DISTRIBUTION AND ECOLOGY OF *AUSTROPOTAMOBIUS PALLIPES* IN GERMANY.

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ABSTRACT

In Germany, three species of native freshwater crayfish are found : the noble crayfish (*Astacus astacus*), the stone crayfish (*Austropotamobius torrentium*) and the white-clawed crayfish (*Austropotamobius pallipes*), which occurs very rarely.

The distribution of white-clawed crayfish (*A. pallipes*) in Germany is restricted to parts of the south-west, east of the Rhine in the area of the city Freiburg (Germany). This is the north-eastern limit of the distribution. The occurrence of this species in Germany was first described in 1989 (TROSCHEL and BERG, 1989). It has now been discovered in eight localities. To characterize the biotops, the hydrochemistry was investigated and the structure of two typical streams evaluated. The wide variation of the water parameters indicates that the presence of *A. pallipes* is not dependent on the water chemistry.

It is clear that the stream morphology is vital for the occurrence of this species. The variation of depth (0.05 - 0.5 m) and width (1 - 5 m) is large and there are numerous hiding places for the crayfish among the stones, decaying wood and tree roots.

A. pallipes and *A. astacus* are found in the lower parts of the river whereas *A. torrentium* is found more in the headwaters.

These three species are protected by the Fish Protection Act. Normally, non-native species do not invade the biotops of *A. pallipes* and the danger of transported *Aphanomyces astaci* is small.

Key-words : *Austropotamobius pallipes*, water parameters, distribution, Germany.

RÉPARTITION ET ÉCOLOGIE D´*AUSTROPOTAMOBIUS PALLIPES* EN ALLEMAGNE.

RÉSUMÉ

Il existe trois espèces d'écrevisses originaires d'Allemagne : l'écrevisse à pattes rouges (*Astacus astacus*), l'écrevisse de torrent (*Austropotamobius torrentium*) et l'écrevisse à pieds blancs (*Austropotamobius pallipes*) que l'on trouve cependant rarement.

La répartition de l'écrevisse à pieds blancs est limitée à certains endroits du sud-ouest de l'Allemagne, plus précisément à l'est du Rhin dans la région de Fribourg en Brisgau. C'est la limite nord-est de la répartition.

La fréquence de cette espèce en Allemagne a été décrite la première fois en 1989 (TROSCHEL et BERG, 1989). Depuis, on a pu l'observer à huit endroits différents. En vue de préciser le biotope, des recherches ont été faites sur l'hydrochimie dans deux ruisseaux nous paraissant typiques. La présence d'*Austropotamobius pallipes* ne dépend pas de la composition de l'eau. Il est évident que la morphologie du ruisseau est vitale pour la fréquence de cette espèce. Les variations de profondeur (0.05 - 0.5 m) et de largeur (1 - 5 m) sont importantes et il existe de nombreux endroits où l'écrevisse peut se cacher parmi les cailloux, le bois mort et les racines d'arbres.

On trouve *A. pallipes* et *Astacus astacus* plutôt dans les parties basses des rivières et *Austropotamobius torrentium* plutôt dans les parties hautes.

A. pallipes est protégée par la loi sur la sauvegarde du poisson. Normalement, les espèces exotiques n'envahissent pas le biotope d'*A. pallipes* et le danger de contagion par *Aphanomyces astaci* est réduit.

Mots-clés : *Austropotamobius pallipes*, répartition, conditions des eaux, Allemagne.

