

BREAKDOWN AND COLONIZATION OF ALDER IN REGULATED ITALIAN WATERCOURSES

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SUMMARY

This paper summarises the results of studies carried out on three different Italian watercourses. We compared the breakdown rates and macroinvertebrate colonization of alder (*Alnus glutinosa* L.) leaves, incubated: 1) in spring and autumn in the Bidente (Appenines), and its tributary, the Bacine, both regulated; 2) in summer and winter along the Gardena (Alps), a regulated stream with some eutrophic reaches. Our results confirm the influence of human disturbance on leaf breakdown and colonization. In addition, we give some suggestions for using leaf packs to assess the function of watercourses.

INTRODUCTION

Riparian vegetation influences the trophic structure of benthic communities in headwaters, where allochthonous organic matter represents from 50 % to 99 % of the total energy budget (FISHER & LIKENS, 1973; REICE, 1974; POST & CRUZ, 1977). Fallen leaves are the food of detritivorous macroinvertebrates (DOBSON *et al.*, 1992; RICHARDSON, 1992) which, it has been argued, tend to synchronise their life cycles with the period of higher food availability (CUMMINS *et al.*, 1989); in temperate regions this generally occurs during autumn and winter. There is a temporal sequence of different leaf species in the riverbed, determined by the abscission period, the downstream transport, and the different breakdown rate of each species (GERHARDT, 1992). Leaf input can also be important in spring, as a result of lateral transport of leaves deposited in the riparian areas, plus green leaves torn by storms (GARDEN & DAVIES, 1988; LEFF & McARTHUR, 1990; MERRITT & LAWSON, 1992).

Changes to riparian areas lead to changes in life cycles, survival and fertility of aquatic organisms (SMOCK &

McGREGOR, 1988). Disturbances such as deforestation or afforestation with exotics can affect the retention capacity of streams (WINTERBOURN *et al.*, 1981; CUMMINS *et al.*, 1984; MARIDET *et al.*, 1995), as well as food availability and breakdown of debris. This, in turn, can modify benthos structure and composition, affecting even to fish communities (DANCE & HYNES, 1980; TUCHMAN & KING, 1993; CANHOTO & GRAÇA, 1995; ABELHO & GRAÇA, 1996). Therefore, the study of leaf breakdown and associated macroinvertebrates can be used as a method for assessing river function. For this purpose it is necessary to extend these studies to rivers and streams differing in climate, hydrology, morphology, aquatic and riparian vegetation, and human disturbance.

In this paper, we summarise the results of two specific studies carried out on three different Italian watercourses (fig. 1a). We compare the breakdown rates and macroinvertebrate colonization of alder (*Alnus glutinosa* L.) leaves incubated: 1) in spring and autumn in the Bidente (Appenines), and its tributary, the Bacine, both regulated; 2) in summer and winter along the Gardena (Alps), a regulated stream with some eutrophic reaches.

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STUDY SITES

The Bidente - Bacine system.

The Bidente and the Bacine are meandering streams dominated by pools, 2-5 m wide and 20-40 cm deep; substrate is dominated by stones, cobbles and gravel (70-90%), with 10% of sand; the slope is 3-10%, and the right bank of both streams is reinforced with concrete.

We studied leaf breakdown and macroinvertebrate colonization in late spring and late autumn of 1994 in three sites (fig. 1b). The range of water temperature is recorded in table 1; the range of water pH was 8.0- 8.2.

- Site ABi is located downstream from the Ridracoli reservoir, and upstream from the confluence with the Bacine;

- Site BBi is located downstream from the confluence with the Bacine;

- Site ABa is upstream from the confluence with the Bidente and downstream from a flow diversion for hydroelectric purposes.

The vegetation in the three sites mainly consists of *Alnus glutinosa* L., *Ostrya carpinifolia* Scop. and *Populus nigra* L.; gravel bars support shrubs (10-50% coverage) consisting of *Salix alba* L., *S. eleagnos* Scop., *Rhus* spp., and some grasses, especially *Tussilago farfara* L. (SALMOIRAGHI *et al.*, 1997).

The Gardena.

