FACULTAD DE CIENCIAS BIOLÓGICAS
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Final report:

**"Effectiveness of the protected areas of Chile to represent the native freshwater fish species distribution"**

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## ABSTRACT

In this *Research Unit-II*, I made Habitat-Suitability models to estimate the current distribution patterns of freshwater fish species in Chile. I compared the distribution areas of the species in their natural ranges and in the protected areas system (PA); for this, I used the specific environment variables and fragmentation scenarios for freshwater ecosystems previously identified in the *Research Unit-I*. I evaluate the effectiveness of Protected Areas to represent the potential distribution of native freshwater fish species in Chile. Eight species considered Vulnerable and Endangered are also underrepresented in the PA of Chile (0.1-3% of their range distribution).

There are no records of an investigation of this type, and I hope that these results can be used as a tool for the conservation and management of native fish species in Chile, as well as, I expect that the study developed here will be useful in future research related to my doctoral thesis.

## INTRODUCTION

Understanding the spatial distribution patterns of species is of great ecological importance considering the transformations in the structure and dynamics of ecosystems caused by human activities (Baessler & Klotz 2019). The current scenario of water scarcity, ecosystem fragmentation, and contamination of continental aquatic ecosystems have most of Chile's hydrographic basins in a state of high vulnerability (MMA 2017). The freshwater fish populations have been one of the biological groups most affected by the modifications of the water bodies, the construction of hydroelectric dams, and the introduction of different exotic species, left in a state of threat to most of the native freshwater species of Chile (Lacy et al. 2017).

The threats afore-mentioned are acting concomitantly with a system of Protected Areas (PA) that scarcely represent the freshwater ecosystems in Chile, from their conceptualization to implementation the (PA) were planned to the protection of the biodiversity of terrestrial ecosystems, coast, and marine wetlands (Pauchard & Villarroel 2002); Although there are no studies evaluate the representativeness of continental aquatic ecosystems in the PA, in this way, the representativeness of terrestrial ecosystems has been evaluated in the Chilean protected areas system (Pliscoff & Fuente-Castillo 2011), I expect a similar or lesser degree of representativeness trend of the freshwater ecosystems in Chile in the PA.

The main objective of this Research Unit II was to make models that predict accurately the current distribution areas of freshwater fish species in Chile. The distribution areas were mapped and contrasted with the protected area system (AP) and with the habitat fragmentation scenarios of freshwater ecosystems made in the *Research Unit I*, here, I assessed the effectiveness of protected areas to represent the potential distribution of native freshwater fish species in Chile.

### The current state of conservation of freshwater fish species in Chile.

The geomorphology and climatic history of Chile have contributed to the development of unique fish fauna, characterized by a high degree of endemism (Habit et al. 2006). The Andes mountain range to the east, the Pacific Ocean to the west, and the Atacama desert in the north of the country have biogeographically isolated continental waters in Chile (Vila & Habit 2015); This isolation has generated contrasting climatic regimes and precipitation gradients as a result of latitudinal differences, resultant in a unique freshwater fish fauna with ancestral characteristics and restricted distribution ranges, with specific hydraulic and feeding requirements (Vila et al. 1999, Habit et al. 2006).

The taxonomy and systematics of the Chilean freshwater fish fauna have changed in the last twenty years and reviews of the systematic and biogeographical situation based on phylogenetic relationships report 43 species, in 7 Orders, 10 Families, and 19 Genus. Additionally, there are 2 species of lampreys (1 Order, 2 Families, and 2 Genus) that carry out part of their life cycle in continental waters. Considering all the species, except for one species considered functionally extinct, *Diplomystes chilensis* (Arratia & Quezada-Romegialli 2017) and a series of local extinctions (Habit et al. 2010), 42% of the genera and 70% of the species are endemic to Chile

(Dyer 2000, Vila et al. 2011, Alò et al. 2013, Habit et al. 2019).

The information currently available is mostly based on taxonomic studies and classic morphological descriptions, although studies have recently been carried out on the effects of hydroelectric barriers on gene flow in native fish populations (Valenzuela-Aguayo et al. 2020). The knowledge of the ecology of fishes in Chile is still incomplete and requires updated studies; the knowledge gaps constitute serious limitations for the development of effective conservation and recovery strategies for freshwater fish communities in Chile (Peredo-Parada et al. 2009, Habit et al. 2019), the foregoing becomes more important given the current anthropic pressures on aquatic ecosystems in the country (Vila & Habit 2015).

Different studies document a significant decrease in the abundance and diversity of Chilean native fish species, worsening their already weakened conservation status (Pringle et al. 2000, Vila & Habit 2015), as a result of the effects of multiple stressors on the species, such as the modification of the hydrological regime due to channeling and damming of rivers for hydroelectric purposes (Vila et al. 2001), extraction of water for irrigation and livestock (Habit et al. 2006a), the introduction of exotic species, the mining, changes in land use, effluents and anthropogenic pollution, aquaculture and recreational fishing, which destroy the physical habitat of freshwater species in Chile (Vila et al. 2001, Habit et al. 2006, Habit et al 2010).

The Chilean freshwater fish fauna has increased by almost 50% with the presence of 22 introduced species (Dyers 2000), Chile is one of the six global "hotspots" of freshwater fish invasions (Leprieur et al. 2008), showing patterns of significant homogenization of the fish fauna (Villéger et al. 2011). The salmonids introduced in 1903 in most freshwater ecosystems in Chile seem to have affected the species composition, trophic interactions, and nutrient dynamics (Soto et al. 2001, Iriarte et al. 2005), influencing the distribution patterns, diversity, and the life history of native fishes (McDowall, 2006, Soto et al. 2007, Pascual & Ciancio 2007), currently introduced species dominate in terms of abundance and total biomass in some of the Chilean aquatic ecosystems (Ruiz 1993, Behnke 2002, Soto et al. 2006, Habit et al. 2010). There is no evidence of biotic resistance of native species to the expansion of salmonids (Habit et al. 2012), perhaps, for this reason, the 43 native freshwater species are considered threatened (CONAF 1993); However, studies are required to quantify the effects of introduced fish species on the decline of native fish populations (Dyers 2000, Soto et al. 2006). This information is of vital importance when adopting appropriate conservation measures for each native species and watershed (Habit et al. 2006).

Even though the Chilean continental ichthyofauna is poor in species, it has a high systematic, biogeographical, and conservation value (Habit et al. 2006). However, there is little information on reproductive times and strategies, age cohorts, locomotor capacity, migrations, trophic niche, Spatio-temporal distribution at micro, meso, and macroscale of freshwater fish populations in Chile (Habit et al. 2006), to fill this knowledge gaps, more research is needed to understand the different factors of life history, evolution and ecology that are influencing the population decline of migratory and endemic fish species in Chile (Alò et al. 2020). It is necessary implement mitigation and management measures against the threats that keep a high number of these species at risk of extinction (Habit et al. 2006).

## SNASPE

The National System of Protected Wilderness Areas of the State SNASPE (Sistema Nacional de Áreas Silvestres Protegidas del Estado) protects the natural ecosystems of Chile, this network of protected areas is administrated by the CONAF (Corporación Nacional Forestal). The SNASPE is an *in situ* conservation system with the objective of the conservation of the environmental heritage, preserve of nature, and safeguarding biological diversity; under international preservation and conservation standards.

