

Distribution of Benthic Flora in the Lower Course of the Valdivia River, Chile

CARLOS RAMÍREZ

HERIBERTO FIGUEROA

Institutos de Botánica y Estadística

Universidad Austral de Chile

Casilla 567, Valdivia, Chile

ENRIQUE HAUENSTEIN

DOMINGO CONTRERAS

Departamento de Ciencias Naturales

Universidad Católica de Chile, Sede Temuco

Casilla 15-D, Temuco, Chile

ABSTRACT: The Valdivia River (Lake Region, Chile) originates in Riñihue Lake and flows into the sea at Corral Bay (39°52' S latitude), changing names several times along its course. The aquatic benthic flora (algae and aquatic plants) of the Valdivia River was characterized, based on 22 sites sampled and 124 plant species collected. Four benthic vegetation zones were established using presence-absence data: a freshwater zone and a marine zone were found at the extremes of the transect; an estuarine zone and a discontinuity zone were detected in the middle of this transect. The freshwater zone was characterized by a relatively diverse assemblage of vascular plants, the marine zone was dominated by algae and was rich in species. By contrast, the estuarine zone was inhabited by only a few species but in great abundance, while the discontinuity zone was poor in species and low in cover vegetation.

RESUMEN: El río Valdivia (X Región, Chile) nace en el lago Riñihue y desemboca al mar en la Bahía de Corral (39°52' L S), cambiando varias veces de nombre a lo largo de su curso. Se estudió la flora acuática bentónica (algas y plantas acuáticas) de este río, en 22 lugares de muestreo, colectándose 124 especies. Utilizando datos de presencia/ausencia se establecieron 4 zonas de vegetación bentónica: una zona limnica y otra marina, en ambos extremos del transecto, y en el medio de él, una zona estuarina y otra de discontinuidad. La zona de agua dulce se caracterizó por poseer una mayor diversidad de especies de plantas vasculares, en la zona marina dominaban las algas. Por el contrario, la zona estuarina presentó pocas especies pero abundantes, mientras que la zona de discontinuidad presentó muy pocas especies y con baja cobertura.

Introduction

Freshwater and marine environments usually are separated from one another by a transition region in the lower courses of rivers, in estuaries, and at the outlets of the rivers to the sea (Ottmann 1967). In the zone closest to the marine environment, there is a brackish estuarine region with high biological productivity (Dürschmidt 1978). There is usually a discontinuity zone toward the head of the estuary characterized by desert-like littorals (Díaz-Piferrer 1967). This zone of discontinuity, which mainly affects the benthic flora and fauna, is known as "impoverished brackish water" (Santelices 1980). This zone has a great reduction in halophytic species without an increase in freshwater species. The aim of this investigation is to determine the location and extent of the estuarine discontinuity zone in the littoral benthic flora of

the Valdivia River and its outlet at Corral Bay, Province of Valdivia, Lake Region, Chile.

Study Area

The climate in the region of the Valdivia River is humid temperate (Di Castri and Hajek 1976). The average annual rainfall is 2,415 mm; July is the rainiest month (393 mm) and January is the driest (64 mm). The average annual temperature is 12.1 °C, July is the coldest month (7.6 °C) and January the warmest (16.9 °C). The average relative humidity in the region is 78%. A north wind prevails in winter and a west wind in spring and summer (Huber 1970).

The estuarine environment under study is the lower course of a large river that flows from Riñihue Lake to the sea. The river is called San Pedro from its source to the city of Los Lagos. Here it

changes names to the Calle-Calle River. Finally at the city of Valdivia, it once again changes names, becoming the Valdivia River. The river has a total course of 110 km. Its source is 117 m above sea level and its outlet is located at 39°52'S latitude in the Pacific ocean.

The San Pedro River is fast-flowing, passing through a narrow ravine. When it becomes the Calle-Calle River, the current decreases and the course of the river becomes winding, thus allowing the formation of small islands with gravel beaches. The Valdivia River is wider, with less current, and its banks are generally swampy. At Corral Bay, sandy beaches alternate with rocky zones of flag stone ("piedra laja") and cemented volcanic tuff ("cancagua") (Ramírez et al. 1981).

