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Some effects of DDT on the fauna of the Victoria Nile

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INTRODUCTION

In early 1956 an excellent opportunity was presented to study the fauna of the Victoria Nile at Jinja. On several occasions one or more of the sluice gates in the Owen Falls Dam were shut temporarily, usually for an hour or two at a time, in connection with maintenance work by the Uganda Electricity Board. On each occasion the level of the Victoria Nile fell about a metre for a considerable distance below the dam, with the result that in some places a strip of the river bed 10 to 20 metres wide was uncovered along the bank. This afforded an opportunity to collect animals which would have been virtually inaccessible under normal circumstances. This is well demonstrated by the fact that collections made during the closures yielded more than 200 specimens of a hitherto unknown species of catfish *Clariallabes petricola* GREENWOOD, as well as four individuals of the rare mormyrid, *Petrocephalus degeni* BOULENGER, known previously from only two specimens (from Lakes Victoria and Nabugabo).

The observations made on the river fauna are, however, of an interest much wider than would normally have been the case, because at an early stage during the collections the Nile was treated with DDT as a control measure against *Simulium damnosum* (THEOBALD). The dates upon which collections were made during closures, and their relation to the dates of DDT treatment are given in Table I.

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Table I. — Dates upon which collections were made during closures of the sluice gates at Owen Falls

Date of collection	Days after first DDT treatment on 2 March	Days after last DDT treatment on 4 May
1956 : 24 January	—	—
27 January	—	—
4 February	—	—
16 March	14	—
23 March	21	—
5 April	34	—
13 June	103	40
22 June	112	49
23 July	143	80
1957 : 25 July	510	447

Twice during the last few years the Victoria Nile has been treated with insecticide in order to eliminate larval populations of *Simulium damnosum* living in the torrential reaches between Jinja and Mbulamuti. The first treatment was on 3 June, 1952, when DDT (as a suspension from a 27 % mayonnaise-type emulsion) was poured into the river immediately above the Ripon Falls at Jinja. On that occasion, the dosing represented an average of 1 part of DDT in 2¼ million parts of water per 30 minutes contact. This dosing, the first of its kind in Uganda, was supervised by Mr. G. R. BARNLEY, M.B.E., Senior Entomologist, Uganda Protectorate Medical Department, and has been described in detail elsewhere (BARNLEY, 1953).

The second treatment began on 2 March, 1956, and was also carried out under Mr. BARNLEY's supervision (see BARNLEY, 1956). This time the insecticide was dispensed directly into the river water passing through the main sluice gates of the Owen Falls Dam. The section of the Victoria Nile between the Ripon and Owen Falls had in the meantime been flooded almost to the level of Lake Victoria, and the rate of flow in this region greatly diminished. Thus, the river above the Owen Falls had been rendered ecologically unsuitable for larvae of *Simulium damnosum,* although many other invertebrates of the river fauna were able to maintain populations at the site of the Ripon Falls, where a drop in water level of about 1/3 metre still existed.

The dose administered on 2 March consisted of a 12.5 % solution of DDT in a 50/50 mixture of dieseline and power kerosene. Approximately 950 gallons were dispensed in 31 minutes, but owing to the diminishing head in the tank, the rate of flow was not constant. The dosing was equivalent to approximately one part of DDT in 2 million parts of water, and there was only the one dosing point at the top of the 42-mile stretch of river. The second dose of this series, administered a week after the first, consisted of 650 gallons, equal to 1 part of DDT in 3 million parts of water. After this, subsequent doses were administered at weekly intervals, and all were of the same strength as the second. The total series consisted of 10 doses, the last being on 4 May, 1956.

In view of the widespread control measures being adopted in Africa to control *Simulium* larvae by the application of insecticide to streams and rivers, it is very necessary to know in detail the effects such measures are likely to have on fishes and other freshwater animals. Most of the work on this subject, undertaken in North America, has dealt with the direct effects of DDT on aquatic invertebrates (see JAMNBACK & COLLINS, 1955), there being extensive evidence to show that, at doses effectively lethal to *Simulium* larvae, it need have no direct, harmful effect on fishes. The indirect effects of DDT on fishes, through the medium of their food, is a subject which has received surprisingly little attention, and the work of ADAMS *et al.* (1949) on trout in an Idaho stream appears to be the only study made so far. These workers analysed the stomach-contents of 72 fishes, approximately half before and half after the treatment, and found that the diet of the trout changed considerably, crayfish replacing Ephemeroptera and Trichoptera as the principal food; but they thought it probable that the supply of crayfish became depleted before repopulation of the insects occurred, and that the fishes suffered accordingly from shortage of food.

In the series of observations made in the Victoria Nile, particular attention was paid to the effects of DDT on the feeding habits of insectivorous fishes, and the stomach contents of all fishes available were examined, both before and after the treatment. After the treatment, parallel observations were made on the invertebrate fauna of the river bed, with the view of determining the rate of recolonisation. Accordingly, the information is presented in two sections : first, the invertebrate fauna, its response to the treatment and subsequent recolonisation; and second, the fish fauna and the ways in which it was affected by the DDT and by the closing of the sluice gates.

