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BIOGEOGRAPHICAL EFFECTS OF HYDROELECTRIC INFRASTRUCTURES IN THE RIVER NANSA (CANTABRIA- SPAIN)

Virginia Carracedo Martín and Juan Carlos García Codron
Departamento de Geografía, Urbanismo y Ordenación del Territorio.
Universidad de Cantabria

1. MOTIVATION, OBJECTIVES AND METHODOLOGY

The river Nansa flows into the Bay of Biscay in Cantabria (Northern Spain). Its basin is surrounded by peaks over 2,000 metres high but its surface is only 430 km^2, so the river, which has a length of only 56 km, has a steep slope and the characteristics of a mountain course virtually to its estuary. Its average annual flow is 11.3 m^3/s and the regime shows a main maximum in winter and a secondary one between April and May associated with melting snow. However, the Nansa is also one of the most disturbed rivers in Spain. In just over 40 km of its length it supports four reservoirs and the same number of hydroelectric plants fed by an extensive network of canals and pipes that divert a lot of the flow of the river and of its tributary streams.

The creation of these infrastructures has fragmented the continuity of the river corridor as some of these works are insurmountable for many species. In addition, the river undergoes a very aggressive model of water management that creates significant environmental impacts and a lot of conflicts with the inhabitants of the valley.

Nowadays, the river regime is totally altered showing a severe loss of flow, a seasonal shift of the high and low water periods and the almost total disappearance of natural floods.

The loss of flow is maximum immediately downstream from every dam because most of the water is diverted from them to the pipes that feed the hydroelectric power plants. However, as we move away from these facilities, the river flow recovers thanks to the contributions of tributary streams and to the fact that the effect of water diversion fades gradually. There is no data to ascertain the volume of withdrawals. However, the capacity of the channels that start from the reservoirs is greater than the natural flow estimates.

At the same time, paradoxically, the Nansa river corridor is one of those with better environmental quality in the region. It contains an excellent riparian forest that includes or extends across several habitats of European importance (alder groves, heaths of *Erica ciliaris* and *Erica tetralix*, semi-natural dry grasslands, etc.) and has, or has had until recently, many endangered species such as salmon (*Salmo salar*), lamprey (*Petromyzon marinus*), otter (*Lutra lutra*), Iberian desman (*Galemys pyrenaicus*) or crayfish (*Austropotamobius pallipes*). All these circumstances have justified the inclusion of the river corridor in the Natura 2000 network as «LIC of the Nansa River.»

Given this, the objective of this work is to evaluate the biogeographical consequences of the transformation of the Nansa and to establish the relationship between the status of the main species in the fluvial corridor and the type of management that the river is undergoing.

The starting point was a comprehensive report issued earlier (project «Patrimonio y Territorio» sponsored by the Marcelino Botin Foundation). During this phase we analyzed in detail the environmental problems of the valley and proposed a zoning of the riparian forest. In addition, the subsequent fieldwork has completed the initial data on the distribution of plants and aquatic macroinvertebrates which, in turn, have allowed us to establish quality indices at systematic sampling points selected bearing in mind their representative character.

The quality of the riparian forest has been estimated between La Lastra dam and the Herrerías limit using the QBR index, which facilitates comparisons since it has been used in all the rivers of the region.

2. BIOGEOGRAPHICAL IMPLICATIONS OF INTERVENTIONS IN THE NANSA

2.1. Fragmentation of river corridor

The most obvious biogeographical effect of reservoirs is the fragmentation of river corridors as dams are barriers that some species are unable to cross. The worst affected are diadromous fish species moving between the sea and rivers, such as salmon, trout, eel and lamprey (respectively *Salmo salar, S. trutta*, *Anguilla anguilla*, *Petromyzon marinus*) and potamodromous ones (*S. trutta*) that migrate along the river in some stage of their life cycle. The first three were abundant throughout the lower and middle course of Nansa and were the subject of intense economic and sporting exploitation until the construction of dams in the middle of the last century.