The Valdivia River has an average width of 700 m, and reaches its maximum width (1,000 m) at the Cutipay, between Valdivia and Corral Bay (Arenas 1971). In this last site, the annual mean waterflow is $1,000 \text{ m}^3 \text{ s}^{-1}$ (ENDESA 1972). The river's maximum depth (18 m) is at the City of Valdivia. The river is important as a navigation route as well as a discharge for sewage waters. In Illies's (1961) classification, it is a potamon, since it has little current, a laminar surface, and a muddy substrate. The water level varies seasonally with flooding in winter. Swamplands caused by the sinking of the ground during the 1960 earthquakes are found along the course of the river (Gunckel 1963; Illies 1967).

From the source to the city of Valdivia the river is fresh. From there to the outlet there is a gradual increase in salinity from mixooligohaline to mixopolyhaline (Arenas 1971). The river is isothermal from autumn to winter. During the rest of the year, a vertical thermal gradient is observed, due to the influence of marine waters. The pH fluctuates between 6.6 and 7.4 (Campos et al. 1974). The river is oligotrophic; its soft water (Campos 1979) has little nitrate or phosphate pollution (Dürschmidt 1978). Recently, however, a certain amount of organic contamination from sewage discharge has been observed (Jara 1981).

Materials and Methods

Twenty-two stations on the Valdivia River, between Antilhue (Calle-Calle River) and Corral Bay, were sampled for benthic aquatic flora (Fig. 1). The benthic algae and aquatic plants from each sample site were identified and classified according to Ramírez et al. (1981a, 1982). The different sites were chosen for accessibility, elevations, and depressions. Five-meter, perpendicular transects were established on the river bank. All the species found there were recorded without taking into account their abundance. A sample limit was estab-

lished parallel to the shore, above which the flora was considered to be terrestrial. Thus, samples for this study were considered aquatic or helophytic when the plants were collected in the hydrophase or in the littoral phase, respectively (Ramírez and Stegmaier 1982). Salinity was measured on-site with a portable conductivity meter.

From the samples, a presence-absence table was constructed showing 22 cases (sites) and 124 variables (species) (the original tables with a complete species list, by location, is not included, but is available from the authors). The frequency of the species (number of sites at which a species was found) and their number per sample (number of species found at a site) were analyzed, separating algae from aquatic plants. This information was then put into a data bank, fed into a computer, and was subjected to statistical analyses both to group sites according to similarity in their arrays of species and to group species according to similarity in their sites of occurrence.

Gradients in the distribution of the species in the Valdivia River and Corral Bay were determined using polar ordination (Bray and Curtis 1957; Contreras et al. 1985; Figueroa et al. 1986). The floristic correlation among the various sites surveyed was then estimated. This correlation matrix was used for classification analysis. To put cases (samples) and variables (species) in order, factor analysis was used (Ramírez and Figueroa 1985). Principal components analysis was used to display the relationships among species and among sites according to the synthetic factors defined by the analysis (Anderson 1974; Morrison 1976). Cluster analysis was applied to the cases and variables, using absolute correlation value as a measure of floristic similarity. To form groups and to draw a dendrogram, the single linkage method (nearest neighbor clustering) was used.

Results

One hundred twenty-four plant species were collected from 22 survey sites. Seventy-five of the species (60.4%) were macroscopic algae while 49 (39.5%) were vascular aquatic and marsh plants. The phycological flora is richer than that of the higher plants in the lowest 5 km course of the Valdivia River as well as in Corral Bay. The majority of the species have frequency values below 50% and only 3 reach higher values: *Scirpus californicus*, *Rhodomela* sp., and *Enteromorpha intestinalis*. *Scirpus californicus*, collected in the first twelve sites surveyed, is a freshwater marsh plant which extends into brackish zones (i.e., between San Javier and Cutipay). The species from the *Rhodomela* genus is a small, filamentous red alga of brackish zones which was only found in sample sites 6 to 16.

