Hydroécol. Appl. (2016) Tome 19, pp. 217–243
http://www.hydroecologie.org

DOI: 10.1051/hydro/2015008

Spatial and temporal variation of benthic macroinvertebrates in the Nam Gnom Basin receiving discharged waters from the Nam Theun 2 Reservoir (Lao PDR)

Variabilité spatio-temporelle des macro-invertébrés benthiques du bassin de la Nam Gnom recevant les eaux du Réservoir Nam Theun 2 (RDP du Laos)

S. Clavier[(1)], M. Cottet[(2)*], P. Favriou[(2)], S.S. Phabmixay[(2)], P. Guédant[(2)]

(1) Hydreco, Lab. Environnement de Petit-Saut, BP 823, 97388 Kourou Cedex, French Guyana
(2) Nam Theun 2 Power Company Limited (NTPC), Environment & Social Division – Water Quality and Biodiversity Dept.– Gnommalath Office, PO Box 5862, Vientiane, Lao PDR
mcottet.lao@gmail.com

Abstract – In order to assess the impact of water release in the downstream area of the Nam Theun 2 Reservoir (Lao PDR), the spatial and temporal variation of benthic macroinvertebrates was explored. Between 2010 and 2012, five sites were monitored in the Nam Gnom Basin, a tributary of the Xe Bangfai River, receiving the turbinated waters. Repeated-time collections revealed the presence of 109 taxa mainly identified to the family level, attesting to a rich biota. Preliminary results did not show shifts in diversity, population composition, and feeding metrics. Redundancy Analysis indicated that the altitudinal gradient (*i.e.* altitude and altitude-related variables) remained the major environmental factor influencing the macroinvertebrates distribution before water discharge. The presence of a tributary downstream of the release point, and the respect of the natural river inflow can explain the preservation of natural conditions. More samples and a strengthened ecological knowledge of Southeast Asian macroinvertebrates are still required to confirm these preliminary results.

***Key words* –** freshwater invertebrates, Southeast Asia, biomonitoring, hydropower, downstream section

Résumé – Afin d'évaluer l'impact du relâcher des eaux dans la zone aval du Réservoir Nam Theun 2 (RDP du Laos), la variabilité spatio-temporelle des invertébrés aquatiques a été étudiée. Entre 2010 et 2012, cinq sites ont été échantillonnés sur le bassin de la Nam Gnom, un affluent de la rivière Xe Bangfai, qui reçoit les eaux turbinées. Les prélèvements issus du suivi ont permis de mettre en évidence la présence de 109 taxa principalement identifiés au niveau de la famille, révélant une richesse importante. Les résultats préliminaires n'ont pas montré de changement majeur des métriques de diversité, de composition des populations et des régimes trophiques. L'analyse canonique de redondance indique que le gradient altitudinal (altitude et variables associées) demeure le facteur environnemental prépondérant affectant la distribution des macro-invertébrés devant les eaux turbinées. La présence d'un affluent en aval du point de relâcher ainsi que le respect du débit naturel de la rivière peuvent expliquer la préservation des conditions naturelles. Des échantillons supplémentaires ainsi qu'une meilleure connaissance de l'écologie des macro-invertébrés de cette région restent nécessaires pour confirmer ces résultats préliminaires.

Mots-clés **–** invertébrés aquatiques, Asie du Sud-Est, biomonitoring, projet hydroélectrique, zone aval

1 INTRODUCTION

In regulated systems, upstream and downstream initial characteristics of rivers are modified *e.g.* thermal and hydrologic regime, sediment transport, channel morphology, and water quality (Ward & Stanford, 1979; Dynesius & Nilsson, 1994; Petts, 1984; Nilsson *et al.*, 2005). These alterations cause changes in assemblage structure of aquatic organisms and bioassessment methods can be used to assess environmental consequences of dams. Macroinvertebrates are widely used for that purpose (Armitage, 1984; Boon, 1988; Moog, 1993; Cortes *et al.*, 1998; Ogbeibu & Oribhabor, 2002). Their ubiquitous occurrence, high species richness, and limited migration patterns provide a large spectrum of responses to environmental changes including short to long-term cumulative effects (Resh *et al.*, 1995).

In Southeast Asia, the Mekong River basin is recognized for its high hydropower potential (Lauri *et al.*, 2012; Ziv *et al.*, 2012). An estimation of 200 hydropower projects are located in the "Greater Mekong Sub-region", which includes Thailand, Cambodia, Myanmar, Vietnam, Yunan Province (China) and Lao PDR (Souksavath & Nakayama, 2013). In 2009, the Mekong River Commission (MRC) estimated that the majority of the projects in the Lower Mekong Basin were located in Lao PDR (MRC, 2010). Interest in using macroinvertebrates to assess environmental changes is growing in the region such as in Vietnam (Hoang & Bae, 2006; Jung *et al.*, 2008; Hoang *et al.*, 2010) and in Thailand (Mustow, 2002; Getwongsa & Sangpradub, 2008; Thani & Phalaraksh, 2008; Boonsoong *et al.*, 2008). However, in Lao PDR, knowledge and use of benthic macroinvertebrates for bioassessment studies remain scarce (Davidson *et al.*, 2006; Pathoumthong & Vongsombath, 2007).

In the present article, spatial and temporal variability of macroinvertebrates in the downstream section of the Nam Theun 2 (NT2) hydroelectric project (Lao PDR) was investigated. Between 2010 and 2012, five sites were monitored in the Nam Gnom Basin receiving discharged waters from the NT2 Reservoir (Nam Theun Basin). It has been hypothesized that water discharge would lead to taxonomical and functional changes (Jalon *et al.*, 1994;

Vinson, 2001). More specifically, we hypothesised (i) a reduction of the relative abundance of molluscs as discharged waters had lower conductivity (Chanudet *et al.*, same issue) and diversity and richness of molluscs are known to be closely associated with water conductivity (Dillon, 2000; Horsák, 2006) and (ii) an increase of the relative abundance of collectors-filterers which usually dominate assemblages in downstream area of dams (Schlosser, 1992; Malmqvist & Eriksson, 1995).

To test these hypotheses, the total macroinvertebrate diversity of the studied area was estimated and the macroinvertebrate assemblages were compared between reference's sites (sites outside of influence of discharged waters) and impacted sites (sites under influence of discharged waters) through a taxonomical and a functional approach. Finally, spatial and temporal distribution of macroinvertebrates was explored through an ordination method.

2 MATERIAL AND METHODS

2.1 Study area

The NT2 hydropower area is located in the Khammouane Province in central Lao PDR (Fig. 1). The design of the project is characterized by a water diversion from the Nam Theun Basin (sand-stone dominant watershed) to the Xe Bangfai Basin southward (limestone dominant watershed). The Nam Kathang River is a tributary of the Nam Gnom River reaching the Xe Bangfai River few kilometres downstream. The Nam Kathang River starts after the confluence of two streams: Nam Kathang Noy and Nam Kathang Gnai, flowing into the Regulating Pond, constructed to buffer turbinated waters coming from the Power House. The inflow from the streams in the Regulating Pond is negligible comparing to the one from the Power House (3% *vs.* 97% on an annual basis). Downstream the Regulating Pond, waters are discharged in the Downstream Channel and in the Nam Kathang River through the Regulating Dam. Water release into the river respects an outflow corresponding to the natural inflow with an environmental minimum flow of 0.2 $m^3.s^{-1}$ while the outflow in the Downstream Channel is in yearly average to 220 $m^3.s^{-1}$. Water release from the Power House started for test in March 2010 and showed a stable regime since April 2010 when commercial operations began. Detailed features of the project are provided in Descloux *et al.* (same issue).

Five stations were sampled within the Nam Gnom basin (Fig. 1 and Fig. 2):

(i) Three sites were sampled in the Nam Kathang sub-basin: NKT1, NKT2, and NKT4. NKT1 was located on the Nam Kathang Noy River and NKT2 on the Nam Kathang Gnai River. Both stations were situated upstream of the Regulating Pond in unregulated rivers where no significant human disturbance was observed. NKT4 was located 3.2 km downstream of the Regulating Pond and upstream of the confluence with the Nam Gnom River. Human activities (cloth washing, fishing, and presence of cattle) were reported at this station.

(ii) Two sites were monitored in the Nam Gnom sub-basin. NGM1 was

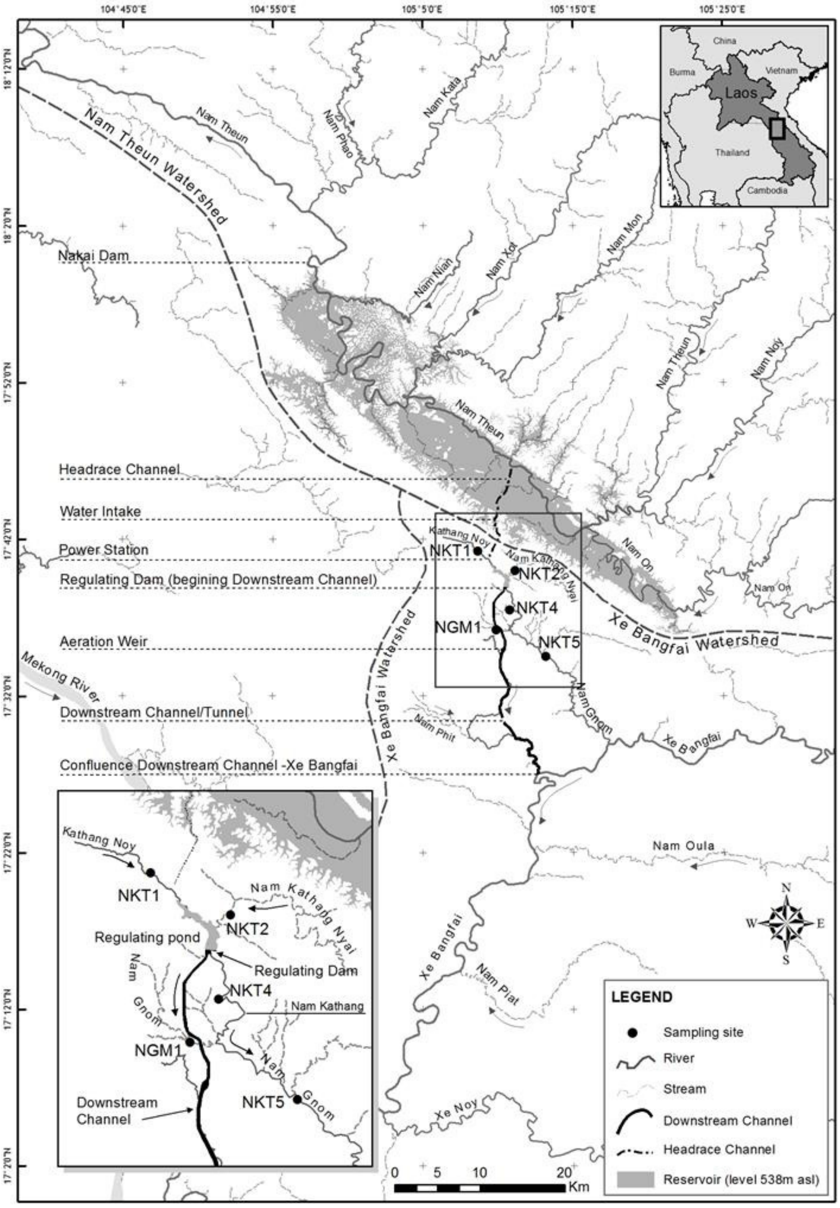


Fig. 1. Location of studies sites in the Nam Gnom Basin.

