ORIGINAL ARTICLE

Predicting spatial distribution patterns and hotspots of fish assemblage in a coastal basin of the central-south of Chile, by geostatistical techniques

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ABSTRACT

Currently the application of geographic information systems in the subjects of biology and ecology has facilitated the study patterns of distribution, richness and diversity of species. However, in freshwater ecosystems the application of geostatistical analysis are scarcely used in the worldwide, including Chile. Therefore, in our study we developed predictive maps using simple Kriging (resolution 12.5 x 12.5 m), based on richness and Shannon-Weaver diversity, and we analyzed spatial autocorrelation of fish assemblages (Moran and Getis-Ord index) present in the Andalién River basin. Our results established a fish assemblage composition of 24 species, most of them native (79%) and with endanger conservation status. Predictive maps showed highest values of richness and diversity of fish species in the potamon zone of the Andalién and Nonguén streams, while the low values were described in the Chaimavida sub-basin and the transition zone of Andalién River. The Moran and Getis-Ord index determined a cluster pattern of the data and define hotspot and coldspot zones, concordant with the predictive maps of richness and Shannon-Weaver diversity. The geostatistical and spatial techniques showed to be relevant tools for the determination of distribution patterns of freshwater species and conservation issues.

INTRODUCTION

The macroecology and biodiversity data show strong spatial patterns, structured as a function of biological processes and usually autocorrelated (Legendre, 1993; Rangel *et al.,* 2006). These structure patterns that govern ecology and biogeography are influenced and correlated with variables such as richness, diversity of species (Fortin and Dale, 2005) and environment configuration (Rangel *et al.,* 2006). These ecological variables sampled and mapped by the application of geographic information system are relevant to determine actions and decisions on conservation issues of protected areas, biological corridors, distribution of endemic species, richness patterns, hotspot, indicator species and mitigate or minimize environmental impacts (Carroll and Pearson, 2000; Williams *et al.,* 2002).

Geostatistics is a key tool to predict and quantify the scale of spatial variation between different species and their spatial distribution. Further, geostatistics is important to understand ecological processes that occur at different spatio-temporal scales, for example, the relationship between species diversity and spatial heterogeneity (Gallardo, 2006).

Matheron in 1963 described the geostatistic term as the application of the formalism of random functions to recognition and estimation of natural phenomena. The origins of the geostatistic techniques are related to geologic disciplines and mining industry (Cressie, 1985; 1990) and applied to continuous spatial data. These techniques range from those used to model spatial relationships (Aubry and Debouzie, 2000) to those used to make optimal predictions (*e.g.* richness of species) at unsampled sites (Carroll and Pearson, 1998). Kriging, one of the most popular geostatistic techniques, has been defined as "a method of interpolation for random spatial" (Ord, 1983). While, Hemyari and Nofziger (1987) describes as a "form of weighted averaging in which the weights are chosen such that the error associated with the predictor is less than for any other linear sum…. The weights depend upon the location of the points used in the prediction process and upon the covariation… reflected in the semivariogram". More recently, this analysis is defined as an interpolation method based in a stochastic spatial variation model that fits well to the reality (Oliver and Webster, 1990), founded on the minimization of the mean standardize error with the prediction (variogram) (Armstrong *et al.,* 1992; Cruz-Cárdenas *et al.,* 2013). The

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hypothesis of the kriging method establishes the fact that spatial variations of the object or study variable are statistically homogeneous over a specific location (Krige, 1951; Isaaks and Srivastava, 1989). Therefore, it is essential to determine the spatial autocorrelation of the object or study variable (Rivoirard *et al.,* 2000), described as patterns of spatial continuity and dependence (Goodchild, 1987; Carroll and Pearson, 1998) which confirms the Tobbler principle (Ramírez and Falcón, 2015).

Many studies have been performed using spatial interpolation methods (*e.g.* kriging group) to establish richness and diversity on vascular flora (Kreft and Jetz, 2007; Hernández-Pérez *et al.,* 2011; Cruz-Cárdenas *et al.,* 2013), brown algae (Hernández-Cervantes *et al.,* 2014), insects (Ballesteros-Mejia *et al.,* 2013), birds (Lin *et al.,* 2008), reptiles (Martínez-Freiría *et al.,* 2009; Martínez and Brito, 2013) amphibians (Reeves *et al.,* 2013), marine fishes (Petitgas, 1992; Ayala-Pérez *et al.,* 2001; Ortiz, 2013), crustaceans (Ruiz-Luna *et al.,* 2010; Ferreira *et al.,* 2016), marine mammals (Monestiez *et al.,* 2006) and fauna in general (Martinez, 2015). But in freshwater fish have been little or no attention, even when this group is relevant as bioindicators of quality water and key species for riverine trophic webs (Northcote, 1988; Parkos *et al.,* 2003). Nevertheless, in fluvial systems, spatial distribution models in freshwater fish have been developed using environmental variables as predictors that determine the structure and spatial composition of fish assemblages. For instance, hydraulic conditions (Marchetti and Moyle, 2001), substratum type (Humpl and Pivnicka, 2006), natural barriers (Rahel, 2007), physicochemical conditions (Matthews, 1998; Buisson *et al.,* 2008) and riparian vegetation (Growns *et al.,* 2003).

Based on the scarce application of geostatistics in freshwater systems as a predictive tool for spatial distribution patterns of ichthyofauna is that this study evaluates patterns of spatial in a coastal central-south basin off Chile. First, we determinate the species richness and diversity for each tributary stream. Second, we performed a kriging interpolation based on both index evaluating almost all the basin, and identify cluster grouping and hotspot/coldspot using general Moran's index and Gi* Getis-Ord along the basin.

METHODS

Study area

The Andalién River basin was defined as the study area, a fourth order basin, situated in the central-south off Chile, specifically on the coastal mountain range, which covers a drainage area of 775 km^2 (Jaque, 1996). The Andalién River is born from the union of the Poñén and Curapalihue streams, at a sector called "Puente Siete", presenting a high sinuosity on rithron and transition zone, while the potamon stretch is an alluvial plain, bordering the city of Concepción. The hydrologic regimen is pluvial, with an average annual flow of 14.3 m^3/s, showing minimal flows in the summer (10 m^3/s) and maximal flow levels in winter (1500 m^3/s) (Jaque, 2008).