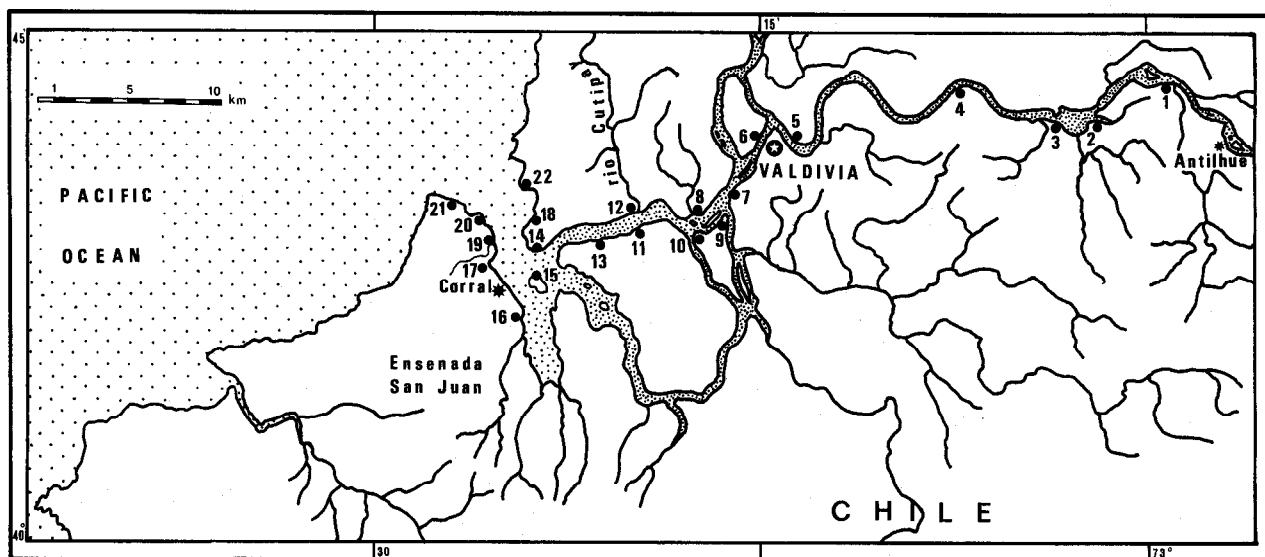


Fig. 1. Location of the vegetation sampling sites in the Valdivia River and Corral Bay, Chile, 1 = San Javier, 2 = Chincún, 3 = Pishuínco, 4 = Huellehue, 5 = Calle-Calle bridge, 6 = Pedro de Valdivia bridge, 7 = Las Mulatas, 8 = Toro Bayo, 9 = Isla Mota, 10 = Tres Bocas, 11 = Isla del Rey, 12 = Cutipay, 13 = Carboneros, 14 = Playa del Piojero, 15 = Isla Mancera, 16 = Punta Rama, 17 = Corral, 18 = Niebla, 19 = Amargos, 20 = San Carlos, 21 = Aguada del Inglés, and 22 = Los Molinos.

Enteromorpha intestinalis, a green alga, had the highest frequency (72.7%); it was collected from the mouth of the bay to the Las Mulatas river port (site 7).

Salinity affects algal and vascular plant abundance (Fig. 2). The sites on the western bank of Corral Bay (Punta del Piojero, Niebla, and Los Molinos) have high salinity and the largest number of algal species sampled. The number of aquatic and marsh plants per site increases from site 1 (San Javier) to site 7 (Las Mulatas), where it reaches its peak. From there, it rapidly decreases to site 12 (Cutipay) where the last representatives are found. There are no vascular aquatic or marsh plants in Corral Bay. The number of algal species gradually starts to increase in sample 14 (Playa del Piojero); however, the curve shows depressions in the sites with low salinity on the western edge of the bay.

A 9-km long discontinuity zone was observed between sites 10 and 13 (Tres Bocas and Carboneros), where both floras (phytological and higher plants) are low in number. It is an unfavorable area for plant development since the salinity is too high for the aquatic plants, but is too low for the growth of algae. Only a few brackish water plants grow in this area, such as *Potamogeton pectinatus*, *Zannichellia palustris*, and *Enteromorpha intestinalis*. The peak in the number of aquatic and marsh plants at site 7 is due to the stillness of the water, as well as to the existence of wetlands with permanent flooding.

