The impact of a paper mill effluent spill on the fish populations of the Elands and Crocodile Rivers (Incomati System, Transvaal)

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Abstract

During September 1989, 700 000 ℓ of black liquor from a paper mill was spilled into the Elands and Crocodile Rivers on the Eastern Transvaal escarpment. The impact of this effluent on the fish populations of these two rivers was monitored. Observations three days after the spill indicated massive fish mortalities in both rivers for a distance of 40 km downstream from the point of discharge down to the town of Nelspruit. A detailed survey in October 1989 indicated that the fish in the Elands River below the spill were largely decimated. Mortalities in the Crocodile River downstream to Nelspruit were lower. Downstream between Nelspruit and the Kruger National Park boundary, mortalities were observed in one species only. In total 14 fish species were affected in the river from the paper mill down to Nelspruit. One threatened species *(Chiloglanis bifurcus)* suffered serious mortalities while another *(Opsaridium zambezense)* was only marginally influenced. During November 1989 and March and June 1990, surveys were undertaken to assess the success of the natural recolonisation of fish in the affected areas. Surveys were primarily undertaken in fast-flowing water and indicated that, although recolonisation is taking place, the species richness and population density in the Elands River in particular is still considerably lower than the numbers found during surveys since 1978. An intensive survey, which duplicated that done in October 1989, was undertaken in September 1990. This survey confirmed that recolonisation of the affected area is taking place. A survey during October 1991 which was limited to the affected part of the Elands River, confirmed the results of the September 1990 survey in this section. It is estimated that the river will probably only recover after several years. Translocation of fish to the most damaged section of the Elands River is an option which will be considered if future surveys do not indicate improved recolonisation rates. The importance of conserving fish refugia as centres from which recolonisation can occur is emphasised by this disaster.

Introduction

On 23 September 1989 a spill of 700 000 ℓ (Regional Court Records, Nelspruit, March 1990) of an effluent generally known as "black liquor" (McKee and Wolf, 1963) and originating from a paper mill, was accidentally released into the Ngodwana River (Incomati System). Approximately 1 km downstream from the mill, this effluent flowed into the Elands River and eventually into the Crocodile River (Fig. 1). Shortly after the spill occurred the paper mill released water from their storage dam in the Ngodwana River, while water was also released from the Braam Raubenheimer Dam in the Crocodile River. The purpose of these water releases was to dilute the effluent and minimise its detrimental effects on the river. The spill lasted for 2 h and caused massive fish mortalities in the Elands and Crocodile Rivers.

The paper mill is situated at the confluence of the Ngodwana and Elands Rivers and generates an average of 25 million ℓ of effluent per day which is disposed of by means of a treatment system (Regional Court Records, Nelspruit, March 1990). The Kraft process is employed by which wood is pulped in digesters with a concentrated solution of sodium hydroxide which also contains sodium sulphate and sodium sulphide. The concentrated alkaline solution which is washed from the wood is known as black liquor. The toxicity of black liquor to aquatic life is mainly related to the sulphur-containing substances, in particular the mercaptans, and the resins and fatty acid components. In addition black liquor has a high biochemical oxygen demand (McKee and Wolf, 1963).

Surveys were conducted to assess the extent to which the fish populations were damaged and also to decide on appropriate management actions.

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Methods

Surveys

The Transvaal Chief Directorate of Nature and Environmental Conservation was informed of the situation two days after the spill had occurred. A preliminary survey was conducted on 26 September and on 27 September 1989 an aerial survey to determine the location of the main concentration of effluent was undertaken. On 28 and 29 September 1989 additional observations were made in the vicinity of Localities 13 and 14 in order to determine the movement of the polluted water (Fig. 1).

From 2 to 4 October 1989 a detailed survey was undertaken. This survey covered 14 sampling localities in the Elands and Crocodile Rivers (Fig. 1):

Sampling Localities 1 to 3: These three localities served as reference localities as they were situated upstream from the confluence of the Elands and Ngodwana Rivers and were not affected by the spill. The habitat consisted of rapids, stony runs and riffles with a limited extent of quiet water in the form of small stony pools and backwaters.

Sampling Locality 4: This locality was situated about 800 m downstream of the confluence of the Elands and Ngodwana River. It consisted of a pool, a strongly flowing, stony rapid, riffles, runs and backwaters.

Sampling Locality 5: Was situated a small distance upstream from the Lupelule tributary of the Elands River and comprised strongly flowing, rocky rapids with small backwater areas.