Fig. 1. Situation géographique des stations prospectées sur le bassin de la Nam Gnom.

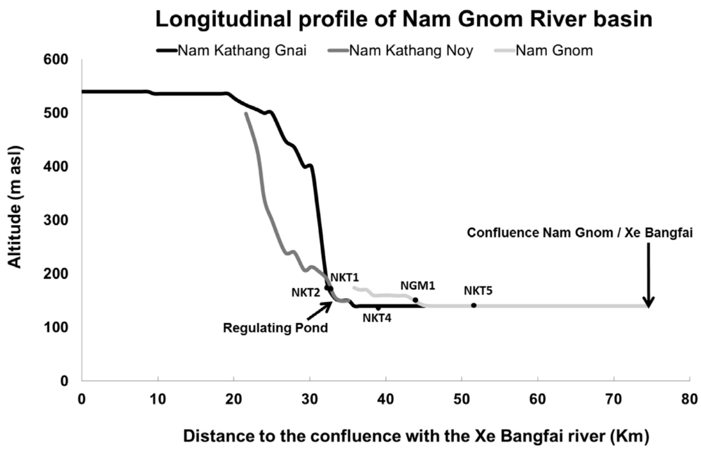


Fig. 2. Location of the station on the longitudinal profile of the Nam Gnom Basin.
Fig. 2. Situation des stations le long du profil longitudinal du bassin de la Nam Gnom.

located 700 m upstream of the confluence with the Nam Kathang River. NKT5 was situated 6 km downstream of the confluence with the Nam Gnom River and 17 km downstream of the Regulating Dam. Both sites were situated downstream of an irrigation dam interrupting the continuum of the Nam Gnom River. Agriculture, presence of cattle, fishing and cloth washing/bathing activities were reported to these stations.

Among the five stations, only NKT4 and NKT5 were influenced by the water release of the NT2 hydropower plant.

2.2 Aquatic invertebrates sampling and identification

Field collections were made during 6 campaigns numbered C1 to C6 from January 2010 to April 2012 (Tab. I).

Samplings were carried out twice a year during the low flow period which is a key driver of the structure, function and condition of river ecosystems (Rolls *et al.*, 2012). Each site was sampled during the cool dry season in January and at the end of the warm dry season in April.

C1 was sampled 2 months before the beginning of water release from the NT2 Reservoir (April 2010) and NKT4 was sampled only until January 2011 (C3). A preliminary study comparing the station with NKT5 (unpublished results) underlined similitude between both stations. After the campaign C3, NKT4 was abandoned and NKT5 became the downstream reference station. Sampling of NKT1 could not be carried out in April 2010 (C2) because of low water level (<1 cm).

The protocol used corresponds to a multi-habitat sampling method. At each station, defined as twice the bankfull width, eight samples were collected with a surber sampler (area of 1/20 m^2, mesh size 500 µm) covering proportionally all

Table I. Summary of field campaigns.
Tableau I. Synthèse des campagnes d'échantillonnage.

Date	Season	Discharging waters from NT2 Reservoir	Code	NGM1	NKT1	NKT2	NKT4	NKT5
January 2010	Cool dry	2 months before	C1	X	X	X	X	X
April 2010	Warm dry	1 month after	C2	X	-	X	X	X
January 2010	Cool dry	10 months after	C3	X	X	X	X	X
April 2011	Warm dry	13 months after	C4	X	X	X	-	X
January 2012	Cool dry	22 months after	C5	X	X	X	-	X
April 2012	Warm dry	25 months after	C6	X	X	X	-	X

habitat types with a share of at least 5% coverage. Samples were preserved with 8% formalin on the field. At the laboratory, aquatic invertebrates' samples were sorted and identified to the family level according to Dudgeon (1999) and Sangpradub & Boonsoong (2006). All biological materials were further preserved in alcohol 75% and were housed in a collection at the Aquatic Environment Laboratory of Nam Theun 2 Power Company.

2.3 Environmental variables

Water temperature, dissolved oxygen (DO), pH, conductivity, and turbidity were directly measured *in situ* using a calibrated HACH HQ40d-multi probe and a HACH 2100P Turbidimeter.

Two physical variables were recorded in the field to characterise habitat:

(i) Relative abundance of substrates. They were categorized as follows: % of aquatic vegetation (macrophytes, bryophytes, and emerged spermatophytes), % of submerged coarse organic elements (roots, trunks), % of mud (<0.5 mm), % of sand (particle size 0.5-2.5 mm), % of gravels (2.5-25 mm), % of pebbles (25-250 mm), and % of boulders (>250 mm).

(ii) Current velocity (V, $cm.s^{-1}$). Five classes were identified: V>150, 150>V>75, 75>V>25, 25>V>5 and V<5.

A mapping of habitats at each station is provided Appendix 2.

Mean values, minimum, and maximum of the physico-chemical and habitat variables are shown in Table II.

2.4 Data analysis

To explore taxonomical and functional changes in the macroinvertebrates assemblage, mean values, minimum, and maximum of diversity, composition, and functional metrics were calculated (Tab. III).

Diversity metrics included the taxonomic richness (S = number of taxa), density ($ind.m^{-2}$), Shannon-Wiener diversity index ($H' = -\Sigma\, p_i \ln p_i$), and Pielou evenness index ($E = H'/\ln S$), where $p_i = n_i/N$, n_i = abundance of the taxon i, N = total abundance.

Composition metrics included the % of Crustacea, % of Annelida, % EPT

Table II. Mean values (minimum - maximum) of abiotic factors measured in the Nam Gnom Basin from January 2010 to April 2012. Altitude, chemical variables and substrates composition were included in RDA.
Tableau II. Valeurs moyennes (minimum - maximum) des variables abiotiques mesurées sur le bassin de la Nam Gnom entre janvier 2010 et avril 2012. L'altitude, les variables physico-chimiques et les pourcentages de substrats ont été intégrés à l'analyse canonique de redondance (ACR).

	NKT1	NKT2	NKT4	NGM1	NKT5
Stream	Nam Kathang Noy	Nam Kathang Gnai	Nam Kathang	Nam Gnom	Nam Gnom
Sub-basin	Nam Kathang	Nam Kathang	Nam Kathang	Nam Gnom	Nam Gnom
Influence of NT2 Reservoir	no	no	yes	no	yes
Other human alterations	-	-	Impoundment, cattle ranching, fishing, washing	Impoundment, cattle ranching, fishing, washing	Impoundment, irrigation, cattle ranching, fishing, washing
Physical variables					
Altitude (m)	183	184	161	134	165
Width (m)	2 - 6	3 - 10	25 - 30	20 - 40	10 - 30
Depth (cm)	15	20	30	20	30
Current velocity ($cm.s^{-1}$)	5 - 25	5 - 25	5 - 25	5 - 25	5 - 25
Chemical variables					
Water temperature (°C)	26.4 (22.6 - 29.0)	23.6 (18.4 - 29.2)	25.1 (21.1 - 31.0)	26.2 (22.0 - 30.3)	27.6 (22.8 - 34.3)
pH	8.3 (8.0 - 8.5)	7.9 (7.6 - 8.4)	7.9 (6.6 - 8.5)	8.2 (7.9 - 8.5)	8.1 (7.5 - 8.4)
Conductivity ($\mu S.cm^{-1}$)	215 (192 - 245)	222 (102 - 448)	43 (31 - 56)	318 (269 - 369)	250 (198 - 290)
Dissolved oxygen ($mg.L^{-1}$)	9.3 (8.4 - 10.2)	8.7 (7.3 - 9.7)	10.7 (10.0 - 11.4)	10.0 (6.3 - 14.9)	9.6 (7.6 - 11.7)
Turbidity (NTU)	4.3 (2.3 - 8.1)	4.2 (1.6 - 8.3)	7.0 (4.4 - 8.5)	8.7 (2.6 - 18.0)	4.1 (2.4 - 6.6)
Substrates composition					
% Aquatic vegetation	5.5 (0 - 16.7)	4.5 (0 - 25)	21.7 (12.5 - 37.5)	0	10.4 (12.5 - 25)
% Submerged coarse organic elements	18.9 (12.5 - 28.6)	15.9 (0 - 37.5)	13 (14.3 - 25)	12.8 (12.5 - 25)	12.5 (12.5 - 22.2)
% Mud	13.5 (0 - 25)	4.5 (0 - 12.5)	4.4 (0 - 12.5)	12.8 (12.5 - 37.5)	2.1 (0 - 12.5)
% Sand	10.8 (0 - 37.5)	6.8 (0 - 25)	0	17 (12.5 - 37.5)	16.7 (12.5 - 37.5)
% Gravels	21.6 (0 - 42.9)	11.4 (0 - 37.5)	21.8 (25 - 37.5)	14.9 (12.5 - 25)	20.8 (12.5 - 25)
% Peebles	24.3(0 - 66.7)	36.4 (0 - 100)	39.1 (25 - 71.4)	42.5 (25 - 100)	31.2 (12.5 - 55.5)
% Boulders	5.4 (0 - 14.3)	20.5 (0 - 40)	0	0	6.3 (12.5 - 25)

Table III. Mean values (minimum - maximum) of macroinvertebrates metrics measured in the Nam Gnom Basin from January 2010 to April 2012.
Tableau III. Valeurs moyennes (minimum - maximum) des métriques mesurées sur le bassin de la Nam Gnom entre janvier 2010 et avril 2012.