INTRODUCTION

The first individual of *Austropotamobius pallipes* to be found in Germany on the east of the Rhine river in recent times occurred during a survey of the fish in the state of Baden-Württemberg (BERG *et al.,* 1989 ; TROSCHEL and BERG, 1989). GESNER (1557) was the first to refer to crayfish species in this area, citing the medieval German names : <<Tulkräbs>> and <<Steinkräbs>>, for the white-clawed and stone crayfish (*A. torrentium*). However, from his work, it is not possible to determine the localities of the crayfish. Presumably, BALDNER (1666) also described these two crayfish : the <<Dulkrebs>> and <<Steinkrebs>>. It was not entirely clear if these old terms actually referred to the species *A. pallipes* and *A. torrentium* until LEREBOULLET (1858) formally described the two species. The distribution of *A. pallipes* in the Upper Rhine valley appears to be natural as shown by these historical descriptions. A later immigration from southern parts of France via the Canal Rhône-au-Rhin into this region was proposed by KLUNZINGER (1882). However, the channel was opened 24 years before LEREBOULLET described the species in 1858 from types he found in Strasbourg watercourses. Considering the short amount of time available, the numerous artificial obstacles and the presumed sub-optimal quality of water, a post-natural distribution in the Upper Rhine appears very unlikely. In northern parts of Switzerland, *A. pallipes* has recently been found in tributaries of the Rhine (BOTT, 1972). In this present paper, the distribution and habitats of *A. pallipes* in south-western Germany are described.

MATERIAL AND METHODS

Initially, we set out to discover localities with *A. pallipes.* Information was verified that we obtained from the literature, private individuals and the fish-survey questionnaire conducted by the state of Baden-Württemberg. Suitable watercourses were located on 1:50 000 scaled maps. The investigation was carried out between the Black Forest and Rhine river from the area around Strasbourg (France) to Basel (Switzerland).

We visited streams during the day and searched them thoroughly at night. Occasionally, special crayfish traps (<<trappy>>), distributed by M. Keller, Augsburg, Germany, were set with fish bait. Crayfish were collected, determined and sexed. Length (mm) and weight (g) were measured for one stream only.

Water quality was measured from January to December 1993, in the streams named Landwassergraben and Kirnbach abbreviated in text as <<Lawa>> and <<Kiba>>. The following parameters were taken every two weeks : water temperature [°C], oxygen saturation [%], pH value, conductivity [μS^*cm^{-1}], nitrate [ppm], ammonium [ppm], chloride [ppm], iron [ppm] and phosphate [ppm]. All parameters were measured with measuring kits from the Macherey-Nagel company, Düren, Germany.

The structure of representative sections of the watercourse was determined according to the method by WERTH (1987). Seven steps of evaluation are described between <<natural>> (1) and <<artificial>> (4).

The biological quality of the streams was investigated with samples of macro-invertebrates using a surber-sampler (0.1 m^2). The collected invertebrates were determined and counted. The calculation of abundance, biological value and indication value of each individual gives the biological water quality as shown in the formula. The collected invertebrates reflect the biological water quality on a scale of 1 to 4, where 1 indicates no pollution and 4 very much pollution (NAGEL, 1989). The formula for the calculation of the biological water quality (NAGEL, 1989) was used in addition to the method of the <<Deutsche Industrie Norm>> (DIN 38410, 1989).

$$S = \frac{\sum_{i=1}^{n} Si^*Ai^*Gi}{\sum_{i=1}^{n} Ai^*Gi}$$

S : biological water quality,
i : calculation for each taxon,
Si: value of biological quality of the taxon <<i>> (1 = oligosaprobe to 7 = polysaprobe),
Ai: abundance of the taxon <<i>> (1 = one individual to 7 = mass of individuals),
Gi: value of indication of taxon <<i>> (factor of 1, 2, 4, 8, and 16),
n : number of taxa.

RESULTS

Eight localities with *A. pallipes* were determined (figure 1). All watercourses run through the mountainous or submountainous region of the western side of the Black Forest between 200 and 460 m altitude above sea-level. The drop in all waters ranged from 0.2 to 2.7 %. Generally, all small streams with a maximum width of five metres were inhabited by *A. pallipes.* The crayfish was found in streams running through forests and agriculturally worked land. One stream was influenced slightly by sewage waste water. The localities where *A. pallipes* was found lie between the sites of *A. torrentium*, but never in the same stream. White-clawed crayfish never occurred in high altitudes, as the stone crayfish. In the documented area, they tend to inhabit more often the lower parts of the waterways.