THE INVERTEBRATE FAUNA

Before 2 March the invertebrate fauna of the river bed was very dense. No attempt at exhaustive collection or quantitative sampling was made, but an idea of the richness and diversity of the fauna then can be obtained from the following list of animals, noted at various times on and amongst the stones of the river bed. In interpreting this, it must be remembered that at this early stage in the study of the African aquatic invertebrates, only a few specific identifications can be made, and also that aquatic insects have been included only if their larvae were present and could be recognized.

GROUPS AND SPECIES OF INVERTEBRATES NOTED IN THE VICTORIA NILE AT JINJA

PLATYHELMINTHES :	Turbellaria	
ANNELIDA :	Oligochaeta	*Alma*
	Hirudinea	
CRUSTACEA :	Ostracoda	
	Cladocera	
	Copepoda	
	Malacostraca-Decapoda	*Potamon niloticus* (MILNE-EWARDS)
INSECTA :	Plecoptera	*Neoperla spio* (NEWMAN)
	Ephemeroptera	*Povilla adusta* NAVÁS
		Afronurus ugandanus KIMMINS
		Caënis
		Euthraulus bugandensis KIMMINS
		Tricorythus tinctus KIMMINS
	Odonata	*Metacnemis valida* SELYS
		Pseudagrion
		Trithemis donaldsoni CALVERT
	Trichoptera	*Cheumatopsyche copiosa* KIMMINS
		C. falcifera (ULMER)
		Phanostoma senegalense BRAUER
		Pseudoleptocerus schoutedeni NAVÁS
		Ecnomus
		Parasetodes ?
		Trichosetodes ?

Hydroptilidae

Coleoptera

Diptera Chironomidae

Tipulidae

MOLLUSCA : Gastropoda

Bellamya jucunda jucunda (SMITH)
B. unicolor costulata (VON MARTENS)
Pila ovata gordoni (SMITH)
Gabbia humerosa humerosa (VON MARTENS)
Melanoides tuberculata dautzenbergi (PILSBRY & BEQUAERT)
Lymnaea natalensis nyansae (VON MARTENS)
Biomphalaria choanomphala (VON MARTENS)
Gyraulus costulatus costulatus (KRAUSS)
Segmentorbis angustus (JICKELI)
Bulinus trigonus strigosus (VON MARTENS)
Burnupia stuhlmanni (VON MARTENS)

Pelecypoda

Caelatura hauttecoeuri hauttecoeuri (BOURGUIGNAT)
C. hauttecoeuri emini (VON MARTENS)
C. hauttecoeuri ruellani (BOURGUIGNAT)
Mutela bourguignati (BOURGUIGNAT)
Aspatharia trapezia (VON MARTENS)
Etheria elliptica LAMARCK
Sphaerium victoriae victoriae SMITH
Pisidium victoriae MANDAHL-BARTH
Byssanodonta parasitica (DESHAYES)

BRYOZOA :

In the region observed, larvae of the filter-feeding mayfly, *Tricorythus tinctus* KIMMINS, and of the caddisfly, *Phanostoma senegalense* BRAUER, were particularly abundant. It is interesting to note that these two species are responsible for the principal insect nuisance at the lights of the Owen Falls Dam.

EFFECTS OF TREATMENT

The most obvious immediate effect of treatment was the disappearance of all Ephemeroptera and Trichoptera (see Table II), with the exception of one small species of *Caënis,* the larva of which was found in small numbers on all post-treatment occasions. On 16 March, 100 stones on the river bed were examined in sites where previously they had supported large numbers of Ephemeroptera and Trichoptera, and only one *Caënis* larva was found to represent these two groups. Several Trichoptera cases were found, but none of these contained a living larva or pupa. The one possible exception was a case of the *Trichosetodes* type which contained a pupa in good condition, perhaps alive, amongst gravel beneath the stones, but otherwise no Ephemeroptera and only dead Trichoptera were seen. It is possible that the usual larval habitat of this species of *Caënis* includes the lower gravel layer of the river bed, and that this region was insulated to some extent from the main flow of the river, and therefore from the effects of the insecticide. It has been noted elsewhere (HOFFMAN *et al.,* 1946; HOFFMAN *et al.,* 1948; ADAMS *et al.,* 1949) that Ephemeroptera and Trichoptera are particularly susceptible to DDT.

Table II. — Occurrence of certain invertebrates on stones after DDT treatment

Group	Percentage occurrence on 50 stones on successive dates				
	23/3	5/4	13/6	22/6/56	25/7/57
Hirudinea	2	12	38	20	10
Afronurus ugandanus	0	4	4	4	80
Tricorythus tinctus	0	4	58	34	66
Other Ephemeroptera	0	2	8	24	42
Phanostoma senegalense	0	0	12	10	6
Gastropoda	15	66	76	62	76
Pelecypoda	0	6	0	4	6
Number of stones without organisms	56	24	8	6	2

Other invertebrate groups were far less affected. There was no noticeable reduction in numbers of Mollusca, Hirudinea and the crab, *Potamon niloticus.* No dead or decaying individuals were observed after treatment, and it is thought that the apparent increase in numbers up to June (Table II) may have been due in part to a lessening of competition for sites on stones. On 23 March, a larva 5 mm. long of the rheophilic dragonfly, *Metacnemis valida,* was found, which strongly suggests that this species too was able to survive the treatment.

