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Water Quality Investigations in the River
Blackwater and River Martin, Co. Cork
—1966-1969

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Water Quality Investigations in the River Blackwater and River Martin, Co. Cork—1966-1969

by

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ABSTRACT.

Investigations in the period 1966 to 1969 showed that the bulk of the waste discharged to the Blackwater and Martin is of an organic nature and arises mainly from industries processing milk, sugar-beet and other foods and to a smaller extent from domestic sewage. Pollution, indicated by increases in the biochemical oxygen demand and suspended solids and depletion in dissolved oxygen, was detected below the towns of Rathmore and Mallow on the main Blackwater, Mitchelstown, on a tributary of the Blackwater, the R. Funcheon, and Rathduff on the R. Martin. Depletion of dissolved oxygen sufficiently large to constitute lethal conditions for fish and other aquatic life was recorded only at Mitchelstown and it appears that the high rates of reaeration operating in most cases prevented more widespread deoxygenation and also reduced the extent of diurnal variation. The concentrations of suspended solids recorded in polluted reaches were well below those which are directly injurious to fish but the accumulation of this material as sludge in slow flowing stretches below outfalls constitutes an extra demand on dissolved oxygen which in combination with the B.O.D. of the water may lead to lethal conditions. In the Funcheon, the presence of this material and of sewage fungus on the substratum invalidates the application of the standard theoretical method for predicting the variation of dissolved oxygen. The partial or complete elimination of the normal flora and invertebrate fauna from riffles below the main waste outfalls and replacement of these by biocoenoses typical of slow flowing silted reaches were recorded in each area. The extent of such changes seemed to be related more to the intensity of sewage fungus growth on the substratum than directly to the chemical quality of the water. Complete elimination of fish was only recorded at Mitchelstown, the stretch affected being half a mile in length. Trout and coarse fish were present in all of the other polluted stretches investigated though in some of these young salmon were absent and trout very few in number. Trout appeared to make better growth in polluted than in unpolluted water, especially at Rathmore, and this is due in part to a greater food supply in the former reaches.

Short surveys of the Blackwater estuary indicated that this reach may be slightly polluted.

While the investigations indicated that severe pollution occurred in several reaches of the Blackwater and Martin, it was considered that the overall productivity of fish in the rivers was unlikely, at that stage, to have been adversely affected by such pollution.

INTRODUCTION.

Water pollution is nowadays a problem of universal concern. It is primarily a result of industrialisation and the widespread adoption of the water-carriage system for the disposal of the wastes from large towns and cities. This is evidenced particularly by the case of England where the pollution of rivers, such as the Thames and Mersey, became so severe in the latter part of the last century that a Royal Commission was instituted to investigate the problem and to recommend measures for its solution. The work of the Royal Commission on Sewage Disposal was the first detailed study of water pollution in this part of the world and led to the establishment of some of the commonly used techniques for measuring water quality, notably the 5-day Biochemical Oxygen Demand.

Ireland possesses little of the raw materials such as coal and iron which are necessary for industrial expansion and the Industrial Revolution brought very little immediate change to most of the country either in the social or economic sphere except in the north-east. Large centres of population did not develop inland and the existing cities such as Cork, Dublin and Belfast, situated on estuaries, have only recently become markedly populous. Even now only Dublin and Belfast have populations greater than 500,000 while Cork has only 150,000 persons. A sure indication of the generally undamaged condition of the country's rivers is the fact that only one of these, the Lagan, on which Belfast is situated, has lost its salmon stock through estuarine pollution. The annual ascent of salmon up the R. Liffey through the centre of the capital city, Dublin, is a situation now almost unknown in developed countries. At a meeting convened in Dublin in October 1967 by the Institution of Civil Engineers of Ireland to discuss the present position with regard to water pollution in this country two papers (McGovern, 1967; Casey, 1967) gave the results of a country-wide

survey of the water quality of the large rivers. Only one of these rivers was classified as grossly polluted, viz. the Camac, a tributary of the R. Liffey, which flows through the most heavily industrialised and densely populated part of Dublin city. All of the other rivers were classified as clean. However, only points between towns were examined and, furthermore, estuarine reaches were not included in the survey; as Casey and McGovern point out, several of these receive large amounts of waste.

The question to be answered now is how long may this state of affairs be expected to continue. Industrialisation in Ireland is undergoing rapid expansion at present, though mainly in the large coastal towns and is not, for the most part, of the sort which leads to the production of great volumes of waste. However, there is one section of industry which is producing increasing amounts of wastes; this section covers the agriculture-based undertakings, e.g. cheese and other dairy produce, sugar manufacturing, meat, poultry and other types of food processing. Most of these industries are situated in inland areas and represent the first sizeable pollution threat to rivers in the stretches above their estuarine reaches. The majority of Irish inland towns have relatively small populations, very few over 10,000, but the setting up of an industry of the sort mentioned above leads to increases in the populations of such towns. The wastes from these industries are, for the most part, of plant and animal origin and similar in composition to domestic sewage so that the greater part of the waste material entering rivers in rural areas of the country is of an organic nature. This is, in one sense, an advantage since organic wastes are easily treated and, in addition, they are broken-down naturally in rivers. Some of the industries giving rise to such wastes only do so seasonally, e.g. beet-sugar production takes place only in winter while food processing and cheese production are activities mainly of summer months. Waste discharges from these industries, then, are not continuous but at peak production they usually account for much greater polluting loads on rivers than do the domestic wastes of the towns in which the industries are situated.