The Gardena is a wooded tributary of the river Adige (fig. 1c), an Alpine river. Its main course is 25 km long and drains a basin of 199 km². The slope varies from 15-20% in the upper reach, to 5-7% in the lower reach. The flow goes from 1 to 3 m³ s⁻¹ in the town of Ortisei. The channel is from 3 to 7 m wide and the substrate is a complex of stones, gravel and cobbles. Several touristic centres result in a downstream increase of N and P concentrations, reaching values up to 1.3 mg l⁻¹ of NO₃⁻ and 3.2 mg l⁻¹ of TP in the interstitial environment.

We studied alder leaf breakdown within six reaches in the summer of 1996 and in the winter of 1997:

Site 1Ga - Plan (1575 m a.s.l.) - located north of the town of Selva Val Gardena. The river is 3-4 m wide and the banks are stabilised with large rocks, revegetated with *Salix* spp., *Alnus glutinosa* L. and *Corylus avellana* L.

Site 2Ga - Santa Cristina (1415 m a.s.l.) - the riverbed is regulated, the banks being stabilised with large rock, and revegetated with *Sulix eleagnos* Scop.

Site 3Ga - Ortisei (1300 m a.s.l.) - the riparian vegetation is dominated by *Salix eleagnos* Scop., *Betula pendula* Roth and

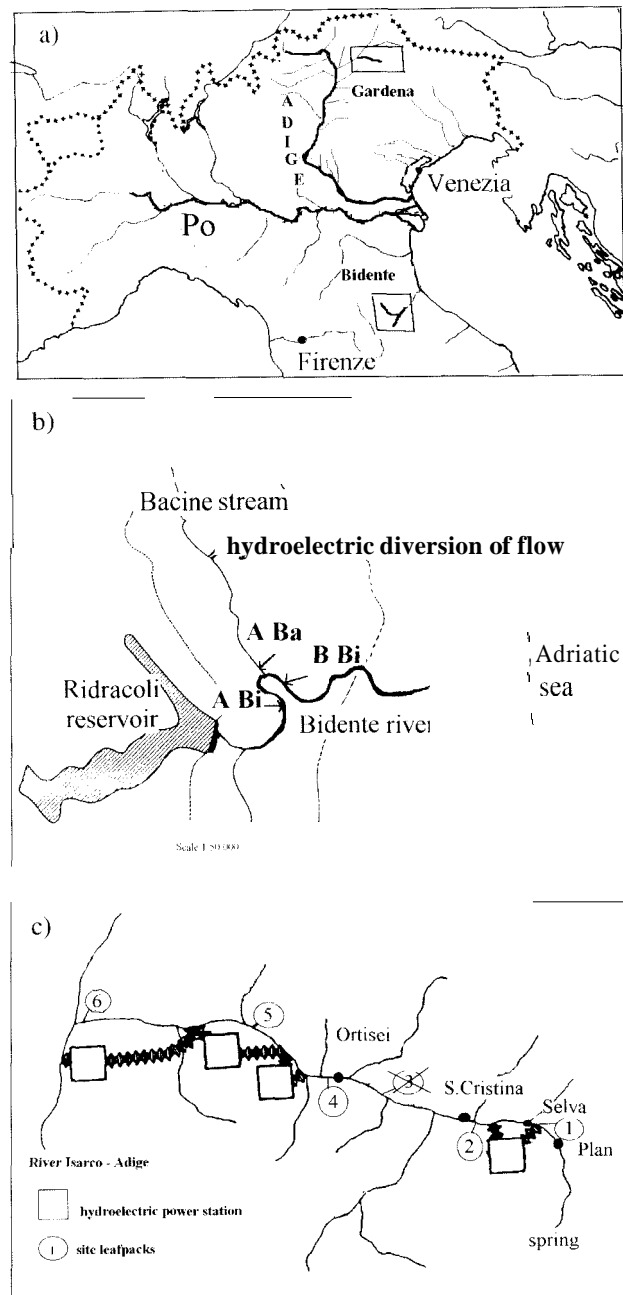


Figure 1.a) The location of the streams; b) Location of the sites in the basin of the Bidente - Bacine; c) Location of the sites and hydroelectric diversion of flow along the Gardena.

Larix decidua Mill.

Site 4Ga - Pontives (1110 m a.s.l.) - The riverbed consists of stones, gravel and mud, and is stabilised by concrete weirs. On the banks, partially concreted, there are *Salix eleagnos* Scop.