Sampling Locality 6: Situated in the Elands River, approximately 4 km upstream from its confluence with the

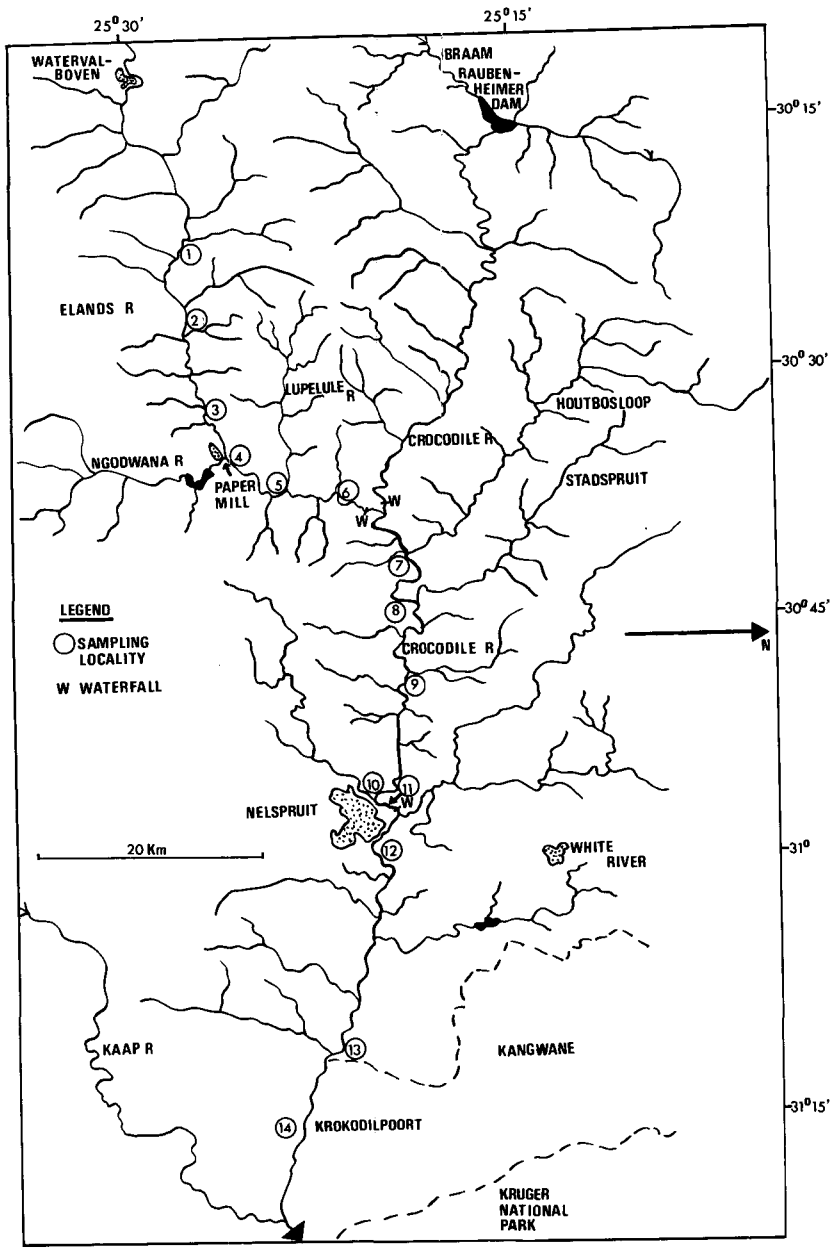

Figure 1
Sampling localities in the Elands and Crocodile Rivers (Incomati System, Transvaal) between September 1989 and October 1991

Crocodile River, with a strongly flowing rocky rapid and a side channel with pools, riffles and backwaters.

The altitude decreases from 1 100 to 850 m above sea level (ASL) at Localities 1 to 6. On average the river was estimated to be 25 m wide in this segment.

Sampling Locality 7: Situated in the Crocodile River downstream of its confluence with the Elands River. It consisted primarily of a run and riffle with backwater areas.

Sampling Locality 8: Was a strongly flowing, rocky rapid, with riffles and backwater areas.

Sampling Localities 9 to 11: Riffles, runs and rapids were comparatively scarce at Localities 9 and 10 and absent at Locality 11. Locality 10 was situated at a large weir near the confluence of the Crocodile River and Gladdespruit.

The altitude decreases from 750 to 650 m ASL at Localities 7 to 11. On average the river was estimated to be 40 m wide in this section.