At present all these species have become extinct, or their natural populations have disappeared, upstream of the Palombera dam, the nearest one to the sea. In the case of the lamprey, if at all, its presence is confined to the estuary, away from the direct influence of the reservoirs.

Other animals badly hit by the barrier effect of the dams are aquatic mammals such as otters (*Lutra lutra*), present throughout the basin and the Iberian desman (*Galemys pyrenaicus*) found in some of the highest sectors. The information available about the distribution of these species is very poor but it appears that the otter exists along the whole river.

There have been no documented consequences of the barrier effect of the reservoirs on other biological groups (crayfish, molluscs, small amphibians, etc.) although, according to the information available about other rivers throughout the world, the consequences could be significant.

2.2. Decrease in water level:

The diversion of water from streams and the channelling from the reservoirs into the pipes have caused a drastic reduction of the flow in the riverbed of the Nansa. The greatest impact occurs in the first kilometre downstream from each dam and it is more pronounced at the foot of those located at the head of the river than those found closer to the mouth.

Thus, for most of the year, the riverbed remains essentially dry or reduced to a narrow channel in much of the middle valley. From here and to the coast, the contributions of tributary streams mask the problem and produce a false appearance of normality in the river.

The appearance of artificial lakes and of these sections that are often deprived of water reinforces the barrier effect of reservoirs generating lentic ecosystems at the expense of the pre-existing lotic ones and reduces the area of habitat and spawning for more demanding aquatic species.

Moreover, the sharp decrease of flow and the retention of sediments and organic matter in reservoirs significantly influence the physical-chemical characteristics of water causing changes that may be relevant for organisms that depend on rivers. In this regard, significant changes have been detected in parameters such as pH, temperature, dissolved oxygen, suspended solids and nutrient loading which are attributable to the effect of dams or to the decrease of discharge flow and loss of self-purification capacity.

2.3. Alteration of the regime and the morphology of the river bed

The aforementioned comments notwithstanding, the most obvious impacts are more complex and are indirect consequences of the change of the river regime, and thus, in the morphology of the riverbed. Reservoirs increase sedimentation upstream of the dam and provoke incision and narrowing downstream. At the same time, regulation of the regime and the drawdowns imply a reduction in the frequency and magnitude of great floods, maintaining the river in a situation similar to that of «low water» interrupted from time to time by small flash floods generated by sudden releases from dams. Gradually, the location of erosion and accumulation areas has changed; the permanent bed has narrowed in most of its length and has become deeper in some sectors while the floodplain, free of the major floods, has been invaded by dense vegetation.

The most obvious result of this evolution is the astonishing development undergone by riparian forest after the construction of reservoirs.

In the upper reaches, above the first dam, the riparian forest is narrow and relatively poor in species but well developed and it forms a continuous canopy over several streams. It includes various types of willow woods (*Salix capraea, S. eleagnos, S. atrocinerea* or some hybrids) with some *Alnus glutinosa, Betula celtiberica, Corylus avellana, Crataegus monogyna, Fagus sylvatica, Fraxinus excelsior, Quercus robur* or others.

In the middle valley the wood becomes wider and more diversified. Depending on the substrate, morphology of the riverbanks and degree of maturity of the vegetation, we observe different types of forests that are combined together to form masses with imprecise limits. The most representative are:

— Mesotrophic alder woods with *Acer campestre*, *A. pseudoplatanus*, *Betula alba*, *Fraxinus excelsior*, *Q. robur*, *S. atrocinerea* and *S. eleagnos*.

— Black willow woods (*S. atrocinerea*) with *Alnus glutinosa*, *Betula alba*, *Corylus avellana*, *Crataegus monogyna*, *Fraxinus excelsior*, *S. eleagnos* and *Sambucus nigra*.

— Osier bed of *S. eleagnos* or *S. purpurea* with *Cornus sanguinea*, *Crataegus mongyna*, *S. atrocinerea* and *Sambucus nigra*.

Finally, in the low and medium-low valley, the mature and well-developed forest acquires more thermophile character which widens considerably thanks to the greater surface of the floodplain.