	NKT1	NKT2	NKT4	NGM1	NKT5
Diversity metrics					
Taxonomic richness	43 (36 - 50)	31 (22 - 41)	37 (28 - 46)	39 (32 - 50)	44 (39 - 48)
Density	10.604 (2.370 - 19.540)	3.683 (1.540 - 6.694)	5.156 (2.658 - 8.575)	10.621 (5.880 - 2.658)	12.142 (7.515 - 17.440)
Shannon diversity	2.00 (1.81 - 2.28)	2.07 (1.03 - 2.4)	2.3 (2.07 - 2.56)	2.38 (2.2 - 2.54)	2.25 (1.61 - 2.54)
Eveness	0.61 (0.56 - 0.7)	0.64 (0.31 - 0.74)	0.71 (0.63 - 0.79)	0.73 (0.67 - 0.78)	0.69 (0.49 - 0.78)
Compositon metrics					
% EPT	23.7 (8.7 - 44.1)	34.8 (7.6 - 55.8)	34.4 (29.1 - 43.9)	37.8 (27.9 - 55)	27.9 (12.5 - 43.3)
% Others insects	48.5 (29.1 - 73.7)	39.8 (9 - 55)	47.2 (37 - 54.6)	51.4 (37.6 - 69.5)	49.8 (40 - 63)
% Molluscs	14.5 (0.3 - 46.8)	24.3 (0 - 83.4)	13.2 (12.9 - 13.4)	6.2 (2 - 11.1)	13.2 (6.1 - 18.4)
% Annelida	13.2 (0 - 39.6)	1 (0 - 4.5)	4.6 (3.3 - 5.8)	4 (0 - 13.4)	7.2 (0.4 - 20.2)
% Crustacea	0 (0 - 0.2)	0 (0 - 0)	0 (0 - 0)	0.1 (0 - 0.3)	0.9 (0 - 4.1)
% Minor groups	0 (0 - 0.1)	0.2 (0 - 0.8)	0.5 (0.1 - 1.3)	0.5 (0 - 1.5)	1 (0.2 - 2.5)
Feeding metrics					
% Shredders	2.2 (1.1 - 3)	4.7 (0.5 - 10.2)	2.6 (1.3 - 4.7)	3.3 (2 - 6.2)	1.5 (1.1 - 2.4)
% Scrapers	28.6 (12.8 - 71.4)	47.2 (17.4 - 85.4)	22.5 (16.4 - 30.4)	25.5 (8 - 45.1)	18.7 (11.4 - 22.8)
% Collector-gatherers	54 (6.2 - 76.8)	36.1 (4.3 - 70.1)	42.1 (31.5 - 53.2)	48.7 (23.3 - 75.1)	63.5 (56.4 - 68.2)
% Collectors-filterers	4.5 (1.2 - 9)	5.4 (2.7 - 11.9)	15.5 (11.7 - 21.9)	7.7 (2.9 - 13)	8.6 (2.2 - 16)
% Predators	10.8 (3.9 - 22.6)	6.5 (4.5 - 8)	17.3 (6.6 - 25.1)	14.8 (9.9 - 26.7)	7.7 (3.2 - 12.3)

(Ephemeroptera, Plecoptera and Trichoptera), % of other insects (*e.g.* Coleoptera, Hemiptera, etc.), % Molluscs, and % of minor groups (*i.e.* Hydracarina, Nematomorpha and freshwater planarians).

Feeding metrics included the % of five functional feeding groups (FFG). FFG were assigned according to Merrit *et al.* (2008) and defined according Cummins & Klug (1979) as follows:

(i) Scrapers (Sc) which consume algae and associated material;
(ii) Shredders (Sh), which consume leaf litter or other Coarse Particulate Organic Matter (CPOM particles >1 mm);
(iii) Collector-gatherers (Co-Ga), which collect Fine Particulate Organic Matter (0.45 µm < FPOM particles <1 mm) from the stream bottom;
(iv) Collectors-filterers (Co-Fi), which collect FPOM from the water column using a variety of filters;
(v) Predators (Pr), which feed on other consumers.

In addition, a species-accumulation curve (method exact, function “specaccum”) and the estimator of species richness Chao 1 (function “specpool”) were used on the whole taxonomic data set to estimate the representativeness of the sampling and estimate the diversity of the benthic macrofauna inhabiting the Nam Gnom basin.

A constrained ordination was conducted to explore spatial and temporal organization of sites and macroinvertebrates assemblage. A previous Detrended Correspondence Analysis (DCA) (function “decorana”) displayed short gradient lengths (<4 standard units) indicating that a linear model was the most valuable (ter Braak & Smilauer, 1998). A Redundancy Analysis (RDA) (function “rda”) was hence processed. Rare taxa (density <0.1%) were previously discarded (Appendix 1). Environmental data set included altitude, chemical variables and substrate composition (Tab. II). We also tested inter-annual (Year) and intra-seasonal (January *vs.* April) variation. All data were log(X+1) transformed with the exception of percentages, for which arcsin transformation was used (Legendre & Legendre, 1998). Statistical significance of the environmental and macroinvertebrates association was verified with anova ($P<0.05$; 9,999 Monte Carlo permutations). Forward selection (function “ordistep”) was used ($P<0.05$; 9,999 Monte Carlo permutations) to determine significant environmental variables.

Data were analysed using R statistical software (R Core Team Development, 2013) and package Vegan (Oksanen *et al.*, 2007). Temporal evolution of S, density, % Molluscs, and % Co-Fi were plotted with GraphPad Prism® 6.0 (GraphPad Software, San Diego, USA).

3 RESULTS

3.1 Environmental variables

Sampling sites represented a range of low altitude (134-184 metres above sea level; Tab. II and Fig. 2) streams (channel width: 2-40 m, water depth: 15-30 cm; Tab. II). Pebbles and gravels were the most common substrates in the Nam Gnom basin. Sand were mainly found in stations downstream (NGM1 and NKT5) while large boulders were widely represented at NKT2 (mean = 20.5% of the total substrates).

The predominance of discharged waters coming from the NT2 Reservoir was confirmed by the analysis of the conductivity (Tab. II). In the Nam Kathang Noy (NKT1) and in the Nam Kathang Gnai (NKT2) average conductivity was 215 $\mu S.cm^{-1}$ and 222 $\mu S.cm^{-1}$ respectively, whereas it dropped down to 43 $\mu S.cm^{-1}$ at NKT4, few kilometres downstream of the Regulating Dam. After the confluence with the Nam Gnom River (NGM1, mean conductivity = 318 $\mu S.cm^{-1}$) the conductivity increases to an average value of 250 $\mu S.cm^{-1}$ (NKT5). Discharged waters did not alter the other parameters which showed close values between upstream and downstream sites. During the six campaigns, all sites showed relatively high DO (mean for all sites and campaigns = 9.5 $mg.L^{-1}$; S.D. = 1.7), temperature (mean for all sites and campaigns = 25.8 °C; S.D .= 3.8), alkaline pH (mean for all sites and campaigns = 8.1; S.D. = 0.4) and low turbidity (mean for all sites and campaigns = 5.4 NTU; S.D. = 3.7).

3.2 Macroinvertebrates survey

3.2.1 General patterns of macroinvertebrates in the Nam Gnom basin

A total of 109 macroinvertebrates taxa were collected in the Nam Gnom basin from January 2010 to April 2012 (Appendix 1). During the six sampling campaigns 69, 72 and 78 taxa were collected at NKT2, NGM1, and NKT5 respectively. At NKT1, 77 taxa were collected during the five sampling campaigns and 55 at NKT4 during the three sampling campaigns. The species-accumulation curve processed in the Nam Gnom Basin did not reach asymptote (Fig. 3) indicating that more samples would be required to estimate the total richness. The richness estimator Chao 1 points out the possible presence of 139 taxa (S.D. = 17.3) within the entire Nam Gnom basin. Consequently, sampling covered around 78.4% of the potential total number of macroinvertebrates' taxa.

Minimum and maximum values of taxonomic richness and density were observed in sites unaffected by the NT2 project suggesting an important natural variability (Tab. III). 22 taxa and 2,370 $ind.m^{-2}$ were collected at NKT2 (January 2011) whereas 50 taxa and 19,540 $ind.m^{-2}$ were collected at NKT1 (January 2012) (Figs. 4a and 4b). Lowest diversity (H' = 1.03) and evenness (E = 0.32) indices were also observed at NKT2 in April 2010 (Tab. III). On the other hand, maximum values of diversity (H' = 2.56) and evenness (E = 0.79) indices were both observed downstream the regulating dam at NKT4 (Tab. III). At this site, taxonomic richness and density decreased after the beginning of water discharge (Figs. 4a and 4b) but the same pattern was also observed in sites unaffected by the NT2 project. For example, between January 2010 and January 2011, taxonomic richness varied from 31 to 22 taxa at NKT2 and density from 12,920 $ind.m^{-2}$ to 5,880 $ind.m^{-2}$ at NGM1. At NKT5, taxonomic richness remained stable during the study period (Fig. 4a) whereas density increased (Fig. 4b)

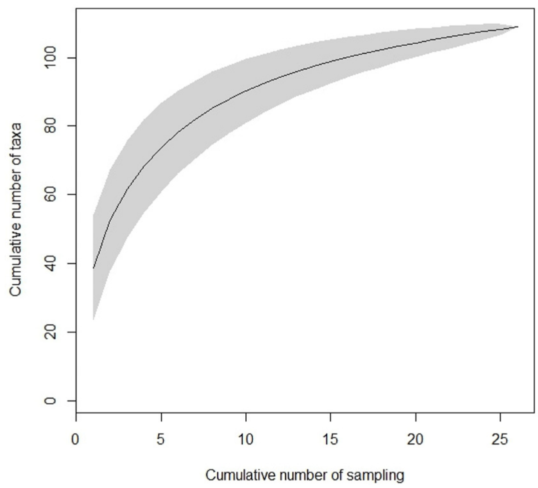


Fig. 3. Species-accumulation curve by cumulative number of sampling (8 surber samples/site) for all stations and dates sampling (n = 26). Shaded area indicates confidence intervals from standard deviation.

Fig. 3. Courbe d'accumulation de la richesse taxonomique en fonction du nombre d'échantillonnage (8 prélèvements au surber/site) sur l'ensemble des stations d'étude et des dates d'échantillonnages (n = 26). La portion grisée représente l'intervalle de confiance de l'écart type.

from 8,093 ind.m^{-2} (January 2010) to 15,105 ind.m^{-2} (April 2012).

3.2.2 Taxonomic composition

Diptera (37.3%), Ephemeroptera (23.6%) and Mollusca (12%) were dominant in samples whereas Crustacea (0.2%) and Plecoptera (1.3%) were the less represented. Trichoptera (20 families) and Coleoptera (16 families) were the richest groups followed by Hemiptera (13 families) and Mollusca (13 families; Appendix 1). Insects remained dominant at all sampling sites representing between 66.3% (NKT2) and 89.7% (NGM1) of the macroinvertebrates community. The EPT group (Ephemeroptera, Plecoptera, and Trichoptera) constituted an important part of the community (Tab. III) ranging from 23.7% (NKT5) to 37.8% (NGM1) but Plecoptera remained generally scarce (<1%). Beside insects, molluscs were the second most important group reaching 24.3% at NKT2. At all sampling sites, annelids showed low relative abundances except at NKT1 where they reached 13.2%. Minor groups and crustaceans accounted for 1% or less in the Nam Gnom basin.