Table 1. Range of water temperature during the incubation of the leafpacks.

Study Sites	Tmin	Tmax	Tmin	Tmax
Bidente-Bache	June 1994		Oct.-Nov.94	
ABi upstream	9	11	5	7
ABa upstream	12	13	6	8.5
BBi downstream	9	11	12	13.5
Gardena	August 1996		Jan.-March 97	
1Ga Plan	4	12	2	4
2Ga S.Cristina	5	11	3	6
3Ga Ortisei	7	13	1	7
4Ga Pontives	8	16	1	5
5Ga S.Pietro	10	15	1	6
6Ga P.Gardena	11	17	0	7

and *Betula pendula* Roth.

Site 5Ga - San Pietro (800 m a.s.l.) - located downstream from the hydroelectric power station of Pontives. The flow is regulated. The banks are made of rocks. The vegetation consists of *Fagus sylvatica* L., *Corylus avellana* L., *Betula pendula* Roth, *Alnus glutinosa* L. and *Salix eleagnos* Scop.

Site 6Ga - Ponte Gardena (480 m a.s.l.) - the flow is regulated. The riverbed is stabilised by weirs, the left bank is made of concrete, and the right bank is covered by shrubs and trees, with some rocks. The vegetation consists of *Fagus sylvatica* L., *Rohinin pseudoacacia* L. and scattered specimens of *Picea excelsa* Lk. and *Pinus silvestris* L.

The water pH at the six sites varies from 8.2 to 8.5. The range of water temperature is recorded in table 1.

MATERIALS AND METHODS

The leaves were collected in autumn before abscission, air-dried and stored. We used the leaf-pack technique described by

PETERSEN & CUMMINS (1974), and MERRITT *et al.* (1979).

Twenty leaf-packs (5 ± 1 g) were placed in each study site. We collected five packs per site and date: the first collection, after 48 hours of incubation, is assumed to reflect the leaching of soluble compounds; thereafter, packs were collected according to temperature accumulation in degree-days (dd), read daily, on maximum-minimum thermometers (table 2).

The packs were taken to the laboratory, rinsed, dried at 50 °C for 48 hours, and reweighed. The decay coefficient (k) was calculated from a negative exponential model (OLSON, 1963; PETERSEN & CUMMINS, 1974). This model includes time as the only independent variable, and weight remaining (corrected for leaching) as the dependent variable. To evaluate the effects of temperature, we also tested the model with two independent variables, as proposed by HANSON *et al.* (1984). This model adds temperature (expressed in dd) to the negative exponential model.

The breakdown rates were compared by Analysis of Covariance (SOKAL & ROHLF, 1981).

Macroinvertebrates in leaf-packs were sorted, identified to genus or family, measured, and assigned to functional feeding groups (MERRITT & CUMMINS, 1984). Biomass was computed from length-weight regressions (SMOCK, 1980; MEYER, 1989; BURGHER & MEYER, 1989) for those species of known regressions.

RESULTS

Weight loss due to leaching of leaves varied among sites and seasons. Alder leaching was significantly ($p < 0.05$) higher (table 3) in spring or summer than in autumn or winter.

The breakdown rates showed a wide spatial and temporal variability (table 4). In the Gardena, alder breakdown in summer was rapid and increased downstream, whilst in winter it was medium or slow. In the Bidente and Bacine, it was always

Table 2. Time elapsed (d) and degree-days (dd) accumulated for the recovery of leafpacks of *A. glutinosa*.

Bidente Basin	June 1994			October-November 1994		
	d	dd	dd	d	dd	dd
ABi Bidente upstream	8 (141)	18 (278)	27 (389)	15 (166)	33 (339)	54 (481)
ABa Bacine upstream	8 (128)	18 (272)	27 (354)	15 (185)	33 (383)	54 (555)
BBi Bidente downstream	8 (141)	18 (285)	27 (439)	15 (172)	33 (352)	54 (508)
Stream Gardena	August 1996			January-March 1997		
1Ga Plan	20 (150)	30 (250)		25 (80)	47 (150)	68 (240)
2Ga S.Cristina	17 (150)	30 (250)	37 (350)	19 (80)	41 (160)	54 (240)
3Ga Ortisei	14 (150)	24 (250)	37 (350)	19 (50)	41 (120)	61 (170)
4Ga Pontives	12 (150)	26 (300)		19 (40)	41 (90)	54 (130)
5Ga S. Pietro	12 (150)	26 (300)		25 (80)	47 (160)	61 (240)
6Ga P.Gardena	11 (150)	22 (300)	24 (350)	25 (80)	54 (160)	68 (240)

Table 3. Leaching (mean \pm standard deviation) of alder leaf-packs, expressed as percentage of initial weight.