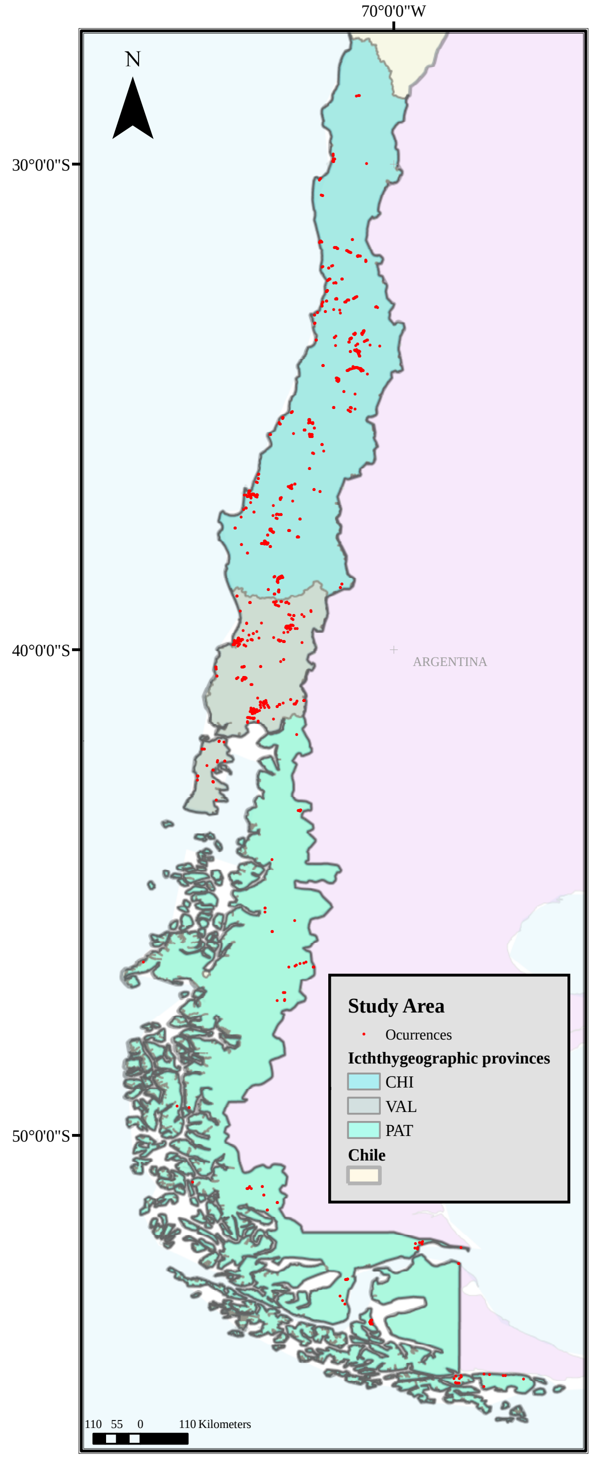
The SNASPE protects 107 of the 127 terrestrial ecosystems present in Chile, of which 35 protected areas achieve the *Aichi Biodiversity Targets* (Juffe-Bignoli et al. 2016), while 72 are under these goals. Currently, the SNASPE covers an area of 18,620,139.08 hectares, an area totaling 106 protected areas (42 National Parks, 46 National Reserves, and 18 Natural Monuments) distributed in all administrative regions of Chile.

## METHODS

### Study Area

I delimited the study area to the Ichthyogeographic provinces within the Chilean territory described by Abell et al. (2008). These freshwater ecoregions are defined as large areas encompassing one or more freshwater basins and body systems; based on patterns of biogeographical, phylogenetic, palaeogeographical, and ecological similarity of freshwater fish communities (Dinerstein et al. 1995).

**Figure 1.** Ichthyogeographic provinces and occurrences in this study.



The research was restricted to three of the six Ichthyogeographic provinces in Chile: Central Andean Basins (CHI), Los Lagos Region – Valdivia (VAL), and Patagonia (PAT). In each one of the provinces the water systems will drain, their flows towards the ocean (exorheic basins) (*see* **Fig. 1**); The provinces of Atacama, Titicaca, and Mar Chiquita provinces were excluded, due to the low number of occurrences and extreme endemism of the freshwater fish species in these provinces (*see* Genus Orestias *Supplementary material* **S1**). Each of the selected provinces is a geospatial unit that represents the patterns of environmental and ecological variables that influence on the large-scale biodiversity distribution of freshwater fishes (Groves 2002).

### Biological Data and sampling design

To get occurrence data for the freshwater fish species reported in the country and using the R package *spocc: Interface to Species Occurrence Data Sources,* the research was conducted in different georeferenced databases, like museum specimens reports and published and unpublished records from 1989 to 2021 (*e.x:* VerNet; FishBase; iNat; iDigBio; GBIF, AMHN and ZMH museums).

I acquired reliable information about 43 native species in Chile. The taxonomy status (Scientific names, authors, years, family, and synonyms) of the species were checked in the *Eschmeyer's Catalog of Fishes* (Fricke et al. 2022. *See Supplementary material* **S1**). Of the 43 species, only 18 species (42%) had enough records on their distribution range (+2 Basins) to filter and snap the occurrences into the gridded hydroclimatic variables of the Ichthyogeographic provinces and the protected areas system (SNASPE) (*See Supplementary material* **S2** and **S3**).

### Environmental variables

To model the distribution area of the freshwater fish species, I used the predictor variables from EarthEnv in 1km² of cell-size resolution (Domisch, et al. 2015) and the hydrologic network dataset of RiverATLAS (Linke et al. 2019). The network was cut by the current

**Table 1.** Information of the freshwater predicts variables used in this study, with their respective variation numbers, units, and forms of measurement.

| Variables | Number of layers | Units | Measure | Source |
|---|---|---|---|---|
| Hydroclimatic variables | 19 | [°C] * 10 / [mm] Hydroclim_weighted_average | Weighted sum | Worldkin |
| Elevation | 2 | M | Elevation and slope of the ground surface derived from digital elevation measurement (DEM CGIAR-CSI SRTM v4.1) | HydroSHEDS |
| Slope | 2 | [°] * 100 | | HydroSHEDS |
| Flow Accumulation | 1 | Count of upstream stream grid cells | # of cells (1 km²) of the upflow grid, # of cells (1 km²) of the upstream catchment water network | HydroSHEDS |
| Flow Length | 1 | Number of upstream catchment grid cells | | HydroSHEDS |
| Land Cover | 1 | Herbaceous vegetation | Range | CLC |
| Geology | 1 | Water | Weighted sum | USGS |

scenario of fragmentation and loss of connectivity previously identified and selected in *Research Unit I* (*see* **Table 1**.) The variables and the hydrologic network provide the most realistic current scenario; this environment exhibits the hydroclimatic, topographic, land cover, and geologic variation of the continental freshwaters of Chile (*Research Unit I*).

I transform the set of Hydroclimatic variables (*see* **Table 1**.) into Rasters-PCA to obtain a workable environment for the distribution modeling process. This orthogonal transformation (Rasters-PCA) is analogous to a conventional Principal Component Analysis (PCA), where, the principal components are images with large information in each of the pixels (Leutner et al. 2019); 3 Rasters-PCA summarize the 93.5% variance of the set of hydroclimatic variables.

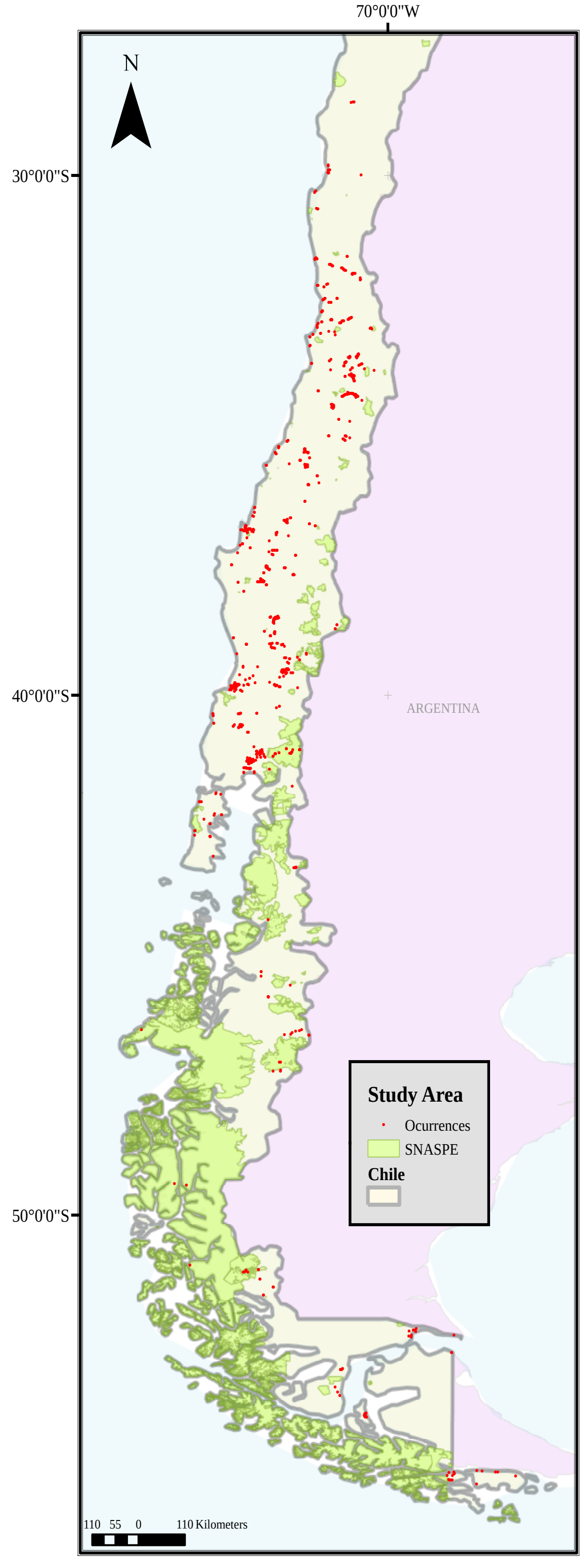
## Mapping the SNASPE

I acquired the georeferenced location of the *National System of Protected Wilderness Areas of the State* (SNASPE) on the Geospatial Database Infrastructure of Chile, IDE Chile ([www.ide.cl](www.ide.cl)); the 96 protected areas in the country were mapped (*see* **Fig. 2**); the type, categories, regions, locations, and size of each protected area are related in *Supplementary Material* **S4**. With this data, I evaluated the effectiveness of the protected area system (SNASPE) to represent the potential distribution of native freshwater fish species.

