

Mejoramiento genético de la resistencia a enfermedades infecciosas en salmones

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- Adams, T.; Black, K.; MacIntyre, C.; MacIntyre, I.; Dean, R. 2012. Connectivity modelling and network analysis of sea lice infection in Loch Fyne, west coast of Scotland. *Aquaculture Environment Interactions*, 3(1), 51–63. <https://doi.org/10.3354/aei00052>
- Barría, A., Christensen, K. A., Yoshida, G. M., Correa, K., Jedlicki, A., Lhorente, J. P., Davidson, W. S., & Yáñez, J. M. 2018. Genomic Predictions and Genome-Wide Association Study of Resistance Against *Piscirickettsia salmonis* in Coho Salmon (*Oncorhynchus kisutch*) Using ddRAD Sequencing. *G3 Genes|Genomes|Genetics*, 8(4), 1183–1194. <https://doi.org/10.1534/g3.118.200053>
- Barría, A., Doeschl-Wilson, A. B., Lhorente, J. P., Houston, R. D., & Yáñez, J. M. 2019a. Novel insights into the genetic relationship between growth and disease resistance in an aquaculture strain of Coho salmon (*Oncorhynchus kisutch*). *Aquaculture*, 511(June), 734207. <https://doi.org/10.1016/j.aquaculture.2019.734207>
- Barria, A., Marín-Nahuelpi, R., Cáceres, P., López, M. E., Bassini, L. N., Lhorente, J. P., & Yáñez, J. M. 2019b. Single-Step Genome-Wide Association Study for Resistance to *Piscirickettsia salmonis* in Rainbow Trout (*Oncorhynchus mykiss*). *G3 Genes|Genomes|Genetics*, 9(11), 3833–3841. <https://doi.org/10.1534/g3.119.400204>
- Bassini, L. N., Lhorente, J. P., Oyarzún, M., Bangera, R., Yáñez, J. M., & Neira, R. 2019. Genetic parameters for *Piscirickettsia salmonis* resistance, sea lice (*Caligus rogercresseyi*) susceptibility and harvest weight in rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 510(August 2018), 276–282. <https://doi.org/10.1016/j.aquaculture.2019.05.008>
- Bishop, S. C., & Woolliams, J. A. 2014. Genomics and disease resistance studies in livestock. *Livestock Science*, 166(1), 190–198. <https://doi.org/10.1016/j.livsci.2014.04.034>
- Cáceres, P., Barría, A., Christensen, K. A., Bassini, L. N., Correa, K., García, B., Lhorente, J. P., & Yáñez, J. M. 2021. Genome-scale comparative analysis for host resistance against sea lice between Atlantic salmon and rainbow trout. *Scientific Reports*, 11(1), 13231. <https://doi.org/10.1038/s41598-021-92425-3>
- Correa, K., Bangera, R., Figueiroa, R., Lhorente, J. P., & Yáñez, J. M. 2017a. The use of genomic information increases the accuracy of breeding value predictions for sea louse (*Caligus rogercresseyi*) resistance in Atlantic salmon (*Salmo salar*). *Genetics Selection Evolution*, 49(1), 15. <https://doi.org/10.1186/s12711-017-0291-8>
- Correa, K., Lhorente, J. P., Bassini, L., López, M. E., Di Genova, A., Maass, A., Davidson, W. S., & Yáñez, J. M. 2017b. Genome wide association study for resistance to *Caligus rogercresseyi* in Atlantic salmon (*Salmo salar* L.) using a 50K SNP genotyping array. *Aquaculture*, 472, 61–65. <https://doi.org/10.1016/j.aquaculture.2016.04.008>
- Correa, K., Lhorente, J. P., López, M. E., Bassini, L., Naswa, S., Deeb, N., Di Genova, A., Maass, A., Davidson, W. S., & Yáñez, J. M. 2015. Genome-wide association analysis reveals loci associated with resistance against *Piscirickettsia salmonis* in two Atlantic salmon (*Salmo salar* L.) chromosomes. *BMC Genomics*, 16(1), 1–9. <https://doi.org/10.1186/s12864-015-2038-7>
- D'Agaro, E., Favaro, A., Matiussi, S., Gibertoni, P. P., & Esposito, S. 2021. Genomic selection in salmonids: new discoveries and future perspectives. *Aquaculture International*, 29(5), 2259–2289. <https://doi.org/10.1007/s10499-021-00747-w>