Sampling Localities 12 to 14: These localities were located downstream from the waterfall in the Crocodile River at the Lowveld Botanical Gardens. The character of the river changes considerably below this waterfall. Long, deep fast-

flowing sections predominate here with few rapids and riffles (Localities 12 and 13). Where the river flows through the Krokodilpoort its character changes once again with rapids, riffles and rocky pools much in evidence. Large boulders and rocks occur in the streambed in this section (Locality 14).

The altitude decreases from 580 to 375 m ASL at Localities 12 to 13. On average the river was estimated to be 40 to 50 m wide in this stretch.

Localities 4 to 14: Were located downstream of the paper mill where the spill occurred.

The results of the October 1989 survey indicated that fish mortalities occurred between sampling Localities 4 and 11 and primarily between Localities 4 and 8. It was, therefore, decided to limit the November 1989 survey to Localities 1 to 11. The fast-flowing habitats at Localities 4 to 8 were monitored during March and June 1990. In September 1990, one year after the spill, Localities 1 to 14 were again sampled. A survey in October 1991 was limited to Localities 4 to 6.

Sampling of fish and determination of abundance

In fast-flowing water with a depth < 1 m an electrical shocking apparatus (850 W, 220 V, AC) was used to capture fish. The number of fish caught per minute (to the nearest 0,5 min) and the percentage contribution of a specific species to the total catch (relative density) was determined and used as an indication of numerical abundance (Kleynhans, 1986).

In small pools and backwaters a seine net of dimensions 10 x 1 m with a bar mesh size of 1 mm was used to sample fish. A seine net of dimensions 80 x 3 m with a bar mesh size of 1,0 cm was used in large pools. A series of gill nets (25 x 3 m; stretch mesh sizes = 70, 90, 110 and 130 mm) were also used in large pools.

For comparing the data after the spill had occurred with historical information, the procedure for calculating the number of fish caught per minute with an electrical shocker has been in use since 1978 at Localities 1 to 8. It was therefore possible to compare the abundance (fish/min) of fish at these localities before and after the spill occurred. No information is available on catch per unit effort for nets in the Elands and Crocodile Rivers before 1989. Consequently, electrofishing data before 1978 and all seine and gill net catch data could only be used for presence/absence comparisons. The fish distribution data base for the Crocodile and Elands Rivers includes data from 1967.

Results

Preliminary survey (26 September 1989)

No live fish were caught or observed at Locality 4. Large numbers of dead and decomposing *Barbus argenteus* and *B. polylepis* with a fork length < 10 cm were washed up on the river bank.

At Localities 7, 9 and 11 no live fish were caught or observed. Considerable numbers of dead and decomposing *B. argenteus* (fork length < 10 cm), *B. marequensis* (fork length > 10 cm) *Labeo molybdinus* (fork length > 10 cm) and *Tilapia sparrmanii* (total length < 10 cm) were washed up on the river bank.

According to farmers a number of hippopotami which lived in the area between Localities 8 and 10 left the river when the polluted water moved through that stretch of the river.

Aerial survey (27 September 1989)

The Elands River from its confluence with the Ngodwana River and the Crocodile River from its confluence with the Elands River downstream to the boundary of the Kruger National Park were surveyed. No accurate identifications of fish were possible. However, it was evident that the majority of dead fish observed were large *Barbus* and *Labeo* spp. At the confluence of the Elands and Ngodwana Rivers two dead *Anguilla mossambica* were observed. Large numbers of dead fish occurred up to Locality 11. Hippopotami were again present in the river between Localities 8 and 10.

Apart from dead fish, the first visible indication of polluted water was observed in the vicinity of Locality 13 where a large concentration of foam and soapy water was moving through a rocky section of the river. Below a weir near Locality 14, skimming salts were observed along the sides of pools. A technician working at the paper mill was of the opinion that these skimmings were part of the spill at Ngodwana. An angler who had fished there the previous day did not observe any dead or dying fish. Below this locality and in the Kruger National Park no dead fish or any abnormalities concerning the general appearance of the water were observed.

Additional survey (28 to 29 September 1989)

Below the weir near Locality 14, a number of dead and dying *Opsaridium zambezense* were observed on 28 September. The main body of foam was at that stage present at the weir. On 29 September it was evident that the foamy water had moved through the Krokodilpoort. No additional fish mortalities were reported after this date.

Intensive surveys

Presence/absence

Before September 1989 a total of six fish species had been recorded at Localities 1 to 3 while the October 1989 survey indicated the presence of seven species. *Anguilla mossambica* was not present in the October survey while *Barbus anoplus* and *B. polylepis*, which had not been recorded at these localities previously, did occur during October (Table 1).