## Models' Assessment

Using the Species Distribution Models (SDM), I bring the occurrences of the species with the environmental variables using of three different mathematical algorithms (Support vector machines - SVM (Tax & Duin 2004, Karatzoglou

**Figure 2.** SNASPE and occurrences in this study.



et al. 2006), Random Forest – RF (Breinman et al. 1984), and Maximum entropy - MaxEnt (Phillips et al. 2006), to predict the Suitability of habitats in sites (Icththyo-geographic provinces or protected areas SNASPE) *i.e* estimates the possible freshwater fish species ranges (Peterson *et al.* 2012, Franklin 2013). The joined use of these algorithms increases the accuracy of predictions of rare species distribution, species with few samples in large undersampled areas, and improve the range predictions of species with different niche tolerances (Araújo & New 2007, Diniz-Filho et al. 2009). Each one of these algorithms was run 100 times per each species using the R packages "*dismo*" (Hijmans et al. 2015), and "*kernlab*" (Karatzoglou al et. 2004) in the R environment program (R Core Team, 2019).

**Models' evaluation**

To evaluate the resulting models, I used the *bootstrap* technique (Efron 1979). Briefly, for each species, I divided random occurrences into two groups, 75% to generate models and 25% to test them (Guisan & Zimmermann 2000). I used the occurrence test group to check for omission or commission errors (Fielding & Bell 1997), *i.e.* the ability of the model to predict each observation of the test group. Using the Area Under Curve (AUC), I assessed the *model sensitivity* - the proportion of presences accurately predicted, and the *model specificity* - the proportion of absences accurately predicted (Allouche *et al.* 2006). I selected the models that had an AUC value equal to or greater than 0.75.

**Ensemble forecasting approach.**

Each model selected by the AUC predicts slightly different scenarios, generating uncertainty about estimates of Habitat-Suitability of the species analyzed (Diniz-Filho *et al.* 2009). To avoid this uncertainty and minimize errors, I used the ensemble forecasting technique, which, used the previous models that obtained the AUC value $\geq 0.75$. AUC is an effective, threshold-independent model evaluation indicator and is also independent of the prevalence (*i.e.* the frequency of occurrence approach) of the species. The ensemble forecasting approach provides the consensus result of multiple models reducing both uncertainty and errors (Araújo & New 2007).

**Threshold and binary maps**

I used the frequency of predictions that indicated, as species were present in each grid; the projections were calculated after transforming each probability map into binary values (presence/absence). The binary maps (0 for absence and 1 for presence) are based on the results of the ensemble models of the Habitat-Suitability of each species; for this, I transform continuous frequencies of the ensemble models outputs, into binary outputs. I applied the threshold: 20th Percentile Training Presence (PTP), this threshold omits all regions with habitat suitability lower than the suitability values for the lowest 20% of occurrence records. This threshold omits a larger region than the Lowest Presence Threshold (LPT) and threshold 10th PTP, *i.e*, it is more conservative in the predictions; this scenario is more realistic in the potential area range distribution of the species with a low number of occurrences, endemics or with limited dispersal aptitude (case of fishes between the basins), for this reason, the 20th PTP threshold is widely used in conservation. Other authors have used successfully the 20th PTP to avoid bias by outlying records (Pearson et al. 2007; Wisz et al. 2008).

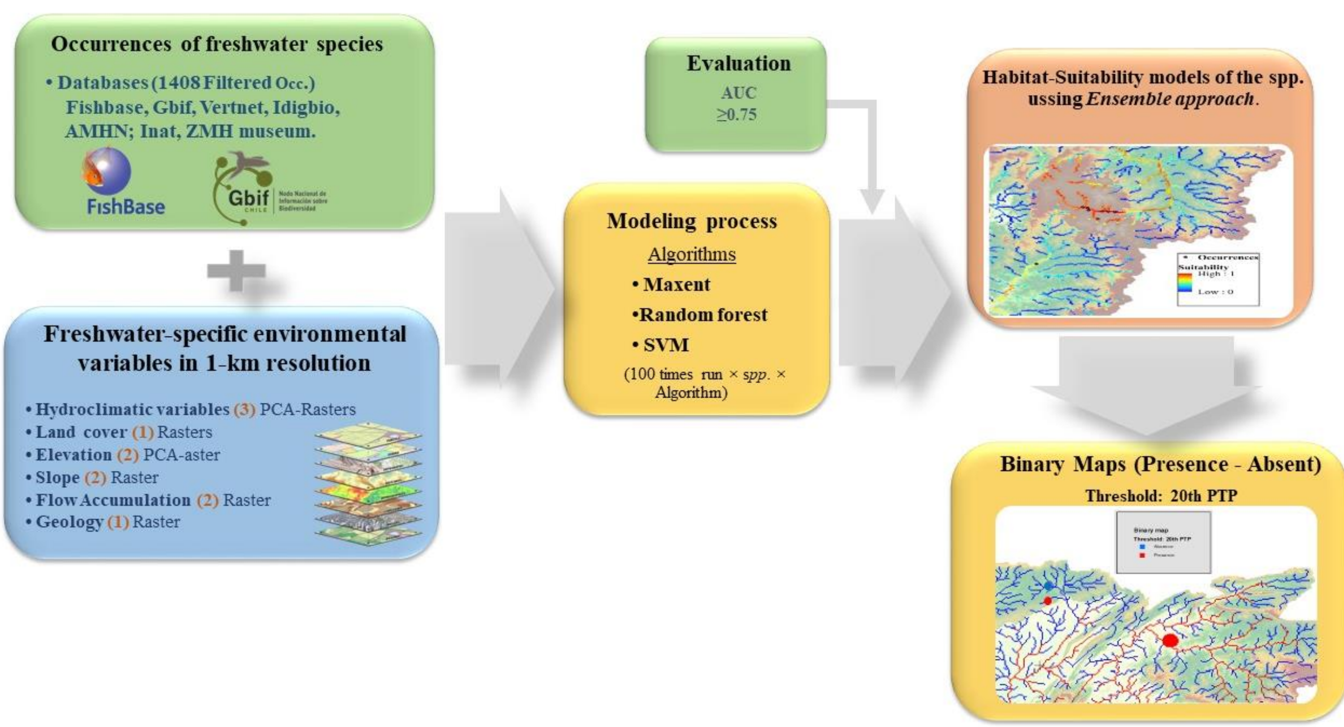
**Analysis of habitat suitability maps**

To perform a comparative analysis of the effectively protected area for the freshwater fish species, I extract the suitability values, for each cell in 1km$^2$ resolution in-stream distance for all water bodies in the study area, from the frequency ensemble models (Presences). This has been done using the tools "*Spatial Analyst Tools*" from ArcToolbox, and the "*XToolsPro*" in the work environment Arc-Map of the software ArcGIS® 10.8. I extract the in-stream habitat-suitability values of the fish species in the natural range (Ichthyogeographic provinces) and the values in the SNASPE.

Statistical and graphical analyzes were performed in the integrated development environment RStudio, for Software in R®, version 3.6.1, using the packages caret, *colorRamps*, *complot*, *factoextra*, *FactoMineR*, *psych*, *raster*, *tidyverse*, *usdm*, *Viridis* and *dplyr*.

The **Fig. 3.** summarizes the approach that I used to estimate the range distribution predictions and the maps of habitat-suitability of the freshwater fishes in the study area.

**Figure 3**. The general schematic process was used to model the distribution ranges of the species in this study.



## RESULTS

In *Supplementary material* **S5** the Habitat-Suitability maps of all species analyzed in this study are available, as well as the evaluations of the algorithms (MaxEnt, Random Forest -RF and Support Vector Machine - SVM) and the AUC metrics used to construct the ensemble of the models. The binary maps indicating suitable habitats in their natural range and the suitable habitats on the SNASPE for all species using the threshold: 20th Percentile Training Presence (PTP) are also found in *Supplementary material* **S5**.

I achieve the objective proposed in this *Research Unit II*, by integrating the environmental variables and habitat fragmentation made in *Research Unit I*, to determine the distribution patterns of the main freshwater fishes o¡in their natural range and in the protected area system in Chile (SNASPE).