Sixty-two (62) sampling sites were analysed along the basin, spatially distributed in the different riverine zones (rithron, transition and potamon). Geographical location of each sampling site was determined by a Garmin GPS, model Montana 650, using Universal Transverse Mercator Projection (UTM, WGS 84 19S). The distribution of the sampling sites between the zones was developed in the following way: thirty-six (36) sites located on potamon zone, nine (9) sites on the transition and seventeen (17) sites correspond to the rithron zone (Fig. 1). A brief description of the physicochemical characteristics of the rithron, transition and potamon zones are described in Tab. 1.

Ecological index

The species richness and Shannon-Weaver diversity estimation was obtained from the data base of fisheries investigations provided by the Government Department of Fisheries and Aquaculture of Chile (SUBPESCA, in Spanish), a review and compilation of freshwater researches (scientific and technical capture reports) and personal fish sampling performed with standardized electrofishing methods along the Andalién River basin.

A data of 10,545 captures freshwater fish was collected, and a maximal richness of 24 species were identified in the Andalién network. Shannon-Weaver diversity was performed using the following equation.

$$H' = \sum pi \;\; \log_2 pi \qquad \text{(eq. 1)}$$

where p_i is the percentage of the individuals represented by the species *i* and is estimated by N_i/N, N_i is the number of individuals of a species and N is the total number of individuals.

To determine significant differences between the ecological index and the different zones a Kruskal-Wallis test was used, a rank-based nonparametric test which null hypothesis describes the median equality between two or more groups (Kruskal and Wallis, 1952). If significant differences came up between the groups, a Dunn`s multiple comparison test was performed to recognise the different groups, using software PAST ver. 3.19 (Hammer *et al.,* 2001).

Structural variables and spatial predictions

To achieve the three-dimensional model and the construction of the networks of Andalién basin, satellite photos where used from the Alaska Satellite Facility platform (https://www.asf.alaska.edu/) processed with ArcGis 10.5 software by the module ArcHydro tools and Hydrology. These photos were taken in 2011, correspond to the ALOS satellite by the PALSAR sensor (Phased Array Type L-band Synthetic Aperture Radar) with a 12.5 m spatial resolution. Once the photos were processed, a Digital Elevation Model (DEM) is obtained for the Andalién River basin. From the DEM, structural variables are estimated; elevation, slope and Strahler order for each site and stream sampled. The stream order was used as a proxy for habitat size and heterogeneity (Ferreira *et al.,* 2016).

To describe the relationship between the ecological index and each structural variable (*i.e.* elevation, slope and Strahler order) defined as an explanatory variable, we performed the multiple regression analysis, using a stepwise procedure for selection of the most important structural predictors (Quinn and Keough, 2002).

Interpolation models

To estimate spatial distribution maps of fish assemblage based on both ecological index we applied kriging interpolation using the Geostatistical analysis extension of ARCGIS 10.6 (ESRI, 2014). The mathematical formulation is established on variograms with weight functions, which express the spatial variation (Oliver and Webster, 1990) and autocorrelation data (Robertson, 1987).

$$\hat{y}(h) = \frac{1}{2n(h)}\sum_{i=1}^{n(h)}[Z(x_i) - Z(x_i + h)]^2 \qquad \text{(eq. 2)}$$

Where (x_i) and $(x_i + h)$ are sampling sites separated by the lag h, and $z(x_i)$ and $z(x_i + h)$ are the values of Z observations (richness, and Shannon-Weaver index) for each site; and $n(h)$ represents the number of pairs sep rated by the lag distance h.

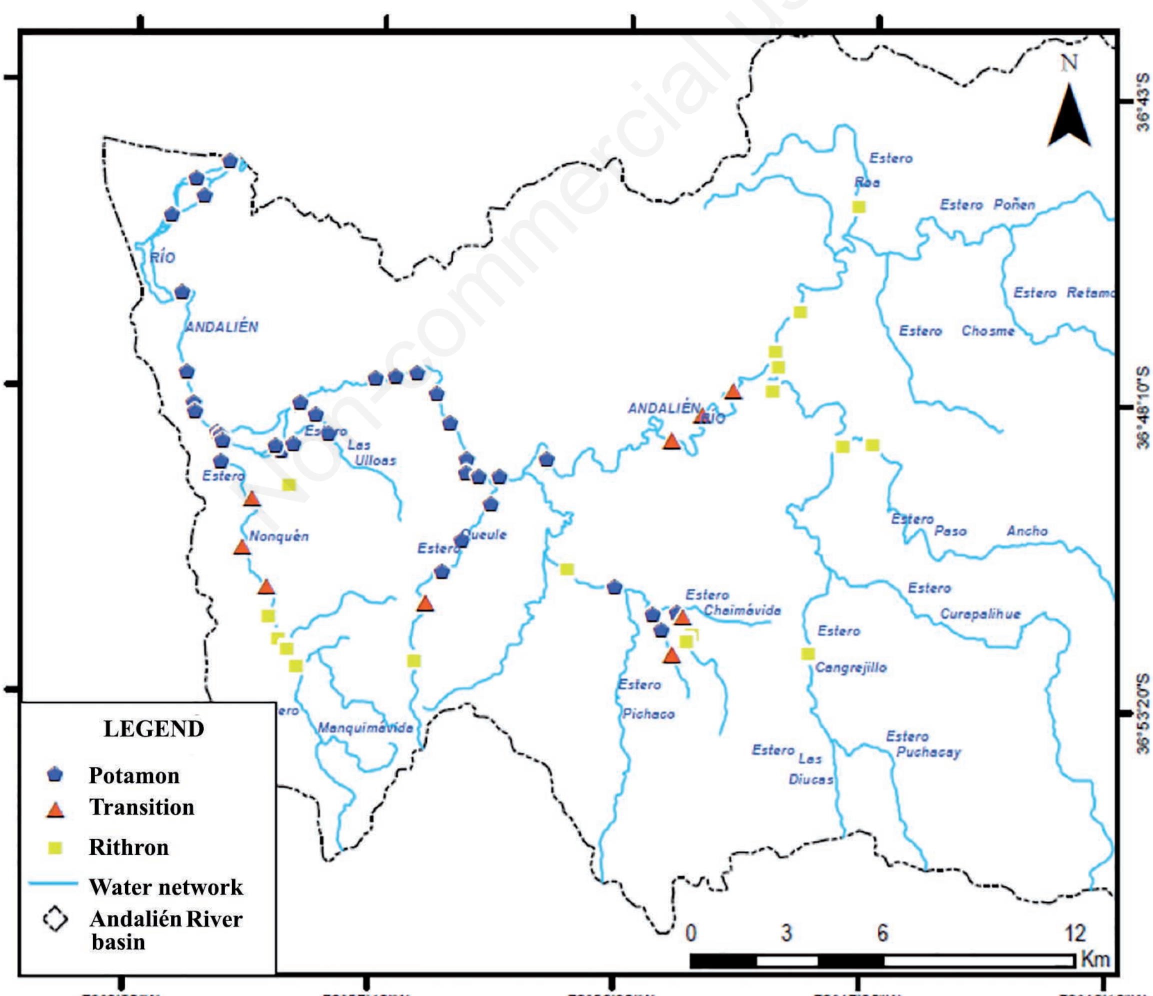

Fig. 1. Sampling sites develop in the Andalién River basin, Chile.