Surprisingly, relative abundance of molluscs did not decrease at NKT4 and NKT5 after receiving poor-mineralised waters (Fig. 4c, Tab. II). Populations remained identic at NKT4 during the whole study. In January 2010, relative abundance of molluscs was 13.4%, while it was 12.9% in April 2010 and 13.2% in January 2011. At NKT5, population of molluscs increased after receiving discharged waters. Three

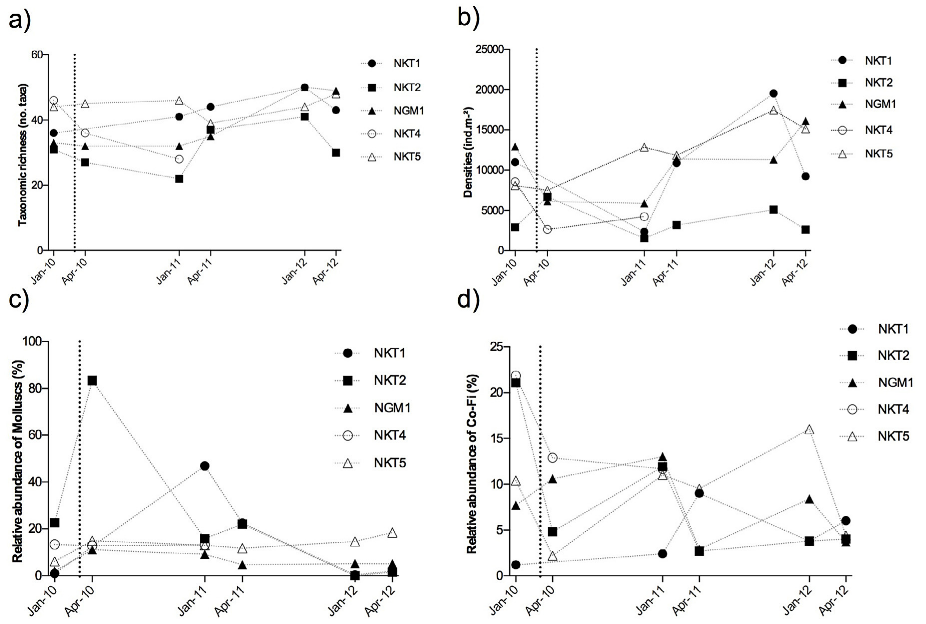


Fig. 4. Temporal variation of taxonomic richness (a), densities (b), relative abundance of mollsuscs (c) and relative abundance of collector-filterers (d) in the Nam Gnom basin. Vertical line corresponds to the beginning of water discharged from the Nam Theun 2 Reservoir. White filled labels correspond to sites under influence of discharged waters.

Fig. 4. Variation temporelle de la richesse taxonomique (a), de la densité (b), de l'abondance relative des mollusques (c) et de l'abondance relative des collecteurs-filtreurs (d) sur le bassin de la Nam Gnom. La ligne verticale indique le début du turbinage des eaux du Réservoir Nam Theun 2. Les labels blancs correspondent aux sites sous influences des eaux turbinées.

months before the beginning of hydropower operation (January 2010), molluscs represented 6.1% of the community. Just after the water discharge (April 2010), molluscs represented 14.9% and 18.4% two years later (April 2012).

3.2.3 Functional feeding groups

The collector-gatherer group (Co-Ga), ranging from 36.1% (NKT2) to 63.5% (NKT1), was dominant at all sampling sites except at NKT2 where scrapers (Sc) dominated (47.2%) (Tab. III). Sc was the second most important dietary group. Minimum average Sc value was observed at NKT5 (18.7%). Other FFG were lower in the Nam Gnom basin. Average contributions of Predators (Pr) and shredders (Sh) did not exceed 17.3% and 4.7% respectively. Collector-filterers (Co-Fi) appeared more abundant in sites influenced by discharged waters, especially at NKT4 where they reached 15.5%.

Although average proportion of Co-Fi appeared to be higher in sites influenced by discharged waters, these populations were halved at NKT4 after the beginning of water release (Fig. 4d). In January 2010, Co-Fi represented 21.9% of the community whereas they represented 11.7% one year after. At NKT5, Co-Fi remained stable during the study period despite a high seasonal variability.

3.2.4 Environmental factors influencing macroinvertebrates communities

The Redundancy Analysis (Figs. 5a and 5b) explained 23.63% of the total variance and resulted in a significant model (P = 0.005). Axes 1 and 2 accounted for 37.68% of the explained variation. Axis 1 explained 25.85% (eigenvalue 6.109) and axis 2 11.83% (eigenvalue 2.797) of the variation fit.

Five environmental variables were retained in the RDA model by the forward selection procedure: Altitude (P = 0.005), Year (P = 0.005), % Aquatic vegetation (P = 0.005), Conductivity (P = 0.01) and % Boulder that had a marginal effect (P = 0.0486) (Fig. 5a).

The first canonical axis associated positively with Altitude (r = 0.768), % Aquatic vegetation (r = 0.088), % Boulder (r = 0.295) and negatively with Conductivity (r = -0.354) and Year (r = -0.232) supports a clear altitudinal gradient (Fig. 5a) whereas the association between axis 2 and the environmental variable Year (r = 0.594) suggested a temporal gradient. Furthermore, the axis 1 makes a clear distinction between the two sub-basins of the Nam Gnom and the Nam Kathang Rivers. NGM1 and NKT5 (Nam Gnom sub-basin) were located on the negative part and were opposed to NKT4, NKT1 and NKT2 (Nam Kathang sub-basin).

Taxa projection (Fig. 5b) indicated that the Potamanthidae family (Ephemeroptera) was the main contributor of the negative part of RDA axis 1 (r = -1.147) and the Hydrophilidae family (Coleoptera) (r = 0.423) the main contributor of the positive part. The Pomatiopsidae family (Gastropoda) was the main contributor of the negative part of the axis 2 (r = -0.769) and the Leptophlebiidae family (Ephemeroptera) the main contributor of the positive part (r = 0.506). Most macroinvertebrates taxa occurred in the negative part of axis 1 and were associated with lowest altitudinal sites.

4 DISCUSSION – CONCLUSION

In addition to the initial bioassessment objectives, this study provided valuable inventory of benthic macroinvertebrates families inhabiting a little studied area of Southeast Asia. A total of 109 macroinvertebrates taxa were identified in the Nam Gnom Basin attesting of a rich biota. Prospecting Northern Vietnam, Jung *et al.* (2008) reported cumulative richness from 61 to 91 families of a wide range of habitat including rivers in national parks. Furthermore, general patterns of diversity were consistent with regional literature. Trichoptera, Hemiptera, and freshwater molluscs were among the most diverse groups. This observation is in line with rivers of the Mekong Basin, known to host one of the highest diversity of these groups (Bogan, 2008; De Moor & Ivanov, 2008; Polhemus & Polhemus, 2008; Strong *et al.*, 2008). On the other hand, the low representation of Plecoptera and Crustacean was predictable.

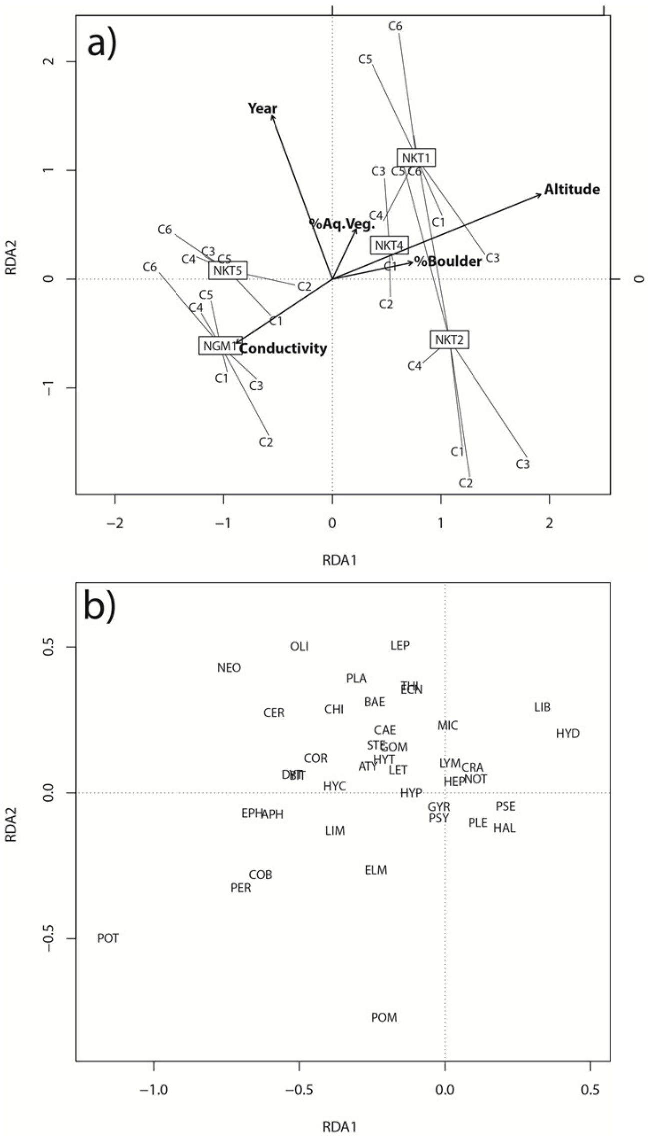


Fig. 5. Axes 1 and 2 of the redundancy analysis (RDA) ordination diagrams. a) Sites-environmental biplot showing significant environmental variables following forward selection. The mean position of the sites was located at the weighted average of corresponding sites. b) Taxa projection. Full taxa names can be found in Appendix 1.

Fig. 5. Axes 1 et 2 de l'analyse canonique de redondance (ACR). a) Graphique sites-variables environnementales significatives selon la procédure de sélection ascendante pas à pas. La position des sites correspond à la position moyenne pondérée des sites correspondants. b) Projection des taxa. Le nom complet des taxa est disponible en Annexe 1.

Plecoptera are known to be scarce in tropical streams (Vinson & Hawkins, 2003) and the surber gear underestimates shrimp abundance due to their high mobility (Ramirez & Pringle, 1998).