Three groups with different degrees of floristic similarity were distinguished by ordination analysis (Fig. 3). One is formed by the first 9 sites, which

are somewhat far apart from each other. Only samples 5 and 6, taken from the urban radius of the city of Valdivia, are close together. A very remote and isolated group is formed by samples 10 and 11 which are found on the other extreme of the figure. The remaining sites are found in the upper half of the diagram. Here, samples 18 through 22 are very close together, while the rest are more dispersed. This diagram confirms the presence of two gradients: a marine algae and a freshwater plants gradient, separated by a discontinuity zone between sites 10 and 13. Furthermore, greater affinity is shown among the sites on the mouth of the bay, with macroscopic algal vegetation, than is

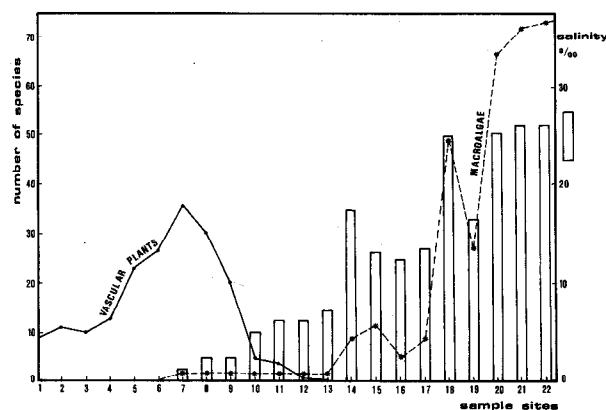


Fig. 2. Number of aquatic plant and algae species in each of the 22 sampling sites. The bars indicate the annual average salinity at the sites.

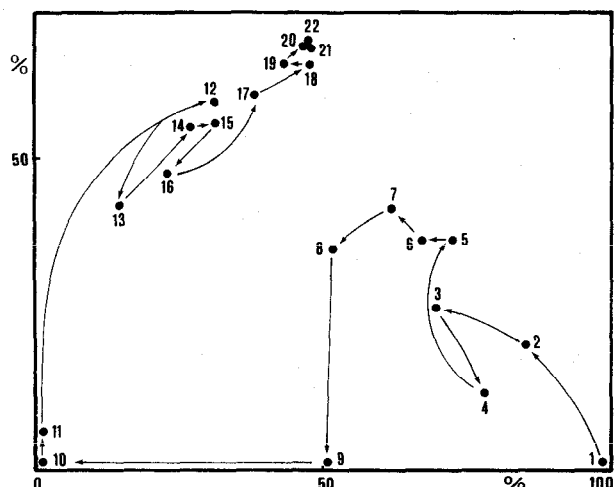


Fig. 3. Ordination after Bray and Curtis (1957) of the sampling sites. Censuses 1 and 10 were used in the first arrangement as extreme points and in the second one, censuses 9 and 22 as they were the most different ones. The arrows show the order of the censuses in the field. The axes correspond to a percentage of similarity.

seen among the sites in the river, which include aquatic and marsh plants.

The distribution of the main species of algae, marsh plants, and aquatic plants on the first two axes of the factor analysis is shown in Fig. 4. The algae tend to be located on the left and in the lower part of the diagram while the aquatic plants are on the upper right. The horizontal axis, because of the arrangement of the species, can be attributed to the salinity gradient which increases from right to left. The vertical axis can be related to the current gradient or rather to water movement which increases in the figure from bottom to top. The species located in opposite quadrants have different ecological requirements. For example, the majority of the aquatic plants are opposite the algae, especially the brown algae. *Enteromorpha intestinalis* as well as the species of the *Rhodomela* genus are also opposite the brown algae. A great ecological affinity is observed between *Egeria densa* and *Scirpus californicus*, though the first is submerged and