The most characteristic formations in this sector are

— Mesotrophic and thermophile alder woods with *Fraxinus excelsior*, *Laurus nobilis*, *Quercus ilex*, *Q. robur*, *Smilax aspera*, *Tilia cordata*, *Ulmus minor*.

— White willow woods (*S. alba*) with *Alnus glutinosa*, *Fraxinus excelsior*, *Populus nigra*, *Q. robur*, *S. atrocinerea*, *S. eleagnos*, *Tilia cordata*, *Ulmus minor.*

These forests form a nearly continuous strip whose only significant disruptions coincide with the villages, the narrowest gorges and with the reservoirs and their immediate environments.

However, the development and continuity of the riparian corridor are recent. The comparison of recent aerial photographs with those taken in 1953, just after the creation of the hydroelectric power system, shows that the riparian forest has experienced a remarkable expansion over the last half century throughout the valley of Nansa.

In 1953 the riparian forest was fragmented into small dotted patches, and dominated by shrubs (probably willows but the source does not allow a greater precision). Its degradation was highest in the vicinity of the settlements where the grasslands or arable lands reached to the river and most of the bed and its margins were uncovered and practically devoid of vegetation.

Currently, however, riparian vegetation forms a virtually continuous strip, even in the vicinity of the nuclei, and is dominated by trees. The meadows are separated from the river by a strip of thick vegetation and the canopy covers much of the width of the river beds.

The recovery of the area occupied by riparian forest and its tendency towards a more complex structure are widespread in the region thanks to the reduction of human pressure. However, the recovery has been especially strong in the Nansa where original features were also observed which can only be explained in relation to the geomorphological consequences of the hydroelectric installations. This is demonstrated by the appearance of a set of patterns in the distribution of vegetation characteristics (but also of aquatic macroinvertebrates and other indicators) that are repeated downstream of each reservoir. The association between this distribution and the sectors of incision, accumulation or changes in the layout and channel margins demonstrates unequivocally the relationship between the new river dynamics, the morphological evolution of the bed and banks and the vegetation development

3. MORPHOLOGICAL AND BIOGEOGRAPHICAL ZONING INDUCED BY RESERVOIRS

The hydroelectric system has modified the geomorphological processes, transforming the characteristics of the river bed and banks and causing a situation with significant biogeographical implications. The repetition of the same geomorphological and biogeographical patterns downstream from each dam allows us to distinguish the following sections:

3.1. Base of the dam: over-excavation area

It is located at the foot of each dam and is up to 50-60 metres in length. In the area where the released water dissipates most of its energy any loose material can be moved, producing an over-excavation in bedrock. This has created large permanently flooded pools which contrast with the rest of the bed that remains dry for much of the year.

In the case of the largest dams, the Cohilla and Palombera ones, the banks have lost their soil and vegetation colonizes only fissures in the rock. The observed plants are always young and small sized individuals and normally they do not survive the most sizeable water releases.

Most of the observed species are common in nearby riparian environments. Among them we can highlight *Alnus glutinosa*, *Corylus avellana*, *Fraxinus excelsior*, *Hypericum androsaemum*, *Salix atrocinerea*, *S. caprea* and *S. eleagnos*.

In La Cohilla, the spillway is located on the hillside at some distance from the dam so the water, which has lost most of its energy before reaching the riverbed, has not produced a visible over-excavation in it. However, there is a displacement of non consolidated materials and only the largest blocks (which can have up to ten metre edges) remain on site. At this point, the Nansa, which is reduced to a trickle of water caused by small leaks, appears almost dry, in permanent shade and has been completely colonized by *Betula*, *Corylus* and megaphorbs communities.

In these sections, the vegetation is sparse and does not form a forest so the QBR index, based on its characteristics, is not the most suitable method for assessing the quality of riparian vegetation. However, it has been used in order to maintain a single criterion for evaluation, providing quality of forest values ranging from «bad» (Rozadío and Palombera) to «intermediate» (La Lastra).