Then, six different models (Stable, Spherical, Circular, Gaussian, Exponential and lineal) were evaluated to find the smallest error (Cressie, 1985). The anisotropy for each model and index was considered.

$$SSE = \sum_{i=1}^{m} w_i \, [\hat{y} - y]^2 \qquad \text{(eq. 3)}$$

Where m is number of lag (two locations separated by a determined distance), $\hat{y}$ are the semivariance values for each distance, y are the semivariance form the prediction model, and w_i are the semivariance factors.

Three kriging methods were analysed (simple, ordinary and universal) and compared through cross-validation, selecting the model with the lowest standardized mean of the error prediction (SMEP) (Cruz-Cárdenas *et al.,* 2013).

$$\text{SMEP}= \frac{1}{N}\sum_{i=1}^{N} \frac{ME}{\sigma^2 x_i} \qquad \text{(eq. 4)}$$

Where N sample size, $\hat{z}(x_i)$ is the estimated value of richness, $z(x_i)$ is the value of richness known and σ is the variance of the measured values of species richness (Kravchenko and Bullock, 1999).

Once the model of interpolation was selected for each index, a buffer of 100 m was established for the stream network to facilitate the visualization of interpolation analysis. To developed maps of ecological index we aggregate the data to a spatial resolution of 12.5 m x 12.5 m UTM grid cells.

Spatial patterns (hotspot and coldspot)

Several studies have been performed to identify biodiversity hotspots (Bonn *et al.,* 2002; Orme *et al.,* 2005) based on multiple criteria and arbitrary conditions, but in this study we used an intuitive measure, which detects spatial clusters containing greater values of diversity and species richness than expected by chance for the study area. To determined spatial autocorrelation, we used Moran statistic index (Moran, 1950). If the results show positive and significant autocorrelation, there is clustering of high values. Negative results and autocorrelation suggests a random pattern. Then, we defined spatial hotspot using the Gi* statistics (Getis and Ord, 1992). This index identifies spatial concentrations of an entity or areas that contain high values. To establish a statistically significant hotspot, an entity must

Tab. 1. Physicochemical and morphometric parameters of the Rithron, Transition and Potamon zones. The mean value and standard deviation are detailed. For physicochemical parameters, measurements are presented for two stations; high and low flow. Morphometric parameters are an average for the three zones (Rithron, Transition and Potamon).

	Unit	High flow			Low flow		
		Rithron	Transition	Potamon	Rithron	Transition	Potamon
Physico-chemical parameters							
Temperature	°C	8.5±1.8	9.0±1.8	10.3±1.9	10.5±3.1	12.0±4.1	12.8±4.2
pH	1-14 (h+)	7.7±0.3	7.5±0.2	7.5±0.1	7.1±0.3	7.1±0.3	7.0±0.3
Conductivity	µs/cm	72.7±14.1	75.8±13.9	89.8±23.1	96.4±27.0	101.4±31.3	114.8±27.9
Dissolved oxygen	mg/L	10.5±0.7	10.3±0.5	10.0±0.3	11.4±0.6	10.9±1.0	10.6±1.0
Total phosphorous	mg/L	0.07±0.07	0.04±0.01	0.1±0.05	0.03±0.01	0.03±0.02	0.08±0.04
Total nitrogen	mg/L	0.29±0.17	0.32±0.09	0.54±0.30	0.28±0.10	0.27±0.05	0.49±0.13
Total dissolved solids	mg/L	33.7±9.1	33.7±7.4	41.0±12.3	37.5±9.1	43.8±10.4	44.2±19.1
Total suspended solids	mg/L	11.8±8.6	12.4±8.6	29.1±18.7	6.9±5.7	6.1±4.7	19.0±15.3
Fecal coliforms	MPN /100 mL	228±114	205±352	15631±11202	6283±14078	332±174	18840±21903
Arsenic	mg/L	-	-	0.001±0.001	-	-	0.001±0.001
Boron	mg/L	-	-	0.3±0.4	-	-	0.2±0.01
Cadmium	mg/L	0.001±0.001	-	6.8±3.0	0.001±0.001	-	5.6±0.6
Cupper	mg/L	0.05±0.006	-	0.015±0.01	0.02±0.001	-	0.016±0.01
Magnesium	mg/L	-	-	3.1±1.2	-	-	3.7±1.3
Mercury	mg/L	0.0001±0.001	-	0.001±0.001	0.0001±0.001	-	0.002±0.001
Morphometric parameters		Rithron	Transition	Potamon			
Elevation	m	131±46.6	112.8±461.3	58.2±33.9			
Strahler strem order	number	1.8±0.7	2.3±1.0	2.6±1.1			
Slope	degree	3.4±5.2	2.6±4.0	2.3±4.3			

have high values and be surrounded by other cells with high values. Accordingly, the local sum for an entity and its neighbors is compared proportionally with the sum of all entities. If the local sum is extremely different from the random expectation, a significant Z score is assigned. Significant values of Z >0 provide evidence for significant hotspots whereas values of Z <0 provide evidence for groups of entities that have lower values than expected by chance (Mitchel, 2005). The statistical determination of hotspots and coldspot was performed in ArcGis 10.3 software (ESRI, 2014).