Response of macroinvertebrate assemblages to water discharge indicated no evident reduction of diversity indices neither a shift in composition community. At all sites, the typical dominance of Chironomidae and Baetidae was observed (Pinder, 1986; Suren, 1994; Galdean *et al.*, 2001; Ferrington, 2008). The sensitive families *e.g.* Ephemeroptera which are known to negatively react to environmental stress (Azrina *et al.*, 2006; Boonsoong *et al.*, 2009), did not show a decline in population among the upstream stations of the Regulating Pond and the downstream stations receiving water discharge. Surprisingly, mollusc's populations didn't decrease in sites located after water discharge. The high representation of macrophytes habitat (Tab. II) at NKT4 and NKT5 could explain the persistence of mollusc populations. Vegetation composition is a key factor explaining the variation in mollusc species (Horsák & Hájek, 2003).

Furthermore, no functional group changes were apparent. At all sites, the dominance of collector-gatherers was observed, except at NKT2 where scrapers dominated due to the presence of large boulders (>2 m) with low surface heterogeneity. This habitat was poorly colonised by insects' taxa but was largely covered by freshwater snails feeding on an abundant periphyton (*e.g.* Pomatiopsiade; Appendix 1). These results suggested that the capacity to process organic matter was not altered by water release. In addition, the shredders group, represented by few taxa (Tab. III), known to decrease under increasing perturbation (Boonsoong *et al.*, 2009), did not show relevant differences between the upstream and downstream stations. However, the use of the functional feeding groups (FFG) determined for temperate taxa and the family level assignment of FFG has clear limitations (Tomanova *et al.*, 2006, Ramírez & Gutiérrez-Fonseca, 2014). FFG studies at species-level and regionally based, would have allowed more precise conclusion.

In addition, redundancy analysis showed that altitude remained the main driver affecting the distribution of macroinvertebrates taxa in the Nam Gnom Basin before water release. Furthermore, no association among impacted sites was observed. The other environmental factors retained by the forward selection procedure are closely related to altitude. For instance a negative correlation between conductivity and elevation is generally observed (Wilcox *et al.*, 1957; Rundle *et al.*, 1993) and the positive correlation between altitude and the percentage of boulders reflects the sediment transport implying the presence of larger rocks mainly in the upstream part and finer sediments in the downstream part. This altitudinal distribution of habitats is underlined by a clear differentiation of the taxa distribution. For instance, Potamanthidae was the main contributor of the negative part of RDA axis 1 (lower altitude, higher conductivity). The knowledge on the ecology of this family supports this finding as nymphs are known to inhabit downstream sections such as fourth-order stream (Munn & King, 1987). Then, our results are in accordance to literature that underlined that most macroinvertebrates taxa showed a positive correlation with lower altitudinal sites (Jacobsen, 2004). Interannual variation appeared to be a variable playing a significant role on the macroinvertebrates population structure and composition. Pomatiopsidae showed the highest correlation with the temporal gradient suggesting a turnover of populations in accordance to Attwood & Upatham (2012) who identified natural growth-decline cycles in Thailand and central Lao PDR.

Then, two mains factors may explain the relative conservation of natural conditions:

(i) An environmental minimum flow respecting the natural inflow. Flow regime has a strong influence on the biodiversity of rivers and importance of keeping the flow as close as possible to the natural regime is attested (Stanford *et al*., 1996; Poff *et al*., 1997) and confirmed by the interest in restoring natural flow regime to recover biotic integrity all around the world (Sparks, 1995; Petts, 1996; Galat *et al*., 1998; Sparks *et al*., 1998; Dudgeon, 2000; Robinson *et al*., 2003; Attwood & Cottet, same issue).

(ii) The presence of a tributary downstream of the release point. Tributaries are known to structure longitudinal biotic patterns (Rice *et al*., 2001) and their importance in regulated rivers are recognized (Petts & Greenwood, 1985; Stevens *et al*., 1997). According to the serial discontinuity concept (Ward & Stanford, 1983), recovery of large regulated rivers downstream from a dam is limited by relative tributary size. Here, the Nam Gnom River allows to recover biotic integrity of the Nam Kathang River.

Finally, the preliminary results of aquatic invertebrates bioassessment in the Nam Gnom basin allows to draw a general trend of communities in this region. All results of our study are based on a bioassessment at the family-level. Using family level identification is recommended in case of incomplete taxonomic knowledge (Thorne & Williams, 1997) and is qualified as sufficient to assess environmental disturbance (*e.g.* in Thailand; Boonsoong *et al*., 2008). Recent studies conducted in tropical areas showed that family-level resolution successfully detect anthropogenic impairment (Dedieu *et al*., 2015). However, genus-level would have provided more accurate information on water integrity (Lenat & Resh, 2001) and on environmental factors influencing communities (*e.g.* differentiation in the FFG, species-level sensitivity). This approach would have given more confidence to guide management decisions (Rosenberg *et al*., 1986). Even no significant conclusion could be raised due to the few available data before water release, the study allows to strengthen the local knowledge in terms of macroinvertebrates population and environmental factors that could influence them. Bioassessment is at its early stage in Lao PDR. Additional taxonomical and ecological knowledge of benthic macroinvertebrates in the tributaries of the Mekong River are still required to develop robust bioassessment tools, particularly promising in this fast-growing region.

ACKNOWLEDGEMENTS

This research has been conducted at the Aquatic Environment Laboratory of Nam Theun 2 Power Company in Lao PDR whose Shareholders are Électricité de France, Lao Holding State Enterprise and Electricity Generating Public Company Limited of Thailand.

We would like to thank NTPC, Water Quality and Biodiversity Dept, Aquatic Environment Laboratory (AEL) field sampling and at the laboratory analysis (hydrobiology and chemistry teams). We want also to thank all other NTPC teams for their support during the survey and especially Liankham Payasane (GIS team), the logistic team, and Mr Paul Dumbrell who reviewed and improved this version of the manuscript as a native English speaker. Additionally, we thank Olivier Dezerald and all the family-owned HYDRECO team, particularly Claire Montigny and Nicolas Dedieu for their appreciated support. Finally, we would like to thank the reviewer for the comments and helpful advices to improve the manuscript.

REFERENCES

Armitage P.D., 1984. Environmental changes induced by stream regulation and their effect on lotic macroinvertebrate communities. *Regul. River* : 139-165.

Attwood S.W. & Cottet M. Malacological and parasitological surveys along the Xe Bangfai and its tributaries in Khammouane Province, Lao PDR. *Hydroécol. Appl.* 19 *(same issue).*

Attwood S.W. & Upatham E.S., 2012. Observations on *Neotricula aperta* (Gastropoda: Pomatiopsidae) population densities in Thailand and central Laos: implications for the spread of Mekong Schistosomiasis. *Parasite. Vector.* 5 (126) : 1-13.

Azrina M.Z., Yap C.K., Rahim Ismail A., Ismail A. & Tan S.G., 2006. Anthropogenic impacts on the distribution and biodiversity of benthic macroinvertebrates and water quality of the Langat River, Peninsular Malaysia. *Ecotox. Environ. Safe.* 64 : 337-347.

Bogan A.E., 2008. Global diversity of freshwater mussels (Mollusca, Bivalvia) in freshwater. *Hydrobiologia* 595 : 139-147.

Boon P.J., 1988. The impact of river regulation on invertebrate communities in the UK. *Regul. River.* 2(3) : 389-409.

Boonsoong B., Sangpradub N. & Barbour M.T., 2008. Development of rapid bioassessment approaches using benthic macroinvertebrates for Thai streams. *Environ. Monit. Assess.* 155(1-4) : 129-147.

Boonsoong B., Sangpradub N., Barbour M.T. & Simachaya W., 2009. An implementation plan for using the biological indicators to improve assessment of water quality in Thailand. *Environ. Monit. Assess.* 165(1) : 205-215.

Chanudet V., Guédant P., Rode W., Guérin F., Serça D., Deshmukh C. & Descloux S. Evolution of the physico-chemical water quality in the Nam Theun 2 Reservoir for the first 5 years after impoundment. *Hydroécol. Appl.* 19 *(same issue).*

Cortes R.M.V., Ferreira M.T., Oliveira S.V. & Godinho F., 1998. Contrasting impact of small dams on the macroinvertebrates of two Iberian mountain rivers. *Hydrobiologia* 389(1-3) : 51-61.

Cummins K.W. & Klug M.J., 1979. Feeding ecology of stream invertebrates. *Annu. Rev. Ecol. Syst.*10 : 147-172.

Davidson S.P., Kunpradid T., Peerapornisal Y., Nguyen T.M.L., Pathoumthong B., Vongsambath C. & Pham A.D., 2006. *Biomonitoring of the Lower Mekong and selected tributaries*. MRC Technical Paper 13. Mekong River Commission,106 p., Vientiane.

Dedieu N., Clavier S., Vigouroux R., Cerdan P. & Céréghino R., 2015. A Multimetric Macroinvertebrate Index for the Implementation of the European Water Framework Directive in French Guiana, East Amazonia. *River. Res. Appl.*, doi: 10.1002/rra.2874.

De Moor F.C. & Ivanov V.D., 2008. Global diversity of caddisflies (Trichoptera: Insecta) in freshwater. *Hydrobiologia* 595(1) : 393-407.

Descloux S., Guédant P., Phommachanh D. & Luthi R. Main features of the Nam Theun 2 hydroelectric project (Lao PDR) and the associated environmental monitoring programme. *Hydroécol. Appl.* 19 *(same issue).*

Dillon R.T., 2000. *The ecology of freshwater molluscs*. Cambridge University Press, 509 p.

Dudgeon D., 1999. *Tropical Asian Streams: Zoobenthos, Ecology and Conservation*. Hong Kong University Press, Hong Kong, 830 p.

Dudgeon D., 2000. Large-Scale Hydrological Changes in Tropical Asia: Prospects for Riverine Biodiversity The construction of large dams will have an impact on the biodiversity of tropical Asian rivers and their associated wetlands. *Bioscience* 50(9) : 793-806.

Dynesius M. & Nilsson C., 1994. Regulation of River Systems in the Northern Third of the World. *Science* 266 : 753-762.

Ferrington L.C., 2008. Global diversity of non-biting midges (Chironomidae; Insecta-Diptera) in freshwater. *Hydrobiologia* 595 : 447-455.

Galat D.L., Fredrickson L.H., Humburg D.D., Bataille K.J., Bodie J.R., Dohrenwend J. & Semlitsch R.D., 1998. Flooding to restore connectivity of regulated, large-river wetlands natural and controlled flooding as complementary processes along the lower Missouri River. *Bioscience* 48(9) : 721-733.

Galdean N., Callisto M. & Barbosa F.A.R., 2001. Biodiversity assessment of benthic macroinvertebrates in altitudinal lotic ecosystems of Serra do Cipó (MG, Brazil). *Rev. Bras. Biol.* 61(2) : 239-248.