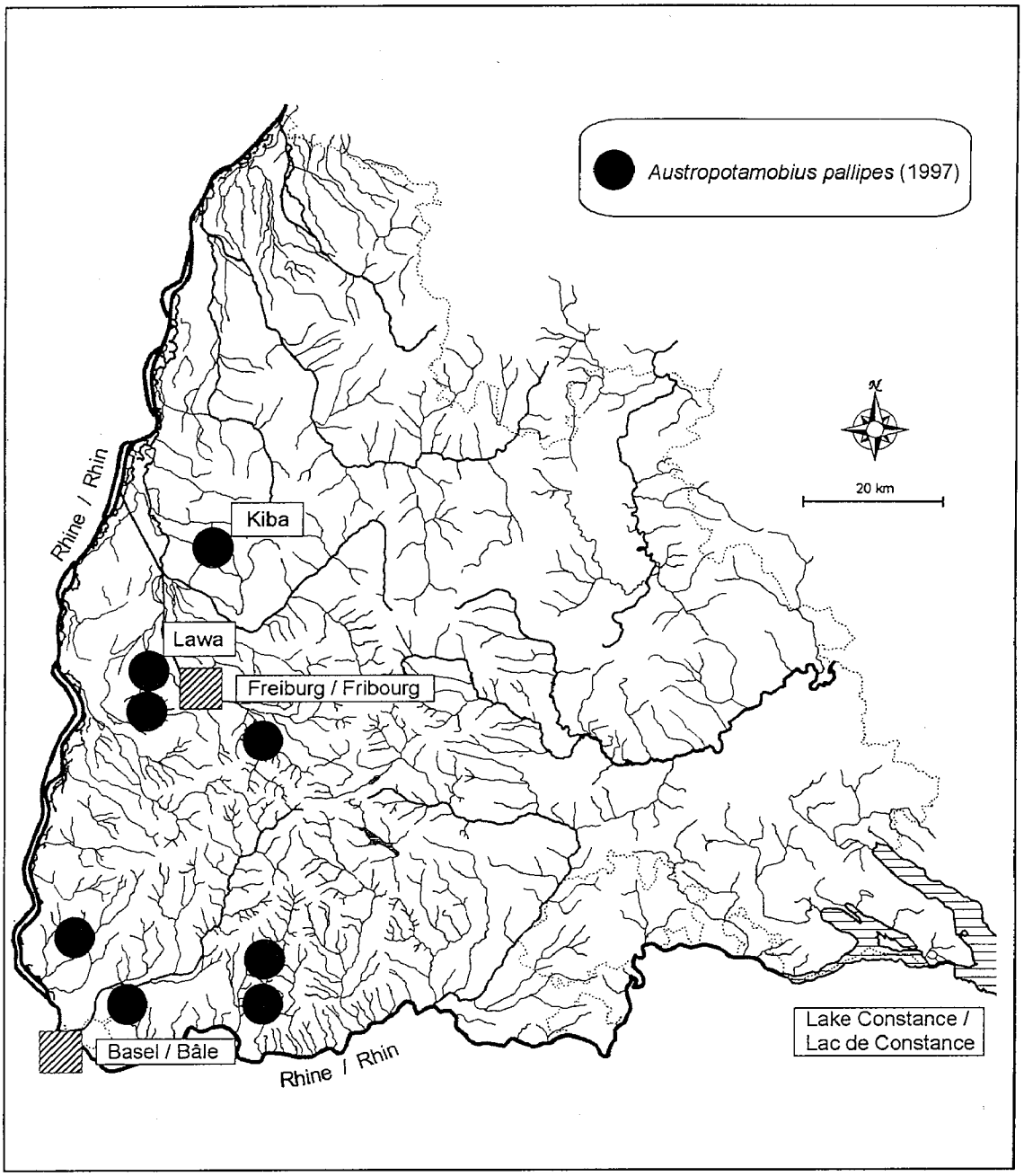

Figure 1

Distribution of *A. pallipes* in the state of Baden-Württemberg, Germany.

Figure 1

Répartition d'*Austropotamobius pallipes* dans le pays de Bade, Allemagne.

Water quality

Water parameters were measured in two streams (Kiba and Lawa) every two weeks throughout the year. All parameters with minimum, maximum and average are given in table I.

