meyer, A.; Sadler, R.; Cowled, B.; Mackenzie, C.; Stevenson, M.; Ward, M.P.; Lagno, A.L.G.; Cameron, A. Effectiveness of antimicrobial treatment of salmonid rickettsial septicaemia in commercial salmon and trout farms in Chile. *Aquaculture* 2020, 525, 735323.
- Rise, M.L.; Jones, S.R.; Brown, G.D.; von Schalburg, K.R.; Davidson, W.S.; Koop, B.F. Microarray analyses identify molecular biomarkers of Atlantic salmon macrophage and hematopoietic kidney response to *Piscirickettsia salmonis* infection. *Physiol. Genom.* 2004, 20, 21–35.
- Rozas-Serri, M. Why Does *Piscirickettsia salmonis* Break the Immunological Paradigm in Farmed Salmon? Biological Context to Understand the Relative Control of *Piscirickettsiosis*. *Front. Immunol.* 2022, 13, 856896.
- Tacchi, L.; Bron, J.E.; Taggart, J.B.; Secombes, C.J.; Bickerdike, R.; Adler, M.A.; Takle, H.; Martin, S.A.M. Multiple tissue transcriptomic responses to *Piscirickettsia salmonis* in Atlantic salmon (*Salmo salar*). *Physiol. Genomic.* 2011, 43, 1241–1254.
- Gaete-Carrasco, A.; Rosenfeld, C.; Gallardo, A. Análisis epidemiológico del programa de vigilancia activa de *Piscirickettsia salmonis* del Servicio Nacional de Pesca y Acuicultura de Chile. *Rev. Sci. Tech.* 2019, 38, 823–849.
- Rees, E.E.; Ibarra, R.; Medina, M.; Sanchez, J.; Jakob, E.; Vanderstichel, R.; St-Hilaire, S. Transmission of *Piscirickettsia salmonis* among salt water salmonid farms in Chile. *Aquaculture* 2014, 428–429, 189–194.
- Happold, J.; Meyer, A.; Sadler, R.; Cowled, B.; Mackenzie, C.; Stevenson, M.; Ward, M.P.; Lagno, A.L.G.; Cameron, A. Effectiveness of antimicrobial treatment of salmonid rickettsial septicaemia in commercial salmon and trout farms in Chile. *Aquaculture* 2020, 525, 735323.
- Rise, M.L.; Jones, S.R.; Brown, G.D.; von Schalburg, K.R.; Davidson, W.S.; Koop, B.F. Microarray analyses identify molecular biomarkers of Atlantic salmon macrophage and hematopoietic kidney response to *Piscirickettsia salmonis* infection. *Physiol. Genom.* 2004, 20, 21–35.
- Rozas-Serri, M. Why Does *Piscirickettsia salmonis* Break the Immunological Paradigm in Farmed Salmon? Biological Context to Understand the Relative Control of *Piscirickettsiosis*. *Front. Immunol.* 2022, 13, 856896.
- Tacchi, L.; Bron, J.E.; Taggart, J.B.; Secombes, C.J.; Bickerdike, R.; Adler, M.A.; Takle, H.; Martin, S.A.M. Multiple tissue transcriptomic responses to *Piscirickettsia salmonis* in Atlantic salmon (*Salmo salar*). *Physiol. Genomic.* 2011, 43, 1241–1254