Getwongsa P. & Sangpradub N., 2008. Preliminary Study on Development of Biotic Index for Rapid Bioassessment in Mekong II Basin (Thailand). *KKU Sci. J.* 36 (Suppl.) : 122-136.

Hoang D.H. & Bae Y.J., 2006. Aquatic insect diversity in a tropical Vietnamese stream in comparison with that in a temperate Korean stream. *Limnol.* 7 : 45-55.

Hoang T.H., Lock K., Dang K.C., De Pauw N. & Goethals P.L.M., 2010. Spatial and temporal patterns of macroinvertebrate communities in the du River basin in northern Vietnam. *J. Freshwater Ecol.* 25(4) : 637-647.

Horsák M., 2006. Mollusc community patterns and species response curves along a mineral richness gradient: a case study in fens. *J. Biogeography* 33(1) : 98-107.

Horsák M. & Hájek M., 2003. Composition and species richness of molluscan communities in relation to vegetation and water chemistry in the western Carpathian spring fens: the poor–rich gradient. *J. Mollus. Stud.* 69(4) : 349-357.

Jacobsen D., 2004. Contrasting patterns in local and zonal family richness of stream invertebrates along an Andean altitudinal gradient. *Freshwater Biol.* 49(10) : 1293-1305.

Jalon D., Garcia D., Sanchez P. & Camargo J.A., 1994. Downstream effects of a new hydropower impoundment on macrophyte, macroinvertebrate and fish communities. *Regul. River.* 9(4) : 253-261.

Jung S.W., Nguyen Q.H. & Bae Y.J., 2008. Aquatic insect faunas and communities of a mountain stream in Sapa Highland, northern Vietnam. *Limnol.* 9(3) : 219-229.

Lauri H., De Moel H., Ward P.J., Räsänen T.A., Keskinen M. & Kummu M., 2012. Future changes in Mekong River hydrology: impact of climate change and reservoir operation on discharge. *Hydrol. Earth Syst. Sci.* 9(5) : 6569-6614.

Legendre P. & Legendre L., 1998. *Numerical ecology*. 2nd English edition. Elsevier, Amsterdam, 853 p.

Lenat D.R. & Resh V.H., 2001. Taxonomy and stream ecology–the benefits of genus-and species-level identifications. *J. N. Am. Benthol. Soc.* 20(2) : 287-298.

Malmqvist B. & Eriksson Å., 1995. Benthic insects in Swedish lake-outlet streams: patterns in species richness and assemblage structure. *Freshwater Biol*. 34(2) : 285-296.

Merrit R.W., Cummins K.W. & Berg M.B., 2008. *An introduction to the aquatic insect of North America.* Fourth Edition. Ed. Dubuque, Iowa, 1158 p.

Moog O., 1993. Quantification of daily peak hydropower effects on aquatic fauna and management to minimize environmental impacts. *Regul. River.* 8(1-2) : 5-14.

MRC, 2010. State of the Basin Report 2010. Mekong River Commission, Vientiane, Lao PDR, 123 p.

Munn M.D. & King R.H., 1987. Ecology of Potamanthus myops (Walsh) (Ephemeroptera: Potamanthidae) in a Michigan stream (USA). *Hydrobiologia* 146 : 71-75.

Mustow S.E., 2002. Biological monitoring of rivers in Thailand: use and adaptation of the BMWP score. *Hydrobiologia* 479 : 191-229.

Nilsson C., Reidy C.A., Dynesius M. & Revenga C., 2005. Fragmentation and flow regulation of the world's large river systems. *Science* 308(5720) : 405-408.

Ogbeibu A.E. & Oribhabor B.J., 2002. Ecological impact of river impoundment using benthic macro-invertebrates as indicators. *Water Res.* 36(10) : 2427-2436.

Oksanen J., Kindt R., Legendre P., O'Hara B., Stevens M.H.H., Oksanen M.J. & Suggests M.A.S.S., 2007. The vegan package. *Community ecology package*.

Pathoumthong B. & Vongsombath C., 2007. Macroinvertebrate Pilot Study for Ecological Health Monitoring in the Lower Mekong Basin. *Southeast Asian Water Environment* 2, 123 p.

Petts G.E., 1984. *Impounded rivers: perspectives for ecological management*. John Wiley, New York, 326 p.

Petts G.E., 1996. Water allocation to protect river ecosystems. *Regul. River.* 12(4-5) : 353-365.

Petts G.E. & Greenwood M., 1985. Channel changes and invertebrate faunas below Nant-Y-Moch dam, River Rheidol, Wales, UK. *Hydrobiologia* 122(1) : 65-80.

Pinder L.C.V., 1986. Biology of freshwater Chironomidae. *Annu. Rev. Entomol.* 31(1) : 1-23.

Poff N.L., Allan J.D., Bain M.B., Karr J.R., Prestegaard K.L., Richter B.D., Sparks E.E. & Schomberg J.C., 1997. The natural flow regime: A paradigm for river conservation and restoration. *Bioscience* 47 : 769-784.

Polhemus J.T. & Polhemus D.A., 2008. Global diversity of true bugs (Heteroptera: Insecta) in freshwater. *Hydrobiologia* 595 : 379–391.

R Core Team Development, 2013. R: A language and environment for statistical computing. *R Foundation for Statistical Computing*, Vienna, Austria. URL http://www.R-project.org/.

Ramírez A. & Gutiérrez-Fonseca P.E., 2014. Functional feeding groups of aquatic insect families in Latin America: a critical analysis and review of existing literature. *Rev. Biol. Trop.* 62 : 155-167.

Ramirez A. & Pringle C.M., 1998. Invertebrate drift and benthic community dynamics in a lowland neotropical stream, Costa Rica. *Hydrobiologia* 386 : 19-26.

Resh V.H., Norris. R.H., & Barbour M.T., 1995. Design and implementation of rapid assessment approaches for water resource monitoring using benthic macroinvertebrates. *Aust. J. Ecol.* 20(1) : 108-121.

Rice S.P., Greenwood M.T. & Joyce C.B., 2001. Tributaries, sediment sources, and the longitudinal organisation of macroinvertebrate fauna along river systems. *Can. J. Fish. Aquat. Sci.* 58(4) : 824-840.

Robinson C.T., Uehlinger U. & Monaghan M.T., 2003. Effects of a multi-year experimental flood regime on macroinvertebrates downstream of a reservoir. *Aquat. Sci.* 65(3) : 210-222.

Rolls R.J., Sheldon F. & Marsh N., 2012. *Macroinvertebrate responses to prolonged low flow in sub-tropical Australia*, National Water Commission, Canberra, 30 p.

Rosenberg D.M., Danks H.V. & Lehmkuhl D.M., 1986. Importance of insects in environmental impact assessment. *Environ. Manage.* 10(6) : 773-783.

Rundle S.D., Jenkins A. & Ormerod S.J., 1993, Macroinvertebrate communities in streams in the Himalaya, Nepal. *Freshwater Biol.* 30 : 169-180.

Sangpradub N. & Boonsoong B., 2006. *Identification of Freshwater Invertebrates of the Lower Mekong River and its Tributaires*. Mekong River Commission, Vientiane, LAO PDR, 267 p.

Schlosser I.J., 1992. Effects of life-history attributes and stream discharge on filter-feeder colonization. *J. N. Am. Benthol. Soc.* 11(4) : 366-376.

Souksavath B. & Nakayama M., 2013. Reconstruction of the livelihood of resettlers from the Nam Theun 2 hydropower project in Laos. *Int. J. Water Resour. D* 29 : 71–86.

Sparks R.E., 1995. Need for ecosystem management of large rivers and their floodplains. *Bioscience* 45(3) : 168-182.

Sparks R.E., Nelson J.C. & Yin Y., 1998. Naturalization of the flood regime in regulated rivers. *Bioscience* 48 : 706-720.

Stanford J.A., Ward J.V., Liss W.J., Frissell C.A., Williams R.N., Lichatowich J.A. & Coutant C.C., 1996. *A general protocol for restoration of regulated rivers*. US Department of Energy Publications, 43 p.

Stevens L.E., Shannon J.P. & Blinn D.W., 1997. Colorado River benthic ecology in Grand Canyon, Arizona, USA: dam, tributary and geomorphological influences. *Regul. River.* 13(2) : 129-149.

Strong E.E., Gargominy O., Ponder W.F. & Bouchet P., 2008. Global diversity of gastropods (Gastropoda; Mollusca) in freshwater. *Hydrobiologia* 595 : 149-166.

Suren A.M., 1994. Macroinvertebrate communities of streams in western Nepal: effects of altitude and land use. *Freshwater Biol.* 32(2) : 323-336.

ter Braak C.J.F. & Smilauer P., 1998. CANOCO Reference Manual and User's Guide to Canoco for Windows: Software for Canonical Community Ordination (version 4), Microcomputer Power, Ithaca, New York, 352 p.

Thani I. & Phalaraksh C., 2008. A preliminary study of aquatic insect diversity and water quality of Mekong River, Thailand. *KKU. Sci. J.* 36 (Suppl.) : 95-106.

Thorne R.S.J. & Williams W.P., 1997. The response of benthic macroinvertebrates to pollution in developing countries: a multimetric system of bioassessment. *Freshwater Biol.* 37 : 671-686.

Tomanova S., Goitia E. & Helešic J., 2006. Trophic levels and functional feeding groups of macroinvertebrates in neotropical streams. *Hydrobiologia* 556(1) : 251-264.

Vinson M.R., 2001. Long-term dynamics of an invertebrate assemblage downstream from a large dam. *Ecol. Appl.* 11 : 711-730.

Vinson M.R. & Hawkins C.P., 2003. Broad-scale geographical patterns in local stream insect genera richness. *Ecography* 26 : 751-767.

Ward J.V. & Stanford J.A., 1979. *The ecology of regulated streams*. New York: Plenum Press, 398 p.

Ward J.V. & Stanford J.A., 1983. The serial discontinuity concept of lotic ecosystems. In: Fontaine T.D. III & Bartell S.M. (Eds.), *Dynamics of Lotic Ecosystems*, Ann Arbor Science Publishers: Ann Arbor, 29–42.

Wilcox J.C., Holland W.D. & Mc Dougald J.M., 1957. Relation of elevation of a mountain stream to reaction and salt content of water and soil. *Can. J. Soil Sci.* 37(1) : 11-20.

Ziv G., Baran E., Nam S., Rodríguez-Iturbe I. & Levin S.A., 2012. Trading-off fish biodiversity, food security, and hydropower in the Mekong River Basin. *P. Natl. Acad. Sci. USA* 109(15) : 5609-5614.

Appendix 1. Densities (ind.m^{-2}) of aquatic invertebrates collected in the Nam Gnom Watershed from January 2010 to April 2012.
Annexe 1. Densités (ind.m^{-2}) des invertébrés aquatiques collectés sur le bassin de la Nam Gnom entre janvier 2010 et avril 2012.