The assessment of macroinvertebrates is consistent because it shows that the quality is bad in Palombera and Rozadío, where we find gastropods, *Oligochaetes*, *Diptera* (*Chyromydae* and *Simuliidae*), *Coleoptera* and *Hemiptera* (pond skaters), and intermediate in La Lastra

3.2. Accumulation and deepening zone

Downstream from the previous zone and at a distance between 50 and 120 metres from the dam, there is an accumulation of boulders and pebbles mobilized by the releases of water forming a heterometric deposit covering most of the riverbed. This deposit is composed of irregular boulders of metric dimensions but it also contains rubble (bricks, concrete blocks, etc.) and some pebbles caught between the blocks while the fine materials are scarce and occupy especially protected places among the rocks. There are no real soils.

The permanent bed is constricted to one of the banks surrounding the deposit of blocks. It is very narrow and shows a tendency to deepening. The water flows quickly and, where the accumulation of sediments was not excessive, it has brought to the surface the bedrock, which appears polished and with the joints worked by erosion.

In these places there is no true riparian forest. However, both the banks and the deposits are covered by very mixed vegetation including typically riparian plants along with other opportunistic ones or those common to humanized environments and abundant mosses. The juveniles dominate but there are some mature shrubs and trees in whose trunks we can observe damage of varying degrees caused by the water releases and evidence of sporadic submersions. Among the species observed we can highlight *Acer campestre*, *Alnus glutinosa*, *Cornus sanguinea*, *Corylus avellana*, *Fraxinus excelsior*, *Crataegus monogyna*, *Humulus lupulus*, *Hypericum androsaemum*, *Laurus nobilis*, *Platanus hybrida*, *Prunus avium*, *Robinia pseudoacacia*, *Rubus* sp., *Sambucus nigra*, *Salix atrocinerea*, *S. caprea*, *S. eleagnos*, *Ulmus minor*.

In the accumulation and deepening zone the values of the riparian forest quality range from «bad» (Palombera) to «intermediate» (Rozadío and La Lastra)

According to macroinvertebrates, the quality is intermediate and even good at Rozadío, which shows large numbers of caddisflies (with and without case), and *Plecoptera*, *Diptera* (*Athrycia*) and *Ephemenoptera*, among others.

3.3. Area of maximum impact: channel narrowing

The section located in the following 300 to 500 metres suffers severely from the effects of hydrological alterations. The permanent bed appears to be very diminished by the lack of flow during much of the year. In contrast, the rest of the old bed, which undergoes occasional flooding produced by dam releases but has ceased to suffer major floods characteristic of the natural system, has been fully colonized by vegetation. The substrate is irregular and it is dominated by blocks and boulders although there are accumulations of sand and silt in places that remain flooded for most of the time, such as paleobeds or concave sections of ground, contributing to the generation of quite diverse microenvironments .

This is the area with the greatest expanses of vegetation, which consists of a dense riparian forest rich in species and with a predominance of shrubs or under-tree taxa but where herbaceous plants and vines are also abundant. The most abundant plants are various types of willow shrubs, such as *S. atrocinerea*, *S. eleagnos* or *S. caprea* but we can also find *Acer campestre*, *Alnus glutinosa*, *Betula alba*, *Cornus sanguinea*, *Corylus avellana*, *Fraxinus excelsior*, *Laurus nobilis*, *Platanus hybrida*, *Populus nigra*, *Rubus*, sp. and *S. alba*.

In this area the QBR index, calculated at about 500 metres from the dams, indicates a forest of «good» or «very good» (Rozadío) quality but the analysis of aquatic invertebrates indicates ecosystems of intermediate or poor quality (La Lastra).

3.4. Attenuated zone of influence

Farther from the dams alterations are increasingly difficult to discern at first sight. The river regains permanent flow thanks to contributions from creeks and the lower bed widens while the floodplain is reduced proportionally. The most common situation is that the bed is covered by blocks and boulders but there are also places with slow flow in which there are fine fraction sediments. The low flow rate coupled with the disappearance of large natural floods and the progressive loss of strength of the releases mean that in these sectors the river puts less stress on the riparian forest, which can attain a level of maturity and development different from what would occur in a natural river system, but at the cost of a loss in its structural diversity.