Study sites	% S.D.	% S.D.
Bidente-Bache	June 94	Oct. -Nov. 94
ABi Bidente upstream	17.00 \pm 1.09	10.36 \pm 4.66
ABa Bacine upstream	19.75 \pm 0.64	14.38 \pm 2.94
BBi Bidente downstream	18.30 \pm 0.62	14.55 \pm 4.43
Gardena	August 1996	Jan. - March 97
1Ga Plan	21.04 \pm 1.77	16.09 \pm 1.95
2Ga S.Cristina	20.59 \pm 1.85	16.57 \pm 1.32
3Ga Ortisei	20.72 \pm 2.46	16.64 \pm 0.73
4Ga Pontives	18.44 \pm 3.60	18.40 \pm 8.86
5Ga S. Pietro	21.52 \pm 0.86	17.02 \pm 0.22
6Ga P.Gardena	21.44 \pm 1.56	17.61 \pm 1.72

medium, both in autumn and in spring, the seasonal differences not being significant (ANCOVA). In spring breakdown was significantly faster in the Bidente than the Bacine, a pattern that disappeared in autumn (SALMOIRAGHI *et al.*, 1997). The regression as a function of dd did not increase in significance, except for site 1Ga where k (dd^{-1}) was 0.001 ($r^2 = 0.276$, $p < 0.0001$).

Invertebrates colonizing leaf packs in the Appenine streams showed a strong seasonal difference. *Ephemera*, *Protonemura*, *Habrophlebia* and Rhyacophilidae were recorded almost exclusively during the spring, the time when Corinoneurinae, *Leuctra*, *Epeorus*, Simuliidae and *Centroptilum* were at their most abundant. *Isoperla*, *Amphinemura*, *Paraleptophlebia*, and *Torleya*, in contrast occurred in this sites only in autumn, a period of higher density for *Habroleptoides*

and Athericidae (table 5).

The richness of benthic invertebrate communities associated with alder leaves showed a different seasonal trend (table 6). The number of Systematic Units (S.U.) increased during the first stages of the breakdown and reached the maximum at 300 dd. Then, it levelled off or decreased. It was slightly lower in autumn than in spring within the sites of the Bidente. The S.U. number was almost constant in the Bacine (ABa), and lower than in the Bidente.

The average invertebrate density per gram of leaf mass also increased with time, peaking at about 300 dd in spring at all the three sites of Bidente-Bacine, but in autumn only in the Bidente (fig. 2). In general, the values were higher in spring than in autumn. The collectors were important in all seasons and sites, except for site ABi in autumn. Among collectors, filterers (mainly Simuliidae and Hydropsychidae) sometimes occurred in large numbers (SALMOIRAGHI *et al.*, 1997). The percentage of shredders was low in spring (from 6 to 15 % in ABi and BBi, up to 30 % in ABa), while in autumn it increased (up to 56 % in the Bidente).

The biomass of macroinvertebrates per remaining dry weight of leafpacks followed a similar trend in spring, being highest at about 300 dd (fig. 3). In contrast, during the autumn, it increased during the entire study. The comparison between biomass and density showed that the macroinvertebrates occurring in spring were much more abundant, but small (the mean body biomass of shredders varied from 0.057 to 0.16 mg per specimen, depending on the site), while in autumn there were fewer individuals, but with a greater biomass (the mean body biomass of shredders was from 0.21 to 0.77 mg per specimen). In

Table 4. Breakdown rates, confidence intervals, and correlation coefficients of the leaf-packs of *A. glutinosa*