While it is true that Irish river systems are for the most part unpolluted there are many locations where pollution is severe enough to kill fish. There is, at the moment, a growing public awareness of river pollution, indicated by the correspondence, reports and articles in newspapers. Much of this stems from isolated cases of sudden and dramatic fish kills resulting from accidental or malicious discharge of noxious substances. The more persistent but less evident type of pollution is, perhaps, regarded as inevitable, but such evidence of the increasing awareness of the phenomenon of water pollution may in turn be taken to indicate the growing threat to Irish rivers. It is time to take stock of the situation.

The present investigations may be regarded as a pilot study of the type which will, at some stage, have to be undertaken for most Irish rivers when the establishment of water pollution control standards is being considered. The Blackwater, one of the most important salmon rivers in the country with valuable commercial fisheries in its estuarine reaches, and the Martin, a typical small trout stream, are both unpolluted in the sense used by McGovern (1967) and Casey (1967). There are, however, several towns on the Blackwater and one on the Martin, a much smaller river. Several factories are situated in or near these towns so that the Blackwater and Martin may be regarded as typical of most Irish rivers and streams, i.e. in a generally unpolluted condition but with short stretches where conditions are not so satisfactory.

Since the survey team was small (two people) it was decided that only certain stretches of the rivers should be investigated, these being in the vicinity of towns and factories known to give rise to significantly large effluents. Originally the towns of Rathmore, Mallow and Fermoy on the Blackwater and Rathduff and Blarney on the Martin were selected, but subsequent to a preliminary survey of the Blackwater in July, 1966, it was found that very little effect on water quality by pollution would be encountered at Fermoy while at Mitchelstown, on a tributary of the Blackwater, the R. Funcheon, very severe pollution was being caused by an overloaded sewage works. It was decided, therefore, to limit the scope of the investigations in the Fermoy area but to make an intensive study of the Mitchelstown situation in addition to the other areas mentioned.

The original aim of the project was to estimate the effects of pollution on the overall productivity of fish in the two rivers but it soon became obvious that pollution is so localised it is unlikely to have any serious effect on productivity at this stage. (The investigations finished before October, 1969 when widespread mortality of fish took place in the Blackwater between Mallow and Fermoy following prolonged drought conditions. Such heavy mortality had not occurred previously nor has it occurred since). The investigations were mainly concerned with a survey of water quality in the vicinity of the larger towns, though in these cases effects on fish stocks were considered.

Field work commenced in June, 1966 and was terminated in July, 1969. Except for the months of June, July and August of 1966, laboratory work was carried out in the Zoology Department, University College, Cork. The first three months of the investigation were spent on a preliminary survey of the river, laboratory work in this period being carried out in the premises of the Irish Sugar Co. Ltd. at Mallow at the kind invitation of the management.

The work was supervised by Professor F. J. O'Rourke, Professor of Zoology, U.C.C; Dr. B. A. Southgate, former head of the British Water Pollution Research Laboratory at Stevenage, acted as consultant. The authors are very grateful to them and to the officers of the Fisheries Division of the Department of Agriculture and Fisheries for help and advice throughout the course of the work. The assistance and cooperation of officials of the Cork, Kerry and Waterford County Councils, the Lismore and Cork Boards of Fishery Conservators and of the various industrial concerns, particularly of An Comhlucht Siuicre Eireann Teo., are gratefully acknowledged.

Information on the flows of the rivers and of the effluents in each area is taken from unpublished data collected by Mr. D. Murphy, Fisheries Division, Department of Agriculture and Fisheries.

THE RIVERS

R. BLACKWATER

The R. Blackwater (Fig. 1) rises at about 1,400 feet in the Mullaghereirk mountains in east Co. Kerry and flows due south to Rathmore for the first eleven miles (18 km) of its course, along the border of counties Cork and Kerry. At this point it turns due east to flow for the greater part of its course (approximately 50 miles (80 km)) through Co. Cork. It then enters Co. Waterford and six miles (9.6 km) further downriver at Cappoquin, turns again due south to flow for about fifteen miles (24 km) to the estuary mouth at Youghal. Most of the initial elevation of the river is lost in the first ten miles so that from Rathmore, eastwards, it runs through a broad valley though without exhibiting much meandering and retaining a relatively fast current almost to the estuary.

The river receives most of its tributaries from the north side, the larger of these being the Owentaraglin and Allua, which also flow from the Mullaghereirk Mts., the Awbeg and Funcheon rising on the Ballyhoura and Galtee Mts. respectively, and the Araglin which rises on the Knockmealdown Mts. From the south the Finnow, Glen and Clyda rivers flow off the Boggeragh Mts. while the R. Bride, flowing south of and parallel to the main river, drains the Nagles Mts. and enters the west side of the estuary. The Finisk and Lickey Rivers also enter the estuary, coming in from hilly country east of this stretch.