The remaining result is observed in ***table 2***., here, is a comparison of the potential distribution areas predicted by the Habitat-Suitability models, between the natural distribution range of the species and the distribution range of the species in the protected areas by the SNASPE.

**Table 2.** Percentage of the natural distribution range of the native freshwater fish species in Chile protected by the SNASPE, using the estimates of  Habitat-Suitability models.

| ID | Native species | Natural Range/Km² | Range in the SNASPE/Km ² | % A² of range protected by SNASPE |
|---|---|---|---|---|
| 1 | *Aplochiton taeniatus* Jenyns 1842 | 43 741 | 10 121 | 23.14 % |
| 2 | *Aplochiton zebra* Jenyns 1842 | 54 936 | 12 237 | 22.28 % |
| 3 | *Basilichthys microlepidotus* (Jenyns 1841) | 25 133 | 768 | 3.06 % |
| 4 | *Brachygalaxias bullocki* (Regan 1908) | 21 567 | 610 | 2.83 % |
| 5 | *Bullockia maldonadoi* (Eigenmann 1928) | 6 568 | 2 | 0.03 % |
| 6 | *Cheirodon australe* Eigenmann 1927 | 57 166 | 10 778 | 18.85 % |
| 7 | *Cheirodon galusdae* Eigenmann 1927 | 8 899 | 9 | 0.10 % |
| 8 | *Cheirodon pisciculus* Girard 1855 | 20 908 | 177 | 0.85 % |
| 9 | *Galaxias maculatus* (Jenyns 1842) | 64 553 | 13 250 | 20.53 % |
| 10 | *Galaxias platei* Steindachner 1898 | 35 019 | 10 335 | 29.51 |
| 11 | *Geotria australis* Gray 1851 | 34 078 | 4 661 | 13.68 |
| 12 | *Mordacia lapicida* (Gray 1851) | 27 507 | 3 700 | 13.45 |
| 13 | *Nematogenys inermis* (Guichenot 1848) | 12 070 | 24 | 0.20 % |
| 14 | *Odontesthes mauleanum* (Steindachner 1896) | 23 589 | 6 89 | 2.92 % |
| 15 | *Percichthys melanops* Girard 1855 | 12 755 | 19 | 0.15 % |
| 16 | *Percichthys trucha* (Valenciennes 1833) | 38 194 | 5 857 | 15.33 % |
| 17 | *Percilia gillissi* Girard 1855 | 1 263 | 746 | 59.07 % |
| 18 | *Trichomycterus areolatus* Valenciennes 1833 | 39 275 | 5 693 | 14.50 % |
| | **Total** | 527 221 | 191 788 | 36.38 % |

## DISCUSSION AND CONCLUSIONS

The models created here don't show the *realized niche* of the native freshwater fishes (*i.e* interactions with introduced species above mentioned and population dynamics are ignored) (Davis et al. 1998), but the Habitat-Suitability models (*fundamental niche*) shown by the models, can be a useful tool for the conservation management of the studied species (Peterson et al. 2011). In this sense, it is important to highlight that the worst represented species (8 species) in the protected areas in Chile (SNASPE) according to this study (0.1-3%, **Table. 2**), are those the same species that are in a high degree of threat (Vulnerable and Endangered), according to the conservation status of the freshwater fishes of Chile by Campos et al. (1998), (See details in *Supplementary Material* **S6**).

Although works such as those by Zamorano et al. (2019) consider the effect of fish size is important when modeling the distribution of the fish species, their study was made on a small scale (1or 2 basins in southern Chilean rivers); here I don't consider this relevant factor in the distribution of species on large scale (This study).

I expect the results obtained here can be a useful tool for prioritizing areas for the integrated and sustainable management of hydrobiological resources and freshwater species and facilitate the future stages of my research (Thesis) serving as criteria and justification to use the Refuges for Climate Change approach in the establishment of protected areas in freshwater ecosystems.

## REFERENCES


- Aguirre-Gutiérrez, J., Carvalheiro, L. G., Polce, C., van Loon, E. E., Raes, N., Reemer, M., & Biesmeijer, J. C. (2013). Fit-for-purpose: Species distribution model performance depends on evaluation criteria – dutch hoverflies as a case study. PLoS ONE, 8(5), e63708. https://doi.org/10.1371/journal.pone.0063708
- Allouche, O., Tsoar, A., & Kadmon, R. (2006). Assessing the accuracy of species distribution models: Prevalence, kappa and the true skill statistic (Tss). Journal of Applied Ecology, 43(6), 1223–1232. https://doi.org/10.1111/j.1365-2664.2006.01214.x
- Alò, D., Lacy, S. N., Castillo, A., Samaniego, H. A., & Marquet, P. A. (2021). The macroecology of fish migration. Global Ecology and Biogeography, 30(1), 99–116. https://doi.org/10.1111/geb.13199
- Anderson, R. P., Lew, D., & Peterson, A. T. (2003). Evaluating predictive models of species' distributions: Criteria for selecting optimal models. Ecological Modelling, 162(3), 211–232. https://doi.org/10.1016/S0304-3800(02)00349-6
- Araújo, M. B., & Guisan, A. (2006). Five (Or so) challenges for species distribution modelling. Journal of Biogeography, 33(10), 1677–1688. https://doi.org/10.1111/j.1365-2699.2006.01584.x
- Arratia, G. y C. Quezada-Romegialli 2017. «Understanding Morphological Variability in a Taxonomic Context in Chilean Diplomystids (Teleostei: Siluriformes), Including the Description of a New Species ». PeerJ 5: e2991.
- Arthington, A. H., Dulvy, N. K., Gladstone, W., & Winfield, I. J. 2016. Fish conservation in freshwater and marine realms: status, threats and management. Aquatic Conservation: Marine and Freshwater Ecosystems, 26(5), 838–857. doi:10.1002/aqc.2712

- Austin, M. (2007). Species distribution models and ecological theory: A critical assessment and some possible new approaches. Ecological Modelling, 200(1–2), 1–19. https://doi.org/10.1016/j.ecolmodel.2006.07.005
- Baessler, C., & Klotz, S. (2019). Introduction to part ii: Drivers and their risks for ecosystems, their functions, and services. In M. Schröter, A. Bonn, S. Klotz, R. Seppelt, & C. Baessler (Eds.), Atlas of Ecosystem Services (pp. 35–38). Springer International Publishing. https://doi.org/10.1007/978-3-319-96229-0_7
- Barbarossa, V., Schmitt, R. J. P., Huijbregts, M. A. J., Zarfl, C., King, H., & Schipper, A. M. (2020). Impacts of current and future large dams on the geographic range connectivity of freshwater fish worldwide. Proceedings of the National Academy of Sciences, 117(7), 3648–3655. https://doi.org/10.1073/pnas.1912776117
- Barria, A. M., Zamorano, D., Parada, A., Labra, F. A., Estay, S. A., & Bacigalupe, L. D. (2020). The importance of intraspecific variation for niche differentiation and species distribution models: The ecologically diverse frog pleurodema thaul as study case. Evolutionary Biology, 47(3), 206–219. https://doi.org/10.1007/s11692-020-09510-0
- Bean, W. T., Stafford, R., & Brashares, J. S. (2012). The effects of small sample size and sample bias on threshold selection and accuracy assessment of species distribution models. Ecography, 35(3), 250–258. https://doi.org/10.1111/j.1600-0587.2011.06545.x
- Breiman, L., Friedman, J. H., Olshen, R. A., & Stone, C. J. (2017). Classification and regression trees. Routledge.
- Campos, H., Dazarola, G., Dyer, B., Fuentes, L., Gavilán, J. F., Huaquín, L., ... & Vila, I. (1998). Categorías de conservación de peces nativos de aguas continentales de Chile. Boletín del Museo Nacional de Historia Natural (Chile), 47, 101-122.
- Castillo, E. J., & Huaico-Malhue, A. 2020. COVID-19 EN TIEMPOS DE ESCASEZ HÍDRICA, UNA MIRADA HACIA LAS ZONAS RURALES. Geográfica del Sur, 9(1), 6-7.
- Clark, P. U., S. J. Marshall, G. K. C. Clarke, S. W. Hostetler, J. M. Licciardi & J. T. Teller, 2001. Freshwater forcing of abrupt climate change during the last glaciation. Science 293: 283–287
- Comte, L., & Grenouillet, G. (2013). Species distribution modelling and imperfect detection: Comparing occupancy versus consensus methods. Diversity and Distributions, 19(8), 996–1007. https://doi.org/10.1111/ddi.12078
- CONAF (Corporación Nacional Forestal).1993. Libro rojo de los vertebrados terrestres de Chile. Segunda edición. Corporación Nacional Forestal, Santiago, Chile. 65 pp
- Crook, D. A., Lowe, W. H., Allendorf, F. W., Erős, T., Finn, D. S., Gillanders, B. M., ... & Hughes, J. M. (2015). Human effects on ecological connectivity in aquatic ecosystems: integrating scientific approaches to support management and mitigation. Science of the Total Environment, 534, 52-64.
- Davis, Mark A., et al. 'Don't Judge Species on Their Origins'. Nature, vol. 474, no. 7350, June 2011, pp. 153–54. DOI.org (Crossref), https://doi.org/10.1038/474153a.
- Díaz, G., Arriagada, P., Górski, K., Link, O., Karelovic, B., Gonzalez, J., & Habit, E. (2019). Fragmentation of Chilean Andean rivers: Expected effects of hydropower development. Revista Chilena de Historia Natural, 92(1), 1. https://doi.org/10.1186/s40693-019-0081-5
- Díaz, G., Górski, K., Heino, J., Arriagada, P., Link, O., & Habit, E. (2021). The longest fragment drives fish beta diversity in fragmented river networks: Implications for river management and conservation. Science of The Total Environment, 766, 144323. https://doi.org/10.1016/j.scitotenv.2020.144323
- Diniz-Filho, J., Bini, L., Fernando Rangel, T., Loyola, R., Hof, C., Nogues-Bravo, D., & Araujo, M. (2009). Partitioning and mapping uncertainties in ensembles of forecasts of species turnover under climate change. Ecography, 32(6), 897–906. https://doi.org/10.1111/j.1600-0587.2009.06196.x