RESULTS

Fish species composition

The ichthyofauna registered in the Andalién River basin was 24 species, belonging to 11 orders and 15 families (Ruiz, 1993; Habit and Victoriano, 2005; Habit *et al.,* 2006; 2007) (Tab. 2). Seventy-nine percentage (79%) of the species were native, some of them with serious conservation state (Campos *et al.,* 1998). The richest order was represented by Perciformes with 6 species (25%), followed by Silurifomes with 4 species (16.7%) and Atheriniformes with 3 species (12.5%); the remaining orders summarized 11 species (45.8%). The analysis of species richness distribution showed a variation related with the riverine zone, revealing the highest values for the sampling sites E-6 (17 species) and E-11 (14 species) located in the potamon of Andalién and Nonguén streams, respectively. Meanwhile the lowest values of richness were reported in the Quebrada Ulloa and Chaimavida sub-basin (Las Puyas and Curapalihue tributaries) (Fig. 2).

A low global diversity was estimated for the Andalién network (1.077±0.223 bit/ind) exhibiting some picks at the sampling sites E-10 and E-12 located in the Nonguén stream, and E-7 in the Andalién stream, all of them situated in the potamon zone. Whereas Chaimavida sub-basin showed lowest diversity values (Las Puyas and Curapalihue tributaries) (Fig. 3).

Additionally, fish assemblage composition (richness and diversity) for each stream showed significant differences between the tributaries and streams of the Andalién network (Tab. 3).

Tab. 2. List of fish species identified in the Andalién River basin.

Order	Family	Species
Petromyzontidae	Petromyzontidae	*Mordacia lapicida* Gray 1851
	Geotriidae	*Geotria australis* Gary 1851
Characiformes	Characidae	*Cheiron galusdae* Eigenmann 1928
Siluriformes	Trichomycteridae	*Nematogenys inermis* (Guichenot 1848)
		Trichomycterus areolatus (Valenciennes 1848)
		Trichomycterus chiltoni (Eigenmann 1927)
		Bullockia maldonadoi (Eigenmann 1928)
Osmeriformes	Galaxidae	*Galaxias maculatus* (Jenyns 1842)
		Brachygalaxias bullocki (Regan 1908)
Mugiliformes	Mugilidae	*Mugil cephalus* Linnaeus 1758
Atheriniformes	Atherinopsidae	*Odontesthes mauleanum* (Steindachner 1896)
		Odontesthes regia (Humboldt 1821)
		Basilichthys microlepidotus (Jenyns 1841)
Perciformes	Percichthyidae	*Percichthys trucha* (Valenciennes 1833)
		Percichthys melanops Girard 1855
	Perciliidae	*Percilia irwini* Eigenmann 1927
		Percilia gillissi Girard 1855
	Eleginopsidae	*Eleginops maclovinus* (Valenciennes 1830)
	Cichlidae	*Cichlasoma fascetum* (Jenyns 1842)
Clupeiformes	Clupeidae	*Brevoortia maculata* (Valenciennes 1847)
Cypriniformes	Cyprinidae	*Carassius carassius* (Linneo 1758)
Cyprinodontiformes	Poecilidae	*Gambusia holbrooki* (Girard 1859)
Salmoniformes	Salmonidae	*Oncorhynchus mykiss* (Smith & Stearley 1989)
		Salmo trutta (Linneo 1758)

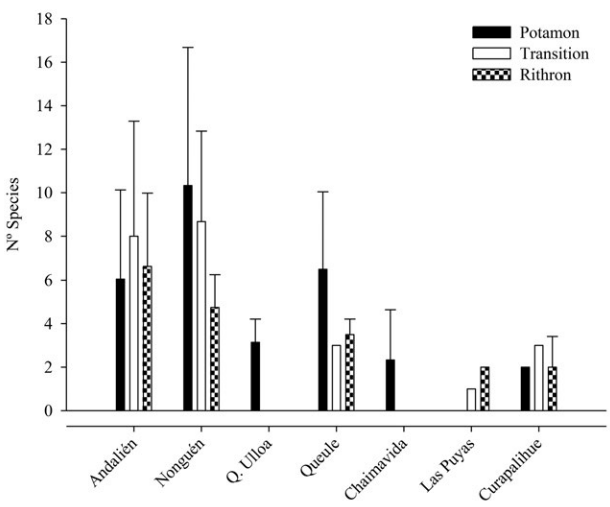

Fig. 2. Species richness determinate for each stream and fluvial zone present in the Andalién River basin.

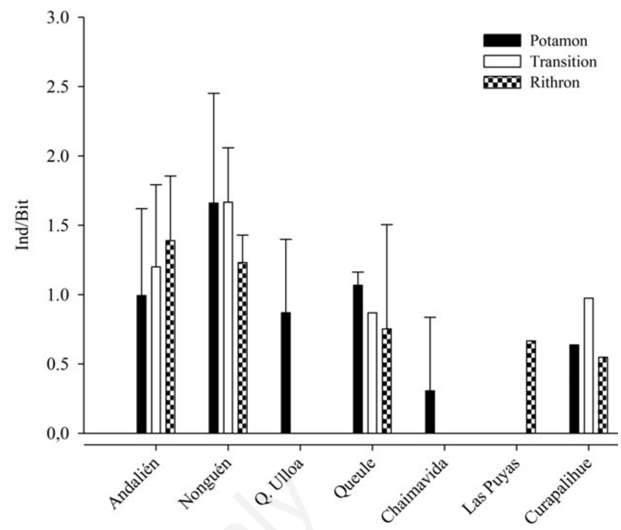

Fig. 3. Shannon-Weaver diversity index calculated for each stream and fluvial zone present in the Andalién River basin.

Tab. 3. Comparison of ecological index (Shannon diversity and richness) for each tributary and fluvial zone.

Index	Fluvial zone	Kruskal-Wallis		Dunn's *post-hoc*	
		K-W	P-value	Pairwise comparation	P-value
Shannon-Weaver	Potamon	26.93	***	Andalién/Chaimavida	***
				Andalién/Curapalihue local	**
				Andalién/Nonguén	***
				Andalién/Quebrada Ulloa	**
				Andalién/Queule	***
	Transition	7.21	ns	Curapalihue/Nonguén	**
				Nonguén/Queule	**
	Rithron	11.09	ns	Andalién/Chaimavida	***
				Andalién/Curapalihue	***
				Andalién/Nonguén	***
				Andalién/Quebrada Ulloa	***
				Andalién/Queule	***
Richness	Potamon	39.63	***	Andalién/Chaimavida	***
				Andalién/Curapalihue	***
				Andalién/Nonguén	***
				Andalién/Quebrada Ulloa	***
				Andalién/Queule	***
	Transition	8.82	*	Andalién/Las Puyas	**
				Nonguén/Curapalihue	*
				Nonguén/Las Puyas	*
				Nonguén/Queule	*
	Rithron	12.51	*	Andalién/Curapalihue local	*
				Andalién/Nonguén	*
				Curapalihue/Nonguén	*
				Curapalihue local/Las Puyas	*
				Las Puyas/Nonguén	**
				Las Puyas/Poñen	*