- Difford, G. F., Haugen, J. E., Aslam, M. L., Johansen, L. H., Breiland, M. W., Hillestad, B., Baranski, M., Boison, S., Moghadam, H., & Jacq, C. 2022. Variation in volatile organic compounds in Atlantic salmon mucus is associated with resistance to salmon lice infection. *Scientific Reports*, 12(1), 1–10. <https://doi.org/10.1038/s41598-022-08872-z>
- Doeschl-Wilson, A. B., Bishop, S. C., Kyriazakis, I., & Villanueva, B. 2012. Novel methods for quantifying individual host response to infectious pathogens for genetic analyses. *Frontiers in Genetics*, 3(DEC), 1–9. <https://doi.org/10.3389/fgene.2012.00266>
- Flores-Kossack, C., Montero, R., Köllner, B., & Maisey, K. 2020. Chilean aquaculture and the new challenges: Pathogens, immune response, vaccination and fish diversification. *Fish & Shellfish Immunology*, 98(December 2019), 52–67. <https://doi.org/10.1016/j.fsi.2019.12.093>
- Gervais, O., Barria, A., Papadopoulou, A., Gratacap, R. L., Hillestad, B., Tinch, A. E., Martin, S. A. M., Robledo, D., & Houston, R. D. 2021. Exploring genetic resistance to infectious salmon anaemia virus in Atlantic salmon by genome-wide association and RNA sequencing. *BMC Genomics*, 22(1), 1–14. <https://doi.org/10.1186/s12864-021-07671-6>
- Goddard, M. 2009. Genomic selection: prediction of accuracy and maximisation of long term response. *Genetica*, 136(2), 245–257. <https://doi.org/10.1007/s10709-008-9308-0>
- Goddard, M. E., & Hayes, B. J. 2009. Mapping genes for complex traits in domestic animals and their use in breeding programmes. *Nature Reviews Genetics*, 10(6), 381–391. <https://doi.org/10.1038/nrg2575>
- González, M. P., Marín, S. L., Vargas-Chacoff, L. 2015. Effects of *Caligus rogercresseyi* (Boxshall and Bravo, 2000) infestation on physiological response of host *Salmo salar* (Linnaeus 1758): Establishing physiological thresholds. *Aquaculture*, 438, 47–54. <https://doi.org/10.1016/j.aquaculture.2014.12.039>
- Gratacap, R. L., Regan, T., Dehler, C. E., Martin, S. A. M., Boudinot, P., Collet, B., & Houston, R. D. 2020. Efficient CRISPR/Cas9 genome editing in a salmonid fish cell line using a lentivirus delivery system. *BMC Biotechnology*, 20(1), 35.

- Hayes, B., & Goddard, M. 2010. Genome-wide association and genomic selection in animal breeding. *Genome*, 53(11), 876–883. <https://doi.org/10.1139/G10-076>
- Houston, R. D. 2017. Future directions in breeding for disease resistance in aquaculture species. *Revista Brasileira de Zootecnia*, 46(6), 545–551. <https://doi.org/10.1590/S1806-92902017000600010>
- Houston, R. D., Davey, J. W., Bishop, S. C., Lowe, N. R., Mota-Velasco, J. C., Hamilton, A., Guy, D. R., Tinch, A. E., Thomson, M. L., Blaxter, M. L., Gharbi, K., Bron, J. E., & Taggart, J. B. 2012. Characterisation of QTL-linked and genome-wide restriction site-associated DNA (RAD) markers in farmed Atlantic salmon. *BMC Genomics*, 13(1), 244. <https://doi.org/10.1186/1471-2164-13-244>
- Houston, R. D., Taggart, J. B., Cézard, T., Bekkaert, M., Lowe, N. R., Downing, A., Talbot, R., Bishop, S. C., Archibald, A. L., Bron, J. E., Penman, D. J., Davassi, A., Brew, F., Tinch, A. E., Gharbi, K., & Hamilton, A. 2014. Development and validation of a high-density SNP genotyping array for Atlantic salmon (*Salmo salar*). *BMC Genomics*, 15(1), 1–13. <https://doi.org/10.1186/1471-2164-15-90>
- Lhorente, J. P., Araneda, M., Neira, R., & Yáñez, J. M. 2019. Advances in genetic improvement for salmon and trout aquaculture: the Chilean situation and prospects. *Reviews in Aquaculture*, 11(2), 340–353. <https://doi.org/10.1111/raq.12335>
- Lhorente, J. P., Gallardo, J. A., Villanueva, B., Araya, A. M., Torrealba, D. A., Toledo, X. E., & Neira, R. 2012. Quantitative genetic basis for resistance to *Caligus rogercresseyi* sea lice in a breeding population of Atlantic salmon (*Salmo salar*). *Aquaculture*, 324–325, 55–59. <https://doi.org/10.1016/j.aquaculture.2011.10.046>
