RELATIONSHIPS BETWEEN CHANGES IN HABITAT CONDITIONS AND POPULATION DENSITY OF AN INTRODUCED POPULATION OF SIGNAL CRAYFISH (*PACIFASTACUS LENIUSCULUS*) IN A FLUVIAL SYSTEM.

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ABSTRACT

After the disappearance of the native crayfish in many rivers in Biscay, Basque Country, Spain, the signal crayfish *Pacifastacus leniusculus* was introduced in the main fluvial stretches and several breeding populations have established. One of the most productive zones was the Cadagua River, where the population was established from 1989 (first introduction) to 1995. Starting from that year, a marked decrease in population was recorded downstream, and this fact is studied in relation to fluctuations in physical and chemical conditions caused by human perturbations in the fluvial corridor mainly caused by the construction of a road.

Key-words : *Pacifastacus leniusculus*, crayfish, non-native species, population, river, ecology, road construction, Spain.

RELATIONS ENTRE LES VARIATIONS DES CONDITIONS D'HABITAT ET DE LA DENSITÉ DE POPULATION D'UNE POPULATION INTRODUITE D'ÉCREVISSE SIGNAL (*PACIFASTACUS LENIUSCULUS*) DANS UN SYSTÈME FLUVIAL.

RÉSUMÉ

Après la disparition de l'écrevisse autochtone (à pieds blancs) de beaucoup des fleuves de Biscaye (Pays Basque, Espagne), l'écrevisse signal *Pacifastacus leniusculus* a été introduite dans des tronçons des principaux fleuves et quelques populations s'y sont établies. La rivière Cadagua était une des zones les plus productives où une population avait été établie avec succès depuis 1989 (première introduction) jusqu'en 1995. À partir de cette même année, un fort déclin de la population a été observé en aval et ce fait a été mis en rapport avec les fluctuations des conditions physiques et chimiques dues aux perturbations humaines dans le corridor fluvial liées à la construction d'une route.

Mots-clés : *Pacifastacus leniusculus*, écrevisse, espèces allochtones, population, rivière, écologie, construction de routes, Espagne.

INTRODUCTION

In many European countries the signal crayfish *Pacifastacus leniusculus* Dana (originating from the Sacramento river, California) was introduced from America as a supposedly vicarious (ecologically homologous) species to replace the almost-disappeared native species in terms of both ecological roles and human fishing demands, and also (so

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was thought at the date) to stop the invasion of the exotic crayfish *Procambarus clarkii* Girard, the « red swamp crayfish », introduced in a non controlled manner from astaciculture plants (MASON, 1977 ; MATTHEWS *et al.*, 1993 ; ALONSO *et al.*, 2000).

In the year 2000 in the Basque Country, the native crayfish *A. pallipes* is only found in small springs, at the headwaters of certain rivers and in some isolated ponds (ALONSO *et al.*, 2000 ; GARCÍA-ARBERAS and RALLO, 2000 ; RALLO and GARCÍA-ARBERAS, 2000). Healthy populations of the red swamp crayfish can be found, but in restricted and non expanding areas (ponds, lower part of some rivers influenced by salt marshes), and the signal crayfish *Pacifastacus leniusculus* is living in main fluvial stretches, where fishing has been allowed since 1995. One of the most productive zones was the Cadagua River, where average productivity rates of 0.1 g/g per day have been recorded (GARCÍA-ARBERAS *et al.,* in publication). But since that same year a decline in population numbers, and even a disappearance of crayfishes, has been recorded in the lower part of the stretch. The aim of this work is to find out the possible causes of this situation.

STUDY AREA

The Cadagua river drains a 577 km^2 area in the northern basins of the Iberian Peninsula, carrying waters to the Bay of Biscay (Figure 1). A general description of basins in the Basque Country is recorded in DOCAMPO *et al.* (1991). The Cadagua basin has two parts. The first runs from the river sources to the town of Balmaseda (Valle de Mena ; catchment area = 309 km^2), and features dispersed agroforestry land uses. The condition of the river is very natural and well conserved, but it runs through a diapiric (salt and gypsum) area, which causes high conductivity values. In the second part, from Balmaseda (about 7 000 habitants) to the Nervión estuary near Bilbao, industrial, urban and tertiary uses are mixed with traditional farmsteads. Water is taken away for urban supplies, and urban and industrial waste waters are collected and processed in sewage plants. The year on year average discharge of the Cadagua is 10.2 m^3/s (ORIVE and RALLO, 1997).

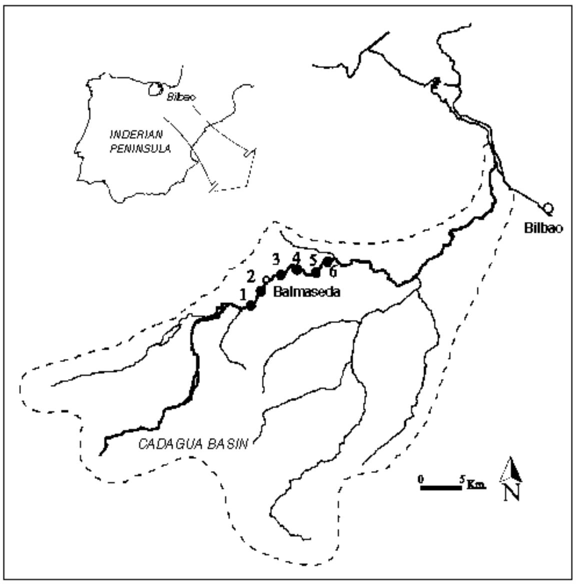

Figure 1
Map of the study area : the Cadagua river catchment area.