Table I

Water parameters of the streams Kiba and Lawa with occurrence of *A. pallipes* (1993).

Tableau I

Composition des eaux des ruisseaux Kiba et Lawa et fréquence d'*A. pallipes* (1993).

Watercourse	Kiba			Lawa		
parameter (n=24)	min	max	average	min	max	average
water temperature [°C]	0.3	16.8	8.6±5.2	3.3	15.8	10.0±3.8
oxygen [%]	56	100	85±18	78	98	85±11
pH value	7.0	7.9	7.6±0.4	6.8	7.4	7.2±0.3
conductivity [µS*cm^{-1}]	245	325	267±56.5	268	288	277±6.0
nitrate [ppm]	0.5	3.5	2.62±1.60	0.05	5.0	3.04±1.47
ammonium [ppm]	< 0.01	0.04	0.03±0.01	< 0.01	0.07	0.03±0.02
chloride [ppm]	10	60	33.3±13.6	20	50	33.3±7.9
iron [ppm]	0.1	0.5	0.5±0.12	< 0.1	< 0.1	< 0.001
phosphate [ppm]	< 0.001	0.2	0.03±0.07	< 0.001	0.008	0.008±0.003

The maximum water temperature of 16.8 °C was measured in August. Average water temperature differed little between both streams, depending on the distance to their sources. Oxygen concentration was measured to be between 56 and 100 %. The low oxygen concentration in Kiba appeared during periods of low water in September together with a high water temperature. The pH value is very constant around the neutral point, only with a break (min) after a strong rain in July. Conductivity depends on the geological formation at the river catchment. Data from Lawa showed very small standard deviation (s.d.) due to low environmental influences and a constant supply of water. The Kiba however differed more greatly in these parameters apparently due to the changing drain volume. In the first half of the year, nitrate measurements varied considerably but became more regular in the second half. No influence resulting from sewage treatments or agriculture was noticed in these two streams. The average of ammonium concentration was normal for streams (KLEE, 1990). A peak concentration of ammonium (about 0.07 ppm) in Lawa was obviously due to a strong rain that removed ammonium from organic material. Both streams showed normal river concentrations of chloride. The iron concentration (hydroxide) in Kiba is related to the catchment of red sandstone. The other stream did not show any measurable concentration (< 0.1 ppm). The Kiba had a higher concentration of phosphate than the Lawa. This however does not indicate pollution from sewage treatments that exceeded 1.0 ppm (KLEE, 1990).

The data indicate that there is only a small human influence on these two streams. The biological quality of Lawa has a value of 1.8 and Kiba of 2.0 on a scale of 1 to 4. Some of the eight habitats lie within agriculture areas or near villages where pollution of several kinds is suspected and the water quality is probably sub-optimal. The indication value of some invertebrates like *Tubifex sp.* or *Chironomus sp.* (table II) shows that *A. pallipes* can exist in slightly polluted watercourses like Kiba.

Structure of the watercourses

In the two streams, Kiba and Lawa, the structure of the watercourse and its surroundings were investigated. Both streams pass through forest areas, a deciduous woodland for the Lawa and a conifer forest for the Kiba. Table III gives an overview on the structural description of the two streams.

Table II

List of macro-invertebrates in Kiba and Lawa (1993) from one sampling (0.1m²).

Tableau II

Liste de macro-invertébrés de Kiba et de Lawa (1993) d'une collection (0.1m²).

species / espèce	Kiba		Lawa		si *)	Gi *)
	[n]	Ai *)	[n]	Ai *)		
Dugesia gonocephala	-	-	12	3	1.6	8
Chloroperla sp.	12	3	2	1	1,3	8
Amphinemura sp.	3	2	8	3	1,4	8
Ephemerella major	7	2	1	1	1,4	4
Baetis rhodani	25	4	3	2	2,3	8
Sialis fuliginosa	-	-	5	2	2,0	8
Ecdyonurus sp.	52	6	5	2	1,7	8
Elmis maugetii	2	1	1	1	1,5	8
Sericostomatinae	34	5	20	4	1,5	8
Gammarus pulex	165	7	120	7	2,1	4
Rhyacophila sp.	-	-	3	2	1,5	8
Ancylus fluviatilis	-	-	7	3	2,0	4
Tabanus sp.	-	-	3	-	-	-
Chironomus plumosus-groupe	65	6	4	2	3,4	4
Tubifex sp.	14	3	1	1	3,5	4

*) For si, Gi and Ai, see the formula of biological water quality in Material and Methods.