In the upper part of its course the main river flows over Coal Measures, Shales and Sandstone. Beyond Banteer the river passes intermittently over Carboniferous Limestone strata as far as Fermoy. The bedrock is of Coal Measures and Old Red Sandstone from this point to the mouth of the estuary except for small stretches of limestone which are traversed in the estuarine reaches. The tributaries entering from the south flow over Old Red Sandstone for most of their course except for the R. Bride which runs through a narrow limestone valley. To the north, the Owentaraglin and Allua Rivers flow, like the main river, mainly over Coal Measures. The Awbeg and Funcheon though rising in Coal Measures and Old Red Sandstone flow for most of their courses through limestone valleys. The water of the main river, especially in the upper reaches, is rather soft (see below). In the lower reaches, below Mallow, the water becomes more markedly alkaline and the contents of calcium and magnesium increase.

The results of inorganic analyses of samples of river water taken at several points in the Blackwater system in April 1969 are set out below.

Location	As p.p.m. CaCO ₃				Tot.PO ₄ p.p.m.	Silicon p.p.m.SiO ₂	Tot.Diss Sols.p.p.m.	Chloride p.p.m.
	Tot. Alk.	Tot. Hard	Ca.	Mg.				
Above Rathmore ...	25	34	16	18	0.07	7	52	20
Above Mallow ...	62	77	49	28	0.09	5	94	21
Ballyduff ...	128	146	123	23	0.17	4	184	21
Mitchelstown (Funcheon) ...	103	115	87	28	0.32	4	166	16

The total catchment area of the river system, including that part lying around the estuarine reaches, is approximately 1,300 square miles. Such a large catchment area together with a large annual rainfall (ranging between 950 and 1,300 mm.) leads to a very wide variation in river flow. A flow gauge is maintained by the Office of Public Works at Ballyduff, about eight miles (12.8 km) above the top of the tidal part of the estuary. The highest recorded flow at this point (in February) was 9,850 cusec (equivalent to 5,319 million gal/day) while the lowest was 200 cusec (107 million gal/day). A flow gauging station has been maintained by the Irish Sugar Co. Ltd, at their Mallow factory for about twenty years and, in summer, flows as low as 90 cusec (50 million gal/day) have been recorded at this point. Maximum flow at Mallow is not known as the height of the gauge is insufficient but flows of up to 3,890 cusec (2,100 million gal/day) are on record. However, some six miles below Mallow at Killavullen an O.P.W. gauge has recorded a flow of 9,900 cusec (5,350 million gal/day).

The catchment area of the Blackwater system is predominantly rural and the towns are relatively small, all having populations under 10,000. Mallow is the largest of these, its population being about 6,000 while Youghal (5,000) and Fermoy (4,000) are next in size. Mitchelstown and Kanturk have each approximately 2,500 inhabitants while the remaining towns and villages have 1,000 or less. The total population of the catchment area is about 80,000. Agriculture is of the mixed type but is mainly geared to dairy produce, creameries being situated in most of the towns and collecting depots in most of the villages. Sheep rearing is important on the surrounding hills and mountains. Farms are smaller on average in the western part of the catchment area than in the east and in the latter area store cattle are as important as dairy cattle. Beet and pea growing for the sugar and food processing plants at Mallow are also carried out to some extent but much of the supplies for these industries comes from outside the catchment area. In some towns more specialised industries based on milk production have been set up, e.g. cheese making at Mitchelstown and chocolate crumb manufacture at Rathmore, Mallow and Mitchelstown.

In its upper reaches the Blackwater runs mainly through open country but from Mallow downriver there are many wooded areas near the banks, much of these being originally planted in the large demesnes which up to recently stretched along the river valley between Mallow and Youghal. Afforestation is at present being undertaken in the Nagles and Boggeragh Mts. to the south of the river and on the Galtee, Knockmealdown and Kilworth Mts. to the north. There are also extensive plantations on the hills surrounding the estuary.

R. MARTIN

The Martin river, a small stream in the Lee system, rises on the southern slopes of the Nagles Mts. at an altitude of 600 feet and flows almost due south for fifteen miles (24 km) to Blarney (see Fig. 1). At this point it turns south west flowing for a further mile (1.6 km) to its confluence with the Blarney River. The latter flows for another mile to join the Shournagh River which in turn flows into the Lee. The Martin is narrow in its upper reaches (0.5—1.0 metre) but between Rathduff, three miles from the source, and Blarney it receives several smaller tributary streams so that in the vicinity of the latter location it is considerably larger in volume and width (up to 4 metres).

The stream flows for the most part through a narrow valley and the catchment area, about 25 sq. miles, is relatively small. The bedrock of the area is Old Red Sandstone, the stream running directly on top of this in some sections. The flow is moderate to very rapid for most of the course, though in the stretch below Rathduff pools alternate regularly with the faster riffles. Above Rathduff, the stream has in recent years been dredged in connection with land drainage and has only become recolonised by plants within the period of the investigation. About one mile above Blarney, the river is dammed to form a roughly triangular shaped pond nearly threequarters of a mile (1.2 km) long. This supplies a mill race for the town. The bed of the mill pond is silted near the dam where its greatest depth is about eight feet.