Figure 1
Carte de la zone étudiée : le bassin de la rivière Cadagua.

Historically, the native crayfish *A. pallipes* inhabited the Cadagua fluvial network, including the 15 km long-stretch from sampling point 1 to sampling point 6. Riverside people used to catch them as a much-appreciated fishing resource. Changing of land uses first, and subsequently aphanomycosis did away with the crayfish fauna in the main course of the river at least ten years before the introduction of the signal crayfish.

METHODS

In the autumn period for seven years (from 1993 to 1999), up to six sample sites on the 15 km stretch of the Cadagua river from sampling point 1 (just upstream from Balmaseda, in the well conserved part) to sampling point 6 were visited. At each site a minimum reach length of 500 m was studied.

Relative abundance of crayfish

Crayfish were captured using a set of forty trap devices (cylinders : 40 cm long x 25 cm diameter ; 8 cm opening door included in the inverted entry cones at both ends), baited with ox heart placed at sunset. Animals were collected next morning, measured and put back into the river. Population numbers were estimated by the average number of individuals per trap at each sampling site in each year. That index of catchment effort showed a good correlation to theoretic population estimates calculated by capture-recapture methods, which were applied whenever possible (SKURDAL *et al.*, 1995 ; RALLO *et al.,* 1998 ; GARCÍA-ARBERAS *et al.*, in publication).

Habitat characterisation

At the sampling site, water temperature, pH, conductivity and dissolved oxygen concentration were measured. Samples of water were taken in plastic bottles, refrigerated and sent to be analysed (for hardness, chlorides, sulphates, sodium, potassium, magnesium, silica, phosphates, calcium, nitrates, nitrites and ammonium) in a certified laboratory using standard methods (APHA-AWWA-WPCF 1994). Data on river size (depth, width) and flow velocity (to calculate instantaneous discharge), riverbank vegetation and substrate were also recorded.

Statistical analyses

Standard descriptive statistics were used to test the normal distribution of variables, learn their behaviour and use adequate data analysis procedures (SOKAL and ROHLF, 1981). Before any other data processing, original values were normalised if required (Log transformation in the cases of discharge, nitrites and phosphates).

For each variable, variance analysis was used to look into the differences between cases classified by sampling site, year and period (defined as per Results below). Modelling was made by discriminate analysis (forward adding of variable method). All the data analyses were made using STATGRAPHICS Plus 4.0.

RESULTS

Introduction of species and population establishment and decline

The introduction of the exotic species began in 1989, some years after the disappearance of the native crayfish, when juveniles of *Pacifastacus leniusculus* were put into the Cadagua river stretch previously cited. The populations were reinforced yearly up to 1996 (RALLO *et al.,* 1998 ; GARCÍA-ARBERAS *et al.*, in publication). By 1992 a population of *Pacifastacus leniusculus* was well established. The evolution of the introduced population was monitored firstly by field observations of specimens or moulting parts in the river. When the success of the introduction was confirmed, an evaluation of population numbers in sequential adjacent zones was made. The average of individuals trapped per catchment-effort unit increases from 1993 to 1994 ; increment stops in 1994-95 and a major decline is recorded in 1996-97. After that a new increment in population numbers is detected. Associated errors are large in 1996 and 1999 (Figure 2).

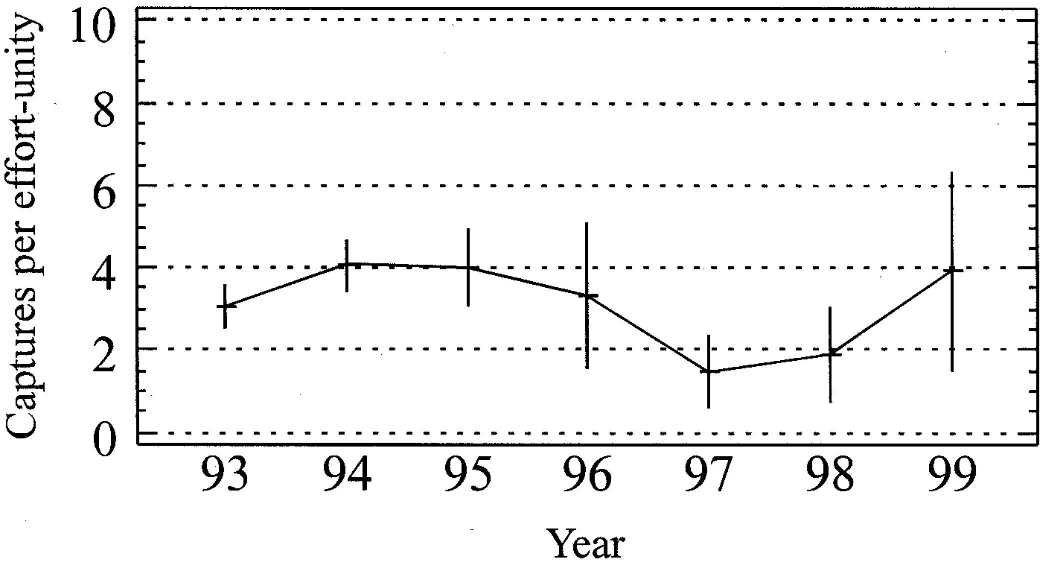

Figure 2

Evaluation of averages and associated errors of population-number estimates of *Pacifastacus leniusculus* population for 1993 to 1999 on a 15-km stretch of the Cadagua river.