Before September 1989 there were eight species known at Localities 4 to 6 below the confluence of the Elands and Ngodwana Rivers. Following the spill, no fish were caught in October 1989. In November 1989 one *Anguilla mossambica* was found at Locality 5. Three species were caught in March and June 1990. Sampling in September 1990 indicated the presence of eight species. However, the majority of species were found at Locality 4 which is in close proximity to the unpolluted upstream section of the Elands River. *Clarias gariepinus*, which was caught in September 1990, had not been found in the Elands or Ngodwana Rivers before this time (Gaigher, 1969; Kleynhans, 1984). This species was, however, recorded from a dam in the Ngodwana River where it had been apparently released by anglers and it is accepted that its presence in the Elands River can be ascribed to escapees from this dam. The survey in October 1991 indicated an increase in the number of species present at Locality 5 (5 species) and Locality 6 (2 species). At Locality 4, *Micropterus salmoides* was also sampled for the first time in the Elands River. Only juveniles (fork length = 2,0 to 2,5 cm) of this species were caught and it

TABLE 1
THE OCCURRENCE OF FISH SPECIES AT LOCALITIES 1 TO 3 AND 4 TO 6 IN THE ELANDS RIVER BEFORE AND AFTER SEPTEMBER 1989

Species	Occurrence								
	Localities 1 to 3		Localities 4 to 6						
	Before Sept. 89	Oct. 89	Before Sept. 89	Oct. 89	Nov. 89	March 90	June 90	Sept. 90	Oct. 91
Anguilla mossambica	1	0	4	0	5	0	0	4	4,5,6
Amphilius uranoscopus	1,2,3	2,3	4,5,6	0	0	0	0	4	5
Barbus anoplus	0	2	4,6	0	0	0	4	6	5
Barbus argenteus	1,2,3	1,2,3	4,5,6	0	0	4	5,6	4,5	4,5
Barbus polylepis	0	1,2	6	0	0	0	0	0	4
Chiloglanis bifurcus	1,2,3	1,2,3	4,6	0	0	4	0	4	0
Chiloglanis pretoriae	1,2,3	1,2,3	4,5,6	0	0	4	4	4	4,5,6
*Clarias gariepinus**	0	0	0	0	0	0	0	4	0
Tilapia sparrmanii	2,3	2	4,5,6	0	0	0	0	4	4
*Micropterus salmoides**	0	0	0	0	0	0	0	0	4
Total number of species	6	7	8	0	1	3	3	8	8

0 : Absent
* : Introduced

TABLE 2
THE OCCURRENCE OF FISH SPECIES AT LOCALITIES 7 AND 8 IN THE CROCODILE RIVER BEFORE AND AFTER SEPTEMBER 1989

Species	Occurrence Localities					
	Before Sept. 89	Oct. 89	Nov. 89	March 90	June 90	Sept. 90
Anguilla mossambica	8	0	0	0	0	0
Amphilius uranoscopus	8	0	0	0	0	0
Barbus anoplus	7	0	0	0	0	0
Barbus argenteus	7,8	8	0	0	0	0
Barbus marequensis	7,8	7,8	7,8	7,8	7	7,8
Barbus polylepis	0	0	0	7,8	7,8	0
Chiloglanis bifurcus	7,8	0	0	7	0	7
Chiloglanis pretoriae	7.8	0	8	7	0	7
Clarias gariepinus	0	0	0	0	0	7
Labeo molybdinus	0	0	0	0	0	7
Pseudocrenilabrus philander	7,8	0	8	0	0	0
Tilapia sparrmanii	0	0	0	8	0	0
Total number of species	7	2	3	5	2	5

0: Absent

is suspected that they were escapees from either farm dams occurring along the river or from the dam in the Ngodwana River where the species had been introduced for angling purposes (Table 1).

There were seven species known in the Crocodile River at Localities 7 and 8 before September 1989. These records are based on sampling efforts with an electrical shocker and a small seine net. During October 1989 only *B. marequensis* and *B. argenteus* were caught at these two localities. Data for November 1989 indicated the presence of three species. During March 1990, five species were sampled. However, in June 1990 only two species were found. Five species occurred in September 1990. Two of these *(C. gariepinus* and *L. molybdinus)* were caught in gill nets which had not previously been employed at these localities (Table 2).

Of the 13 known species from Localities 9 to 11, the October 1989 survey disclosed the presence of seven species. The surveys in November 1989 and September 1990 were hampered by the strong flow of water and the few sections of rapids and riffles that were usually sampled could not be investigated. Only gill nets were employed in large pools and weirs during these two months and in November 1989 and September 1990 respectively four and three species were recorded (Table 3). However, gill nets employed in October 1989 also only caught three species. During October 1989 the marginal vegetation at the weir at locality 10 was partly covered with a sticky brown substance with a strong resinous smell.