Farming in the vicinity is mainly devoted to the raising of dairy cattle, much of the milk produced going to a cheese factory at Rathduff. A piggery about half a mile away takes the whey from the cheese factory as animal feed. Blarney is the only town on the river and has a population of about 1,000. There are some 200 persons living in the village of Rathduff and the surrounding farms. Besides the cheese factory at Rathduff there is a woollen mill at Blarney. Minimum river flows in summer 1968 were 1.5 cusec (0.8 million gal/day) at Rathduff and 5.0 cusec (2.7 million gal/day) at Blarney.

Trout, salmon, eel and stickleback occur in the R. Martin but the salmon do not penetrate further upstream than the weir above Blarney. Trout angling is carried out to a small extent on the stream but the enclosed nature of its banks makes the Martin unsuitable for the sport for most of its course above Blarney.

Set out below are the results of inorganic analyses of samples taken at Rathduff and Blarney in April, 1969:

	As p.p.m. CaCO ₃				Tot. PO ₄ p.p.m.	Silicon p.p.m. SiO ₂	Tot. Diss Sols. p.p.m.	Chloride p.p.m.
	Tot. Alk.	Tot. Hard	Ca.	Mg.				
Rathduff ...	27	46	37	9	0.26	5	120	22
Blarney ...	36	63	46	17	0.15	4	134	22

SOURCES OF POLLUTION

RATHMORE (see Fig. 2)

There are three effluents entering the R. Blackwater at Rathmore viz. domestic sewage, creamery wastes and wastes from a chocolate crumb factory, the last being the largest.

Creamery Wastes

The washings of churns and other plant from a small creamery in Rathmore village are discharged to the small Cullavaw stream which enters the Blackwater about a quarter of a mile (0.4 km) beyond the outfall. The intake to the creamery is about 10,000 gallons milk per day during the peak season in late spring and summer. The volume of the washings is about the same and these are discharged without treatment to the Cullavaw. The discharge is intermittent, the bulk of it entering the stream around midday and at this point the small stream is heavily polluted, with a B.O.D. some times over 100 p.p.m. On entry to the main river, the polluted stream causes a temporary rise in B.O.D. there so that a band of polluted water is formed which, passing downstream, results in very variable conditions in the river at the points at which it receives other discharges in the Rathmore area. Analyses carried out on the stream in summer and autumn 1967 and 1968 are summarised below:

	Temp°C	pH	D.O.p.p.m.	B.O.D. p.p.m.	NH ₃ p.p.m.	NO ₃ -N p.p.m.	Susp.Sols. p.p.m.
Mean ...	16.0	6.3	8.0	31.3	0.35	0.3	10.5
Range ...	10.7—20.5	5.7—6.8	5.8—10.3	3.9—136.0	0.14—0.68	Nil—2.0	1.3—25.8

Domestic Sewage

The sewerred population of Rathmore is about 300 and the sewage is treated on a small percolating filter with associated primary settlement tanks and sludge drying beds. The works are not very well maintained and the B.O.D. of the effluent is variable. In addition, the ammonia content is very high at times and suggests an outside source for this substance. Analyses of the final effluent made in 1967 and 1968 are summarised below:—

	Temp°C	pH	D.O.p.p.m.	B.O.D. p.p.m.	NH ₃ p.p.m.	NO ₃ -N p.p.m.	Susp.Sols. p.p.m.
Mean ...	13.8	6.7	5.3	37.8	82.7	4.0	55.4
Range ...	12.0—15.0	6.0—7.0	2.8—7.3	5.6—91.5	5.6—320.0	Nil—9.0	23.0—85.1

Chocolate Crumb Factory Wastes

The intake of milk to the Fry-Cadbury chocolate crumb, skim milk and butter oil production plant at Rathmore in the summer peak period is about 100,000 gal/day. Wastes derive from the washing of factory plant which takes place twice a day, around midday and midnight. A weak caustic solution is used in cleaning. The wastes are treated in a modern installation consisting of a balancing tank, primary and secondary

settlement tanks and three percolating filters, one of which is used as a "roughing" filter and the others in double alternation at peak periods. At times the capacity of the pumps is exceeded (especially during the washing down of plant) and at such times excess waste goes straight to the river. The treated wastes are diluted with condenser and cooling water and the volume discharged to the river is around 2 million gal/day. Analyses of the final effluent made in 1967 and 1968 are summarised below:

	Temp°C	pH	D.O.p.p.m.	B.O.D. p.p.m.	NH ₃ p.p.m.	NO ₃ -N p.p.m.	Susp.Sols. p.p.m.
Mean ...	23.7	6.3	6.3	43.3	0.81	0.2	39.1
Range ...	19-28	5.9-7.0	4.9-8.3	12.4-103.5	0.32-1.20	Nil-1.0	22.1-66.2