Figure 2

Évaluation des valeurs moyennes et de l'erreur associée aux estimations numériques de la population de *Pacifastacus leniusculus* de 1993 à 1999 dans le tronçon de 15 km du fleuve Cadagua.

But this population decline is not homogeneous all along the river stretch. Two substretches can be observed : upstream, including two sampling sites, and downstream, with the other four sites (Figure 3). These substretches show very different behaviour patterns : whilst the downstream stretch (where the population density was previously higher) suffers the decline from 1994 onwards, and loses crayfish fauna in 1997, the upstream stretch is almost unaffected, showing only a slight population decline in 96-97 (maybe because of natural fluctuations ?). In this part of the river, population numbers are not only recovered but also increasing in 1999 (and this trend seems to be corroborated by the 2000 data, which have not been completely studied yet). The analysis of the variance (taking into account interactions between stretch and time period) shows significant differences (F-ratio = 32.3, p-value = 0.000, n = 42) (Figure 4).

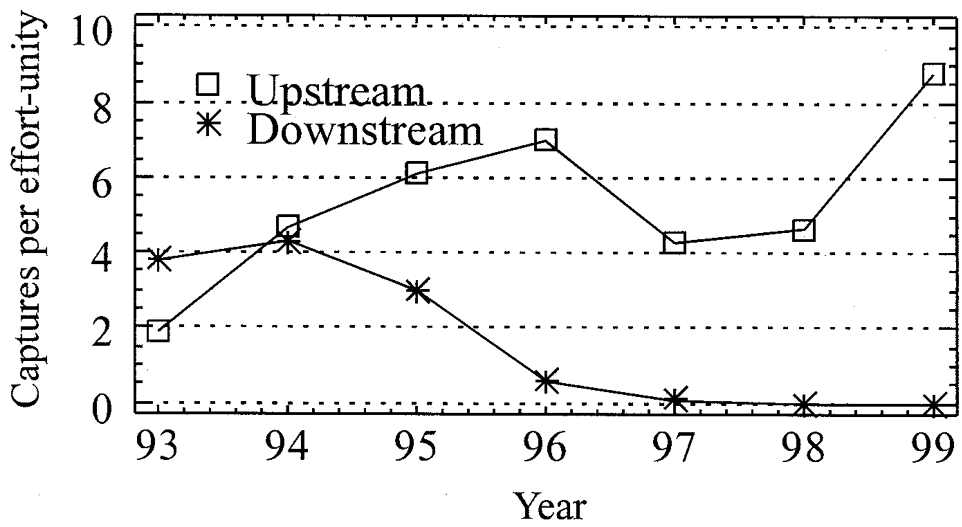

Figure 3
Evaluation of averages and associated errors of population-number estimates of *Pacifastacus leniusculus* population for 1993 to 1999 on two substretches defined by a possible zone of habitat perturbation in the Cadagua river.

Figure 3
Évaluation des valeurs moyennes et de l'erreur associée aux estimations numériques de la population de *Pacifastacus leniusculus* de 1993 à 1999 dans les deux sous-tronçons définis selon une possible zone d'habitat perturbé dans le fleuve Cadagua.

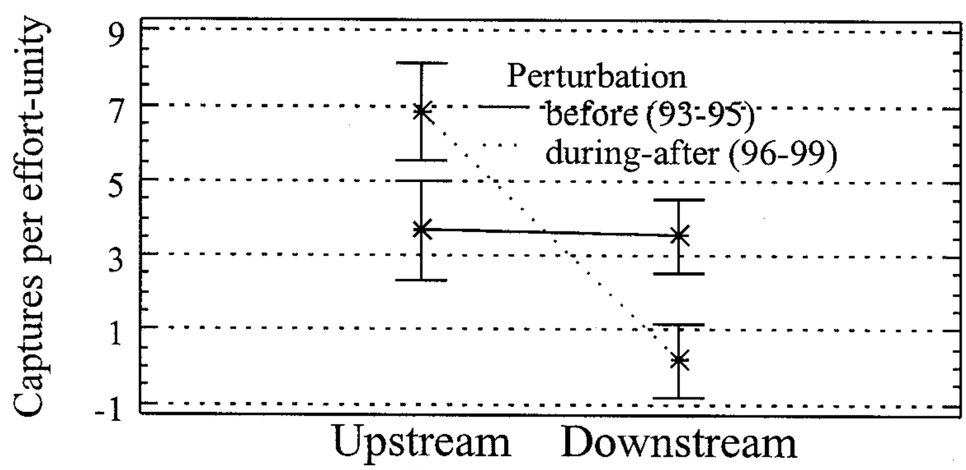

Figure 4
Average values and 95 % percent confidence intervals of the population estimates of signal crayfish in the Cadagua river, considering interactions between fluvial stretches (upstream and downstream) and period (1993-95 and 1996-99).