****P<0.001; **P<0.01; *P<0.05; ns, not significant.*

Spatial predictions

For the spatial prediction, seven models were evaluated, finding the stable model that better fitted to the data of species richness and Shannon-Weaver diversity. A simple Kriging, first order, was performed exhibiting the lowest standardized mean of the prediction error according to the cross-validation test (Cruz-Cárdenas *et al.,* 2013) (Tab. 4). The simple kriging estimate the major richness of species related to the potamon and transition zone of Nonguén stream, and the terminal stretch of Andalién, Poñen and Curapalihue streams. Meanwhile the lowest values where found in the middle stretch of Andalién and Chaimavida sub-basin (Fig. 4).

Shannon-Weaver diversity spatial prediction was performed using a simple kriging, first order, based in a Gaussian model, which described the lowest error (Tab. 4). Kriging results established the highest values (1.525 - 1.905 bit/ind) in the same zones that described richness predictions, but with an increment in the extension in the terminal and convergence zone of Poñen and Curapalihue streams. Low diversity values (>0.381 bit/ind) showed the

Tab. 4. Cross-validation test of mean standardization of the error prediction for the different Kriging techniques.

Kriging method	Mean standardization error prediction	
	Richness index	Diversity index
Universal	$4.3e^{28} \pm 9.7e^{28}$	1.14 ± 0.36
Ordinary	5.35 ± 1.53	0.61 ± 0.04
Simple	4.59 ± 0.51	0.52 ± 0.08

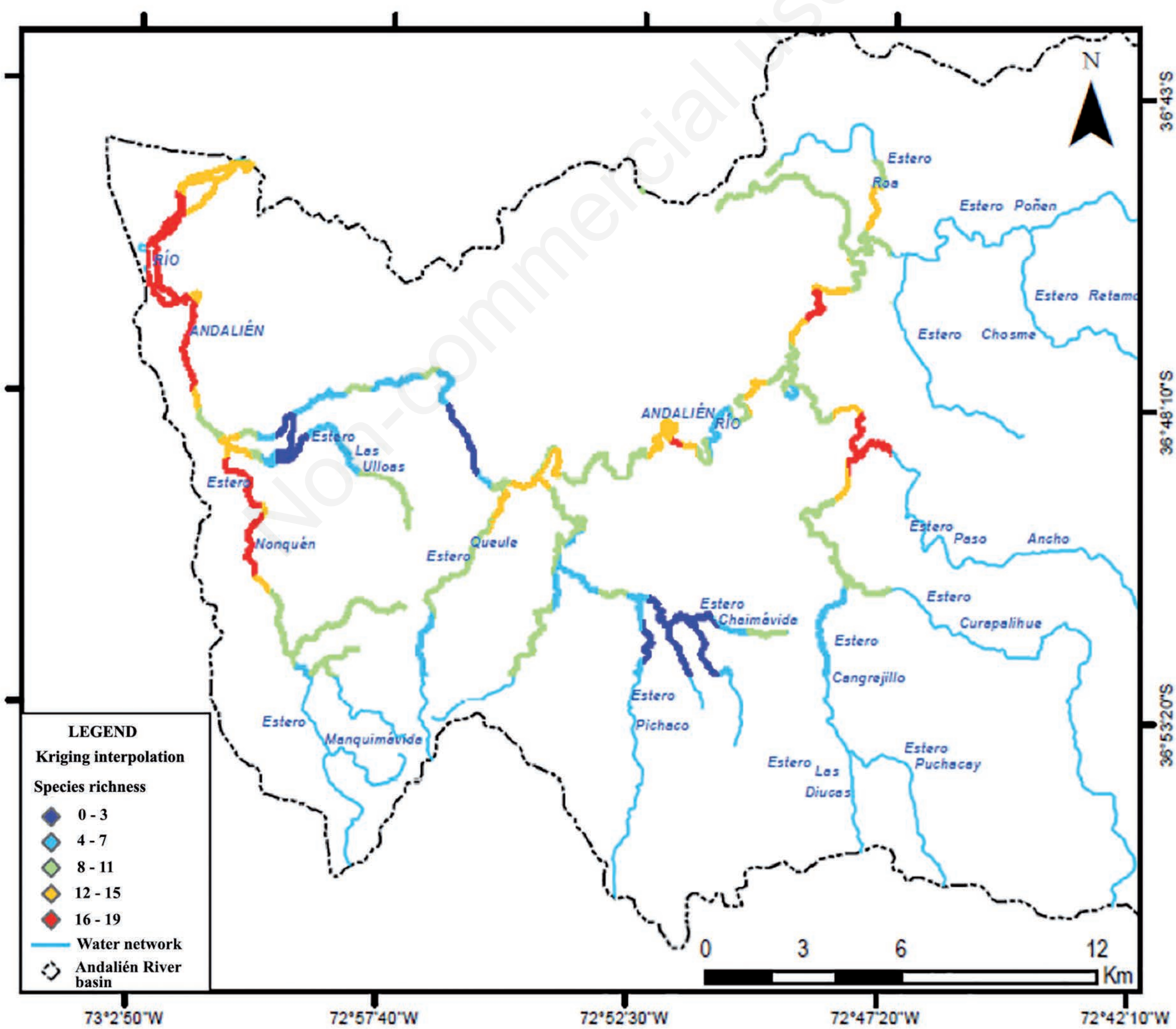

Fig. 4. Spatial prediction for species richness (fish assemblage) using simple Kriging interpolation in the Andalién River basin.

same trend as species richness prediction map labelled principally at Chaimavida sub-basin (Fig. 5). The variographic analysis parameters obtained for the estimation of species richness and Shannon-Weaver diversity are described in Tab. 5.

Spatial patterns

Global Moran´s index test revealed a clustered pattern for richness records (Z = 2.247; P=0.024) and Shannon-Weaver diversity index (Z = 3.227; P=0.001). Getis-Ord Gi* spatial statistic showed a hotspot of species richness in a few points in the potamon and transition zone of Andalién and Nonguén streams (Fig. 6). While the diversity index described hotspot distribution only in the discharge of the Nonguén stream and a coldspot random distribution located near the discharge of the Nonguén stream, middle zone of Andalién and Chaimavida sub-basin (Fig. 7).