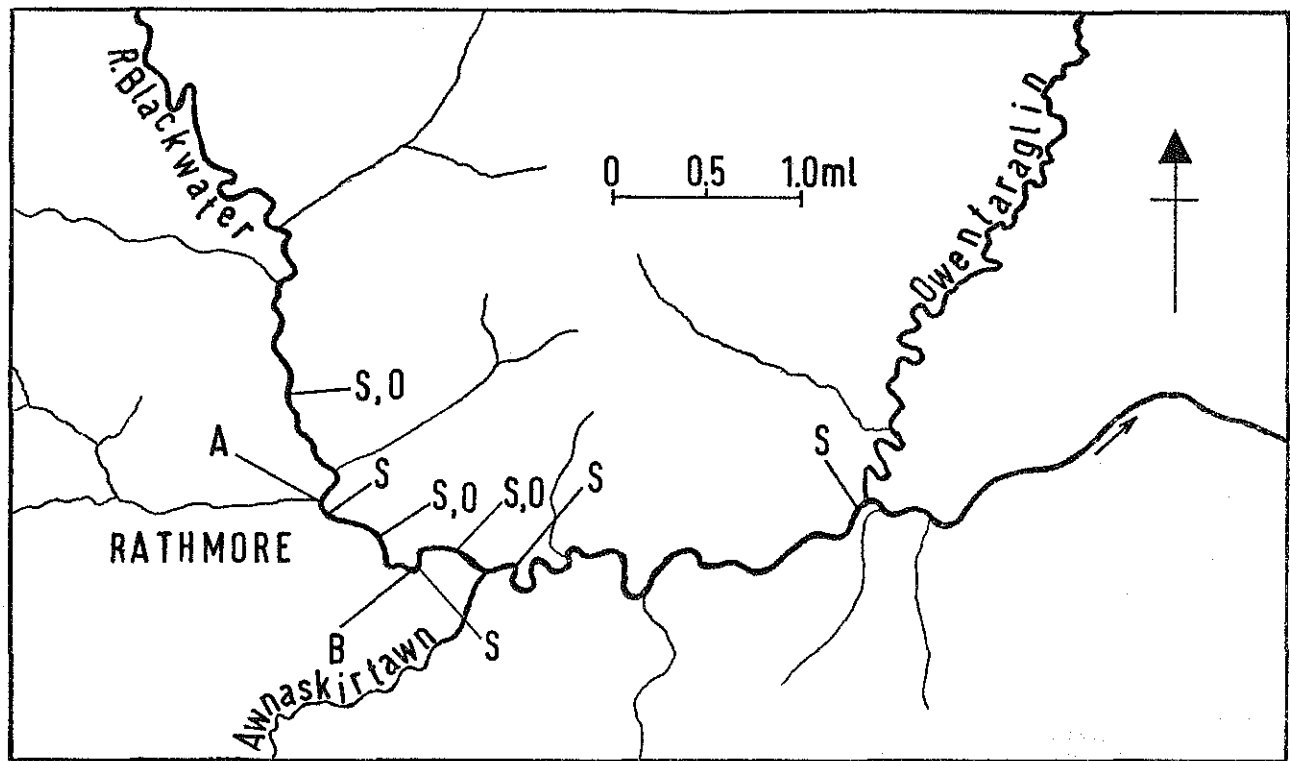


Fig. 2. R. Blackwater at Rathmore. The points at which daytime (S) and overnight (O) sampling of the river were carried out in the summer and autumn of 1967 and 1968 are indicated. A : outfall of small sewage works and entry point of small stream intermittently polluted with creamery wastes; B : outfall of waste treatment plant at chocolate-crumb factory.

MALLOW (see Fig. 3)

In addition to domestic sources, wastes arise at Mallow from beet sugar manufacture, vegetable and other food processing, chocolate crumb manufacture and from a large creamery.

Beet Sugar and Food Processing Factories

The associated factories of the Irish Sugar Co. Ltd., and Erin Foods Ltd. are situated on the south bank of the Blackwater about three miles west of Mallow. The wastes from these factories are treated in a series of lagoons and discharged through the same effluent channels. The beet sugar factory is in operation from the beginning of October to early January each year and processes some 3,000 tons of beet each day. All process water is recirculated so that the bulk of the waste consists of transport and wash water in addition to condenser water. Retention in the lagoons is on average for four days. The efficiency of the lagooning decreases throughout the campaign and the B.O.D. of the final effluents may become very high towards the end of the

period. The total volume discharged per day remains fairly constant between 7 and 8 million gal. Analyses of the effluent carried out between October 1968 and January 1969 are summarised below:—

		Effluent A	Effluent B
B.O.D.p.p.m.	Mean	920	781
	Range	100—2300	300—2350
Temp.°C	Mean	20.5	12.4
	Range	18—25	8.4—15.2
pH	Mean	6.9	6.7
	Range	6.5—7.8	6.3—7.0

Effluent A arises from wash water, condenser water, surface drainage and any wastes which may be coming from the food processing factories. Effluent B arises from unrecycled transport water. The mean B.O.D. is biased by the very high concentrations recorded towards the end of the campaign; for much of the period B.O.D. is between 300 and 400 p.p.m.