Rivers	Sites - Season	k (d^{-1})	Category	95 % I.C.	r2	P
Bidente upstream	A Bi spring	0.009	Medium	0.007 - 0.011	0.841	<0.0001
	A Bi autumn	0.010	Medium	0.006 - 0.015	0.542	0.0002
Bacine upstream	A Ba spring	0.006	Medium	0.004 - 0.007	0.767	<0.0001
	A Ba autumn	0.006	Medium	0.004 - 0.007	0.731	<0.0001
Bidente downstream	B Bi spring	0.009	Medium	0.007 - 0.010	0.900	<0.0001
	B Bi autumn	0.006	Medium	0.004 - 0.009	0.551	0.0002
Gardena	1 Ga - summer	0.007	Medium	0.002 - 0.014	0.254	0.0556 NS
	2 Ga - summer	0.020	Fast	0.009 - 0.031	0.486	0.0019
	3 Ga - summer	0.024	Fast	0.017 - 0.031	0.748	<0.0001
	5 Ga - summer	0.031	Fast	0.018 - 0.044	0.718	0.0003
	6 Ga - summer	0.063	Fast	0.045 - 0.081	0.790	<0.0001
	1Ga - winter	0.004	Medium	0.002 - 0.006	0.443	0.0026
	2Ga - winter	0.002	Slow	0.001 - 0.003	0.496	0.008
	3Ga - winter	0.006	Medium	0.003 - 0.009	0.581	0.0001
4Ga - winter	0.002	Slow	0.001 - 0.004	0.578	0.012 NS	
5Ga - winter	0.004	Medium	0.003 - 0.005	0.672	<0.0001	
6Ga - winter	0.006	Medium	0.003 - 0.008	0.611	<0.0001	

autumn, the shredders made up more than 35 % of the biomass of the invertebrate community, while in spring they were from 5 to 13 % of the total in sites ABi and BBi. In autumn, the biomass of large scrapers (*Ecdyonurus* and *Epeorus*) was as important in sites with low flow and with stone-cobble-gravel substratum (fig. 3, table 5).

DISCUSSION

It is well-known that several factors, such as current speed, water temperature and pH, and leaf characteristics (REICE, 1974; STEWART & DAVIES, 1989; CHERGUI & PATTEE, 1990), affect leaching, and subsequent leaf conditioning by fungi and bacteria (CHERGUI & PATTEE, 1988; MERRITT &

LAWSON, 1992; STEWART, 1992; POZO, 1993). Leaching of alder leaves in our mountain streams was lowest in the cold season, even below the range 20-40 % cited by CUMMINS *et al.* (1989), which confirms the influence of the temperature. The influence of water pH (CARPENTER *et al.*, 1983) can be excluded because all the sites considered have well buffered alkaline water.

In the Gardena, the breakdown of alder leaves was rapid in summer, and medium-slow in winter. In all the three sites of the Bidente-Bacine, highly flow-regulated streams, it was always medium, both in autumn and in spring. The differences between the Bidente-Bacine and Gardena *in summer* are thought to be induced by the high summer concentration of nutrients in the Gardena, because of the large tourist population and of the

Table 5. Density of the taxa of macrobenthos found on the leaf-packs in the streams Bidente-Bacine (total number of specimens in the five replicates)