Environmental variables and spatial predictions

Spatial prediction for both ecological indices seems to be related to structural variables of the basin. By a

Tab. 5. Parameters for variographics analysis for estimation of species richness and Shannon-Weaver diversity.

Spatial parameters	Species richness	Shannon-Weaver diversity
Nugget effect	0.343	0.949
Partial sill	0.188	0.154
Range	4.028	11.577

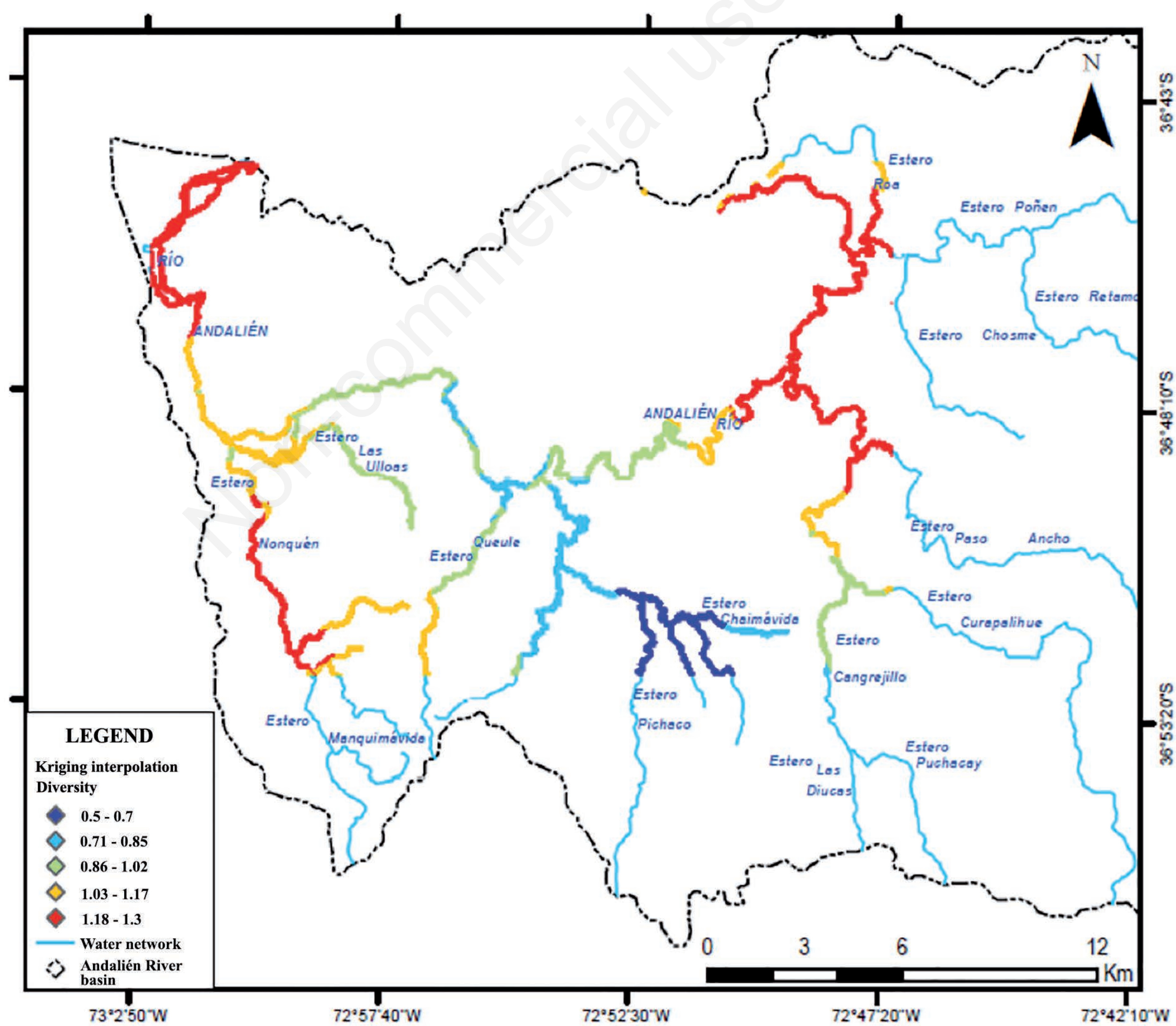

Fig. 5. Spatial prediction for Shannon-Weaver diversity index (fish assemblage) using simple in the Andalién River basin.

multiple regression model between the both index and all the explanatory variables (structural variables, Strahler order, slope and elevation) explained less than 15% of all the variation of the fish assemblage (Tab. 6). Showing that the predictions patterns of the ecological index were weakly explained by local scale structural variables, especially slope and elevation data which did not exhibited significant value as Strahler order showed

Tab. 6. Coefficients for structural variables related with the ecological index, results from multiple regression stepwise.

Ecological index	Structural variable	GLM					
		Estimate	Std. Error	t	P	R^2	AIC
Richness	Elevation	1.5e-04	0.01	-1.53	ns	0.04	345.12
	Strahler order	1.18	0.44	2.67	***	0.15	340.55
	Slope	-5.0e-03	0.09	-0.06	ns	0.0	347.50
Shannon-Weaver	Elevation	-6.9e-04	1.5e-03	-0.46	ns	0.0	121.30
	Strahler order	0.06	0.1	0.65	ns	0.01	124.84
	Slope	7.3e-05	0.01	0.01	ns	0.0	121.52