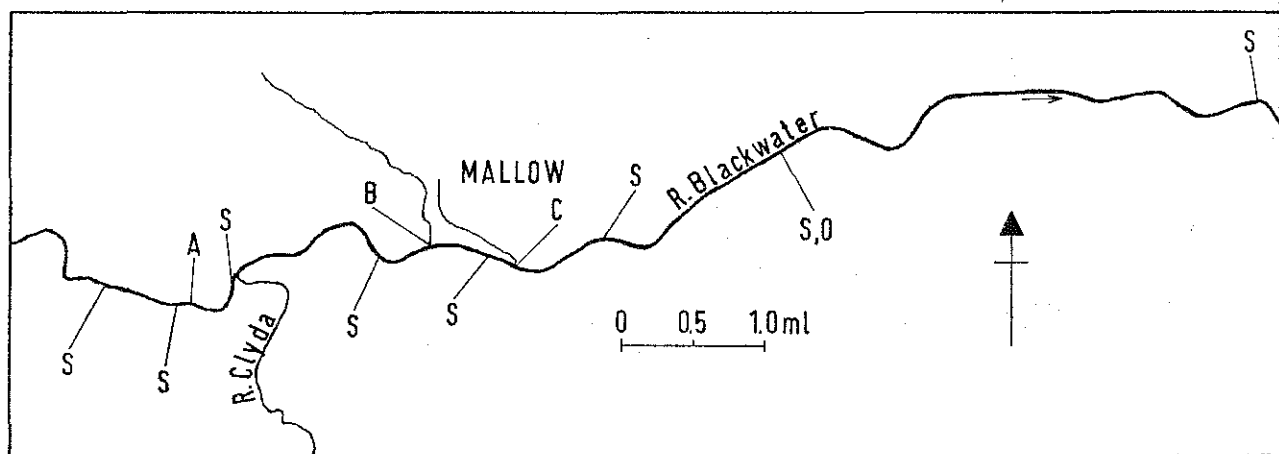


Fig. 3. R. Blackwater at Mallow. The points at which daytime (S) and overnight (O) sampling of the river were carried out in the summer and autumn of 1967 and 1968 are indicated. A: outfall of waste from lagoons at food-processing plant; B: entry point of small stream intermittently polluted with creamery wastes; C: town sewage outfall.

The food processing plant, which freeze dries peas, turnips and other vegetables, is active mainly during the summer months, there being very little waste discharged from the factories between the end of the beet campaign in January and the start of the pea campaign in July. Analyses of the effluent from the lagoons in the off-season and during the summer campaigns are summarised below:—

		Temp°C	pH	D.O.p.p.m.	B.O.D.p.p.m.
Offseason:	Mean	20.1	7.7	6.8	24.2
	Range	16—27	6.8—8.3	3.3—8.2	12—60
Summer Campaign	Mean	20.3	7.6	1.8	91.5
	Range	15.6—24.0	6.9—9.4	Nil—7.4	40—160

The volume of waste discharged during the summer campaign is between 1 and 2 million gal/day.

Creamery and Chocolate Crumb Factories

The wastes from these factories are spray irrigated on fields adjoining the river during the peak season in late spring and summer. In the off season, when the volume of waste is generally reduced, discharge is direct.

Domestic Sewage

The main sewerage system in Mallow town caters for about 4,000 people and sewage is discharged to the river untreated. The domestic sewage of the remaining 1,600 persons living in the town is passed to septic tanks or directly to the river in a 50:50 ratio approximately.

MITCHELSTOWN (see Fig. 4)

Trade and domestic wastes are treated together at Mitchelstown in a modern disposal system consisting of settlement tanks, percolating filters used in double alternation, and sludge drying beds. The trade wastes arise from a creamery, a cheese factory and a chocolate crumb factory. During the peak season in summer and autumn these wastes represent a much greater waste loading on the sewage works than do the domestic wastes of the town (population 2,600). The effluent is discharged to the Gradoge, a small stream which enters the Funcheon about half a mile below the outfall.