Although insects living in the main river apparently experienced the full effects of the DDT, there is indirect evidence (from fish stomachs) to show that those living in a grass swamp, on the east bank about 200 metres below the Owen Falls, were protected from the main flow of the river, since they seeemed unaffected by the dosing. This accords with the observations of HOFFMAN *et al.* (1946), who recorded that animals living amongst leaf drifts were insulated from the effects of insecticide in a stream.

The facts recorded above show that in the Victoria Nile the selective destruction of the invertebrate fauna followed a pattern similar to that observed in North America (see JAMNBACK & COLLINS, 1955).

RECOLONISATION

In order to obtain a quantitative expression of the rate of recolonisation, counts were made of the animals on the stones of the river bed. Within the collecting site, two regions were recognized, an upper and a lower, differing slightly with regard to the shape and size of the stones and their exposure to the main flow of the river. Whenever possible, during a closure, 50 stones from each region were examined, and the animals on them recorded, but on certain occasions this could only be done in the upper region. As time for examination was limited, 14 easily-recognisable items of the fauna were selected for recording. These were as follows :

1. Platyhelminthes : Turbellaria.
2. Mollusca : Gastropoda.
3. Mollusca : Pelecypoda.
4. Annelida : Oligochaeta.
5. Annelida : Hirudinea.

Insect larvae :

6. Plecoptera : *Neoperla spio* (NEWMAN).
7. Odonata : Zygoptera.
8. Odonata : Anisoptera.
9. Ephemeroptera : *Tricorythus tinctus* KIMMINS.
10. Ephemeroptera : *Povilla adusta* NAVÁS.
11. Ephemeroptera : species other than 9 and 10.
12. Trichoptera : *Phanostoma senegalense* BRAUER.
13. Diptera.
14. Insect eggs.

Recolonisation of stones in the upper region has been expressed quantitatively in Table III, which gives the average numbers of items per stone on successive days after treatment. When counts from the lower region were made they showed a similar trend.

Table III. — Recolonisation of river bed after DDT treatment

Date	Average number of items per stone (see text)
1956 : 23 March	0.36
5 April	1.02
13 June	2.00
22 June	2.14
1957 : 25 July	2.98

On 5 April larvae of *T. tinctus* were seen again for the first time after treatment (Table II). Thus this species can tolerate DDT in a concentration of at least 1/3 p.p.m. of water. The larvae present on 5 April were small and probably recently hatched. Other workers have found that filter-feeding insects are particularly vulnerable to DDT in solution (HOFFMAN *et al.*, 1946), even more so when it is in suspension (TAUFFLIEB, 1955; NOËL-BUXTON, 1955), and that this may account for the ready susceptibility of *Simulium* larvae. Thus it is perhaps surprising to find larvae of *T. tinctus* re-establishing themselves so soon. It is likely, however, that eggs of this species are less vulnerable to DDT than are larvae, and that for this reason it was able to re-establish itself sooner than would otherwise have been the case. HOFFMAN *et al.* (1946), working in Pennsylvania, obtained results which strongly suggested that the mayfly, *Ephemerella rotunda,* had survived a dosing with DDT because the population had been in the egg stage at the time.

Larvae of *P. senegalense* did not reappear in the sampling region until 13 June, when they were still rare (Table II). Since they had been very abundant previously, it appears that they are more susceptible than *T. tinctus*; though here it must be remembered that the reappearance of different species is governed not only by their susceptibility to DDT and by the availability of fresh immigrants, but also by their rates of growth. Thus in this instance the slower return of *P. senegalense* could have been explained by its having spent longer in the egg. There can be little doubt, however, that this species found re-establishment difficult, because even in July, 1957 its numbers were still far smaller than they had been before the treatment.

It is interesting to note that the abrupt removal of larval populations in this way can provide useful data on rates of growth, often unobtainable by other means in tropical regions where there is commonly a continuous succession of generations. In the case of *T. tinctus,* full-grown larvae were first found on 13 June, when there were many present. This suggests that a large proportion of them was derived from larvae as yet unhatched, or else too small to be seen, on 5 April, and that therefore the larval duration is at the most 69 days (about 10 weeks), but possibly much less. Considering the difference in larval size, this accords reasonably well with the larval duration of another filter-feeding mayfly, *P. adusta,* which is about 104 days (CORBET, 1957).

The above observations show that in this case recolonisation took place rapidly after treatment, most of the affected species having become re-established within 100 days or less of the first dosing, and within 40 days of the last. There can be little doubt that the region of the Victoria Nile immediately below the dam was repopulated by insects flying downstream from the Ripon Falls, where most species of the rheophilic fauna (with the notable exception of *Simulium damnosum*) were still breeding. Had the populations at the Ripon Falls been eliminated also, the consequences of the treatment would have been very different, as they can be in temperate regions, where the reproductive period of aquatic invertebrates is restricted seasonally, and where their growth rates are relatively slow. There can be little doubt that the simultaneous treatment of the Ripon and Owen Falls would have had a serious effect on the rheophilic Ephemeroptera and Trichoptera in the upper reaches of the Victoria Nile.