Kiba is a typical stream of the mountainous region with many stones and decaying wood. The crayfish find abundant hiding places, about the size of their head or larger, among the tree roots, dead wood and stones. The availability of places to dig themselves into a hole is very rare. The water supply can vary greatly, from near desiccation to high floods. There is a high variation of depth and width with different currents. The estimation of the structural value after WERTH (1987) scored the second best on the scale with a 1-2 (<<natural>>). During high floods, large stones and rocks protect the crayfish, while the deeper sections ensure survival in dry periods.

In the Lawa, there are no stones and the sandy bottom offers no hiding places, in contrast with Kiba. *A. pallipes* was found to dig holes in the banks or hide under roots of *Alnus sp.* The water supply is steady, however there are no fast currents. At night, the crayfish prefer to search for food in sites with organic sediment. Some juveniles, however not adults, were found in bundles of *Callitriche sp.* A former chanelization from about 30 years ago seems not to have an influence nowadays, although the structural estimation gives a value of 2, <<some influence>> (WERTH, 1987).

The characteristics of the other six habitats of *A. pallipes* are similar to the two streams mentioned. All streams were small and offer many hiding places along the banks or under stones. Only one watercourse had an indication of some pollution.

Table III

Structural description of the streams Kiba and Lawa, Baden-Württemberg, Germany.

Tableau III

Description de la structure des ruisseaux Kiba et Lawa dans le pays de Bade, Allemagne.

parameter	Kiba	Lawa
watercourse	some curves	straight
width [m]	2-5	2-5
depth [m]	0.1-0.5	0.05-0.40
water supply	changing	normal, steady
current [m*s^{-1}]	0.2-0.8	0.1-0.3
areas without current [%]	40	50
shadow [%]	80	80
artificial constructions	none	none
river bed pelal [%]	10	60
psammal [%]	20	40
lithal [%]	70	-
roots in the water [%]	5	10
submerged plants [%]	5	10
geology	new red sandstone	alluvial deposits (clay, sand, gravel)

Fish were recorded as they were seen during the investigations. In Kiba, only *Salmo trutta forma fario* was found. They were rare but were able to reproduce there. In Lawa, the fish community differed. *Salmo trutta f.f., Babartulus babartulus, Phoxinus phoxinus, Leuciscus cephalus* and *Lampetra planeri* were found. Brown trout and chub may on occasion take *A. pallipes* as prey. The eel (*Anguilla anguilla*) did not appear or was very rare in both streams, no doubt due to artificial obstacles downstream.

Population density

Only in Kiba was the population density estimated. The census was conducted during the day since the water level was very low and some sections were dry. Crayfish were collected from their hiding places and from the more or less dry soil. In a 58 m section, 167 crayfish were found with a body size (rostrum to telson) of 10 to 90 mm. In this section, which was 2 m wide, the density of crayfish was 1.4 per square metre. On average, a crayfish had, theoretically, a territory of about 0.7 m^2. The density in Lawa was not measured but seems much lower. During night-time trials, we never caught more than 20 individuals in a 100 m section. With additional data, it would be interesting to investigate a possible relationship between water depth or hiding places and crayfish body size.

Eggs were found on females sized 65 mm to 74 mm total length. The average size of egg carrying females was 68.6 ± 3.4 mm (n = 7) total length, which is defined as the average size for maturity. The proportion of males was 54 %, females 46 %. Additional data about size at maturity were given by GRANDJEAN *et al.* (1997) from French crayfish sites.