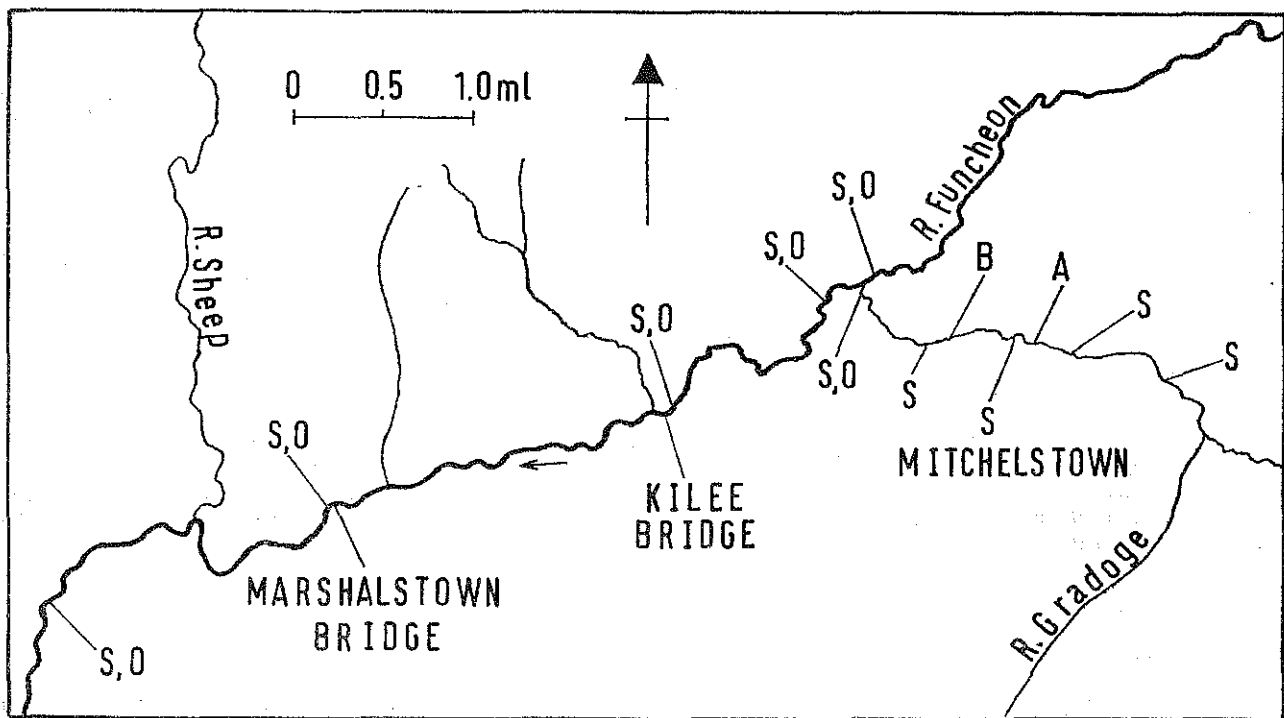


Fig. 4. Rivers Funcheon and Gradoge at Mitchelstown. The points at which daytime (S) and overnight (O) sampling of the rivers were carried out in the summer and autumn of 1967 and 1968 are indicated. A: outfall of overflow pipe through which creamery wastes are intermittently discharged; B: outfall of town sewage works.

The treatment plant was originally designed to take a loading of 615,000 gal/day at an incoming B.O.D. of 200 p.p.m. The milk-based industries in the town, having paid part of the cost of installation, received treatment rights and at that time the load from these sources was set at 70,000 gal/day at an incoming B.O.D. of 150 p.p.m. The waste from the cheese factory is now in the region of 500,000 to 700,000 gal/day in the peak season with a B.O.D. ranging between 1,000 and 2,000 p.p.m. Gross overloading of the treatment plant occurs in summer when the total volume of waste entering the works is about 1 million gal/day. The B.O.D. of the final effluent is very high though a marked improvement was noted in 1968 over the quality in 1967, which

was due to more careful practices in the factories and sewage works. The analyses of the effluents for 1967 and 1968 are set out below:—

	Temp°C	pH	D.O.p.p.m.	B.O.D.p.p.m.	NH ₃ p.p.m.	NO ₃ —N p.p.m.	Susp.Sols. p.p.m.
1967 Mean ...	18.5	7	1.0	247	70	Nil	55
Range ...	16.9—24.0	None	0.1—2.1	215—289	44—200	—	40—64
1968 Mean ...	19.7	7.1	2.1	95	Not measured	Not measured	39
Range ...	17.0—21.5	6.8—7.5	0.8—3.1	33—130	Not measured	Not measured	27—48

A bacon processing factory is located in Mitchelstown and the wastes from this are sprayed on fields some distance from the river. A piggery, which takes some of the whey from the cheese factory, discharges wastes to a lagoon adjacent to the Gradoge near its confluence with the Funcheon. There is an overflow ditch between the lagoon and the stream. The discharge was not measured but was never observed in any quantity. Some distance upstream of the sewage works outfall an overflow pipe discharges milk wastes into the Gradoge when these cannot be handled by the treatment plant. As a result the stream is already heavily polluted at times above the main outfall. (See Fig. 12).

RATHDUFF (see Fig. 5)

Creamery

The R. Martin receives one very variable but continuous discharge from the Rathduff Creamery during summer. This was not measured as there is no distinct discharge channel and the waste is allowed to run across the ground for about 50 feet from the creamery to the river.

Cheese Factory

Situated beside the creamery mentioned above is the Rathduff Cheese Factory which uses 30,000 gal. of milk per day in peak periods and is continuously increasing production. Cheese only is manufactured here and whey and wastes from washing of plant are pumped to a nearby pig farm (see below) for use as food. Water is not abstracted from the river and the only direct discharge arises from a septic tank.

Piggery

Rathduff Pig Farm, with approximately 5,000 pigs, uses whey from Rathduff Cheese Factory as food for the stock. Piggery wastes, urine and faeces, as well as excess whey, are passed to lagoons and afterwards sprayed on farmland about the river. During wet weather, especially, there is a considerable run-off from the land and much of this enters the river through a ditch at the point indicated on the map in Fig. 5. The quantity and quality of this discharge was not measured.

BLARNEY (see Fig. 5)

Woollen Mill

The effluent from a woollen mill (Martin Mahony & Co. Ltd.) at Blarney is treated by precipitation with alumino-ferric, settlement and filtration. The wastes arise from the scouring and dyeing of the wool and their total volume is about 80,000 gal. per day. The final effluent is diluted fifteen times with river water before discharge and in times of low flow the entire river below the discharge may consist of the final effluent, as all water upstream may be abstracted for dilution purposes. The average B.O.D. of the effluent is 7.2 p.p.m. with a range of 3.2 to 13.9 p.p.m. The presence of pesticides arising from the wool was not investigated.