THE FISH FAUNA

The fishes listed below were collected from two collecting sites in the Victoria Nile, about 200 and 500 metres, respectively, below the Owen Falls Dam, on several occasions when the sluice gates were closed. The upper of the two sites included the marginal grass swamp, referred to previously.

Barbus altianalis radcliffi BOULENGER
Barbus sp. or *spp.*
Engraulicypris argenteus (PELLEGRIN)
Bagrus docmac (FORSKAL)
Clariallabes petricola GREENWOOD
Clarias alluaudi BOULENGER
C. carsoni BOULENGER
C. mossambicus PETERS
Synodontis afro-fisheri HILGENDORF
Gnathonemus longibarbis HILGENDORF
G. victoriae WORTHINGTON
Marcusenius grahami NORMAN
Mormyrus kannume FORSKAL
M. macrocephalus WORTHINGTON
Petrocephalus degeni BOULENGER
Mastacembelus victoriae BOULENGER
Protopterus aethiopicus HECKEL
Gara johnstoni (BOULENGER)
Tilapia variabilis BOULENGER
Haplochromis spp.

EFFECTS OF TREATMENT

No harm to fishes was observed which could be ascribed directly to DDT. Indirect effects, through the medium of their food, will be described below. The lowering of the river level, however, affected the swamp-living fishes in a way sufficiently interesting to deserve brief mention. These effects were observed to a marked degree on 13 June, 22 June, 1956 and 25 July, 1957, and therefore could not have been associated with the DDT treatment, which finished on 4 May.

Soon after the river level fell, water began to pour steadily out of the swamp into the main river. Within a short time large numbers of the swamp fishes appeared at the surface in a distressed condition. These consisted almost entirely of Mormyridae, most of the fishes visible at the surface being *G. victoriae*. Other species affected similarly were *G. longibarbis, M. grahami, M. macrocephalus, P. degeni, S. afro-fischeri, T. variabilis*, and one or more small species of *Barbus*. *M. grahami* succumbed more quickly than the other fishes, and many specimens were found lying dead on the bottom of the swamp pool while *G. victoriae* and other species still swam at the surface. The symptoms of distress shown by these fishes appeared to be related to a change in the nature of the swamp water. The few which were able to escape into open pools associated with the main river swam actively in a normal manner. The outlet of the swamp into the river was such that a wall of rock permitted only the surface water to spill over and drain away. In view of the fact that water beneath a grass swamp is commonly very deficient in oxygen compared with that at the surface (CARTER, 1955), it seems probable that in these instances the upper layer of water, on which the fishes had been depending for oxygen, was being progressively removed, thus forcing them into the unfavourable bottom water. On each of the three occasions mentioned above, many Jaluo fishermen came to collect the incapacitated fishes.

Since collections of fishes were examined both before and after 2 March, the effects of the DDT on their food and feeding habits could be followed closely. The species collected in sufficient numbers for this purpose are listed in Table IV.

These fishes responded in different ways, and will therefore be dealt with separately.

Table IV. — Fishes examined for stomach contents

Species	Numbers examined:		
	Before 2/3/56	16/3 to 22/6/56	25/7/57
Barbus altianalis radcliffi	8	23	0
Clariallabes petricola	71	214	14
Gnathonemus longibarbis	9	52	22
Mormyrus kannume	19	7	13
Mastacembelus victoriae	170	57	24

CLARIALLABES PETRICOLA

When first collected on 27 January, this species was found to be undescribed, and has since formed the subject of a paper by GREENWOOD (1956). It appears to live amongst and beneath the stones and pebbles of the river bed. An analysis of its food before 2 March appears in Table V.

Table V. — The food of *C. petricola* and *M. victoriae* before DDT treatment

Food-type	Percentage occurrence and (percentage main contents)		
	C. petricola	*M. victoriae*	
Lithophilic insects	90 (47)	97 (80)	98 (79)
Lithophilic Ephemeroptera	83 (41)	93 (40)	90 (67)
Tricorythus tinctus	67 (26)	77 (28)	81 (49)
Lithophilic Trichoptera	36 (5)	58 (17)	47 (4)
Chironomidae	28	7	5
Hydropsychidae	24	53 (15)	47 (2)
Plant material (dead)	12	2	—
Cheumatopsyche falcifera	10	18	23
Ostracoda	9	2	2
Afronurus ugandanus	9 (2)	27	18
Cheumatopsyche copiosa	7	32 (3)	25
Hydroptilidae	5	—	4 (4)
Hydracarina	5	—	—
Mollusca	5	3	—
Phanostoma senegalense	2	37 (8)	11
Coleoptera (Staphylinidae)	2	—	—
Ecnomus sp.	2	—	—
Fish eggs	—	3	—
Gastropoda	—	3	—
Potamon niloticus	—	—	2
Neoperla spio	—	—	2
Plant material (living)	—	—	2
Pelecypoda	—	2	—
Hirudinea	—	2	—
Number of fish examined	67	66	58
Number containing food	58	60	57
Size range of fish (cm.)	3-9	4-22	7-23
Site (metres below dam)	500	200	500
Dates of collection (1956)	27/1 & 4/2	24, 27/1 & 4/2	4/2

In Tables V and VI, the category « main contents » contains items occupying more than half the volume of food in the stomach. All values have been given to the nearest whole percentage, and only stomachs containing food have been considered. The food-types listed refer to the larval stages of the various insect groups unless stated otherwise. It will be realised that the grouping of the items has an important effect on the interpretation of the table. Thus Trichoptera larvae only achieve a « main contents » status when the several species are considered together.