Figure 4
Valeurs moyennes et intervalles de confiance pour des estimations de la population de l'écrevisse signal dans le fleuve Cadagua tenant compte des interactions entre le tronçon fluvial (amont et aval) et la période (1993-95 et 1996-99).

Physical and chemical river conditions

The physical and chemical conditions of fluvial water have been measured (Table I). Possible differences or changes in values of each of the variables by stretch and period are investigated using ANOVA. As regards substretches no significant differences were detected except in incompletely oxidised nitrogenous compounds (ammonium and nitrites) (significant at 99.9 %) and perhaps phosphates (at 90 %), whose mean concentrations are markedly higher downstream. The pH also changes : it is slightly lower in this part of the river.

In terms of periods, many highly significant differences are evident in calcium, chloride, carbonate, potassium, magnesium, silica and sulphate concentrations and also in conductivity and hardness (above 95 %) and sodium (almost reaching the 95 % significance level). Unlike the substretches, it seems that there are no significant differences in variables belonging to the nutrients group (nitrogen compounds and phosphates).

An exploratory classification of the waters of the Cadagua river based upon its overall chemistry conditions shows that most of the variables can be grouped in three clusters (Figure 5A) : 1) major variables as a mineralization cluster, with two subgroups : calcium and hardness, and sulphate, magnesium, chloride and sodium, related to diapiric sites with marine salt and gypsum, 2) nitrates and potassium (suggesting a fertilizer origin), and 3) nitrites and ammonium, mainly related to urban runoff. The rest of the dissolved ions, bicarbonates, phosphates and silicates, plus conductivity and pH, do not group at a reasonable level (as defined in Statgraphics by the Agglomeration Distance Plot). But if the supposedly impacted downstream substretch is considered by itself (Figure 5B) a new group appears relating silica to pH. This relation supports the idea that an increase in silica (related to pH decline) is caused by runoff discharges from nearby land.

Table I

Means and standard deviations for the values of physical and chemical variables. N = 42. Data are in mg/l, except discharge (m^3/sg), conductivity (µS/cm), hardness (French degrees) and pH (Significant at 95 % or more. * Significant among 90-94.9 %). For ANOVA, data were normalized when required (Log of discharge, NO_2 and PO_4).**

Tableau I

Valeurs moyennes et écart types des variables physiques et chimiques. N = 42. Les donnés sont en mg/l, sauf l'écoulement ($m^3.sg^{-1}$), la conductivité ($µS.cm^{-1}$), la dureté (degrés français) et le pH (signification à 95 % ou plus. * signification entre 90-94.9 %). Pour l'ANOVA, les données ont été normalisées si nécessaire (log de l'écoulement, NO_2 et PO_4).**

	All data	Two period data				Two stretches data			
Variable		1993-95	1996-99	F-ratio	P-value	Upstream	Downstream	F-ratio	P-value
Ca^{++}	84.93 ± 19.98	93.12±20.29	77.12±16.61	*9.39*	0.004**	86.06 ± 22.85	84.27 ± 18.57	*0.29*	0.596
Flow	2.49 ± 1.72	2.55 ± 2.02	2.44 ± 1.42	*0.17*	0.678	2.78 ± 1.59	2.33 ± 1.72	*1.30*	0.262
Cl^-	34.30 ± 15.11	38.85 ± 15.33	29.96 ± 13.88	*4.92*	0.031**	34.88 ± 15.79	33.96 ± 15.00	*0.19*	0.668
Conduct.	595.09 ± 230.37	732.70 ± 140.10	464.03 ± 224.78	*24.96*	0.000**	608.15 ± 251.92	587.55 ± 221.85	*0.53*	0.430
Hardness	26.33 ± 6.58	28.51 ± 7.10	24.24 ± 5.41	*4.63*	0.037**	27.22 ± 7.48	25.81 ± 6.09	*1.07*	0.306
HCO_3^-	154.11 ± 22.51	169.12 ± 15.72	139.81 ± 18.40	*37.3*	0.000**	153.44 ± 21.69	154.50 ± 23.38	*0.04*	0.851
K^+	1.18 ± 0.66	1.42 ± 0.27	0.95 ± 0.83	*5.91*	0.020**	0.98 ± 0.57	1.29 ± 0.69	*2.50*	0.121
Mg^{++}	14.20 ± 5.07	16.34 ± 5.36	12.16 ± 3.88	*9.39*	0.040**	14.61 ± 5.73	13.96 ± 4.74	*0.42*	0.5198
Na^+	25.34 ± 10.39	28.23 ± 9.90	22.58 ± 10.32	*3.92*	0.055*	25.04 ± 11.94	25.51 ± 9.63	*0.00*	0.9838
NH_4^+	0.22 ± 0.19	0.24 ± 0.20	0.20 ± 0.18	*0.99*	0.326	0.03 ± 0.03	0.33 ± 0.15	*52.47*	0.000**
NO_2^-	0.12 ± 0.10	0.12 ± 0.10	0.11 ± 0.10	*0.18*	0.675	0.03 ± 0.01	0.17 ± 0.09	*31.82*	0.000**
NO_3^-	4.96 ± 0.63	4.96 ± 0.68	5.01 ± 0.59	*0.13*	0.712	4.91 ± 1.98	3.68 ± 2.18	*0.17*	0.682
pH	8.26 ± 0.14	8.28 ± 0.11	8.23 ± 0.16	*1.34*	0.253	8.30 ± 0.15	8.23 ± 0.13	*2.96*	0.093*
PO_4^{3-}	0.25 ± 0.25	-0.25 ± 0.06	0.25 ± 0.19	*1.18*	0.285	0.22 ± 0.30	0.29 ± 0.23	*4.06*	0.051*
Silicates	3.19 ± 1.16	2.17 ± 0.30	4.17 ± 0.74	*143.9*	0.000**	3.43 ± 1.21	3.06 ± 1.13	*2.70*	0.108
SO_4^{2-}	138.8 ± 63.35	170.75 ± 61.20	108.40 ± 49.77	*15.12*	0.000**	135.613 ± 70.10	140.66 ± 60.50	*0.00*	0.962