A total of 13 species were previously known from Localities 12 to 14. In October 1989 and September 1990 respectively 13 and 11 species were recorded (Table 3).

TABLE 3
THE OCCURRENCE OF FISH SPECIES AT LOCALITIES 9 TO 11 AND 12 TO 14 IN THE CROCODILE RIVER BEFORE AND AFTER SEPTEMBER 1989

	Occurrence						
	Localities 9 to 11				Localities 12 to 14		
Species	Before Sept. 89	Oct. 89	Nov. 89	Sept. 90	Before Sep. 89	Oct. 89	Sept. 90
Anguilla mossambica	10	0	0	0	13,14	0	14
Barbus argenteus	10	10	0	0	0	0	0
Barbus marequensis	9,10,11	10,11	11	9,10,11	13,14	12,13,14	12,13,14
Barbus trimaculatus	10	0	0	0	13,14	12	0
Barbus unitaeniatus	0	0	0	0	13,14	13	0
Chiloglanis bifurcus	9	0	0	0	0	0	0
Chiloglanis pretoriae	9,11	0	0	0	13,14	12,13	12,13,14
Clarias gariepinus	10,11	10,11	10,11	11	12,13	12	12
Labeo cylindricus	10,11	0	0	0	13,14	13	14
Labeo molybdinus	10,11	10,11	10,11	11	12,13,14	0	12,14
Marcusenius macrolepidotus	0	0	0	0	0	0	14
Mesobola brevianalis	0	0	0	0	0	14	12,13,14
Oreochronis mossambicus	11	0	10,11	0	13	12,13	12
Opsaridium zambezense	0	0	0	0	13,14	14	13,14
Pseudocrenilabrus philander	9,10,11	11	0	0	12,13	12	0
Schilbe intermedius	0	0	0	0	0	0	12
Tilapia sparrmanii	10,11	10	0	0	0	12	0
*Xiphophorus helleri**	10,11	11	0	0	12	12	0
Total number of species	13	7	4	3	13	13	11

0: Absent
*: Introduced

TABLE 4
THE ABUNDANCE OF FISH CAUGHT WITH AN ELECTRICAL SHOCKING APPARATUS IN FAST-FLOWING WATER IN THE ELANDS AND CROCODILE RIVERS FROM 1978 TO 1988 OR 1989

	Upstream from Locality 4 1978-89			Localities 4 to 6 1978-88			Localities 7 to 8 1978-88		
Species	Fish/min[a]	Relative density (%)[b]	Frequency of occurrence (%)[c]	Fish/min[d]	Relative density (%)[e]	Frequency of occurrence (%)[f]	Fish/min[g]	Relative density (%)[h]	Frequency of occurrence (%)[i]
Anguilla mossambica	0,004	0,09	4,5	0,04	2,4	25,0	0	0	0
Amphilius uranoscopus	0,49	9,9	69,6	0,21	12,9	37,5	0,02	0,9	20
Barbus anoplus	0	0	0	0	0	0	0,08	3,6	20
Barbus argenteus	0,91	18,6	39,1	0,40	24,7	62,5	0,64	29,5	40
Barbus marequensis	0	0	0	0	0	0	0,02	0,9	20
Barbus polylepis	0,01	0,2	8,7	0,02	1,2	12,5	0	0	0
Chiloglanis bifurcus	0,13	2,6	47,8	0,08	4,7	37,5	0,17	8,0	80
Chiloglanis pretoriae	3,36	68,3	87,0	0,85	51,8	100	1,14	52,7	80
Pseudocrenilabrus philander	0	0	0	0,02	1,2	12,5	0,10	4,5	40
Tilapia sparrmanii	0,02	0,4	17,4	0,02	1,2	12,5	0	0	0

0: Absent

[a]: Total number of fish/min=4,91; total duration of sampling effort=220 min
[b]: n=1 081
[c]: Total number of sampling points=23

[d]: Total number of fish/min=1,64; total duration of sampling effort=52 min
[e]: n=85
[f]: Total number of sampling points=8

[g]: Total number of fish/min=2,15; total duration of sampling effort=52 min
[h]: n=112
[i]: Total number of sampling points=5

Abundance

All results in this section pertain to fish caught in fast-flowing water with an electrical shocking apparatus.

Upstream from Locality 4:

Up to and during September 1989, 4,91 fish/min were sampled in this river segment (Table 4).