From Table V it can be seen that *C. petricola* fed on a wide range of organisms, but that its food consisted very largely of lithophilic insect larvae, amongst which those of *T. tinctus* predominated. Two weeks after the dosing, its food had undergone a great change (Table VI). Chironomid larvae had replaced those of *T. tinctus* as the principal food, and tipulid larvae, Pelecypoda and plant material had become important items, whereas lithophilic insect larvae had ceased to be significant.

On 23 March, chironomid larvae had become unimportant, whereas Copepoda and plant material were now the main food, with Mollusca also playing a prominent part. Its diet on 5 April was much the same, except that Copepoda had become even more important. The large number of fishes with sand grains in the stomach indicates that a good deal of feeding was taking place amongst the lower stratum of the river bed. By 13 June, 1956, there were already signs of a return to the original feeding habits, with lithophilic Ephemeroptera larvae featuring in 68 % of stomachs and providing the main contents in 11 %. A sample taken in July, 1957 showed that the feeding habits had returned to their pre-treatment pattern. The progressive changes in the main items of food as a result of the treatment have been summarised in Table VII.

A point worthy of note is that throughout the period of observation the proportion of fishes with empty stomachs underwent no significant change — a clear indication that starvation was not occurring. Thus, throughout the treatment, *C. petricola* showed a remarkable plasticity of trophic behaviour in a changing environment, being able to feed at different times mainly on Ephemeroptera, Chironomidae, Copepoda and plant material. This species demonstrated well how a facultative feeder can respond under such circumstances.

Table VI. — The food of *C. petricola* after DDT treatment

Food-type	Percentage occurrence and (percentage main contents) on successive dates (1956)			
	16/3	23/3	5/4	13/6
Lithophilic insects	21 (2)	6 (4)	7	73 (11)
Lithophilic Ephemeroptera	20 (2)	2 (2)	4	68 (11)
Tricorythus tinctus	—	—	—	32 (3)
Lithophilic Trichoptera	—	—	—	11
Chironomidae	62 (7)	8	11	95 (38)
Hydropsychidae	—	—	—	5
Plant material (dead)	22	18 (6)	11	—
Cheumatopsyche falcifera	—	—	—	3
Ostracoda	5	2	4	14
Hydroptilidae	1	2	—	—
Hydracarina	7	8	7	8
Mollusca	16	26 (2)	—	—
Phanostoma senegalense	—	—	—	3
Terrestrial insects	—	—	11	—
Ecnomus sp.	—	—	4	—
Plant material (living)	—	10 (2)	11	8
Pelecypoda	12 (4)	18 (2)	7	—
Hirudinea	—	2	—	—
Tipulidae	37 (6)	8	—	22
Plant material (bitten)	27 (5)	44 (8)	14	—
Copepoda	24	60	82 (11)	3
Caënis sp.	13 (2)	2 (2)	—	3
Gastropoda	5	4	14	—
Chironomidae (pupae)	5	—	11	27
Chironomidae (adults)	1	—	—	—
Coleoptera (rheophilic)	1	4 (2)	—	—
Hymenoptera (adult)	1	—	—	—
Diptera *indet.*	1	—	—	—
Povilla adusta	1	—	—	—
Cladocera	—	2	—	—
Simulium (pupa)	—	2	—	—
Baëtis ssp. (sensu lato)	—	—	—	54
Tipulidae (pupa)	—	—	—	3
Sand grains	10	10	46 (4)	8
Number of fish examined	87	54	31	42
Number containing food	82	50	28	37
Size range of fish (cm.)	3-8	2-9	3-8	3-8

All fishes collected from the site 500 metres below the dam.

Table VII. — Changes in the food of *C. petricola*

Food-type	Percentage occurrence on successive dates Before 2/3	16/3	23/3	5/4	13/6	25/7/57
Lithophilic Ephemeroptera	83	20	2	4	68	100
Lithophilic Trichoptera	36	0	0	0	11	43
Tricorythus tinctus	67	0	0	0	32	93
Chironomidae	28	62	8	11	95	14
Mollusca	5	16	26	21	0	14
Tipulidae	0	37	8	0	22	7
Copepoda	0	24	60	82	3	0
Plant material (living)	0	27	54	14	8	0
Number examined	71	87	54	31	42	14
Number containing food	61	82	50	28	37	14

MASTACEMBELUS VICTORIAE

M. victoriae appears to be well adapted for living amongst the stones of the river bed, and for feeding on the insects on them. Before 2 March this species was common in the sampling area. At that time almost the whole of its food consisted of lithophilic insects, these being mainly larvae of *T. tinctus* (see Table V). The important items of its diet were much the same as those eaten by *C. petricola,* but in the case of *M. victoriae* they formed a far greater proportion of the total food. There can be little doubt that members of this population were specialised feeders — a conclusion which received ample confirmation after the treatment.