- Dollar, E. S. J., James, C. S., Rogers, K. H., & Thoms, M. C. 2007. A framework for interdisciplinary understanding of rivers as ecosystems. Geomorphology, 89, 147–162. https://doi-org.ezproxy.unal.edu.co/10.1016/j.geomorph.2006.07.022
- Domisch, S., Amatulli, G., & Jetz, W. (2015). Near-global freshwater-specific environmental variables for biodiversity analyses in 1 km resolution. Scientific Data, 2(1), 150073. https://doi.org/10.1038/sdata.2015.73
- Dormann, C. F., Schymanski, S. J., Cabral, J., Chuine, I., Graham, C., Hartig, F., Kearney, M., Morin, X., Römermann, C., Schröder, B., & Singer, A. (2012). Correlation and process in species distribution models: Bridging a dichotomy: Bridging the correlation-process dichotomy. Journal of Biogeography, 39(12), 2119–2131. https://doi.org/10.1111/j.1365-2699.2011.02659.x
- Downing, J. A., J. J. Cole, C. M. Duarte, J. J. Middelburg, J. M. Melack, Y. T. Prairie, P. L. Kortelainen, R. G. Striegl, W. H. McDowell & L. J. Tranvik, 2012. Global abundance and size distribution of streams and rivers. Inland Waters 2: 229–236.
- Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z.-I., Knowler, D. J., Lévêque, C., Naiman, R. J., Prieur-Richard, A.-H., Soto, D., Stiassny, M. L. J., & Sullivan, C. A. (2006). Freshwater biodiversity: Importance, threats, status and conservation challenges. Biological Reviews, 81(2), 163–182. https://doi.org/10.1017/S1464793105006950
- Dunham, J. B., Angermeier, P. L., Crausbay, S. D., Cravens, A. E., Gosnell, H., McEvoy, J., … Sanford, T. 2018. Rivers are social-ecological systems: Time to integrate human dimensions into riverscape ecology and management. Wiley Interdisciplinary Reviews: Water, 5(4), e1291. doi:10.1002/wat2.1291
- Dyers B. 2000. Systematic review and biogeography of the freshwater fishes of Chile. Estud. Oceanol. 19: 77 - 98, 2000 ISSN 0071-173X
- Earthenv. (n.d.). Retrieved September 10, 2021, from http://www.earthenv.org/
- Efron, B. (1979). Bootstrap methods: Another look at the jackknife. The Annals of Statistics, 7(1). https://doi.org/10.1214/aos/1176344552
- Elith, J. C.H. Graham, R.P. Anderson, M. Dudík, S. Ferrier, A. Guisan, R.J. Hijmans, F. Huettmann, J.R. Leathwick, A. Leahmann, J. Li, L.G. Lohmann, B.A. Loiselle, G. Manion, C. Moritz, M. Nakamura, Y. Nakazawa, J.M. Overton, A.T. Peterson, S.J. Phillips, K.S. Richardson, R. Scachetti-Pereira, R.E. Schapire, J. Soberón, S. Williams, M.S. Wisz, N.E. Zimmermann. 2006. Novel methods improve prediction of species' distributions from occurrence data. Ecography, 29, pp. 129-151 https://doi.org/10.1111/j.2006.0906-7590.04596.x
- Fierro, P., Valdovinos, C., Arismendi, I., Díaz, G., Ruiz De Gamboa, M., & Arriagada, L. (2019). Assessment of anthropogenic threats to Chilean Mediterranean freshwater ecosystems: Literature review and expert opinions. Environmental Impact Assessment Review, 77, 114–121. https://doi.org/10.1016/j.eiar.2019.02.010
- Franklin, J. 2013. Species distribution models in conservation biogeography: developments and challenges. Diversity Distrib. 19: 1217-1223. https://doi.org/10.1111/ddi.12125
- Freilich, M. A., Wieters, E., Broitman, B. R., Marquet, P. A., & Navarrete, S. A. (2018). Species co-occurrence networks: Can they reveal trophic and non-trophic interactions in ecological communities? Ecology, 99(3), 690–699. https://doi.org/10.1002/ecy.2142
- Fricke, R., Eschmeyer, W. N. & R. van der Laan (eds) 2022. ESCHMEYER'S CATALOG OF FISHES: GENERA, SPECIES, REFERENCES. Electronic version accessed 25/03/2022. http://researcharchive.calacademy.org/research/ichthyology/catalog/fishcatmain.asp
- Fuentes-Castillo, T., Scherson, R. A., Marquet, P. A., Fajardo, J., Corcoran, D., Román, M. J., & Pliscoff, P. (2019). Modelling the current and future biodiversity distribution in the Chilean Mediterranean hotspot.

The role of protected areas network in a warmer future. Diversity and Distributions, 25(12), 1897–1909. https://doi.org/10.1111/ddi.12988

- Fuster, R., Escobar, C., Lillo, G., & de la Fuente, A. (2015). Construction of a typology system for rivers in chile based on the european water framework directive(Wfd). Environmental Earth Sciences, 73(9), 5255–5268. https://doi.org/10.1007/s12665-014-3772-x
- García-Nielsen J. 2019. River and watersheds restoration in Chile: diagnosis and challenges. Revista de Derecho Administrativo Económico, Nº 29 pp. 139-162. DOI: 10.7764/redae.29.6
- García, A., Jorde, K., Habit, E., Caamaño, D., & Parra, O. (2011). Downstream environmental effects of dam operations: Changes in habitat quality for native fish species. River Research and Applications, 27(3), 312–327. https://doi.org/10.1002/rra.1358
- García, A., Jorde, K., Habit, E., Caamaño, D., & Parra, O. 2011. Downstream environmental effects of dam operations: Changes in habitat quality for native fish species. River Research and Applications, 27, 312–327. https://doi-org.ezproxy.unal.edu.co/10.1002/rra.1358
- Guélat, J., & Kéry, M. 2018. Effects of spatial autocorrelation and imperfect detection on species distribution models. Methods in Ecology and Evolution, 9(6), 1614-1625.
- Guillera-Arroita, G., Lahoz-Monfort, J. J., Elith, J., Gordon, A., Kujala, H., Lentini, P. E., McCarthy, M. A., Tingley, R., & Wintle, B. A. (2015). Is my species distribution model fit for purpose? Matching data and models to applications: Matching distribution models to applications. Global Ecology and Biogeography, 24(3), 276–292. https://doi.org/10.1111/geb.12268
- Guisan, A., & Zimmermann, N. E. (2000). Predictive habitat distribution models in ecology. Ecological Modelling, 135(2–3), 147–186. https://doi.org/10.1016/S0304-3800(00)00354-9
- Habit, E. M., P. Piedra, D. E. Ruzzante et al. 2010. Changes in the Distribution of Native Fishes in Response to Introduced Species and other Anthropogenic effects. Global Ecology and Biogeography 19(5): 697-710
- Habit, E., Belk, M. C., & Parra, O. (2007). Response of the riverine fish community to the construction and operation of a diversion hydropower plant in central Chile. Aquatic Conservation: Marine and Freshwater Ecosystems, 17(1), 37–49. https://doi.org/10.1002/aqc.774
- Habit, E., Belk, M. C., & Parra, O. 2006. Response of the riverine fish community to the construction and operation of a diversion hydropower plant in central Chile. Aquatic Conservation Marine and Freshwater Ecosystems, 17(1), 37–49. doi10.1002aqc.774 B)
- Habit, E., Dyer, B., Vila, I., z. 2006 Current state of knowledge of freshwater fishes of Chile. Gayana (1): 100-112. A)
- Habit, E., García, A., Díaz, G., Arriagada, P., Link, O., Parra, O., & Thoms, M. (2019). River science and management issues in chile: Hydropower development and native fish communities: river science and management in chile. River Research and Applications, 35(5), 489–499. https://doi.org/10.1002/rra.3374
- Habit, E., García, A., Díaz, G., Arriagada, P., Link, O., Parra, O., & Thoms, M. (2019). River science and management issues in chile: Hydropower development and native fish communities: river science and management in chile. River Research and Applications, 35(5), 489–499. https://doi.org/10.1002/rra.3374
- Habit, E., García, A., Díaz, G., Arriagada, P., Link, O., Parra, O., Thoms, M., 2019. River science and management issues in Chile: hydropower development and native fish communities. River Res. Appl. 35 (5), 489–499. https://doi.org/10.1002/rra.3374
- Habit, E., K. Górski, D. Alò, E. Ascencio, A. Astorga, N. Colin, T. Contador, P. de los Ríos, V. Delgado, C. Dorador, P. Fierro, K. García, O. Parra, C. Quezada- Romegialli, B. Ried, P. Rivera, C. Soto-Azat, C. Valdovinos, I. Vera-Escalona, S. Woelfl. (2019). Biodiversidad de Ecosistemas de Agua Dulce. Mesa Biodiversidad-Comité Científico COP25; Ministerio de Ciencia, Tecnología, Conocimiento e Innovación. 64 páginas.