Localities 4 to 6:

Prior to September 1989, 1,64 fish/min had been sampled with an

TABLE 5
THE NUMBER OF FISH CAUGHT WITH AN ELECTRICAL SHOCKING APPARATUS IN FAST-FLOWING WATER IN THE ELANDS RIVER AT LOCALITIES 4 TO 6 FROM OCTOBER 1989 TO OCTOBER 1991

	Locality 4						Locality 5						Locality 6					
Species	**Oct. 89**	**Nov. 89**	**March 90**	**June 90**	**Sept. 90**	**Oct. 91**	**Oct 89**	**Nov. 89**	**March 90**	**June 90**	**Sept. 90**	**Oct. 91**	**Oct. 89**	**Nov.89**	**March 90**	**June 90**	**Sept. 90**	**Oct.91**
Anguilla mossambica	0	0	0	0	1	1	0	1	0	0	0	1	0	0	0	0	0	2
Amphilius uranoscopus	0	0	0	0	2	0	0	0	0	0	0	1	0	0	0	0	0	0
Barbus anoplus	0	0	0	1	0	0	0	0	0	0	0	4	0	0	0	0	1	0
Barbus argenteus	0	0	5	0	3	2	0	0	4	13	2	2	0	0	0	2	0	0
Barbus polylepis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chiloglanis bifurcus	0	0	2	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Chiloglanis pretoriae	0	0	10	9	68	53	0	0	0	0	0	11	0	0	0	0	0	8
*Clarias gariepinus**	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
*Micropterus salmoides**	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0
Pseudocrenilabrus philander	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tilapia sparrmanii	0	0	0	0	23	0	0	0	0	0	0	0	0	0	0	0	0	0
Time (min) sampled	8	8	14,5	15	23	19,5	14,5	9	34	21	26	25	13	9	10	9,5	20	32
Total number of fish	0	0	17	10	102	60	0	1	4	13	2	19	0	0	0	2	1	10
Total number of fish/min	0	0	1,17	0,67	4,43	3,08	0	0,11	0,12	0,62	0,08	0,76	0	0	0	0,21	0,05	031
Number of species	0	0	3	2	6	4	0	1	1	1	1	5	0	0	0	1	1	2

*: Introduced
0: Absent

electrical shocker at these localities (Table 4).

Following the effluent spill, no fish were caught with an electrical shocker at Localities 4 to 6 during October 1989. With the exception of one *A. mossambica* caught at Locality 5, the situation at Localities 4 to 6 remained the same during November 1989 (Table 5).

During March 1990, 1,17 and 0,12 fish/min were caught at Localities 4 and 5 respectively. No fish were caught at Locality 6.

During June 1990, 0,67, 0,62 and 0,21 fish/min were caught respectively at Localities 4, 5 and 6. The corresponding results for September 1990 are 4,43, 0,08 and 0,05 fish/min, and those for October 1991, 3,08, 0,76 and 0,31 fish/min (Table 5).

Localities 7 and 8:

Before September 1989, 2,15 fish/min had been caught at these 2 localities (Table 4).

During October 1989, 0,07 fish/min were caught at Locality 7 and none at Locality 8. In the following months the number of fish caught per minute varied considerably at both localities. This can be ascribed primarily to relatively large numbers of *Barbus marequensis* and *B. polylepis* juveniles (fork length = 2,0 to 2,5 cm) which sporadically occurred in the catch (Table 6).

Discussion

Immediate effects of the spill

Results for October 1989 indicate that the severest fish mortalities occurred downstream from the confluence of the Ngodwana and Elands River up to the confluence of the Elands and Crocodile Rivers (Localities 4 to 6). Virtually all fish in this segment were destroyed during the spill. Seven fish species were found amongst mortalities in this segment, including *C. bifurcus*. This species has been rated as vulnerable in the *South African Red Data Book - Fishes* (Skelton, 1987) and is endemic to the Crocodile and Elands Rivers (Gaigher, 1969) and one tributary of the Komati River (Heymans, 1987). The detrimental effects of flow regulation in the Crocodile River by the Braam Raubenheimer Dam and the possibility of the accidental spillage of chemicals into the Elands River by the paper mill on the survival of *C. bifurcus* was pointed out by Kleynhans (1984; 1986). *Chiloglanis bifurcus* suffered heavy mortalities in 38 per cent of its habitat in the Crocodile and Elands Rivers during the spill. A population of *B. polylepis* which is isolated by a waterfall in the Elands River from populations downstream in the Crocodile River (Gaigher, 1969) also suffered heavy mortalities.