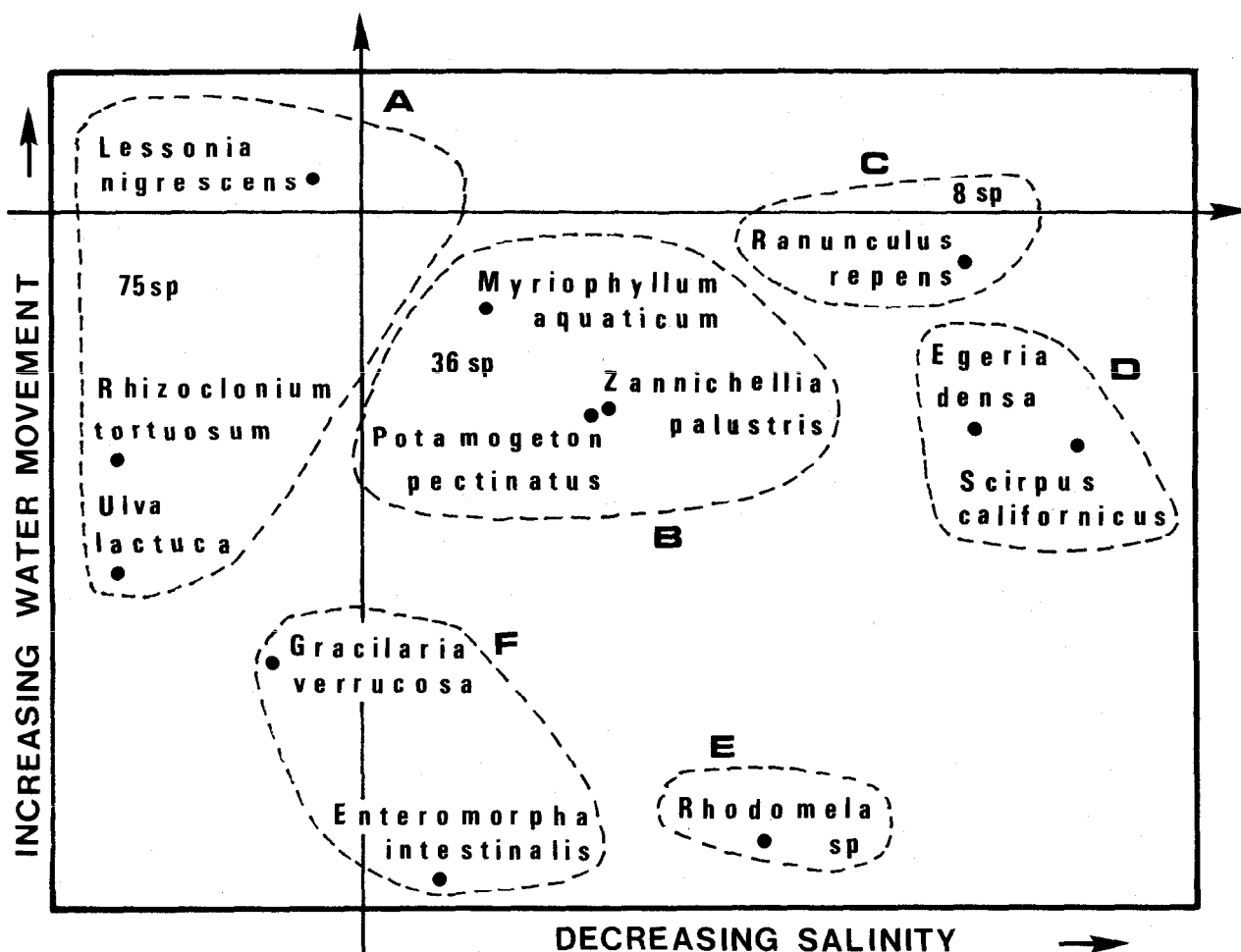


Fig. 4. Distribution of the species along the first two axes of the factorial analysis. The dotted lines link the groups defined by the cluster analysis (information on the cluster analysis is available from the authors). Top quadrants = high water movement, bottom quadrants = quiet water, left quadrants = high salinity, right quadrants = brackish and freshwater.