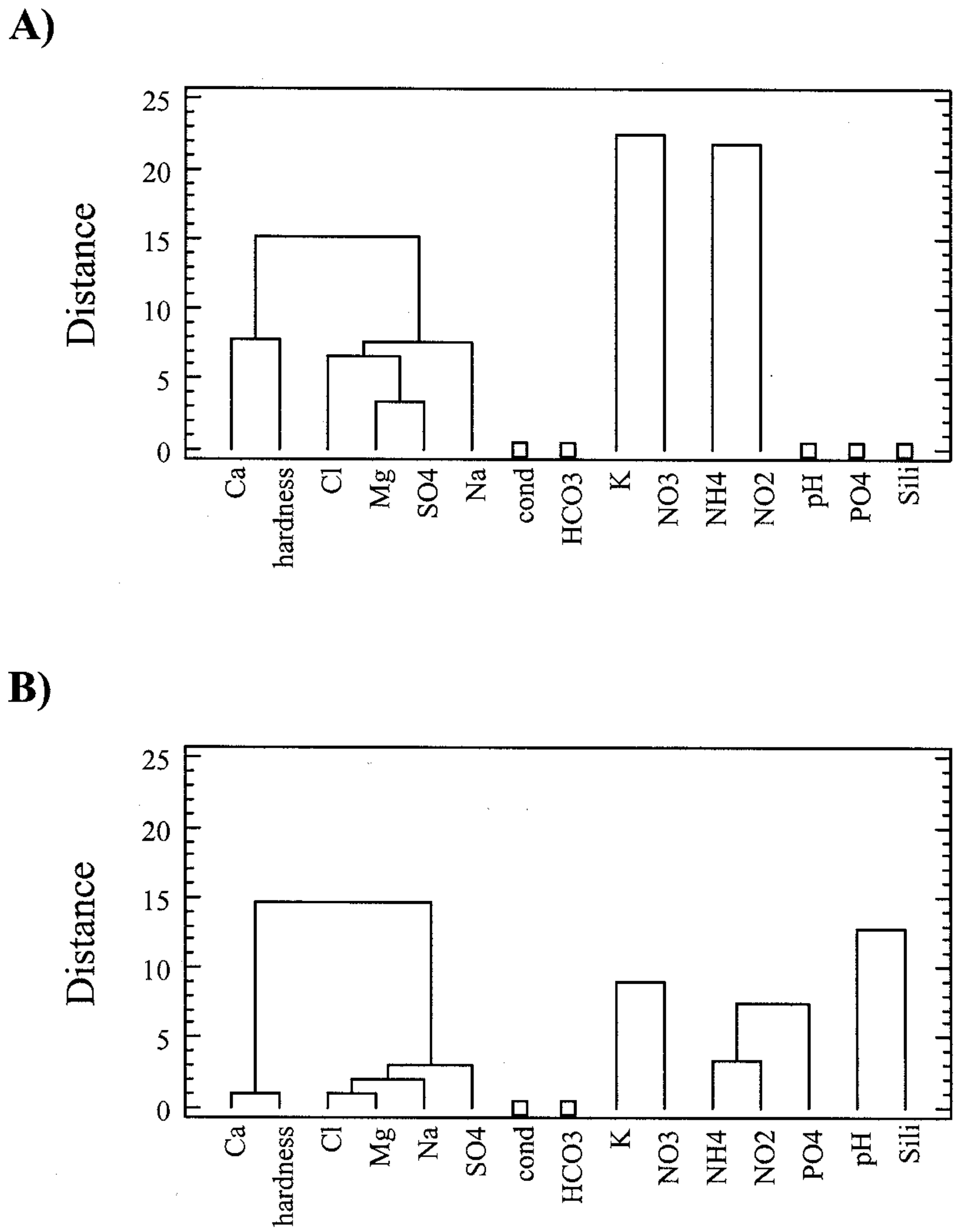

Figure 5

Cluster analysis of association among variables (standarized values). Distance Metric : Squared Euclidean, Clustering Method : Furthest Neighbour (Complete Linkage). A) considering all data ; B) considering only the data from the impacted stretch.

Figure 5

Dendrogramme montrant les similarités entre des variables (valeurs standardisées). La méthode de groupement : à liens complets et la distance métrique : carré euclidien ont été employées. A) toutes les données ont été considérées ; B) il n'a été considéré que les données du tronçon perturbé.