DISCUSSION

In Germany, *Austropotamobius pallipes,* the white-clawed crayfish, as opposed to *Austropotamobius torrentium* (TROSCHEL and DEHUS, 1993), is restricted to a very small area. With a distribution of only eight known sites in an area of 45 to 90 km, the risk of extinction is very high for this species. Contrary to *A. pallipes, A. torrentium* appears in many mountain streams in southern Germany. Both species are naturally protected since their habitats are generally in forested areas where little or no pollution occurs (TROSCHEL, 1993). However, they are often restricted to streams that pass through

villages or agriculture areas. The possibility exists here of negative influence by environmental poisons, other types of pollution and erosions of soil. The tolerance to the biological water quality in the investigated two streams was smaller than expected. BOHL (1989) found *A. torrentium* at values up to 2.6 and *A. astacus* up to 3.2. The biological water quality in habitats of *A. pallipes* should be further investigated.

No crayfish was found in streams with a fine soil material that covers over potential hiding places. The number of hiding places is apparently a very important factor that regulates the population density. The number of crayfish was low in the Lawa, which also exhibited a smaller amount of adequate hiding places. Contrary to *A. pallipes,* the highest population density of *A. torrentium* was 8.15 ± 5.7(s.d.) individuals per square metre (TROSCHEL, 1993).

The range of measured chemical and physical water parameters is wide but did not reveal the limits. The twice weekly measurements failed to show extreme conditions that may endanger the crayfish population. Some crayfish died, when a part of the Kiba dried out. Dangerously, high water temperatures were never reached as high as those reported from Spain (23 °C, LAURENT, 1988). The pH ranged between 6.8 and 8.3, extreme values did not occur even in the catchment with rocks of low carbonate concentration. LOWERY (1988) found *A. pallipes* in English waters with pH values between 7 and 9, and a calcium concentration above 5 mg/l. BOHL (1989) described an occurrence of *A. torrentium* at pH 6.1 where the calcium concentration must have been lower. The water parameters in table I show that *A. pallipes* lives in clean waters of the mountainous region.

The question why *A. pallipes* appears exclusively in these eight streams cannot be clearly answered at present. The uppermost sections of these waterways serve as refuges for the crayfish since they represent the more undisturbed areas. There are no or very few predators (eel, otter) or economic influences which might endanger these populations today. They are protected by artificial obstacles downstream that prevent a) the immigration of the fungus *Aphanomyces astaci* which is transported by foreign species and b) the occurrence of eel which is the crayfish's most important predator (SVÄRDSON, 1972). In the past century, the crayfish plague did not exterminate these isolated populations (SMOLIAN, 1926). Although at present, the crayfish are unable to spread into other areas, at least we can say, we have isolated populations of *A. pallipes.* The survival of these isolated groups may be endangered in the future, not only because they are isolated but because they have a low population density.

In historical times, the population of *A. pallipes* in southern Germany, France and Switzerland (BOTT, 1972) was more or less connected. Presumably, all nowadays isolated populations of *A. pallipes* in the river Rhine catchment had the same origin. Yet, we cannot explain the formation of the distribution pattern where *A. torrentium* and *Astacus astacus* sometimes occur in the direct neighbourhood of each other. *A. pallipes* was never found together with other crayfish species in stream systems like that LACHAT and LAURENT (1987) described in river Morvan, France.

CONCLUSION

The results show that the rare populations of *A. pallipes* in Germany do not have any preference for special water parameters or water quality above 2.5 (worst water quality : 4.0). Most important for their survival is the availability of hiding places, in addition to the absence of natural predators, pollution, economic interests and immigrating alien crayfish species hosting the fungus *Aphanomyces astaci.*

Fortunately, the isolated refuges are protected naturally since they pass through forests and are not located near regions of heavy anthropogenic influence. To ensure the continued survival of *A. pallipes* in south-western Germany, it should be introduced from high density populations to new and suitable waterways.

REFERENCES

BALDNER L., 1666. Vogel-, Fisch- und Thierbuch. - Faksimileausgabe 1973, vol. II, Verlag Müller und Schindler, Stuttgart, 191-199.

BERG R., BLANK S., STRUBELT T., 1989. Fische in Baden-Württemberg. Ministerium für Ländlichen Raum, Ernährung, Landwirtschaft und Forsten Baden-Württemberg, Stuttgart, 158 p.