Downstream from the confluence of the Elands and Crocodile Rivers, mortalities were also severe at Localities 7 and 8 but downstream from this segment mortalities were lower as indicated by the presence of fish at Localities 9 to 11 during October 1989. In the Crocodile River downstream from the waterfall at the Lowveld Botanical Gardens up to Krokodilpoort (Localities 12 to 14), monitoring results for October 1989 do not indicate any severe mortalities. The dead *Opsaridium zambezense* which was observed at Locality 14 during September 1989, appears to be an isolated incident which can probably be ascribed to the concentration of effluent at this point by the obstruction to flow caused by a weir. This species prefers clear, well-aerated water and appears

TABLE 6
THE NUMBER OF FISH CAUGHT WITH AN ELECTRICAL SHOCKING APPARATUS IN FAST-FLOWING WATER IN THE CROCODILE RIVER AT LOCALITIES 7 AND 8 FROM OCTOBER 1989 TO SEPTEMBER 1990

	Locality 7					Locality 8				
Species	**Oct. 89**	**Nov. 89**	**March 90**	**June 90**	**Sept. 90**	**Oct. 89**	**Nov. 89**	**March 90**	**June 90**	**Sept. 90**
Amphilius uranoscopus	0	0	0	0	0	0	0	0	0	0
Barbus anoplus	0	0	0	0	0	0	0	0	0	0
Barbus argenteus	0	0	0	0	0	0	0	0	0	0
Barbus marequensis	1	52	8	0	4	0	1	57	2	16
Barbus polylepis	0	0	0	36	0	0	0	0	0	0
Chiloglanis pretoriae	0	0	1	0	2	0	1	0	0	0
Chiloglanis bifurcus	0	0	1	0	2	0	0	0	0	0
Pseudocrenilabrus philander	0	6	6	0	0	0	0	0	0	0
Time (min) sampled	14	7	7,5	3	12	14	6	7	8	10
Total number of fish	1	52	16	36	8	0	2	57	2	16
Total number of fish/min	0,07	7,43	2,13	12	0,67	0	0,33	8,14	0,25	1,6
Number of species	1	2	4	1	3	0	2	1	1	1

0: Absent

to be particularly sensitive to environmental disturbances (Skelton, 1987).

Despite the release of water from dams in the Ngodwana and Crocodile Rivers, the main body of effluent was still clearly recognisable in the Crocodile River downstream from Nelspruit 5 days after the spill. It is indeed possible that the release of water accelerated the movement of the effluent without effectively dispersing or diluting it. As a consequence the effluent could have caused more fish mortalities over a larger distance than it would have, had it moved slower and been allowed to settle and break up in natural pools and at weirs.

In total 14 fish species have suffered mortalities of some degree because of this spill.

Recovery of the river

At Localities 4 to 6 recolonisation by fish was expected to occur from the upstream section of the Elands River which had not been polluted and from a number of small tributaries. However, an important tributary such as the Lupelule is only 2 to 4 m wide and contains only certain species of fish which occur regularly in the Elands River e.g. *Amphilius uranoscopus, B. argenteus, C. pretoriae* and *Tilapia sparrmanii.* Other species such as *B. anoplus* and *A. natalensis* are also present in the Lupelule but do not occur regularly in this segment of the Elands River. A waterfall in the Elands River near its confluence with the Crocodile is expected to limit any upstream movement of fish e.g. downstream in the Crocodile River before its confluence with the Elands and then upstream with the Elands River. Of the fish species involved, only *Chiloglanis* spp. and juveniles of the *Anguilla* spp. are known to ascend such obstacles (Jubb, 1967).

The only evidence of recolonisation at Localities 4 to 6 during November 1989 was the presence of one *A. mossambica* at Locality 5. Electrofishing results for March and June 1990 indicated that fish were starting to recolonise the river segment at Localities 4 to 6. As would be expected, recolonisation was most evident at Locality 4 due to its close proximity to the upstream, unpolluted section of the Elands River. Only *B. argenteus* was able to move into the stretch of river at Localities 5 and 6. The erratic recolonisation in this segment can be ascribed to the small size of tributaries in this area and the comparatively small size of fish populations occurring in them. The number of species present and the total number of fish caught per minute at Locality 4 during September 1990, indicated that recovery at this locality was continuing. The number of fish caught per minute was actually higher than previously observed for this locality and was comparable with the upstream, unpolluted part of the Elands River. In contrast, the number of species present and the number of fish caught per minute at Localities 5 and 6 during September 1990, did not show any improvement when compared with data for March and June 1990. However, the increase in the number of species and the number of fish caught per minute during October 1991 is an indication that recolonisation is still taking place at these two localities.