Site Season	ABa			ABi			BBi			ABa			ABi			BBi		
	Spring 94									Autumn 94								
dd	150	300	450	150	300	450	150	300	450	150	300	450	150	300	450	150	300	450
<i>Amphinemura</i>										1	1	1	1		2	1	2	
<i>Isoperla</i>										3			5	6	8	21	16	32
<i>Leuctra</i>	374	506	140	46	266	146	59	122	126	16	10	16	4	30	57	59	82	56
<i>Nemoura</i>	21	60	70	5	16	16		9	22	48	19	22	2	8	6	16	28	20
<i>Protonemuru</i>				3	4	1	2	12	1									
Hydropsychidae		7	2	7	20	16	108	216	11		2		4	1	1	2	7	
Hydroptilidae			2	3			2			19	21	6						
Limnephilidae											2			3				
Polycentropodidae	5		2	4	1	5	4	1	2		1	8		1				
Rhyacophilidae	3	11	15	6	24	51	26	42	65		2	2						7
<i>Baetis</i>	45	75	13	31	58	26	73	91	44	1		1	3	18	19	12	44	39
<i>Cuenis</i>				5	4	1	8	5	10		1				1			
<i>Centroptilum</i>	265	15	44	10	3	2	24	1	5	11	54	104		2				1
<i>Ecdyonurus</i>	4	5	7	50	77	12	24	27	9	11	14	35	4	26	19	12	17	14
<i>Epeorus</i>				47	67	112	91	76	67	1			1	1	9	2	3	4
<i>Ephemerella</i>		5	3	19	30	8	13	20	10									
<i>Habroleptoides</i>					1		2		2	21	29	33	5	13	39	20	16	13
<i>Habrophlebia</i>	31	23	16	3	4	8	30	12	17									
<i>Paraleptophlebia</i>										21	6	6	4	3	7	9		
<i>Torleya</i>											3			1		1	2	6
Elmidae					3	2	1	1			1							
Athericidae			1							3	10	7						
Ceratopogonidae			1	1	6	1		1	11							3	2	2
Chironomidae	133	301	248	172	1116	458	175	379	382	25	38	21	14	25	19	81	102	52
Ernptidae		30	2		20	3		6					1	1		1	2	3
Simuliidae	6	38	4	53	136	41	268	211	3									1
Tanypodinae	200	401	161	95	274	185				9	18	7	2	11	8	45	33	23
Corynoneurinae	528	331	147	132	645	135	216	386	143	100	56	23	11	9	2	35	30	3
Naididae		2	3	15	11	7	6	15	3	1	6	12	5	7	1	14	18	29
Tubificidae		12	2	6	10	7	6	15	3			1	1	2				

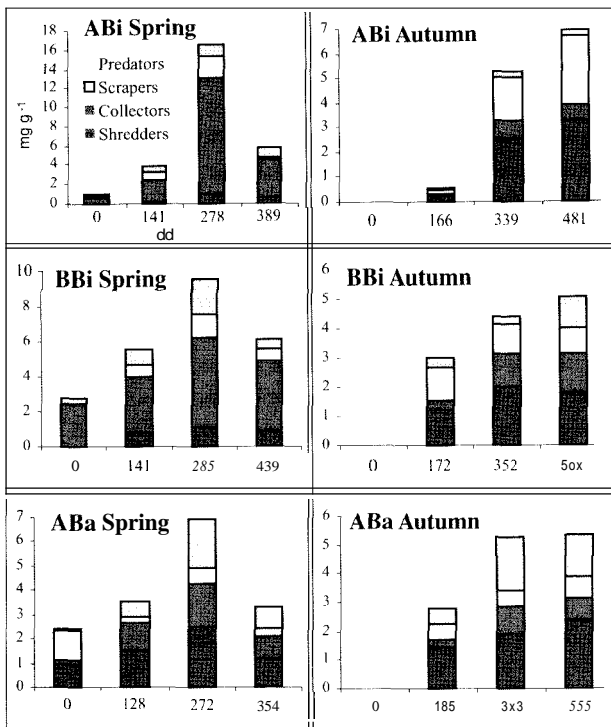


Figure 2. Ratio between the density (number of specimens in the five leaf packs) and the mean remaining dry weight (g) in leaf-packs of *A. glutinosa* related to dd.

bypass of the waste-treatment system located upstream from the study stretches.

With regards to the macroinvertebrates colonizing the leaves, both the composition and density depended on the environmental features of the sites (SCHADE & FISCHER, 1997; SCHULZE & WALKER, 1997). The same leaf species placed in different sites was colonized differently according to stream typology and human disturbance. The relative abundance and richness in taxa of invertebrates changed much according to

Table 6. Range of the number of taxa (n. S.U.) during the colonization of the leaves of *A. glutinosa*.

site stream	season	dd	n S U	season	dd	n. S U
ABi	spring	141	20-11	autumn	166	11-4
		278	24-17		339	15-7
Bidente	spring	389	17-11	autumn	481	11-6
		128	15-9		185	12-8
ABa	spring	272	17-12	autumn	383	18-11
		354	16-12		555	17-12
BBi	spring	141	21-10	autumn	172	14-10
		285	20-17		352	15-11
Bidente	spring	439	18-13	autumn	508	17-10