The effects of the DDT on this species were immediate and serious. On 16 March and subsequently, great difficulty was experienced in finding specimens and, although collecting effort was intensified, far fewer fishes were obtained from the same areas than previously. It is difficult to avoid the conclusion that a significant number of fishes had either left the sampling area or else died of starvation. The high proportion (94 %) of stomachs containing food before the dosing shows that feeding is more or less continuous, and that removal of the principal food is likely to have rapid consequences.

The effects of the treatment on the food and feeding-habits are summarised in Table VIII. An important fact is that, of the 36 fishes caught in March and April, when the treatment was having its most severe effect on the Ephemeroptera and Trichoptera, only 18 contained any food. The commonest items of food were Hirudinea and small fishes, animals which had not been found in the stomachs before, save in a single individual. The remaining types of food were scant and variable, and included larvae of the resistant species of *Caënis*, Pelecypoda, terrestrial insects and, surprisingly, a *P. adusta* larva.

Table VIII. — Changes in the food of *M. victoriae*

Food-type	Percentage occurrence on successive dates: Before 2/3	16/3 to 5/4	13/6 & 22/6	25/5/57
Lithophilic Ephemeroptera	92	11	83	100
Lithophilic Trichoptera	53	0	50	21
Tricorythus tinctus	79	0	61	79
Afronurus ugandanus	22	0	11	8
Chironomidae	5	0	61	0
Number examined	170	36	21	24
Number containing food	161	18	18	24

On 13 and 22 June, fishes had become easier to collect, and 86 % contained food, this being of a type similar to that eaten before 2 March. The specimens examined in June appeared to have been feeding more heavily on chironomid larvae than previously, but otherwise their diet had more or less returned to normal. The only noteworthy feature of the sample of July 1957 is that Trichoptera larvae were being eaten less than previously. This may have been a reflection of the density of larvae, since counts of the fauna in July showed Trichoptera to have decreased since 1956.

These observations show that *M. victoriae* is normally a very specialised feeder in this habitat, and that, when deprived of its principal food, it cannot readily adapt its trophic behaviour to new conditions.

GNATHONEMUS LONGIBARBIS AND *MORMYRUS KANNUME*

Collections of these two species were small (see Table IV), but nevertheless sufficient to indicate the way in which insectivorous fishes of this type may be expected to respond to DDT treatment.

Before 2 March, the principal food of *G. longibarbia* appeared to be small Trichoptera larvae of the family Hydroptilidae, these occurring in all of the 9 fishes examined, and providing the main contents in 6 of them; the hydroptilid larvae were living in small cases attached to stones on the river bed. The other contents of the stomachs confirmed that a considerable part of the feeding was taking place on the river bed, *T. tinctus* larvae occurring in 7 stomachs, *P. senegalense* in 2, and *Cheumatopsyche* spp. and *A. ugandanus* in one. Unlike *C. petricola* and *M. victoriae,* however, *G. longibarbis* had been feeding also in a sheltered region containing fine silt. Evidence for this was provided by the presence in stomachs of mud tubes constructed by chironomid larvae. It seems very likely that *G. longibarbis* obtained these in the marginal grass swamp referred to previously, since there were very few places of this kind nearby where fine silt could have accumulated. The occurrence of many chironomid larvae, large Hydracarina and an Odonata larva (*Trithemis sp.*) lent strong support to the interpretation that *G. longibarbis* was obtaining its food from the swamp also.

After the dosing, it became clear that almost all the food was now being obtained from the swamp habitat. A large quantity of finely-divided plant débris had been ingested, together with chironomid larvae, their mud cases, *Chaoborus* larvae and Odonata larvae (*Trithemis* and *Pseudagrion* spp.). As no fishes with empty stomachs were encountered, it is clear that many insects living in the swamp must have survived the treatment, presumably having been protected from the main flow of the river. Of the 24 fishes examined on 16 March and 5 April, only 7 contained Hydroptilidae and 2 *P. senegalense,* whereas 4 contained *Odonata* larvae. Of the 28 collected on 13 June, 7 contained Hydroptilidae, 6 *P. senegalense* and 11 Odonata larvae. A sample of fishes taken on 25 July, 1957 showed that the feeding habits had once more returned to the pre-treatment pattern, with most of the food being obtained from the river bed, and a small amount from the swamp. Hydroptilidae occurred in 15 of the 22 fishes examined and provided the main contents in 6. *T. tinctus* occurred in 12 (main contents in 1), *P. senegalense* in 7, and *Cheumatopsyche sp.* and *A. ugandanus* each in 2.

M. kannume seemed to respond to the insecticide in a similar fashion, although its feeding habits were apparently disturbed more than those of *G. longibarbis.* Before the treatment only 1 of the 19 fishes examined was empty. In the remainder, hydroptilid larvae occurred in 9 (main contents in 5), *T. tinctus* in 10 (1), *chironomid* larvae in 8 (1), *C. copiosa* larvae in 1 (1), *P. senegalense* larvae in 5 and Hydracarina in 5. The predominance of chironomid larvae and the numerous Hydracarina in two stomachs indicated that a certain amount of feeding was occurring in a sheltered swamp habitat, but probably considerably less than in *G. longibarbis.*

Three of the 7 fishes found after the dosing (on 16 March and 5 April) were empty — an exceptionally high proportion in this species, even when allowance is made for the small size of the sample — and the rest had been eating a variety of unusual items. Thus tipulid larvae, plant débris and sand grains each constituted the main contents of one stomach, whereas chironomid larvae occurred in 3 and Hydracarina in 2. Hydroptilidae, *T. tinctus* and *P. senegalense* had not been eaten at all.