With reference to the data for June and September 1990, it took between 6 and 11 months for Locality 4, which is 800 m downstream from the Ngodwana/Elands River confluence and 13 km upstream from the Elands River waterfall, to recover to a level where the number of species present and the fish abundance were comparable with the situation upstream from this locality and with historical data for this locality. The rate of recovery was, therefore, between 1,6 and 0,872 km per year. Based on this it would take between 8 and 15 years for this segment to recover. These estimates may be positively influenced if recolonisation from tributaries begins to make a larger contribution. Some evidence that this may be happening is provided by the data for October 1991 at Localities 5 to 6.

At Localities 7 and 8 recolonisation by fish was expected to occur from the Crocodile River upstream from its confluence with the Elands River. Although a waterfall which may limit the downstream movement of fish is present in the Crocodile River before its confluence with the Elands River, a section of approximately 1 km below the waterfall up to the Elands

confluence, was not polluted (Fig. 1). It is accepted that a full complement of the fish inhabiting Localities 7 and 8 before the spill, occurs in this section below the waterfall. Other sources of recolonisation are the Houtbosloop and Stadspruit where species such as *A. uranoscopus, B. argenteus, B. marequensis, B. polylepis, C. pretoriae, C. bifurcus, T. sparrmanii* and *Pseudocrenilabrus philander* occur.

During October 1989, one individual each of *B. argenteus* and *B. marequensis* was caught at Locality 7 which serves as an indication that the water quality was again suitable for the survival of fish. The number of species present and the number of fish caught per minute at Localities 7 and 8 varied considerably from November 1989 to September 1990. However, the number of fish species found and the number of fish caught per minute, proved that the recolonisation was more successful at Locality 7. The *B. marequensis* and *B. polylepis* juveniles which were caught at these localities during November 1989 and March, June and September 1990 are an indication that conditions were suitable again for breeding to take place. Due to the erratic recolonisation of this river segment no predictions on its complete recovery can be made at this stage.

Although surveys following the pollution were less intensive at Localities 9 to 11 than at the points upstream, the lower intensity of fish mortalities in this segment indicates that recovery here should be more rapid than upstream. This statement is to an even larger extent also applicable to Localities 12 to 14 where mortalities were limited.

Effects of chronic paper mill effluent spills

It is of relevance that the spill of September 1989 was not the first case of water pollution caused by the paper mill. A "large" spill occurred in February 1985 and "small" spills of approximately 5 000 ℓ in July 1986 and June 1989 (Regional Court Records, Nelspruit, March 1990). The spill in February 1985 resulted in limited fish mortalities in the Elands River while the spills in July 1986 and June 1989 were not reported to the Chief Directorate. It cannot be established whether any low intensities of water pollution had occurred prior to 1985.

Of particular concern in this regard is the fact that certain resin acids which form part of this effluent, such as dehydroabietic acid, persist in both water and sediment. It has been shown that fish exposed to Kraft mill effluent accumulate this acid to a level that may cause sublethal toxic effects (Fox, 1977). Although speculative, it is possible that the lower number of fish caught per minute at Localities 4 to 6 compared to the number caught per minute upstream of Locality 4 before the spill in September 1989, may be an indication that sublethal toxicity was already influencing the fish abundance.

Conclusions

It appears that the recovery of the fish populations of the Elands River in particular is relatively slow. A specific aspect of concern is the recovery of *C. bifurcus* in this part of the river. Although the JLB Smith Institute of Ichthyology initiated a project for the artificial propagation and eventual release of *C. bifurcus* into the affected part of the river (Bruton, 1990), the re-introduction of this and the other species involved will have to be considered concerning the river segment at Localities 4 to 6 if future surveys do not indicate an improvement in recolonisation rates. Fish from the upstream section of the Elands River which was not affected by the spill, can be used for this purpose.

The owners of the paper mill responsible for this specific pollution incident of the Elands and Crocodile Rivers are currently investigating measures to limit the possibility of the recurrence of such a disaster. It must be realised, however, that whatever measures are taken, pollution remains a possibility. Moreover, paper mill spills are not the only factors which have a detrimental affect on the Elands and Crocodile Rivers. During the last 8 to 10 years the catchments of both rivers have been subjected to the large-scale establishment of exotic plantations while along certain sections of these rivers, the extensive use of agricultural chemicals must be a reason for concern.

The importance of refugia from which fish can recolonise a damaged river after habitat condition have improved, is illustrated by this case. It is of extreme importance that such refugia should be identified by conservation organisations and that such areas should not be subjected to potentially detrimental development, especially in environmentally sensitive areas such as the Eastern Transvaal escarpment.

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