					NKT1					NKT2						NGM1						NKT4			NKT5					
ARHTROPODA			FFG	RDA Code	C1	C3	C4	C5	C6	C1	C2	C3	C4	C5	C6	C1	C2	C3	C4	C5	C6	C1	C2	C3	C1	C2	C3	C4	C5	C6
CRUSTACEA		*Atyidae*	Co-Ga	ATY	0	0	18	0	3	0	0	0	0	0	0	0	0	0	0	0	40	0	0	0	56	300	3	25	0	15
		Palaemonidae	Co-Ga		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	5
		Gecarcinucidae	Co-Ga		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
		Parathelphusidae	Co-Ga		0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	5	0	0	0	0	0	0	3	0	18
		Potamidae	Co-Ga		0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	10	0	0	5	0
ARACHNIDA		*Hydracarina*	Pr	HYC	0	0	0	0	0	0	0	0	18	0	0	0	0	0	15	8	40	0	0	6	0	0	8	18	130	23
INSECTA	Coleoptera	*Chrysomelidae*	Sh		6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Curculionidae	Sh		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
		Dryopidae	Sh		11	0	3	0	0	44	0	0	30	0	0	0	0	0	0	0	0	0	3	0	0	3	0	0	0	0
		Dytiscidae	Pr	DYT	14	25	43	5	3	0	0	0	20	25	0	378	11	3	78	525	145	3	10	6	296	170	55	5	15	105
		Elmidae	Sc	ELM	154	98	123	163	15	240	54	618	218	93	115	3628	1737	697	743	668	208	68	40	26	156	163	133	145	60	260
		Gyrinidae	Pr	GYR	0	0	3	0	0	0	0	15	0	0	0	0	0	0	0	3	0	0	0	3	9	158	0	0	5	3
		Haliplidae	Sh	HAL	0	10	0	0	0	0	0	30	93	0	0	0	0	0	0	0	0	60	0	0	0	0	3	0	0	0
		Helophoridae	Sh		0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Hydraenidae	Pr		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0
		Hydrochidae	Sh		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	9	8	0	0	0	0
		Hydrophilidae	Pr	HYD	86	3	10	20	73	12	6	0	20	40	3	0	0	0	0	3	0	78	5	0	29	15	0	0	0	0
		Hydroscaphidae	Sc		0	0	0	5	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Noteridae	Pr	NOT	0	283	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	5	6	0	115	3	0	0	0
		Psephenidae	Sc	PSE	131	180	70	48	25	56	83	93	73	15	3	25	6	0	48	8	3	5	3	3	73	33	125	8	65	30
		Scirtidae	Co-Fi		0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Staphylinidae	Pr		0	0	0	0	0	0	0	0	0	18	0	0	0	0	0	0	0	5	0	0	0	0	5	0	0	0
	Collembola		Co-Ga		0	0	0	0	0	0	0	0	0	10	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Diptera	*Athericidae*	Pr		0	5	0	5	0	0	3	0	0	0	0	0	0	0	0	3	3	3	0	9	4	0	3	0	0	0
		Ceratopogonidae	Pr	CER	6	0	45	315	73	12	0	0	30	23	60	290	29	43	215	198	335	98	45	57	27	283	123	303	130	220
		Chironomidae	Co-Ga	CHI	4700	55	2525	9645	4520	696	143	28	988	1843	790	3095	446	1291	4195	2003	7103	3650	825	477	2756	3098	4580	4788	10455	5098
		Culicidae	Co-Fi		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0
		Empididae	Pr		0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	3	0	3	0	0	0	0	0	0	3	0
		Limoniidae	Sh	LIM	49	8	13	43	33	28	11	0	8	5	0	128	83	289	115	238	65	45	38	17	142	20	38	58	85	25
		Simuliidae	Co-Fi		3	0	0	0	25	0	0	0	0	0	53	0	0	0	0	5	0	0	0	0	0	0	0	0	0	3
		Stratiomyidae	Sh		0	5	0	5	0	0	0	0	0	3	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
		Tabanidae	Pr		0	0	0	0	0	0	0	0	0	5	0	20	6	3	5	5	73	0	0	0	2	0	5	0	0	0
		Tipulidae	Sh		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	63	0	0	0	0	0	0	0	0	0	0
	Ephemeroptera	*Baetidae*	Sc	BAE	1009	118	403	1590	643	12	31	28	445	425	238	310	89	189	693	3805	373	1098	248	863	729	220	1100	153	1740	525
		Caenidae	Co-Ga	CAE	131	90	218	3733	218	20	134	155	145	538	553	200	77	971	1248	245	400	478	135	606	589	40	783	648	65	643
		Ephemerellidae	Co-Ga	EPH	0	0	0	13	3	0	0	8	28	130	0	248	11	29	203	193	173	10	3	6	107	10	305	30	83	25
		Ephemeridae	Co-Ga		0	0	5	20	5	0	0	0	3	25	38	75	0	14	10	13	0	3	0	0	0	0	0	0	0	10
		Heptageniidae	Sc	HEP	157	73	10	425	40	100	17	3	83	340	0	48	54	3	10	93	63	48	18	94	187	38	115	38	218	8
		Leptophlebiidae	Sc	LEP	1003	75	40	108	190	16	0	3	5	233	35	40	3	3	10	65	50	68	73	83	522	128	500	583	200	303
		Neoephemeridae	Co-Ga	NEO	0	0	0	1438	98	0	0	0	0	313	353	190	89	9	288	85	590	5	0	0	16	38	38	55	115	285
		Polymitarcyidae	Co-Ga		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0
		Potamanthidae	Co-Ga	POT	0	3	0	0	0	48	9	0	0	0	0	408	571	406	343	503	3110	0	0	0	647	238	1480	1613	438	908
		Prosopistomatidae	Sc		0	0	0	0	0	4	0	0	0	3	0	25	126	3	3	0	10	0	0	0	9	3	0	0	3	5
		Teloganodidae	Sh		0	5	0	8	0	0	6	0	0	45	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0

Appendix 1. Continued.

Annexe 1. Suite.

				NKT1					NKT2						NGM1						NKT4			NKT5					
		FFG	RDA Code	C1	C3	C4	C5	C6	C1	C2	C3	C4	C5	C6	C1	C2	C3	C4	C5	C6	C1	C2	C3	C1	C2	C3	C4	C5	C6
Hemiptera	*Aphelocheiridae*	Pr	APH	83	13	38	0	3	8	0	0	8	20	3	1178	454	406	383	68	128	30	245	903	149	5	170	403	53	130
	Corixidae	Pr	COR	0	3	8	5	165	0	146	0	15	48	50	3	6	100	143	313	243	48	140	9	13	50	265	53	40	125
	Gerridae	Pr		0	0	5	10	5	0	0	0	8	8	0	0	3	0	0	0	3	3	0	0	16	0	3	0	0	0
	Helotrephidae	Pr		0	0	3	0	0	0	0	0	28	0	0	0	0	0	0	3	30	0	0	0	0	0	0	3	0	0
	Hydrometridae	Pr		0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Leptopodidae	Pr		0	3	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Mesoveliidae	Pr		0	0	0	23	3	0	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Micronectidae	Pr	MIC	0	0	20	0	155	0	0	0	0	0	0	0	0	0	0	0	48	0	0	0	0	0	0	0	0	0
	Naucoridae	Pr		9	3	10	0	5	0	0	0	0	5	0	13	0	0	0	5	0	3	3	0	2	0	5	0	13	0
	Nepidae	Pr		0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	0	0	0	0
	Notonectidae	Pr		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0	0	0	0	0	0	0
	Pleidae	Pr	PLE	77	0	0	0	3	60	6	35	0	13	0	0	0	0	0	43	93	23	18	0	27	10	10	0	23	5
	Veliidae	Pr		3	3	0	0	0	0	0	13	13	0	0	0	0	0	0	0	3	13	0	0	0	0	18	0	0	0
Lepidoptera	*Crambidae*	Sh	CRA	137	8	68	40	108	12	40	8	5	15	0	163	0	23	3	35	0	28	55	9	13	70	13	15	3	20
Odonata	*Aeshnidae*	Pr		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
	Amphipterygidae	Pr		0	0	0	5	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	3	8	3
	Calopterygidae	Pr		0	0	0	13	0	0	0	0	0	5	0	0	0	0	0	5	0	15	0	0	0	0	0	0	0	0
	Chlorocyphidae	Pr		0	0	0	0	0	0	11	3	0	0	0	0	0	0	0	0	0	0	0	0	13	8	40	0	0	0
	Coenagrionidae	Pr		0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	4	3	0	0	0	0
	Corduliidae	Pr		0	20	3	5	5	0	3	0	0	0	0	0	3	0	0	0	0	5	3	0	2	0	10	0	0	3
	Euphaeidae	Pr		29	5	0	3	0	4	43	0	0	0	0	3	0	0	0	0	0	3	0	0	0	0	0	0	0	0
	Gomphidae	Pr	GOM	34	10	68	48	1475	12	6	0	3	0	8	55	37	77	30	58	20	8	3	14	20	5	33	13	20	8
	Lestidae	Pr		0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	8	3	0	0	0	0	0	0	0	0	0
	Libellulidae	Pr	LIB	291	10	65	213	115	4	46	8	3	10	5	0	0	0	8	3	8	43	3	29	7	15	20	5	5	0
	Platycnemididae	Pr		0	0	18	8	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
	Protoneuridae	Pr		6	5	3	50	0	0	0	0	0	0	0	0	0	0	0	0	25	23	3	0	11	0	8	0	0	10
Plecoptera	*Nemouridae*	Sh		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	0
	Perlidae	Pr	PER	3	0	8	8	0	16	6	3	0	8	3	785	1074	103	98	115	393	5	13	0	107	33	75	75	18	85
Trichoptera	*Beraeidae*	Co-Ga		0	0	0	0	0	0	0	0	0	0	0	0	43	0	0	0	0	0	53	0	0	5	0	0	0	0
	Brachycentridae	Co-Fi		0	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Dipseudopsidae	Co-Fi		3	3	8	3	3	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Ecnomidae	Pr	ECN	0	3	0	88	3	0	0	0	0	118	60	3	9	0	0	0	3	0	33	23	0	43	15	13	38	8
	Glossosomatidae	Sc		0	0	0	0	0	80	0	0	13	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Goeridae	Sc		0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
	Helicopsychidae	Sc		0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Hydrobiosidae	Pr		0	0	0	0	0	0	0	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Hydropsychidae	Co-Fi	HYP	109	30	128	688	518	380	97	175	18	178	50	908	240	397	78	790	223	775	65	29	369	15	320	50	458	143
	Hydroptilidae	Sc	HYT	14	45	63	95	170	28	160	0	35	20	28	255	6	151	43	10	118	78	105	126	138	125	245	88	95	53
	Leptoceridae	Sh	LET	54	35	23	218	80	128	14	45	63	433	13	173	34	54	153	83	245	28	13	29	44	10	153	180	80	110
	Molannidae	Sc		23	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
	Odontoceridae	Sh		0	0	20	0	3	0	0	0	10	0	0	0	0	0	0	30	48	0	18	0	0	0	0	30	0	5
	Philopotamidae	Co-Fi		0	0	0	53	0	8	0	0	13	0	3	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0
	Phryganeidae	Sh		0	0	0	75	5	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	0
	Polycentropodidae	Pr		0	0	20	48	3	0	29	0	3	3	8	0	0	0	0	0	13	0	0	0	24	0	0	0	0	0