Among the species characteristic of the upper reaches are *Alnus glutinosa*, *Betula alba*, *Cornus sanguinea*, *Corylus avellana*, *Crataegus monogyna*, *Euonymus europaeus*, *Fagus sylvatica*, *Fraxinus excelsior*, *Prunus spinosa*, *Rosa* sp., *Rubus* sp., *S. atrocinerea*, *S.eleagnos*, *S.caprea* and *Sambucus nigra*. In the middle sector of the valley, birch, beech and *S. caprea* disappear while *Acer campestre*, *Castanea sativa*, *Erica vagans*, *Genista hispánica*, *Populus nigra*, *Quercus robur*, *Rhamnus alaternus* and *Salix alba* appear instead. Finally, in the lower reaches there are also *Laurus nobilis, Ligustrum ovalifolium*, *Platanus hybrida*, *Quercus ilex*, *Robinia pseudoacacia*, *Tilia cordata* and *Ulmus glabra*.

The quality index of riparian forest is «good» or «very good» (La Lastra), although the differences detected are more dependent on human factors namely, roads, land use, etc. than strictly on fluvial dynamics. The quality of aquatic ecosystems, according to the analysis of invertebrates, is intermediate in the middle valley, and high in Palombera.

3.5. Reservoirs

Finally, in the sections occupied by reservoirs, the original environments associated with the river and the banks are gone, replaced by new ones with their own characteristics, which are not strictly riverine and that we have not discussed in detail.

In the case of La Cohilla and Palombera, which experience significant fluctuations in water level, the strip located just below the maximum water level, affected by the submersion-emersion alternations and covered by accumulations of silt forming crustings on drying, there is no permanent vegetation. Due to its biological poverty, this strip forms a clear boundary in either a transverse (between the aquatic and terrestrial), or a longitudinal (upstream-downstream) direction.

However, at the mouth of the river in the reservoir the accumulation of fine material forms small semi-submerged deltas that have been occupied by virtually monospecific willows. Present at the four reservoirs, they are significant only in Palombera

4. SUMMARY, DISCUSSION AND CONCLUSIONS

The work done demonstrates that the hydroelectric use of the river Nansa has caused significant environmental changes.

The most obvious are the breaks in continuity of the river corridor caused by the combined effect of dams and the drastic reduction of flow that leaves large sections of the riverbed completely dry for much of the year.

Diadromous fish are most affected by the barrier effect of the reservoirs and the dried sections and they have disappeared or are kept artificially upstream of the first obstacle. In the case of salmon, the most emblematic and vulnerable Cantabrian fish, extinction is almost inevitable in the present circumstances in most of the River.

In addition, there are indications that the appearance of lentic environments associated with reservoirs and stretches of low flow has influenced the composition of the fish and amphibians.

Moreover, the modification of the regime and river hydrodynamics has produced significant changes in the morphology of the riverbed and its banks provoking the recovery of riparian forest and influencing its composition. The phenomenon has peculiarities that can be explained only taking into account the transformation experienced by the river. Reservoirs disrupt the continuity of the river corridor that loses quality close to each one of them; however, this quality comes back downstream as the consequences of the dams diminish. Thus, the transformation of the river has opposite effects interrupting the continuity and causing impoverishment of the forest near major infrastructures but encouraging its development in the rest of the valley.

In parallel, the quality of water and associated ecosystems reflects these alternations although in the case of water, the problems are much more associated with the loss of discharge than with the direct effect of the dams, which generate less significant impacts in relative terms. For this reason, the quality is worse in the middle and high valley than in the low part, where the flow rate is higher.

All of this justifies the need to integrate these issues into the future management of this space that, according to Law 42/2007 about Natural Heritage and Biodiversity of Cantabria is supposed to become a protected area which should have its consequent management plans. The black or white vision of a supposedly «natural» environment as opposed to an «artificial environment» under constant threat from any human action is too reductionist and more holistic approaches are needed in order to integrate the complex system of interactions that occur between the natural and social spheres of our geographical environment.