In Lake Victoria, *M. kannume* is mainly a bottom-feeder when compared with *G. longibarbis,* which obtains much of its food from marginal swamp. Therefore, in this instance, *M. kannume* was perhaps unable to utilise the swamp habitat to as great an extent. Fourteen months after the dosing, its food had returned to normal again. On 25 July, 1957, 13 fishes were examined. One was empty, and in the rest chironomid larvae occurred in 10 (3), *T. tinctus* in 10 (2), *P. senegalense* in 9, *Cheumatopsyche spp.* in 8 (1), and Hydroptilidae in 5.

G. longibarbis and *M. kannume* provide examples of fishes originally exploiting two different habitats for food, which responded to the changed conditions by obtaining a larger proportion of their food from the single source which remained unaffected. *G. longibarbis* seemed better able to adapt itself in this way than was *M. kannume.*

BARBUS ALTIANALIS RADCLIFFI

Only a few specimens of this species were collected, most of them by angling with a lure. It is therefore to be expected that these individuals would have been feeding on small fishes. An analysis of their food showed that fish remains (mainly *E. argenteus*) occurred in 6 (3), green plant fragments mostly *Najas sp.)* in 7, *Potamon niloticus* in 1 (1) and insects in 1. None of the 8 stomachs was empty.

Of the 23 fishes examined after the treatment (up to 13 June, 1956), 3 were empty (quite a normal proportion for fishes caught in the river in this way) and of the remainder, green plant fragments were found in 13 (7), fishes in 8 (3), insects in 11, Mollusca in 4 (1) and plant débris in 2 (2). Most of the insects eaten were adults of terrestrial species (*e. g.* Hymenoptera and Lepidoptera) which had been taken at the surface. Although in some localities, and when a certain size, *B. altianalis* does feed on lithophilic insects, Mollusca constitute a far more important item of its diet, and therefore effects of DDT on its feeding habits are likely to be negligible. Of the five species of fishes considered in this paper, *B. altianalis* may be expected to be affected least by riverine applications of DDT.

DISCUSSION

In the foregoing account an attempt has been made to show how the treatment of the Victoria Nile with DDT in March, 1956, affected some of the fishes and invertebrates in the river immediately below the dosing point. It will be realised that the short time available for collecting material meant that the scope of the data is necessarily rather limited. But it is considered nevertheless that the results probably give a good indication of the changes to be expected in an invertebrate fauna, and of the ways in which certain types of fish will respond to the disappearance of preferred items of their food. In any case, since there appears to be only one other study of the effects of DDT on the feeding habits of river fishes (ADAMS *et al.*, 1949), the observations recorded here will have to carry weight until more extensive data can take their place.

It has been shown that, depending on their feeding habits, fishes respond in different ways to insecticidal treatment. A fish such as *B. altianalis* remains virtually unaffected, since it feeds mainly on small fishes and plants which are resistant to DDT. A facultative feeder, of the *Clariallabes* type, although subsisting almost entirely on lithophilic Ephemeroptera and Trichoptera as a rule, can quickly modify its feeding habits to make use of a wide range of sources of plant or animal protein. Less adaptation is demanded in fishes such as *G. longibarbis* and *M. kannume,* which can obtain their food from two habitats — the river bed and marginal swamp. When the lithophilic insect fauna is depleted, they are able to derive a proportionately greater amount of food from the swamp. Of the two species, *M. kannume* seems less adaptable, and some individuals may find difficulty in obtaining enough food. The least adaptable fishes, and therefore the most severely affected, are specialised insectivores such as *M. victoriae.* This species feeds almost entirely on lithophilic Ephemeroptera and Trichoptera — groups particularly susceptible to DDT. When these insects are removed, *M. victoriae* proves unable to adapt itself adequately to the changed conditions, and starvation results.

It is the response of a specialised insectivore, such as *M. victoriae*, that must be borne in mind when extensive control measures against *Simulium* are planned in African rivers and their headstreams. The work described above, and other studies of the food of fishes in Uganda, have shown that the lithophilic insect fauna in such habitats forms a very important link in the food chain. Such stream-dwelling fishes as *Amphilius jacksoni* BLGR., *Clarias carsoni* BLGR. and *Barbus portali* BLGR., for example, depend mainly on these insects for food, and are therefore likely to be affected severely by insecticidal treatment.

Attempts are now being made to evolve effective methods for controlling breeding in highland streams. A severe drawback to treating stream habitats with DDT is that, especially when they flow through forest, they may vary greatly in width and depth, and consequently the minimum concentration of DDT necessary to achieve control may differ widely from one stretch to another. Thus, to make a campaign worth while, doses far in excess of the minimum lethal to *Simulium* in a suitable stretch may have to be used. Even where this consideration does not apply, however, it is clear from what has been said that control measures against *Simulium* are bound to influence stream-living animals profoundly — the insects directly, and the fishes indirectly, by depriving them of their principal food. Moreover, since most small streams are naturally isolated in their own valleys, recolonisation of the insect fauna is likely to be an extremely slow process, if in many cases it can occur at all. It will be realised that the example of the Victoria Nile at Jinja represents a special case, in so far as breeding populations of most species of Ephemeroptera and Trichoptera survived the treatment untouched at the Ripon Falls. But no such source of relief can be expected in highland streams.