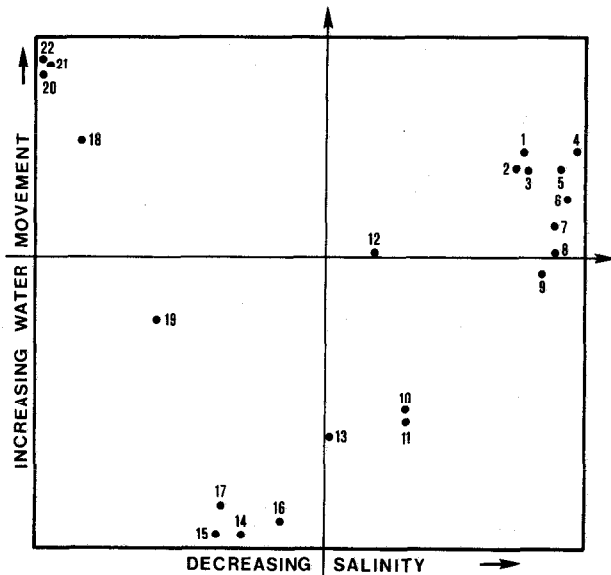


Fig. 5. Distribution of the 22 sampling sites along the first two axes of the factorial analysis. The ecological conditions represented by the quadrants are shown in Fig. 4.

the second is emergent, and between *Rhizoclonium tortuosum*, *Ulva lactuca*, and *Gracilaria verrucosa*, which are placed in the bottom left quadrant with less salinity and minor water movement (Fig. 4). The position of *Myriophyllum aquaticum*, *Zannichellia palustris*, and *Potamogeton pectinatus* is explained by the fact that they tolerate salinity.

The distribution of the sites on the first two axes of the factor analysis is shown in Fig. 5. Sample 12 is not clearly differentiated, on the axis and is isolated. The first samples, which correspond to the sites on the Calle-Calle and Valdivia rivers, are close together in the quadrant of flowing freshwater. Samples 10, 11, and 13 are found in the lower part of the diagram, indicating less water flow and greater salinity. These conditions are accentuated in samples 14, 15, and 17 which are typical estuarine locations in Corral Bay. Finally, samples 18 through 22 are located in the quadrant of greatest salinity and wave action, typical of marine environments. Sample 19 appears somewhat separate because it was in a protected inlet. The distribution of the samples on the diagram reflects their location in the field: the riverine locations on the upper right hand side, samples from the mid-estuarine zone or Corral Bay and San Juan Inlet in the lower center, and finally, the sites on the mouth of the bay, with greatest marine influence, on the upper left. Samples from the discontinuity zone tend to be closer to the intersection of the axes, thus indicating little differentiation with respect to the axes.

Based on the dendrogram (Fig. 6), five groups

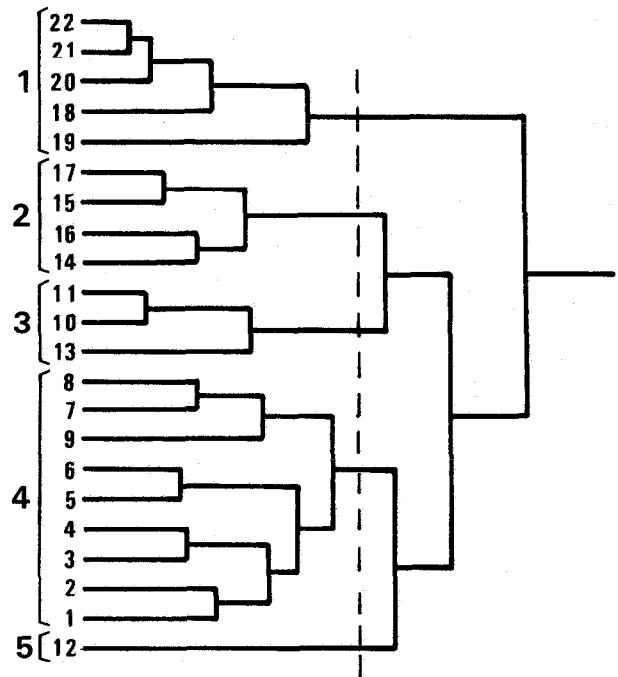


Fig. 6. Dendrogram of the floristic similarity among the 22 sampling sites of the Valdivia River and Corral Bay. The dotted line shows the similarity which was considered to establish the groups.