****P*<0.01; ns, not significant.*

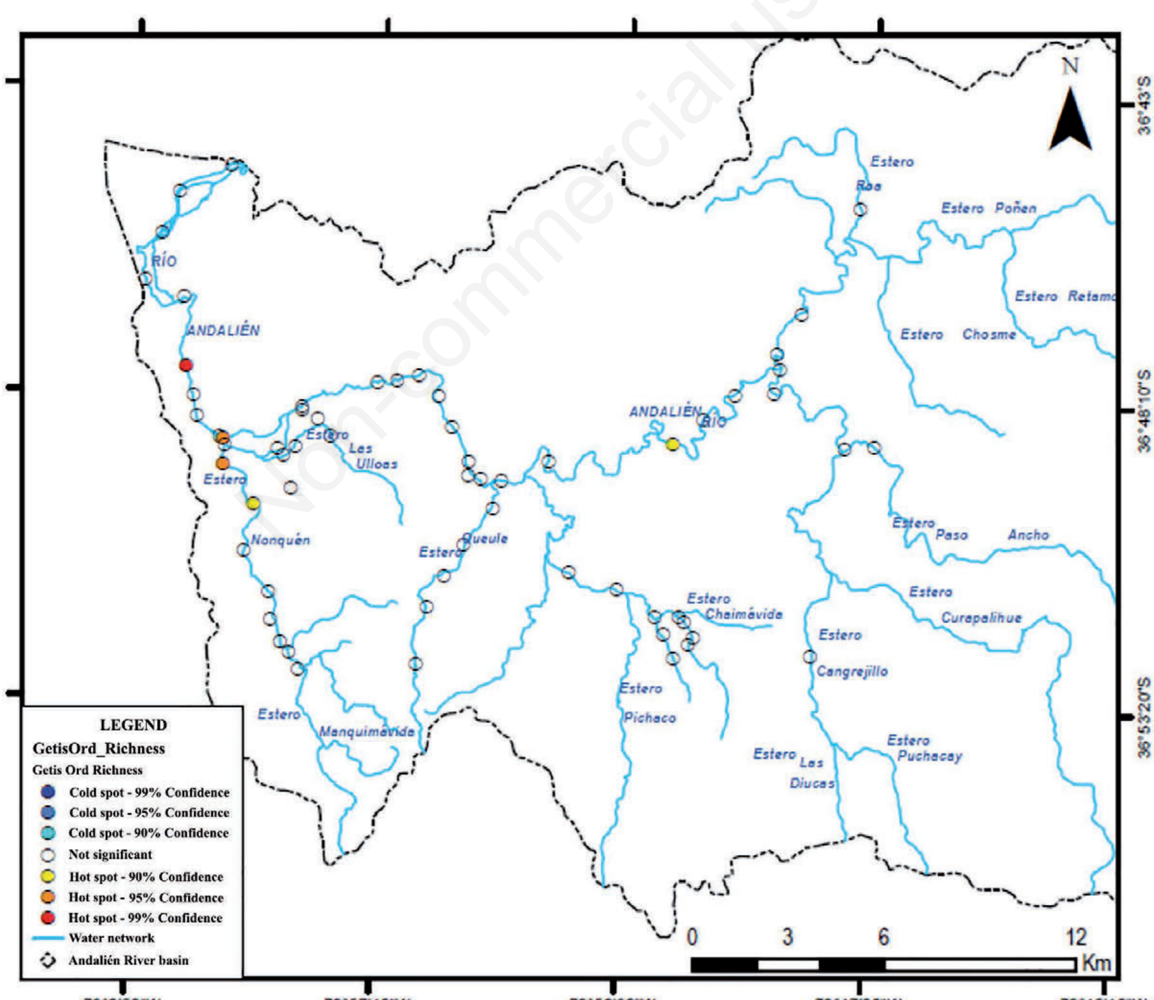

Fig. 6. Getis Ord geostatistical analysis based on species richness index for Andalién River basin.

(Tab. 6). Nevertheless, the coefficient regression described no significant relationship between structural and ecological values.

DISCUSSION

Fish assemblages in riverine systems are described by the typical follow pattern of increasing species richness and diversity from the upstream to downstream (Vannote *et al.,* 1980; Welcomme, 1985). Probably the majority of Chilean rivers have this zonation pattern; where exists a longitudinal gradient of richness and diversity increase in the current direction (Campos *et al.,* 1993; Duarte *et al.,* 1971; Habit *et al.,* 2004; 2007), which is mainly linked to the heterogeneity of habitats and food availability (Oberdorff *et al.,* 1993). However, this typical pattern of richness and diversity may be affected by the presence of fisheries over a relatively short time scale (Welcomme, 1985), an accumulative habitat or environmental degradation resulting from human activities (Wolter *et al.,* 2000; Habit *et al.,* 2005; 2006a). Andalién River basin is located in the Chilean ichthyogeographic zone, specifically in the south-central area (Dyer, 2000) with the greatest fish diversity and endemism (Habit *et al.,* 2006b), even when this network has a low fluvial order (4) and a small drainage area (Jaque, 1996). Our results described a fish community composed of 24 species, mostly native (Ruiz, 1993; Habit *et al.,* 2004; 2007) and endanger conservation status (Campos *et al.,* 1998). This important fish species concentration is explained by the great variety of habitats that this river presents (Ruiz, 1993; Habit and Victoriano, 2005) due to its markedly concave longitudinal profile (Campos *et al.,* 1993) and the existence of some fragments of native forest preserved in the upper reaches (Habit *et al.,*