- Habit, E., K. Górski, D. Alò, E. Ascencio, A. Astorga, N. Colin, T. Contador, P. de los Ríos, V. Delgado, C. Dorador, P. Fierro, K. García, O. Parra, C. Quezada- Romegialli, B. Ried, P. Rivera, C. Soto-Azat, C. Valdovinos, I. Vera-Escalona, S. Woelfl. 2019. Biodiversidad de Ecosistemas de Agua Dulce. Mesa Biodiversidad-Comité Científico COP25; Ministerio de Ciencia, Tecnología, Conocimiento e Innovación. 64 páginas.
- Habit, E., Piedra, P., Ruzzante, D. E., Walde, S. J., Belk, M. C., Cussac, V. E., Gonzalez, J., & Colin, N. (2010). Changes in the distribution of native fishes in response to introduced species and other anthropogenic effects: Distribution patterns of native fish in Chile. Global Ecology and Biogeography, no-no. https://doi.org/10.1111/j.1466-8238.2010.00541.x
- Hall, C. J., Jordaan, A., & Frisk, M. G. (2011). The historic influence of dams on diadromous fish habitat with a focus on river herring and hydrologic longitudinal connectivity. Landscape Ecology, 26(1), 95–107. https://doi.org/10.1007/s10980-010-9539-1
- Hall, C. J., Jordaan, A., & Frisk, M. G. 2011. The historic influence of dams on diadromous fish habitat with a focus on river herring and hydrologic longitudinal connectivity. Landscape Ecology, 26, 95–107. https://doi-org.ezproxy.unal.edu.co/10.1007/s10980-010-9539-1
- Hijmans, R. J., & Graham, C. H. (2006). The ability of climate envelope models to predict the effect of climate change on species distributions: COMPARING CLIMATE ENVELOPE AND MECHANISTIC MODELS. Global Change Biology, 12(12), 2272–2281. https://doi.org/10.1111/j.1365-2486.2006.01256.x
- Hipólito, J., Hasui, É., & Viana, B. F. (2015). Solving problems involving the distribution of a species of unknown distribution via ecological niche modeling. Natureza & Conservação, 13(1), 15–23. https://doi.org/10.1016/j.ncon.2015.03.001
- Hirzel, A. H., Hausser, J., Chessel, D., & Perrin, N. 2002. Ecological-niche factor analysis: how to compute habitat-suitability maps without absence data?. Ecology, 83(7), 2027-2036.
- Hoef, J. M. V., Peterson, E., & Theobald, D. (2006). Spatial statistical models that use flow and stream distance. Environmental and Ecological Statistics, 13(4), 449–464. https://doi.org/10.1007/s10651-006-0022-8
- Iriarte, J., Lobos, G. A., & Jaksic, F. M. 2005. Invasive vertebrate species in Chile and their control and monitoring by governmental agencies. Revista Chilena de Historia Natural, 78(1). doi:10.4067/s0716-078x2005000100010
- Iwasaki, Y., M. Ryo, P. Sui & C. Yoshimura, 2012. Evaluating the relationship between basin-scale fish species richness and ecologically relevant flow characteristics in rivers worldwide. Freshwater Biology 57: 2173–2180.
- Jeschke, J. M., & Strayer, D. L. (2008). Usefulness of bioclimatic models for studying climate change and invasive species. Annals of the New York Academy of Sciences, 1134(1), 1–24. https://doi.org/10.1196/annals.1439.002
- Jiménez-Valverde, A., Peterson, A. T., Soberón, J., Overton, J. M., Aragón, P., & Lobo, J. M. (2011). Use of niche models in invasive species risk assessments. Biological Invasions, 13(12), 2785–2797. https://doi.org/10.1007/s10530-011-9963-4
- Jones, J. P. G. 2011. Monitoring species abundance and distribution at the landscape scale. Journal of Applied Ecology, 48(1), 9–13. https://doi.org/10.1111/j.1365-2664.2010.01917.x
- Juffe-Bignoli, D., Harrison, I., Butchart, S. HM., Flitcroft, R., Hermoso, V., Jonas, H., Lukasiewicz, A., Thieme, M., Turak, E., Bingham, H., Dalton, J., Darwall, W., Deguignet, M., Dudley, N., Gardner, R., Higgins, J., Kumar, R., Linke, S., Milton, G. R., Pittock, J., Smith, K. G., and van Soesbergen, A. (2016) Achieving Aichi Biodiversity Target 11 to improve the performance of protected areas and conserve freshwater biodiversity. Aquatic Conserv: Mar. Freshw. Ecosyst., 26: 133– 151. https://doi.org/10.1002/aqc.2638

- Karatzoglou, Alexandros & Smola, Alex &Hornik, Kurt &Zeileis, Achim (2004) kernlab - An S4 Package for Kernel Methods in R. Journal of Statistical Software, 11 (9). pp. 1-20. ISSN 1548-7660
- Laborde, A., González, A., Sanhueza, C., Arriagada, P., Wilkes, M., Habit, E., & Link, O. (2016). Hydropower development, riverine connectivity, and non-sport fish species: Criteria for hydraulic design of fishways: criteria for hydraulic design of fishways. River Research and Applications, 32(9), 1949–1957. https://doi.org/10.1002/rra.3040
- Lacy, S. N., Corcoran, D., Alò, D., Lessmann, J., Meza, F., & Marquet, P. A. (2019). Main drivers of freshwater fish diversity across extra-tropical Southern Hemisphere rivers. Hydrobiologia, 843(1), 155–172. https://doi.org/10.1007/s10750-019-04044-9
- Lacy, S. N., Corcoran, D., Alò, D., Lessmann, J., Meza, F., & Marquet, P. A. 2019. Main drivers of freshwater fish diversity across extra-tropical Southern Hemisphere rivers. Hydrobiologia. https://doi.org/10.1007/s10750-019-04044-9
- Lacy, S. N., Meza, F. J., & Marquet, P. A. (2017). Can environmental impact assessments alone conserve freshwater fish biota? Review of the Chilean experience. Environmental Impact Assessment Review, 63, 87–94. https://doi.org/10.1016/j.eiar.2016.12.006
- Lacy, S. N., Meza, F. J., & Marquet, P. A. 2017. Can environmental impact assessments alone conserve freshwater fish biota? Review of the Chilean experience. Environmental Impact Assessment Review, 63, 87-94.
- León-Muñoz, J., Echeverría, C., Marcé, R., Riss, W., Sherman, B., Iriarte, J.L., 2013. The combined impact of land use change and aquaculture on sediment and water quality in oligotrophic Lake Rupanco (North Patagonia, Chile, 40.8°S) Journal of Environmental Management 128, 283-291.
- Liermann, C. R., Nilsson, C., Robertson, J., & Ng, R. Y. (2012). Implications of dam obstruction for global freshwater fish diversity. BioScience, 62(6), 539–548. https://doi.org/10.1525/bio.2012.62.6.5
- Liermann, C. R., Nilsson, C., Robertson, J., & Ng, R. Y. 2012. Implications of Dam Obstruction for Global Freshwater Fish Diversity. BioScience, 62(6), 539–548. doi:10.1525/bio.2012.62.6.5
- Lohr, C. A., Hone, J., Bode, M., Dickman, C. R., Wenger, A., & Pressey, R. L. (2017). Modeling dynamics of native and invasive species to guide prioritization of management actions. Ecosphere, 8(5). https://doi.org/10.1002/ecs2.1822
- MacKenzie, D. I., & Nichols, J. D. 2004. Occupancy as a surrogate for abundance estimation. Animal biodiversity and conservation, 27(1), 461-467.
- Marino, J., Bennett, M., Cossios, D., Iriarte, A., Lucherini, M., Pliscoff, P., Sillero-Zubiri, C., Villalba, L., & Walker, S. (2011). Bioclimatic constraints to Andean cat distribution: A modelling application for rare species: Bioclimatic constraints to Andean cat distribution. Diversity and Distributions, 17(2), 311–322. https://doi.org/10.1111/j.1472-4642.2011.00744.x
- Martínez Ruiz, T. 2020. Rojas Hernández, J. y Barra Ríos, R. (eds.). 2020. Seguridad Hídrica. Derechos de agua, escasez, impactos y percepciones ciudadanas en tiempos de cambio climático. Santiago de Chile: RIL Editores, 344 pp. Relaciones Internacionales, (45), 443-446.
- Martinez-Harms, M. J., Bryan, B. A., Figueroa, E., Pliscoff, P., Runting, R. K., & Wilson, K. A. (2017). Scenarios for land use and ecosystem services under global change. Ecosystem Services, 25, 56–68. https://doi.org/10.1016/j.ecoser.2017.03.021
- Martinez-Harms, M. J., Wilson, K. A., Costa, M. D. P., Possingham, H. P., Gelcich, S., Chauvenet, A., Pliscoff, P., Marquet, P. A., & Bryan, B. A. (2021). Conservation planning for people and nature in a Chilean biodiversity hotspot. People and Nature, pan3.10200. https://doi.org/10.1002/pan3.10200
- Mazor et al. 2017. Spatial statistical network models to estimate the spatial representativeness of bioassessment samples.