were identified according to their floristic similarity. The first group was comprised of the samples 18 to 22 corresponding to the estuary mouth. The second group was formed by four samples from Corral Bay and San Juan Inlet, including sites 14 and 17. Here, the environment is estuarine. The third group, characterized by a noticeable lack of species, was formed by the sites just east of Corral Bay (10, 11, and 13). This zone represents the estuarine discontinuity of the benthic flora mentioned in the introduction to this paper.

The fourth group includes the samples from the freshwater environments of the Calle-Calle and Valdivia rivers, which groups all samples from the initial segment of the transect (i.e., from San Javier (1) to Mota Island (9)). Site 12, located 200 m from the outlet of the Cutipay River where there are low salinity marshlands (Fig. 1), appears isolated in the dendrogram, thus forming a fifth cluster. Perhaps its isolation is due to the low number of species present and the mixture of algae and vascular plants, or to the geomorphology of the site.

The 124 plant species of the transect were classified into five groups. The first group consists of 72 algal species. The second group contains 39 aquatic and marsh species from limnic and brackish areas. The third group contains eight halophytic species from limnic environments which also form part of the vegetation of the moist grasslands of

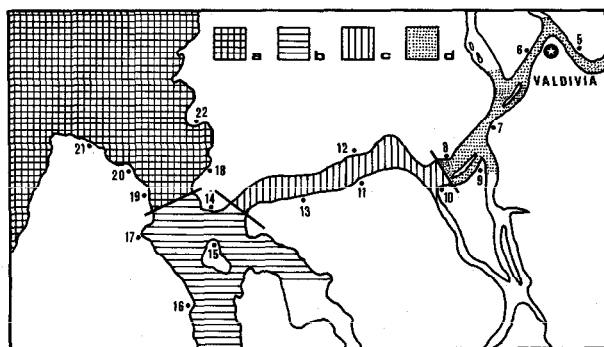


Fig. 7. Zonation of the lower course in the Valdivia River according to these results. The numbers indicate the sampling sites. a = marine zone, b = estuarine zone, c = discontinuity zone, d = limnic zone.

southern Chile. The fourth group is formed by *Egeria densa*, *Scirpus californicus*, and one species of the *Rhodomela* genus. *Scirpus californicus* is abundant in the marshes of southern Chile while *Egeria densa* is restricted to the basin of the Valdivia River. The last group is formed by the algae *Gracilaria verrucosa* and *Enteromorpha intestinalis* which possess euryhaline characteristics.

Discussion and Conclusions

Marsh plants exhibit a marked seasonality in their phenological development (Ramírez and Añazco 1982). During the winter, large amounts of biomass produced during the spring and summer are deposited as detritus on the bottom of the water body. In this way, the marsh plants alter the environment; they raise the riverbed and reduce the water depth (Ramírez and San Martín 1984). This allows terrestrial vegetation to move into the aquatic environment in a process of succession (Steubing et al. 1980). Dead algae eroded by waves are carried away by tides and are deposited on beaches as wrack (Westermeyer and Ramírez 1979). This wrack produces a clear separation between the zones of littoral algae and terrestrial vegetation which normally lacks vegetation or is only colonized by crustacean lichens (Alveal and Romo 1977). However, in the littoral zone of the river, aquatic vegetation gradually changes to terrestrial vegetation, without an interruption between them.

According to this study's results, the lower course of the Valdivia River can be classified by its benthic flora of macroalgae and vascular macrophytes into four vegetation zones. There is a riverine zone with freshwater aquatic and marsh plants in the upper part of the river and, at the other end, there is a marine zone characterized by macroscopic benthic algae. Between the riverine and the marine zones two brackish zones were found. One is an estuarine zone where the phycological flora is reduced from

TABLE 1. Classification of the sampling sites resulting from all the analysis.