Holistic study of trends in changes in river conditions

The evolution over time of the river conditions as a whole is plotted in Figure 6. A discriminant analysis is carried out considering all the initial variables, and backward selection is used in order to choose the most significant ones. Three discriminant functions are extracted to define a space of ordination of cases. The percentages of variability are 67.66, 15.06 and 10.06 for each axis, respectively, so that 92.78 % of the sample variability is explained (eigen-values = 125.142, 27.856 and 18.605, DF = 84, 66 and 50 respectively, p-value = 0.000 in all cases, n = 42). Table II summarizes the three standardized discriminant functions.

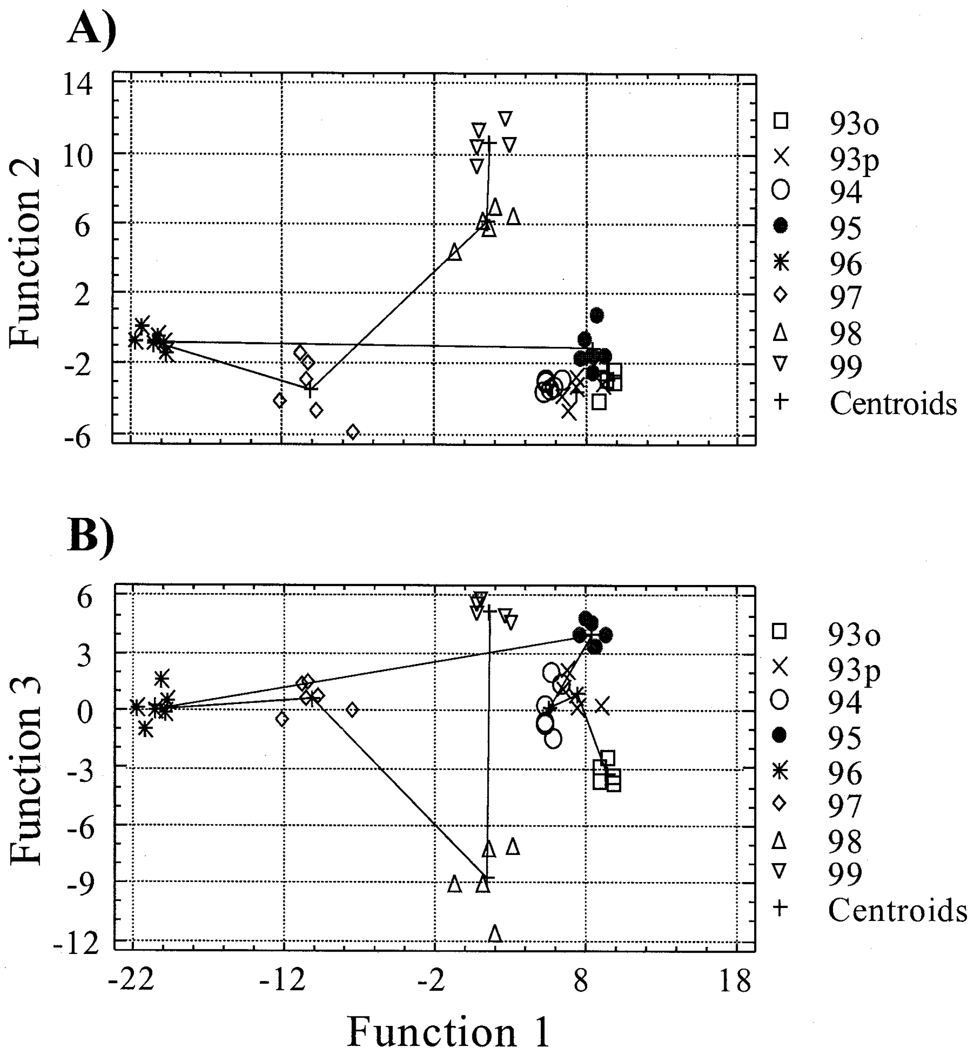

Figure 6

Location of sampling sites in the space defined by the first two (6A) and the first and the third (6B) discriminant axes, considering all physical and chemical variables. Discriminant factor : year.

Figure 6

Localisation des sites d'études dans l'espace défini par les deux premiers (6A) et le premier et troisième axes discriminants (6B) ; toutes les variables physiques et chimiques ont été considérées. L'année est le facteur discriminant.

Table II
Standardized discriminant coefficients of the first three axes that ordinate sampling sites. Discriminant factor : year.

Tableau II
Coefficients discriminants standardisés des trois premiers axes qui ordonnent les sites d'échantillonnage. L'année est le facteur discriminant.

	First axis	**Second axis**	**Third axis**
Conductivity	0,2053	0,0429	0,3164
Hardness	-1,5800	-0,3237	0,3496
Cl^-	1,0510	0,9493	0,3681
NO_3^-	1,2744	0,3481	-0,1559
NO_2^-	-1,4781	-0,8926	-0,2582
Silicates	-1,2589	1,2598	0,1475
Ca^{++}	2,3516	0,1156	-4,2390
Mg^{++}	-0,9125	-2,0199	0,3459
Na^+	-0,6977	2,3176	2,9029
K^+	1,1333	0,3026	0,2661
NH_4^+	-0,5428	0,7645	-0,1905
HCO_3^-	-0,4478	0,0035	1,5093

Discriminant functions do not separate samples for the years up to 1995 (Figure 6). But in « 96 and 97 » the whole river conditions move to the negative part of the first axis before returning to close to the original values on the first axis in « 98 and 99 ». These years are separated from the others by the second function (Figure 6A) and show a quite different evolution when the third discriminant factor is considered (Figure 6B). But the general physical and chemical conditions of the river seem to come back to their original status, in an evolutive change that could be interpreted as a process of recovery after a particular impact.