- McDowall, R. M. (2006). Crying wolf, crying foul, or crying shame: Alien salmonids and a biodiversity crisis in the southern cool-temperate Galaxioid fishes? Reviews in Fish Biology and Fisheries, 16(3), 233–422. https://doi.org/10.1007/s11160-006-9017-7
- McGarvey, D. J., Menon, M., Woods, T., Tassone, S., Reese, J., Vergamini, M., & Kellogg, E. (2018). On the use of climate covariates in aquatic species distribution models: Are we at risk of throwing out the baby with the bath water? Ecography, 41(4), 695–712. https://doi.org/10.1111/ecog.03134
- Meller, L., Cabeza, M., Pironon, S., Barbet-Massin, M., Maiorano, L., Georges, D., & Thuiller, W. (2014). Ensemble distribution models in conservation prioritization: From consensus predictions to consensus reserve networks. Diversity and Distributions, 20(3), 309–321. https://doi.org/10.1111/ddi.12162
- Mi, C., Huettmann, F., Guo, Y., Han, X., & Wen, L. (2017). Why choose Random Forest to predict rare species distribution with few samples in large undersampled areas? Three Asian crane species models provide supporting evidence. PeerJ, 5, e2849. https://doi.org/10.7717/peerj.2849
- Ministerio del Medio Ambiente, Chile. 2017. Estrategia Nacional de Biodiversidad 2017-2030. Disponible en http://bit.ly/34FA8yU.
- Muehlbauer, J. D., S. F. Collins, M. W. Doyle & K. Tockner, 2014. How wide is a stream? Spatial extent of the potential "stream signature" in terrestrial food webs using meta-analysis. Ecology 95: 44–55.
- Nenzén, H. K., & Araújo, M. B. (2011). Choice of threshold alters projections of species range shifts under climate change. Ecological Modelling, 222(18), 3346–3354. https://doi.org/10.1016/j.ecolmodel.2011.07.011
- Nguyen, T., Everaert, G., Boets, P., Forio, M., Bennetsen, E., Volk, M., Hoang, T., & Goethals, P. (2018). Modelling tools to analyze and assess the ecological impact of hydropower dams. Water, 10(3), 259. https://doi.org/10.3390/w1003025
- Oliveira, M. R., Tomas, W. M., Guedes, N. M. R., Peterson, A. T., Szabo, J. K., Júnior, A. S., Camilo, A. R., Padovani, C. R., & Garcia, L. C. (2021). The relationship between scale and predictor variables in species distribution models applied to conservation. Biodiversity and Conservation. https://doi.org/10.1007/s10531-021-02176-w
- Ortega, J. C. G., Agostinho, A. A., Santos, N. C. L., Agostinho, K. D. G. L., Oda, F. H., Severi, W., & Bini, L. M. (2018). Similarities in correlates of native and introduced fish species richness distribution in Brazilian reservoirs. Hydrobiologia, 817(1), 167–177. https://doi.org/10.1007/s10750-018-3508-0
- Pascual, M. A., & Ciancio, J. E. (2007). Introduced anadromous salmonids in patagonia: Risks, uses, and a conservation paradox. In T. M. Bert (Ed.), Ecological and Genetic Implications of Aquaculture Activities (pp. 333–353). Springer Netherlands. https://doi.org/10.1007/978-1-4020-6148-6_18
- Pauchard, A., & Villarroel, P. (2002). Protected areas in Chile: history, current status, and challenges. Natural Areas Journal, 22(4), 318-330.
- Peredo-Parada, M., Martínez-Capel, F., Garófano-Gomez, V., Atenas, M., & Riestra, F. (2009). Eco-hydrological database of chilean rivers: A tool for management of aquatic ecosystem. Gayana (Concepción), 73(1), 119–129. https://doi.org/10.4067/S0717-65382009000100015
- Perkin, J. S., & Gido, K. B. (2012). Fragmentation alters stream fish community structure in dendritic ecological networks. Ecological Applications, 22(8), 2176–2187. https://doi.org/10.1890/12-0318.1
- Peterson, E. E., & Hoef, J. M. V. (2010). A mixed-model moving-average approach to geostatistical modeling in stream networks. Ecology, 91(3), 644–651. https://doi.org/10.1890/08-1668.1
- Peterson, A. Townsend, and Jorge Soberón. 'Species Distribution Modeling and Ecological Niche Modeling: Getting the Concepts Right'. Natureza & Conservação, vol. 10, no. 2, 2012, pp. 102–07. DOI.org (Crossref), https://doi.org/10.4322/natcon.2012.019.
- Phillips, S. J., Anderson, R. P., & Schapire, R. E. (2006). Maximum entropy modeling of species geographic distributions. Ecological Modelling, 190(3–4), 231–259. https://doi.org/10.1016/j.ecolmodel.2005.03.026