- Li, M., & Wang, D. 2017. Gene editing nuclease and its application in tilapia. *Science Bulletin*, 62(3), 165–173. <https://doi.org/10.1016/j.scib.2017.01.003>
- McAllister, P. E., & Owens, W. J. 1995. Assessment of the virulence of fish and mouscan isolates of infectious pancreatic necrosis virus for salmonid fish by challenge of brook trout, *Salvelinus fontinalis* (Mitchill). *Journal of Fish Diseases*, 18(1), 97–103. <https://doi.org/10.1111/j.1365-2761.1995.tb01272.x>
- Moen, T., Torgersen, J., Santi, N., Davidson, W. S., Baranski, M., Ødegård, J., Kjøglum, S., Velle, B., Kent, M., Lubieniecki, K. P., Isdal, E., & Lien, S. 2015. Epithelial cadherin determines resistance to infectious pancreatic necrosis virus in Atlantic salmon. *Genetics*, 200(4), 1313–1326. <https://doi.org/10.1534/genetics.115.175406>
- Ødegård, J., Baranski, M., Gjerde, B., & Gjedrem, T. 2011. Methodology for genetic evaluation of disease resistance in aquaculture species: Challenges and future prospects. *Aquaculture Research*, 42(SUPPL. 1), 103–114. <https://doi.org/10.1111/j.1365-2109.2010.02669.x>
- Pérez-Enciso, M., Rincón, J. C., & Legarra, A. 2015. Sequence- vs. chip-assisted genomic selection: Accurate biological information is advised. *Genetics Selection Evolution*, 47(1), 1–14. <https://doi.org/10.1186/s12711-015-0117-5>
- Reis Neto, R. V., Yoshida, G. M., Lhorente, J. P., & Yáñez, J. M. 2019. Genome-wide association analysis for body weight identifies candidate genes related to development and metabolism in rainbow trout (*Oncorhynchus mykiss*). *Molecular Genetics and Genomics*, 294(3), 563–571. <https://doi.org/10.1007/s00438-018-1518-2>
- Roberts, R. J., & Pearson, M. D. 2005. Infectious pancreatic necrosis in Atlantic salmon, *Salmo salar* L. *Journal of Fish Diseases*, 28(7), 383–390. <https://doi.org/10.1111/j.1365-2761.2005.00642.x>
- Robledo, D., Gutiérrez, A. P., Barría, A., Yáñez, J. M., & Houston, R. D. 2018a. Gene expression response to sea lice in Atlantic salmon skin: RNA sequencing comparison between resistant and susceptible animals. *Frontiers in Genetics*, 9(AUG), 1–10. <https://doi.org/10.3389/fgene.2018.00287>
- Robledo, D., Matika, O., Hamilton, A., & Houston, R. D. 2018b. Genome-wide association and genomic selection for resistance to amoebic gill disease in Atlantic salmon. *G3: Genes, Genomes, Genetics*, 8(4), 1195–1203. <https://doi.org/10.1534/g3.118.200075>
- Rozas, M., & Enríquez, R. 2014. Piscirickettsiosis and *Piscirickettsia salmonis* in fish: A review. *Journal of Fish Diseases*, 37(3), 163–188. <https://doi.org/10.1111/jfd.12211>
- Sonesson, A. K., & Meuwissen, T. H. 2009. Testing strategies for genomic selection in aquaculture breeding programs. *Genetics Selection Evolution*, 41(1), 37. <https://doi.org/10.1186/1297-9686-41-37>
- Tsai, H. Y., Matika, O., Edwards, S. M. K., Antolín-Sánchez, R., Hamilton, A., Guy, D. R., Tinch, A. E., Gharbi, K., Stear, M. J., Taggart, J. B., Bron, J. E., Hickey, J. M., & Houston, R. D. 2017. Genotype imputation to improve the cost-efficiency of genomic selection in farmed Atlantic salmon. *G3: Genes, Genomes, Genetics*, 7(4), 1377–1383. <https://doi.org/10.1534/g3.117.040713>
- Tsai, H.-Y., Hamilton, A., Tinch, A. E., Guy, D. R., Bron, J. E., Taggart, J. B., Gharbi, K., Stear, M., Matika, O., Pong-Wong, R., Bishop, S. C., & Houston, R. D. 2016. Genomic prediction of host resistance to sea lice in farmed Atlantic salmon populations. *Genetics Selection Evolution*, 48(1), 47. <https://doi.org/10.1186/s12711-016-0226-9>