In order to look into this possibility, the behaviour as a whole of the variables that differ significantly depending on the period is studied specially all along the river stretch in the post impact years. This procedure allows us to extract by discriminant analysis a single significant function (Figure 7) that explains 71.1 % of the total variability of the sample (eigen-value = 10.84, DF = 45, p-value = 0.030, n = 22). This first standardized discriminating function is :

- 95,8679*Ca - 10,5808*Cl - 4,38664*cond - 3,51085*SO4 - 19,6931*Mg +

+ 22,832*hardness + 30,993439*Sili + 1,05393*HCO3 + 1,4517*K

Sampling sites upstream and downstream from the supposedly impacted zone become separated by the concentrations of calcium, chlorides, sulphates and magnesium, and conductivity (related to sites upstream), and by silica, carbonate and potassium downstream. Calcium concentration (related to upstream sites) and silica (downstream) have the highest coefficients and weight in the equation.

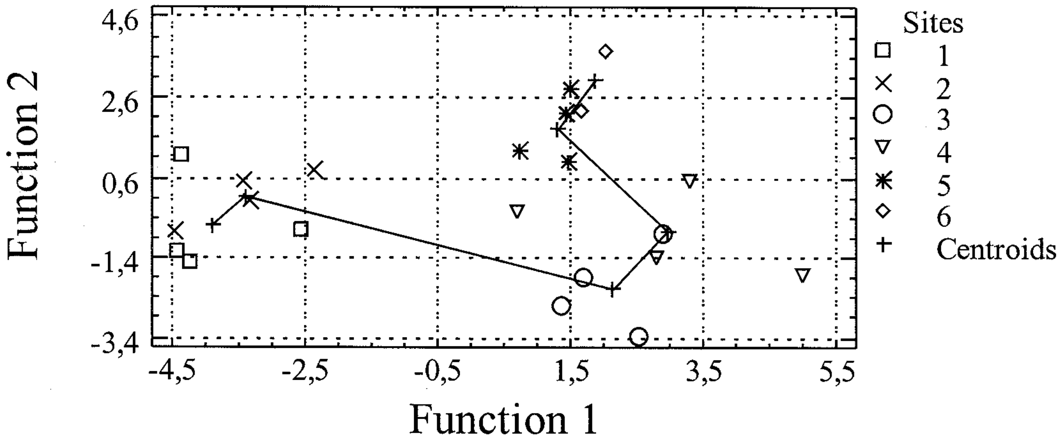

Figure 7

Location of sampling sites in the space defined by the first two (7A) and the first and the third (7B) discriminat axes, considering only variables significantly different in each period (1993-95 and 1996-99). Discriminant factor : year.

Figure 7

Localisation des sites d'études dans l'espace défini par les deux premiers (7A) et le premier et troisième axes discriminants (7B) ; il n'a été considéré que les variables significativement différentes en chaque période (1993-95 et 1996-99). L'année est le facteur discriminant.

DISCUSSION

After an introduction of *Pacifastacus leniusculus* in the Cadagua River, a well-established population was found in the early 90's. But from 1994 onwards there was a major decline in population numbers in the downstream part of the studied stretch. The first question is whether this fact must be accepted as a natural random oscillation of population numbers (ROYAMA, 1992) or is rather caused by defined external factors. The second option can be choose as the more likely because precisely during those same years a wide road was constructed parallel and in some places very near to the stream. The work proceeded in an upstream direction, and population decrease started and went on in the same way. So the hypothesis that ought to be tested is that this construction activity was the main cause of the crayfish population's decline and partial disappearance.

In rivers, water chemistry conditions and spatial and temporal changes depend on several factors. Among those factors, natural conditions (especially geological substrate) and human activities (GIBBS, 1970 ; CHAPMAN, 1996) play the major role. The fluvial water variables of the Cadagua studied in this work showed values in the ranges cited as natural for similar streams with geological substrates dominated by calcareous rocks and influence of oceanic aerosols, but naturally modified because of diapiric salt intrusions (MEYBECK, 1986, MEYBECK and HELMER, 1989, CHAPMAN, 1996). The dominant ions are calcium, sulphate and chloride. As in all rivers in the zone (ORIVE *et al.*, 1989 ; RALLO, 1992), overall analyses separate mineralization and nutrient components.

In European waters the incorporation of nitrogen and phosphorous in rivers is mainly caused by diffuse losses from the rural landscape (KRONVANG *et al.*, 1999). But the differences between the river stretches (upstream and downstream as defined by the different development of crayfish population) can be attributed to the urban impact of the sewage discharge from Balmaseda. Although it clearly affects fish fauna (upstream there is a native, well-established trout population and downstream there is a high ciprinidis production zone -*Barbus, Chondrostoma*-, (DOCAMPO and RALLO, 1987a and 1987b), no effect was recorded upon crayfish from 1989 to 1994. Healthy populations of signal crayfish were found at even higher concentrations of those compounds (RALLO 1992, RALLO *et al*., 1998 ; GARCIA-ARBERAS *et al*., in publication).