Groups	Samples	Environment
1	18, 19, 20, 21, 22	marine
2	14, 15, 16, 17	estuarine
3	10, 11, 13	discontinuity zone
4	1, 2, 3, 4, 5, 6, 7, 8, 9	riverine
5	12	riverine

that of the marine zone and vascular macrophytes are absent. The other zone, which includes samples 10 and 13 and has an extension of about 9 km (Table 1, Fig. 7), is the "estuarine discontinuity zone." Here, a drastic impoverishment of all benthic flora is noted. This part of the estuary flows through a somewhat narrow ravine, bordered by high terraces of erodible, cemented volcanic tuff. Its bed has a notable lack of sediment. Here, the average yearly salinity oscillates between 7‰ and 15‰ and the tidal influence is strong due to the narrowness of the river. This, in turn, impedes the accumulation of sediment. A marked decrease of the sessile fauna has also been observed here. Only beds with mussels (*Mytilus chilensis*) and barnacles (*Elminius kingii*) are found here (Poblete and Deppe 1978). Since the highest density is found in this area (Arenas 1971), the latter species could be considered characteristic of the zone.

The impoverishment of the benthic flora in the estuarine discontinuity zone is marked. Only two euryhaline algae were found in this zone (*Enteromorpha intestinalis* and *Rhodomela* sp.), plus three submerged macrophytes (*Potamogeton pectinatus*, *Zannichellia palustris*, and *Myriophyllum aquaticum*) and two marsh species (*Scirpus californicus* and *Egeria densa*), the first emergent and the second submerged. These last two species have a wide distribution in the Valdivia River because they can tolerate moderate salinities as well as fresh water. During the winter, *Egeria densa* is present in Corral Bay when the greater flow of the river dilutes the water of the bay. *Myriophyllum aquaticum*, under experimental conditions, can withstand a salinity of up to 10‰ when submerged (Haller et al. 1974). *Egeria densa*, on the other hand, only flourishes in salinities up to 5‰ (Hauenstein and Ramírez 1986).

In the estuarine discontinuity zone, the salinity is too low for most algae, but is high enough to hinder the development of most aquatic plants. The wave movement may be insufficient for the growth of larger algae. A sea water wedge, which decreases the temperature at the bottom, is noticeable during the rising tide. The water in the zone is not well oxygenated.

The riverine and estuarine zones encompass a wider range of environmental conditions than the

marine zone, yet the algal flora is much richer in species in the sea. The freshwater flora is poorer in species but includes a greater diversity (Ramírez and Stegmaier 1982). This permits a greater number of different plant associations; however, not as many are noted as in terrestrial situations (Ramírez et al. 1976, 1979, 1980).

The variety of aquatic plants is highest in freshwater environments, low in brackish environments, and very low in the marine environments of the temperate zone (Ramírez and Stegmaier 1982); however, aquatic and marsh plants reached their highest abundances at the sites that border the discontinuity zone. In this zone, subsidence caused by the 1960 earthquakes has led to the development of marshes which, today, are a refuge for wildfowl. Jara (1981) attributed the proliferation of reeds and submerged plants to the sewage discharges to this part of the river.

The slow currents and small wave action of the zone may also contribute to the profuse growth of plants along the shore by allowing the establishment and development of stands of rooted plants.

Sediment deposition occurs in Corral Bay due to the widening of the course as well as to the slowing down of the current. However, salinity is so high that it does not allow the development of most vascular plants. Instead, immense banks of *Gracilaria verrucosa* have grown here (Ramírez et al. 1981), even occupying the living space needed by *Mytilus chilensis* (Poblete and Deppe 1978). Marine algae prefer a firm, rocky substrate, while a swampy substrate, with plenty of organic sediment, is favored by vascular discontinuity macrophytes.

The absence of submerged vascular plants in the marine zone studied may be due to the mild weather of the region. The sea grasses are abundant in warmer water. The only species belonging to this group in Chile has been the *Heterozostera tasmanica*, which was found in Coquimbo, Bahía de la Herradura (30° S latitude) (Ramírez et al. 1979).

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