BOHL E., 1989. Untersuchungen an Flußkrebsbeständen. Bayerische Landesanstalt für Wasserforschung, München, 237 p.

BOTT R., 1972. Besiedlungsgeschichte und Systematik der Astaciden westeuropas unter besonderer Berücksichtigung der Schweiz. *Rev. Suisse de Zool., 79/1 (13), 387-408.*

DIN 38410, 1989. Deutsche Einheitsverfahren zur Wasser- Abwasser- und Schlammuntersuchung ; Biologisch-ökologische Gewässeruntersuchung (Gruppe M 2) ; Verfahren zur Bestimmung des Saprobienindex (M2). Beuth Verlag, Berlin und Cologne.

GESNER C., 1557. Vollkommenes Fisch-Buch. - Faksimileausgabe, Sclütersche Verlagsanstalt und Druckerei, Hannover, part II, vol. 5, 92.

GRANDJEAN F., ROMAIN D., AVILA-ZARZA C., BRAMARD M., SOUTY-GROSSET C., MOCQUARD J.P., 1997. Morphometry, size at maturity and sexual dimorphism of the white-clawed crayfish *Austropotamobius pallipes pallipes* (Lereboullet) from a wild French population (Deux-Sèvres). *Crustaceana, 70 (1),* 31-44.

KLEE O., 1990. Wasser untersuchen. Einfache Analysemethoden und Beurteilungskriterien. Verlag Quelle und Meyer, Heidelberg, 230 p.

KLUNZINGER C.B., 1882. Über die *Astacus*-Arten Mittel- und Südeuropas und den Lereboullet'schen Dohlenkrebs insbesondere. *Jh. Ver. vaterl. Naturkde. Württ., 38, 327-342.*

LACHAT G., LAURENT J.P., 1987. The habitat of *Astacus astacus* L. and *Austropotamobius pallipes* Lere in the Morvan. *Freshwater Crayfish, VII, 61-68.*

LAURENT P.J., 1988. *Austropotamobius pallipes* and *A. torrentium* with observations on their interactions with other species in Europe. *In* Freshwater Crayfish ed. by HOLDICH D.M. and LOWERY R.S., 341-364.

LEREBOULLET D.A., 1858. Description de deux nouvelles espèces d'écrevisses de nos rivières. Mém. Soc. Mus. Hist. Nat. Strasbourg, 5, 11 p.

LOWERY R.S., 1988. Growth, Moulting and Reproduction. *In* Freshwater Crayfish ed. by HOLDICH D.M. and LOWERY R.S., 83-114.

NAGEL P., 1989. Bestimmungsschlüssel der Saprobien. Gustav Fischer Verlag, Stuttgart, 183 p.

SMOLIAN K., 1926. Der Flußkrebs, seine Verwandten und die Krebsgewässer. Handbuch der Binnenfischerei Mitteleuropas, vol. V, 423-524.

SVÄRDSON G., 1972. The predatory impact of eel (*Anguilla anguilla*) on populations of crayfish (*Astacus astacus* L.). *Rep. Inst. Freshwater Res. Drottningholm, 52, 149-191.*

TROSCHEL H.J., BERG R., 1989. Ein Nachweis des Dohlenkrebses (*Austropotamobius pallipes*) Lereboullet (1858) in Baden-Württemberg. *Veröff. Naturschutz Landespflege Bad.-Württ., 64/65, 283-288.*

TROSCHEL H.J., DEHUS P., 1993. Distribution of crayfish in the Federal Republic of Germany, with special references to *Austropotamobius pallipes. Freshwater Crayfish, IX, 390-398.*

TROSCHEL H.J., 1993. Vorkommen und Sicherung der Krebsbestände im Südwesten Baden-Württembergs. Fischereiforschungsstelle des Landes Baden-Württemberg, Langenargen, Germany, 82 p., unpubl.

WERTH W., 1987. Ökomorphologische Gewässerbewertung in Oberösterreich (Zustandskartierung). *Oberösterr. Wasserwirtschaft, 39, 5/6, 122-129.*