- Wargelin, A., Leininger, S., Skafnesmo, K. O., Kleppe, L., Andersson, E., Taranger, G. L., Schulz, R. W., & Edvardsen, R. B. 2016. Dnd knockout ablates germ cells and demonstrates germ cell independent sex differentiation in Atlantic salmon. *Scientific Reports*, 6(5817), 1–8. <https://doi.org/10.1038/srep21284>
- Wurmann, C.; Soto, D., & Norambuena, R. 2022. Regional review on status and trends in aquaculture development in Latin America and the Caribbean – 2020. In *Regional review on status and trends in aquaculture development in Latin America and the Caribbean – 2020*. FAO. <https://doi.org/10.4060/cb7811en>
- Yáñez, J. M., Bangera, R., Lhorente, J. P., Barría, A., Oyarzún, M., Neira, R., & Newman, S. 2016a. Negative genetic correlation between resistance against *Piscirickettsia salmonis* and harvest weight in coho salmon (*Oncorhynchus kisutch*). *Aquaculture*, 459, 8–13. <https://doi.org/10.1016/j.aquaculture.2016.03.020>
- Yáñez, J. M., Houston, R. D., & Newman, S. 2014b. Genetics and genomics of disease resistance in salmonid species. *Frontiers in Genetics*, 5(NOV), 1–13. <https://doi.org/10.3389/fgene.2014.00415>
- Yáñez, J. M., Lhorente, J. P., Bassini, L. N., Oyarzún, M., Neira, R., & Newman, S. (2014a). Genetic co-variation between resistance against both *Caligus rogercresseyi* and *Piscirickettsia salmonis*, and body weight in Atlantic salmon (*Salmo salar*). *Aquaculture*, 433, 295–298. <https://doi.org/10.1016/j.aquaculture.2014.06.026>
- Yáñez, J. M., Martínez, V. (2010). Factores genéticos que inciden en la resistencia a enfermedades infecciosas en salmonidos y su aplicación en programas de mejoramiento. *Archivos de Medicina Veterinaria*, 42(2), 1–13. <https://doi.org/10.4067/s0301-732x2010000200002>
- Yáñez, J. M., Naswa, S., López, M. E., Bassini, L., Correa, K., Gilbey, J., Bernatchez, L., Norris, A., Neira, R., Lhorente, J. P., Schnable, P. S., Newman, S., Mileham, A., Deeb, N., Di Genova, A., & Maass, A. (2016b). Genomewide single nucleotide polymorphism discovery in Atlantic salmon (*Salmo salar*): validation in wild and farmed American and European populations. *Molecular Ecology Resources*, 16(4), 1002–1011. <https://doi.org/10.1111/1755-0998.12503>
- Yatabe, T., Arriagada, G., Hamilton-West, C., ; Urcelay, S. 2011. Risk factor analysis for sea lice, *Caligus rogercresseyi*, levels in farmed salmonids in southern Chile. *Journal of Fish Diseases*, 34(5), 345–354. <https://doi.org/10.1111/j.1365-2761.2011.01238.x>
- Yoshida, G. M., Bangera, R., Carvalheiro, R., Correa, K., Figueiroa, R., Lhorente, J. P., & Yáñez, J. M. 2018a. Genomic prediction accuracy for resistance against *Piscirickettsia salmonis* in farmed rainbow trout. *G3: Genes, Genomes, Genetics*, 8(2), 719–726. <https://doi.org/10.1534/g3.117.300499>
- Yoshida, G. M., Carvalheiro, R., Lhorente, J. P., Correa, K., Figueiroa, R., Houston, R. D., & Yáñez, J. M. 2018b. Accuracy of genotype imputation and genomic predictions in a two-generation farmed Atlantic salmon population using high-density and low-density SNP panels. *Aquaculture*, 491(March), 147–154. <https://doi.org/10.1016/j.aquaculture.2018.03.004>
- Yoshida, G. M., Carvalheiro, R., Rodríguez, F. H., Lhorente, J. P., & Yáñez, J. M. 2019. Single-step genomic evaluation improves accuracy of breeding value predictions for resistance to infectious pancreatic necrosis virus in rainbow trout. *Genomics*, 111(2), 127–132. <https://doi.org/10.1016/j.ygeno.2018.01.008>
- Yoshida, G. M., Lhorente, J. P., Carvalheiro, R., & Yáñez, J. M. (2017). Bayesian genome-wide association analysis for body weight in farmed Atlantic salmon (*Salmo salar* L.). *Animal Genetics*, 48(6), 698–703. <https://doi.org/10.1111/age.12621>