It is felt that extensive *Simulium* control, by riverine application of DDT, may well change completely the biological character of many streams and rivers, and in the process of eliminating local populations of *Simulium*, may render extinct many fishes and insects that are little known or undiscovered. It is of course possible that such a price will have to be paid in order that control of onchocerciasis may be achieved. But if this is so, a strong case exists for the making of collections and biological surveys beforehand. Indeed, a recommendation of this kind has already been made by TAUFFLIEB (1955) who, after observing the heavy mortality amongst stream fauna which resulted from DDT treatment in French Equatorial Africa, advised the co-operation of hydrobiologists in planning further campaigns. It is to be hoped that some such precaution will be taken wherever possible in future, for not only would this rescue much biological information concerning animals which might otherwise remain unknown, but it would also put field workers in a much more favourable position to assess and predict the effects of insecticidal treatment in different kinds of habitat.

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SUMMARY

1. In 1956 the Victoria Nile at Jinja (Uganda) was treated with DDT in order to eliminate populations of *Simulium damnosum* (THÉOBALD) breeding there. On several occasions before and after treatment the sluice gates of the Owen Falls Dam were closed temporarily, thus exposing certain parts of the river bed, and thereby enabling the effects of the DDT on the fauna to be investigated.

2. The invertebrates most susceptible to DDT were the Ephemeroptera and Trichoptera, these being almost eliminated from upper reaches of the river. However, after treatment had ceased, repopulation of these insects occurred promptly, owing to the existence of unaffected populations a short distance above the dosing point. Quantitative observations were made on the rate of recolonisation by the invertebrate fauna after treatment.

3. While the sluice gates were closed, fishes in a marginal swamp below the dam showed signs of asphyxiation. This condition was probably caused by depletion of the surface layer of swamp water.

4. No direct, harmful effect of DDT on fishes was observed, although several species were affected indirectly by the removal of their accustomed insect food. These fishes adapted themselves to the changed cir-

cumstances in different ways : some proved able to exploit a wide range of new foods, some concentrated on those items of their previous diet which remained unaffected, whereas others were apparently obliged either to starve or to move elsewhere. All the species studied returned to their original feeding-habits after recolonisation by the invertebrate fauna had taken place.

5. In view of the effects noted, and of the fact that much *Simulium*-control in Africa is planned for highland streams, where repopulation is unlikely to occur for a considerable time, it is strongly recommended that adequate hydrobiological surveys be made before extensive control measures are put into force. It is felt that such precautions are necessary in order to avoid the severe depletion and perhaps extinction of little known or undiscovered fishes and insects.

REFERENCES

ADAMS, L., HANAVAN, M., HOSLEY, N. & JOHNSTON, D (1949). — The effects on fish, birds and mammals of DDT used in the control of forest insects in Idaho and Wyoming. — *J. Wildlife Manag.*, **13** : 245-254.

BARNLEY, G. R. (1953). — The control of *Simulium damnosum* (THÉOBALD) on the Victoria Nile, Uganda. *W. H. O. Conference on African Onchocerciasis* (Mexico), No. 18.

BARNLEY, G. R. (1956). — *Simulium* control on the Victoria Nile and elsewhere in Uganda. — *Tenth Int. Congress Ent.* (Montreal), in the press.

CARTER, G. S. (1955). — The papyrus swamps of Uganda. — W. Heffer & Sons, Ltd., Cambridge. Pp. 25.

CORBET, P. S. (1957). — Duration of the aquatic stages of *Povilla adusta* NAVÁS (Ephemeroptera : Polymitarcidae). — *Bull. ent. Res.*, **48** : 243-250.

GREENWOOD, P. H. (1956). — A new species of *Clariallabes* (Pisces, Clariidae), from the Nile. — *Proc. zool. Soc. Lond.*, **127** : 555-564.

HOFFMAN, C. H. & MERKEL, E. P. (1948). — Fluctuations in insect populations associated with aerial applications of DDT to forest. — *J. econ. Ent.*, **41** : 464-473.

HOFFMAN, C. H., TOWNES, H. K., SAILER, R. I. & SWIFT, H. H. (1946). — Field studies on the effect of DDT on aquatic insects. — *U. S. Dept. Agric. Bur. Ent. and Plant Quar.*, E-**702** : 1-20.

JAMNBACK, H. & COLLINS, D. L. (1955). — The control of blackflies (Diptera; Simuliidae) in New-York. *N. Y. State Mus., Bull.* No. **350** : 1-113.

NOËL-BUXTON, M. B. (1955). — A new DDT preparation and its use in *Simulium* control experiments. — *Mimeographed Report, Fisheries Dept., Gold Coast,* Pp. 7.

TAUFFLIEB, R. (1955). — Une campagne de lutte contre *Simulium damnosum* au Mayo Kebbi. — *Bull. Soc. Pathol. exot.*, **48** : 564-576.