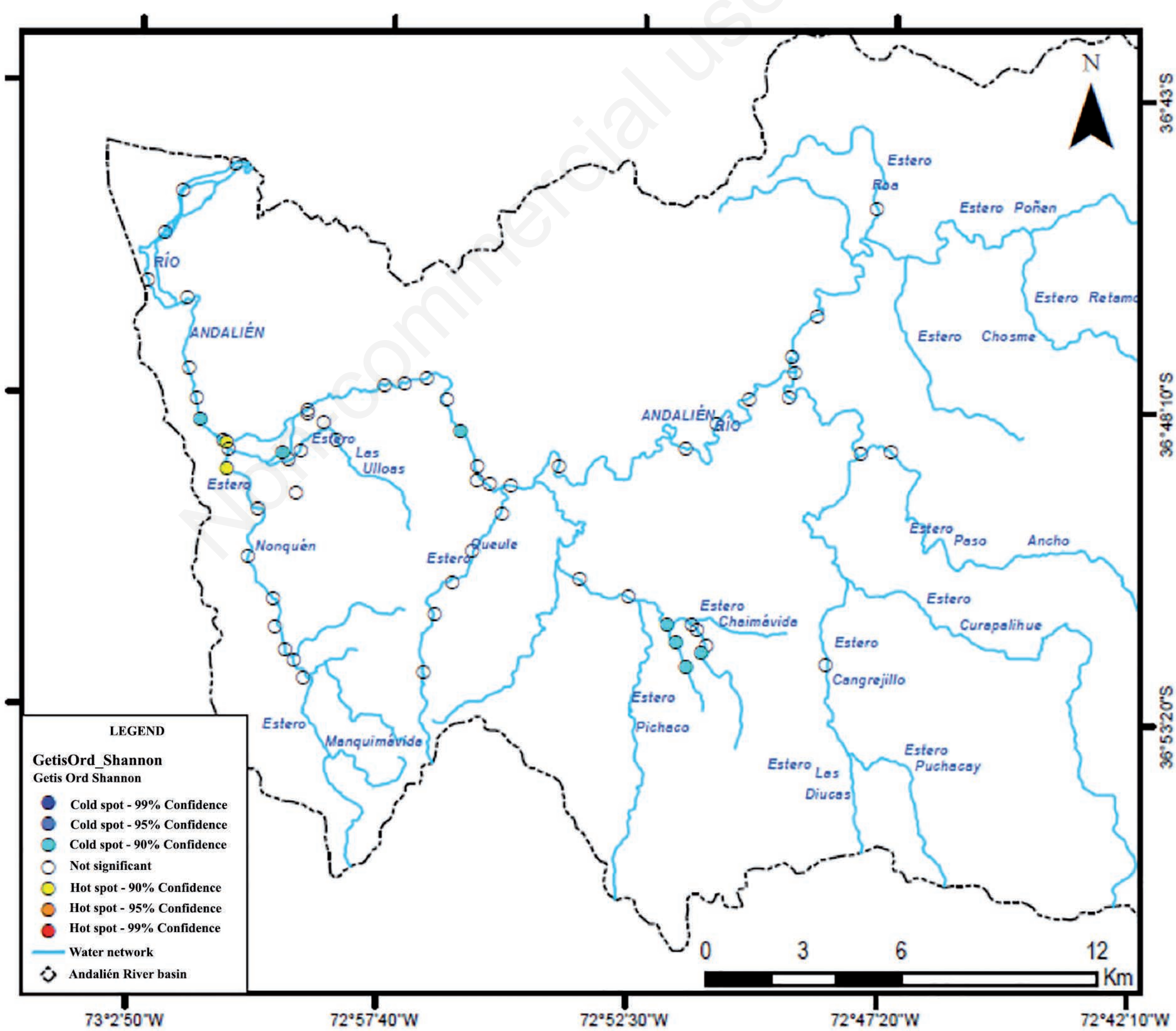

Fig. 7. Getis Ord geostatistical analysis based on Shannon-Weaver index for Andalién River basin.

2004). However, our results described a low value of diversity at basin level, probably because our analysis considers first-order tributaries (*i.e.*, Las Puyas, Curapalihue local), characterized by poor fish representation (Hynes, 1970) as a result of a restricted mosaic of habitats (Welcomme 1985), low trophic levels (Oberdorff *et al.*, 1993) and the presence of natural barriers (Rahel, 2007) that difficult the colonization and occupation of these areas, especially for our native Chilean fish species that are adapted to habitats with low velocity and longitudinal gradient, and thereby restricted to lower zones (Campos *et al.,* 1993; Vila *et al.,* 1999).

The application of geostatistical techniques and spatial interpolation have been widely used for conservation issues (Carroll and Pearson, 1998; 2000; Williams *et al.,* 2002; Pliscoff and Castillo, 2011) specially for research on biodiversity patterns, distribution of endemism, species turnorver rates, hotspot identification zones and alien species colonization (Bonn *et al.,* 2002; Cruz-Cárdenas *et al.,* 2013; Filipa *et al.,* 2017; Hernández-Pérez *et al.,* 2011; Lin *et al.,* 2008, Ruíz-Luna *et al.,* 2010; Martínez-Freiria *et al.,* 2008; Ortiz, 2013; Williams *et al.,* 2002). This approach has allowed to obtain optimal predictions of biological variables at proximate sites where no data has been collected (Carrol and Pearson, 1998; 2000). These findings are fundamental for making decision on conservation issues and species protection actions, focusing efforts in priority sites with the highest values of biodiversity and endemism.

We developed predictive maps using the simple kriging technique that allowed us to establish areas with high fish representation and important zones for environmental conservation for the basin. Both ecological index, species richness and Shannon-Weaver diversity, showed two representative stretches. The first one, from the discharge of the Nonguén stream to the mouth of the Andalién network, and the terminal stretch of the Poñen and Curapalihue streams, possibly due to the variety of habitats of both sections. These fluvial sections should have issues of conservation and protection due to their primitive singularity and high values of endemism species (Vila *et al.,* 1999; Dyer, 2000) specially the last stretch of the basin. But, on the contrary, they are fluvial sections subjected to channel interventions (Ortiz-Sandoval *et al.,* 2009), alterations in water quality (Jaque, 1994) and habitat loss (Smiley and Dibble, 2008), with negative repercussions on the composition, diversity and distribution of the local ichthyofauna (Habit *et al.,* 2005; 2007; Ortiz-Sandoval *et al.,* 2009). This distribution pattern of the assemblage in this basin may be influenced by several factors such as: ecological issues and physical processes (Ganio *et al.,* 2005; Hoef *et al.,* 2006), morphology of the network (Ferreira *et al.,* 2016; Filipa *et al.,* 2017), physicochemical (Buisson *et al.,* 2007) and structural variables of the basin (Ganio *et al.,* 2005). However, in our study structural variables showed a weak predictive power that did not allow us to explain the distribution patterns indicated in the predictive maps. Probably, it is due to the low fluctuation of elevation, slope and fluvial order that the basin presented (Jaque 1996) in relation to a basin of Andean origin (Habit and Victoriano, 2005) and to the variability that can present the data.

On the other hand, spatio-temporal variability and data independence in geostatistical analyzes are requirements that are not always met (Carroll and Pearson, 1998) and in the freshwater stream spatial environments autocorrelation is an intrinsic characteristic (Townsend, 1996; Peterson and Ver Hoef, 2010) which agrees with the results obtained with the general index of Moran in this study. In addition, through the Getis Ord index it was possible to describe a marked hotspot of species richness in the terminal stretch of the Andalién near the discharge of the Nonguén stream, and a coldspot of diversity in the rithron of the basin, specifically in the streams Las Puyas and Curapalihue local, concordant with the statistical analyzes described in this research.

CONCLUSIONS

The results of this study allow us to conclude that the application of geostatistic techniques of prediction and interpolation maps facilitate the establishment of patterns of distribution and species clustering, in this case, the fish assemblage of Andalién network, and thereby generate the bases of information to determine actions and decisions for effective conservation areas for species with endanger conservation status, especially this network which is located in a relevant ecoregion for native and endemic fish species in Chile.

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