The results indicate that during the study period the recorded differences in crayfish sub-populations should be attributed not to spatial changes (substretch : lower or higher nutrients' concentrations) but to temporal changes (period : change more deeply affecting the fluvial system as a whole), and is precisely this temporal change in the lower substretch that mainly affects the signal crayfish population. One of the differences between chemicals in the water before and after the partial disappearance of the crayfish population is in the silica concentration, which is significantly higher in the second case (downstream substretch). A slight decrease in nutrients' concentrations is also detected. The entire silica cycle is insufficiently known as yet (HEIZE *et al.*, 1999) but it is well documented that increased silica discharges can lead to decreased discharges of associated compounds (BENNEKOM, 1999). This silica increase can be attributed to the water runoff coming into the stream because of the road construction, which allows the rapid erosion of forest-acidified and impoverished soils resulting from the intensive cropping of *Pinus radiata* on the mountain slopes nearby (ITURRONDOBEITIA and SALOÑA, 1991). Similar acidification processes are well-known world-wide (DAMBRINE *et al*., 1998 ; NOBLE *et al*., 1999 ; LILIENFEIN *et al*., 2000).

Water runoff from lands modified by human activities can harm surface water resources, and may contain or mobilize high levels of suspended solids, chemicals, etc. Uncontrolled waters from construction sites impact negatively on receiving waters by changing their physical and chemical composition, resulting in habitat destruction or alteration. Water quality impairment results, in part because a number of pollutants are preferentially absorbed into mineral or organic particles found in fine sediments, and also because of the proportional increase of such pollutants. In watersheds experiencing intensive construction activity, the localized impact on water quality may be severe because of high pollutant loads, primarily sediments (USEPA, 1992 ; FENNESEY and JARRETT, 1994). Sediments from road construction activity in Northern Virginia reduced aquatic insect and fish communities by up to 85 % and 40 %, respectively (REED, 1997). Suspended solids affect fauna by degrading habitat quality (QUINN *et al.*, 1992) and also by clogging or abrading the fine epithelium of the gills or other sensitive structures (ROBERTS, 1978). Recently it has been an episode of mortality of crayfishes precisely for this reason, as was clearly demonstrated (RALLO *et al.*, 1996). Also, increases in the sedimentation rate affect granulometry, diminishing the shelter capacity of substrate for larvae and juveniles and the photosynthesis rate of the system and, consequently, weed cover and presence. Shelter capacity of substrate and weed cover are, of course, important factors for the juvenile development of signal crayfish (BLAKE *et al*., 1994 ; BLAKE and HART, 1995).

Other studies have also examined the particular effects of road construction on water quality and sediment yields. Because of the nature of road construction, the disturbance in continental aquatic systems is relatively complete (affecting river or lake hydraulics, water, bed and banks, and vegetation and fauna all together) and long-term, and the system has little or any resistance (PATTEN and OHMART, 1995 ; MAITLAND and MORGAN, 1997). In fluvial systems, the perturbation directly affects hydraulics, and therefore also a determinate stretch of the river above, in and below the construction zone. These changes have direct and indirect impacts on riparian systems. But when operations end, the system shows itself to be quite resilient and exhibits a high potential for restoration, if topography is returned to normal channel contours and conditions (PATTEN and OHMART, 1995). That seems to be the case of the stretch of the Cadagua river studied here : water conditions are coming back to their previous status. As water is the first element of the system to respond, it can be expected that all the others, including crayfish fauna, will return to their previous conditions too. Complementary support for this hope can be found in the fact that there is a healthy, well established population of *Pacifastacus leniusculus* just upstream from the zone impacted by the perturbation.

CONCLUSION

In the Basque Country, the introduced signal crayfish *Pacifastacus leniusculus* inhabits main fluvial stretches. One of the most productive zones has always been the Cadagua River stretch studied in this work. Two substretches can be observed : in the downstream stretch (where previously the population density was higher) there is a decline of the crayfish population from 1994 and a loss of crayfish fauna in 1997, while the upstream stretch is almost unaffected. Differences detected prior to this in the physical and chemical conditions of fluvial water (in nutrients' concentrations) did not affect crayfish fauna. So the differences recorded in crayfish sub-populations should be attributed not to spatial changes (substretch : lower or higher nutrients' concentrations) but to temporal changes (period : a change more deeply affecting the fluvial system as a whole), and is precisely this temporal change in the lower substretch that mainly affects the signal crayfish population.

One of the main differences between the chemicals in the water before and after the partial disappearance of the crayfish population is in the silica concentration, which is significantly higher afterwards (downstream substretch). This silica increase can be attributed to the water runoff coming into the stream because of the road construction at the time, which allows the rapid erosion of forest-acidified and impoverished soils on the mountain slopes nearby. Similar acidification processes are well-known world-wide. These sediments affect fauna by clogging or abrading the fine epithelium of the gills or other sensitive structures. So it can be conclude that the most probable cause of crayfish population decline in the downstream substretch is the impact of road construction.

But although the disturbance caused by this kind of perturbation in aquatic continental systems is relatively complete, when operations end the system may recover if initial conditions are restored. That seems to be the case of the Cadagua river, whose physical and chemical conditions seem to be coming back to their original status, in an evolutive change in dynamics that could be interpreted as a process of recovery after a particular impact. Water is the first element in the system to respond, so we can hope that all the others, including crayfish fauna, will soon return nearly to their previous conditions.

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