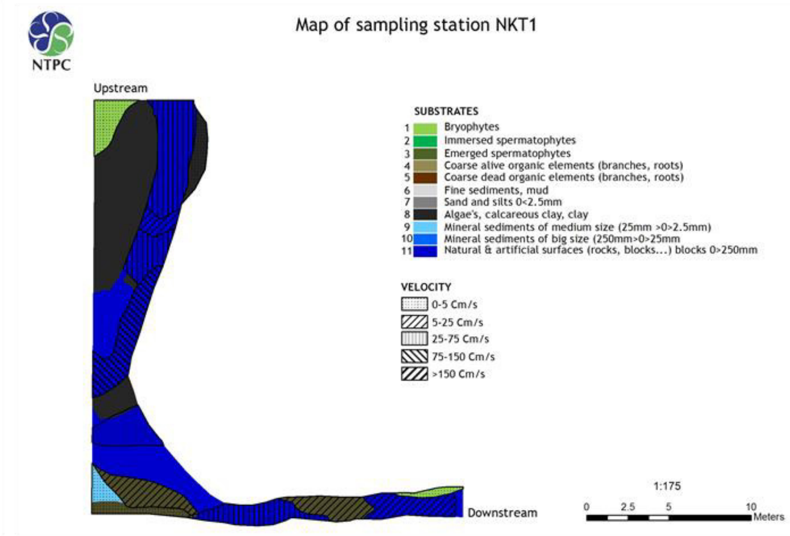
Appendix 1. Continued.

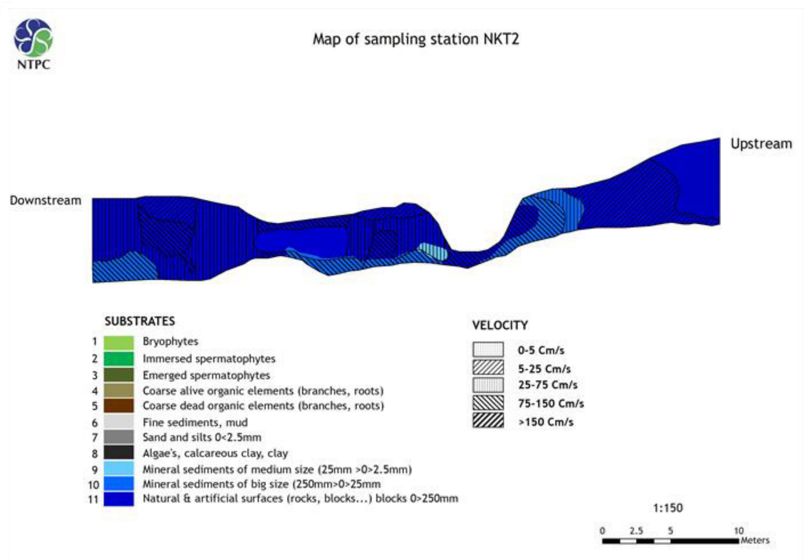
Annexe 1. Suite.

			FFG	RDA Code	NKT1 C1	NKT1 C3	NKT1 C4	NKT1 C5	NKT1 C6	NKT2 C1	NKT2 C2	NKT2 C3	NKT2 C4	NKT2 C5	NKT2 C6	NGM1 C1	NGM1 C2	NGM1 C3	NGM1 C4	NGM1 C5	NGM1 C6	NKT4 C1	NKT4 C2	NKT4 C3	NKT5 C1	NKT5 C2	NKT5 C3	NKT5 C4	NKT5 C5	NKT5 C6
		Psychomyiidae	Pr	PSY	6	10	0	5	0	4	0	0	13	0	0	0	0	9	0	168	0	15	0	0	16	0	5	0	48	0
		Stenopsychidae	Co-Fi		0	0	0	0	0	24	9	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Uenoidae	Sc		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
		Xiphocentronidae	Co-Fi		0	3	0	0	0	196	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	5	0	0
MOLLUSCA	Pelycypoda	*Corbiculidae*	Co-Fi	COB	14	5	825	3	5	0	214	8	58	0	0	85	406	343	248	120	368	1100	278	466	471	118	1035	1065	2333	513
		Dreissenidae	Co-Fi		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	58	0	0	0
		Mytilidae	Co-Fi		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	3	0	0	0	0	0	0	0	0	5
		Unionidae	Co-Fi		0	0	0	0	0	0	0	0	0	0	0	0	3	17	3	0	0	0	0	0	0	3	3	0	0	0
		Viviparidae	Co-Fi		0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28	0	3	3	0
	Gastropoda	*Ampullariidae*	Sc		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
		Bithyniidae	Sc	BIT	0	0	0	3	5	0	0	0	8	0	13	0	0	86	28	50	13	0	0	3	0	13	70	138	105	5
		Buccinidae	Sc		0	0	0	28	38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	0	0	8	30
		Lymnaeidae	Sc	LYM	3	3	335	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	113	0	13	0	0
		Planorbidae	Sc	PLA	6	73	0	35	25	0	0	0	0	0	25	15	0	0	8	3	0	0	0	0	0	0	483	40	8	465
		Pomatiopsidae	Sc	POM	86	3	438	0	0	664	5369	238	640	0	0	155	274	57	253	223	245	45	65	0	22	818	30	135	90	865
		Stenothyridae	Sc	STE	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	28	0	0	0	0	0	0	0	0	878
		Thiaridae	Sc		0	1028	840	0	115	0	0	0	0	0	0	0	0	37	0	180	173	0	0	91	0	0	0	8	13	23
NEMATOMORPHA		Nematoda	Pr		0	0	0	13	3	0	0	0	0	0	5	0	0	0	0	0	10	0	0	0	0	0	0	0	0	3
PLATHYHELMINTHES		*Planariidae*	Pr		3	0	0	0	0	0	0	0	8	3	10	20	3	9	155	5	155	108	5	0	73	15	313	123	10	53
ANNELIDA		*Glossiphonidae*	Pr		0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Oligochaeta	Co-Ga	OLI	2543	0	4275	160	245	0	0	0	35	15	120	3	191	54	1530	240	668	413	88	246	182	895	58	925	110	3045

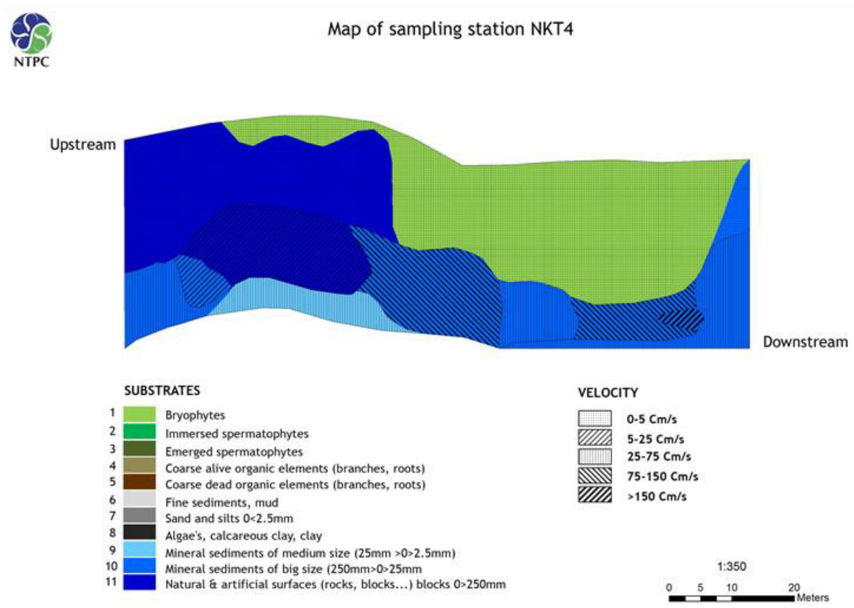
Appendix 2. Substrate types and current velocity mapping of the stations monitored in the Nam Gnom basin.

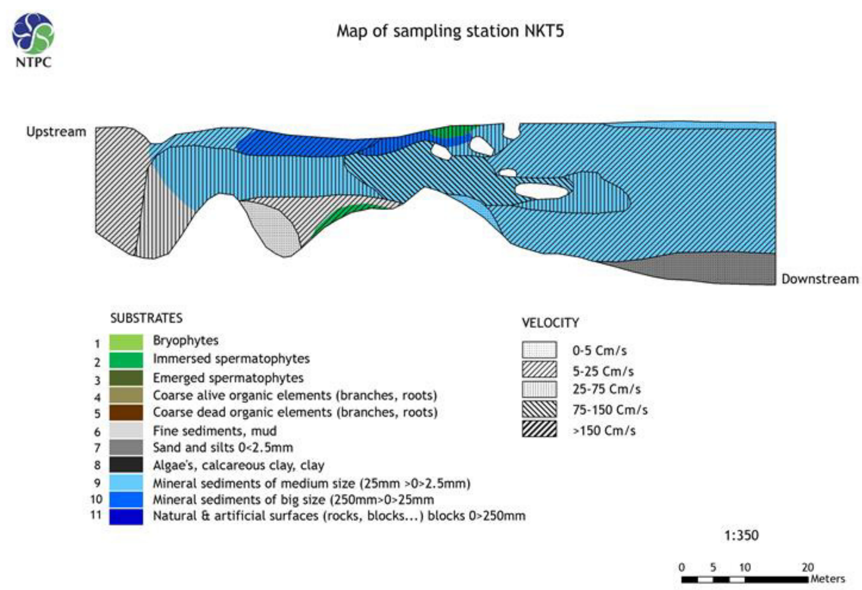
Annexe 2. Cartographie des types de substrat et des vitesses du courant des stations suivies sur le bassin de la Nam Gnom.





Appendix 2. Continued.
Annexe 2. Suite.





Appendix 2. Continued.
Annexe 2. Suite.