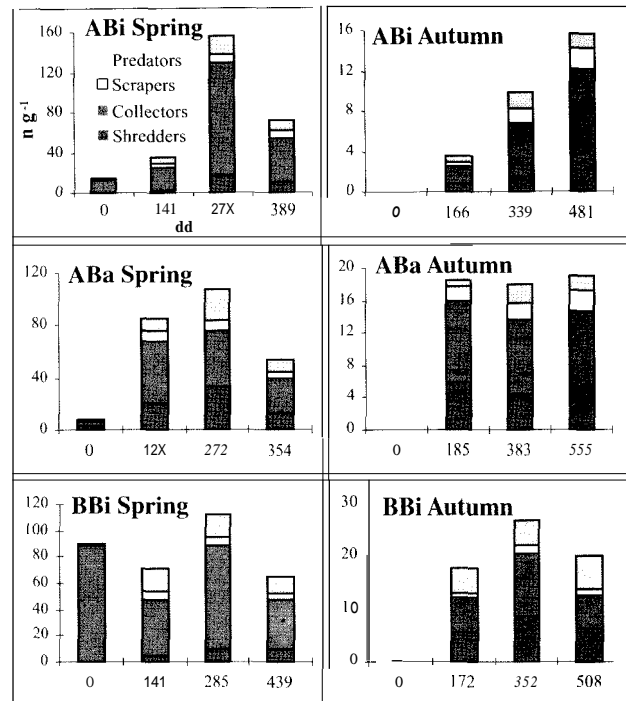


Figure 3. Ratio between the mean biomass of the trophic groups (mg) and the mean remaining dry weight (g) in the leaf-packs of *A. glutinosa* related to dd.

seasons and the different sites considered, as has been reported elsewhere in the literature (REICE, 1974, 1977; MINSHALL *et al.*, 1982). Only the Bidente-Bacine sites followed the “theoretical” trend cited by CUMMINS *et al.* (1989), with highest invertebrate densities in the intermediate stage of the breakdown process.

The seasonal differences of the invertebrate colonization could be a result of the fact that leaf packs placed in spring become an unusual food resource, and are thus quickly colonized by a large number of organisms at their first larval stages (CUMMINS *et al.*, 1989; RICHARDSON, 1992; GESSNER & DOBSON, 1993; CASAS, 1996; ROWE *et al.*, 1996). In particular, collectors, which abound in this season in all sites of the Bidente-Bacine, seem to find a structure for attachment and shelter in the leafpacks, but, above all, a source of FPOM, deriving both from the CPOM breakdown due to shredders, and from the retention of fine particles transported from upstream. For the same reasons, filterers (mainly Simuliidae and Hydropsychidae) occur sometimes in great numbers (SALMOIRAGHI *et al.*, 1997).

Macroinvertebrate biomass data also revealed some important seasonal differences. In spring the organisms were small, while in autumn the leaves were colonized by a lower number of large

organisms, and the role of shredders was greater. The increase of biomass in autumn, corresponding to the period of maximum leaf supply to the riverine environment, confirming that shredders, the main group in leaf breakdown, tend to synchronize their life cycles to the period of maximum allochthonous input (CUMMINS *et al.*, 1989).

FINAL REMARKS

Our research demonstrates that the process of breakdown can be:

1) enhanced by high temperature, or by the interaction between high temperature and nutrient concentrations;

2) retarded by pollution, by the interaction between bank regulation and seasonality, or by excessive flow withdrawal.

Macrobenthic biomass data are complementary to those of density. In order to understand the breakdown process and to distinguish between chemical-physical factors and trophic interactions of the benthic invertebrates, it is essential to have data on total biomass and on trophic-functional groups. They show the effects of the trophic-functional groups (depending on the development stage of the single populations), and allow them to be distinguished from the effects of the mechanical action of the current, or from the chemical-physical features on the breakdown process.

The study of leaf breakdown, if applied and standardised to many other Italian and European watercourses, could become an important tool for assessing the biological quality of running water. Although this method can be more time consuming than Structural Biotic Indexes (*sensu* MATTHEWS *et al.*, 1982) now usually applied within the EEC, it has the advantage of giving indications on the level of functionality of riverine reaches. To assess the function of watercourses with this technique, it is important to study biomass, and to carry out the experiments seasonally, but especially in autumn, when the importance of shredders is higher.

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