- Poff, N. L. (2019). A river that flows free connects up in 4D. Nature, 569(7755), 201–202. https://doi.org/10.1038/d41586-019-01393-2
- Pringle, C. M., Freeman, M. C., & Freeman, B. J. 2000. Regional effects of hydrologic alterations on riverine macrobiota in the new world: Tropical-temperate comparisons. Bioscience, 50, 807–823. https://doi-org.ezproxy.unal.edu.co/10.1641/0006-3568(2000)050[0807:REOHAO]2.0.CO;2
- R: the r project for statistical computing. (n.d.). Retrieved September 10, 2021, from https://www.r-project.org/
- Robertson, M. P., Peter, C. I., Villet, M. H., & Ripley, B. S. (2003). Comparing models for predicting species' potential distributions: A case study using correlative and mechanistic predictive modelling techniques. Ecological Modelling, 164(2–3), 153–167. https://doi.org/10.1016/S0304-3800(03)00028-0
- Rojas, P., Castro, S. A., Vila, I., & Jaksic, F. M. (2020). Exotic species modify the functional diversity patterns of freshwater fish assemblages in continental Chile: Examining historical and geographical patterns. Global Ecology and Conservation, 24, e01355. https://doi.org/10.1016/j.gecco.2020.e01355
- Rolls, R. J., J. Heino, D. S. Ryder, B. C. Chessman, I. O. Growns, R. M. Thompson, & K. B. Gido. 2017. Scaling Biodiversity Responses to Hydrological Regimes. Biological Reviews, 93(2): 971-995
- Segurado, P., & Araújo, M. B. (2004). An evaluation of methods for modelling species distributions: Methods for modelling species distributions. Journal of Biogeography, 31(10), 1555–1568. https://doi.org/10.1111/j.1365-2699.2004.01076.x
- Sinclair, S. J., White, M. D., & Newell, G. R. (2010). How useful are species distribution models for managing biodiversity under future climates? Ecology and Society, 15(1). https://www.jstor.org/stable/26268111
- Soberón, J. M. (2010). Niche and area of distribution modeling: A population ecology perspective. Ecography, 33(1), 159–167. https://doi.org/10.1111/j.1600-0587.2009.06074.x
- Soberón, J. M., Llorente, J. B., & Oñate, L. (2000). [No title found]. Biodiversity and Conservation, 9(10), 1441–1466. https://doi.org/10.1023/A:1008987010383
- Soto, D., Arismendi, I., González, J., Sanzana, J., Jara, F., Jara, C., Guzman, E., & Lara, A. (2006). Southern Chile, trout and salmon country: Invasion patterns and threats for native species. Revista Chilena de Historia Natural, 79(1), 97–117. https://doi.org/10.4067/S0716-078X2006000100009
- Soto, D., Arismendi, I., Prinzio, C. & Jara, F. 2007. Establishment of Chinook salmon (Oncorhynchus tshawytscha) in Pacific basins of southern South America and its potential ecosystem implications. Revista Chilena de Historia Natural, 80, 81–98
- Soto, D., Jara, F., & Moreno, C. 2001. Escaped salmon in the inner seas, southern Chile: facing ecological and social conflicts. Ecological applications, 11(6), 1750-1762.
- Strayer, D. L., & Dudgeon, D. (2010). Freshwater biodiversity conservation: Recent progress and future challenges. Journal of the North American Benthological Society, 29(1), 344–358. https://doi.org/10.1899/08-171.1
- Syfert, M. M., Smith, M. J., & Coomes, D. A. (2013). The effects of sampling bias and model complexity on the predictive performance of maxent species distribution models. PLoS ONE, 8(2), e55158. https://doi.org/10.1371/journal.pone.0055158
- Tax, D. M. J., & Duin, R. P. W. (2004). Support vector data description. Machine Learning, 54(1), 45–66. https://doi.org/10.1023/B:MACH.0000008084.60811.49
- Taylor, A. T., Papeş, M., & Long, J. M. (2018). Incorporating fragmentation and non-native species into distribution models to inform fluvial fish conservation: Distribution Models of a Fluvial Fish. Conservation Biology, 32(1), 171–182. https://doi.org/10.1111/cobi.13024
- Taylor, A. T., Papeş, M., & Long, J. M. 2018. Incorporating fragmentation and non-native species into distribution models to inform fluvial fish conservation. Conservation Biology, 32(1), 171-182.

- Thoms, M. C., Piegay, H., & Parsons, M. 2018. What do you mean, ‘resilient geomorphic systems’? Geomorphology, 305, 8–19. https://doi-org.ezproxy.unal.edu.co/10.1016/j.geomorph.2017.09.003
- Thuiller, W., Richardson, D. M., Pysek, P., Midgley, G. F., Hughes, G. O., & Rouget, M. (2005). Niche-based modelling as a tool for predicting the risk of alien plant invasions at a global scale. Global Change Biology, 11(12), 2234–2250. https://doi.org/10.1111/j.1365-2486.2005.001018.x
- Torremorell A., Hegoburu C, Brandimarte A.B., Costa Rodrigues E., Pompêo M., Cardoso da Silva S., Moschini-Carlos, V., Caputo L., et al. Present and future threats for the ecological quality management of South American freshwater ecosystems. Inland Waters (en prensa)
- Tsoar, A., Allouche, O., Steinitz, O., Rotem, D., & Kadmon, R. (2007). A comparative evaluation of presence-only methods for modelling species distribution. Diversity and Distributions, 13(4), 397–405. https://doi.org/10.1111/j.1472-4642.2007.00346.x
- Valenzuela-Aguayo, F, McCracken, GR, Manosalva, A, Habit, E, Ruzzante, DE. Human-induced habitat fragmentation effects on connectivity, diversity, and population persistence of an endemic fish, Percilia irwini, in the Biobío River basin (Chile). Evol Appl. 2020; 13: 795– 808. https://doi.org/10.1111/eva.12901
- Vargas, C. A., Garreaud, R., Barra, R., Vásquez-Lavin, F., Saldías, G. S., & Parra, O. 2020. Environmental costs of water transfers. Nature Sustainability. doi:10.1038/s41893-020-0526-5
- Ver Hoef, J. M., Peterson, E., & Theobald, D. 2006. Spatial statistical models that use flow and stream distance. Environmental and Ecological statistics, 13(4), 449-464. 19
- Vicuna, S., Hermansen, C., Cerda, J. P., Olivares, M. A., Gomez, T. I., Toha, E., Poblete, D., Mao, L., Falvey, M. J., Pliscoff, P., Melo, O., Lacy, S., Peredo, M., Marquet, P. A., Maturana, J., & Gironas, J. A. (2017). A modeling tool to support decision making in future hydropower development in Chile. AGU Fall Meeting Abstracts, 14. http://adsabs.harvard.edu/abs/2017AGUFM.H14C..06V
- Vila I. & E. Habit. 2015. Current situation of the fish fauna in the Mediterranean region of Andean river systems in Chile. FiSHMED Fishes in Mediterranean Environments 1–19.
- Vila L. 2001. La diversidad acuática: estructura, funciones y salud de las cuencas, bases para el Manejo Integrado en Sustentabilidad, Proyecto PMRH, Ministerio de Obras Públicas, Gobierno de Chile.
- Vila, I., & Habit, E. (2015). Current situation of the fish fauna in the Mediterranean region of Andean river systems in Chile. Fishes in Mediterranean Environments, 2015. https://doi.org/10.29094/FiSHMED.2015.002
- Vila, I., Fuentes, L., & Contreras, M. 1999. Peces Límnicos de Chile. Boletín del Museo Nacional de Historia Natural Chile, 48, 61–75.
- Vila, I., S. Scott, M. A. Mendez, F. Valenzuela, P. Iturra y E. Poulin 2011. «Orestias gloriae, a New Species of Cyprinodontid Fish from Saltpan Spring of the Southern High Andes (Teleostei: Cyprinodontidae) ». Ichthyological Exploration of Freshwaters 22(4): 345-353.
- Villéger, S., Blanchet, S., Beauchard, O., Oberdorff, T., & Brosse, S. (2011). Homogenization patterns of the world’s freshwater fish faunas. Proceedings of the National Academy of Sciences, 108(44), 18003–18008. https://doi.org/10.1073/pnas.1107614108
- Vivancos, A., Górski, K., Manosalva, A., Toledo, B., Reid, M., & Habit, E. (2021). Hydrological connectivity drives longitudinal movement of endangered endemic Chilean darter Percilia irwini (Eigenmann, 1927) . Journal of Fish Biology, 98 (1), 33–43. https://doi.org/10.1111/jfb.14554
- Vörösmarty, C. J., McIntyre, P. B., Gessner, M. O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S. E., Sullivan, C. A., Liermann, C. R., & Davies, P. M. (2010). Global threats to human water security and river biodiversity. Nature, 467(7315), 555–561. https://doi.org/10.1038/nature09440
- Wisz, M. S., Hijmans, R. J., Li, J., Peterson, A. T., Graham, C. H., Guisan, A., & NCEAS Predicting Species Distributions Working Group†. (2008). Effects of sample size on the performance of species distribution models. Diversity and Distributions, 14(5), 763–773. https://doi.org/10.1111/j.1472-4642.2008.00482.x

- Woodman, S. M., Forney, K. A., Becker, E. A., DeAngelis, M. L., Hazen, E. L., Palacios, D. M., & Redfern, J. V. (2019). esdm: A tool for creating and exploring ensembles of predictions from species distribution and abundance models. Methods in Ecology and Evolution, 10(11), 1923–1933. https://doi.org/10.1111/2041-210X.13283
- Xenopoulos, M. A. & D. M. Lodge, 2006. Going with the flow: using species-discharge relationships to forecast losses in fish biodiversity. Ecology 87: 1907–1914
- Zamorano, D., Labra, F. A., Villarroel, M., Lacy, S., Mao, L., Olivares, M. A., & Peredo-Parada, M. (2019). Assessing the effect of fish size on species distribution model performance in southern Chilean rivers. PeerJ, 7, e7771. https://doi.org/10.7717/peerj.7771
- Zorn, T. G., P. W. Seelbach, & M. J. Wiley, 2009. Relationships between habitat and fish density in Michigan streams. State of Michigan Department of Natural Resources, Fisheries Research Report 2091.

- the complete report and the Supplementary Material have already been sent to the teacher; however, due to the maximum capacity of 5MB that the BioSaga platform allows sending, this report is the summarized version without SM.