In addition to the water used for diluting the effluent, the factory abstracts water for its manufacturing processes, and a dam across the river, upstream of the factory, diverts water through a canal, reducing the flow considerably. Drinking water for the town is also abstracted from the river just upstream of the factory.

Sewage

Sewage from Blarney town is passed to drainage channels outside the town and is not discharged to the River Martin.

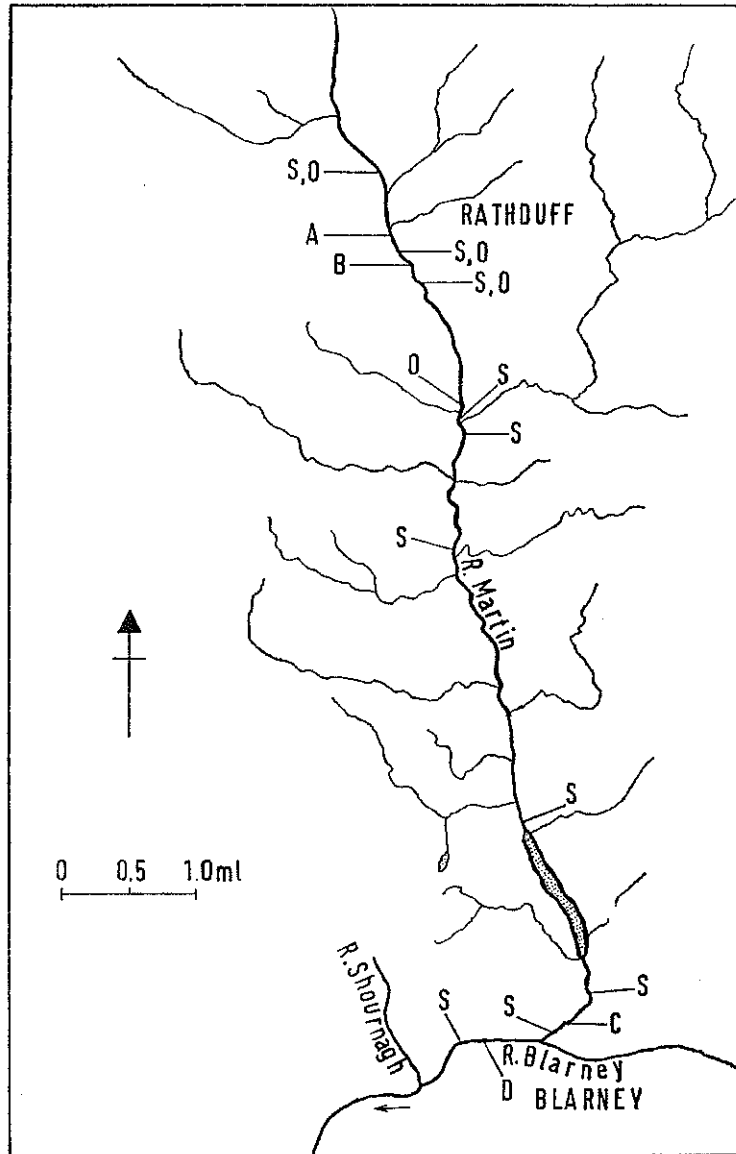


Fig. 5. R. Martin from source to Blarney. The points at which daytime (S) and overnight (O) sampling of the river were carried out in the summer and autumn of 1967 and 1968 are indicated. A: entry point of ditch draining area on which piggery wastes are sprayed; B: entry point of wastes from creamery; C: outfall of waste treatment plant at woollen mill. D: position of drainage ditches to which the sewage of Blarney is discharged.

In addition to these discharges in the areas of investigation, the following information on domestic sewage discharged to the Blackwater and its tributaries was obtained:

Town	Population	Treatment	Receiving River (see Fig. 1)
Fermoy ...	4,000	none	Blackwater
Lismore ...	900	none	"
Cappoquin ...	800	Septic Tank	"
Youghal ...	5,100	none	" (estuary)
Millstreet ...	1,283	Sedimentation Tank Percolating filters and humus tank.	Finnow
Kanturk ...	1,985	Imhoff tank	Allua
Newmarket ...	791	As Millstreet	Dalua
Buttevant ...	981	Imhoff tank and filter	Awbeg
Doneraile ...	725	As Millstreet	Awbeg
Kilworth ...	334	Septic Tank	Funcheon
Tallow ...	1,000	Septic Tank	Bride

Some trade wastes, mostly untreated, arise from these towns, in addition to domestic sewage. The more important are wastes from a large creamery in Kanturk, which severely pollute the Allua to its confluence with the Blackwater, creamery wastes from Ballyduff, near the top of the estuary, and slaughterhouse wastes from Lismore, Cappoquin and Youghal.

CHEMICAL AND PHYSICAL INVESTIGATIONS

It has already been indicated that the bulk of the waste discharged to the Blackwater and Martin is of an organic nature. The primary effect of such waste is to raise the biochemical oxygen demand of the river water and, thereby, to tend to lower the concentration of dissolved oxygen. When the depletion in D.O. becomes large, fish and most of the other aquatic organisms cease to function normally and may die.

In any river or stream the concentration of dissolved oxygen depends, not only on temperature and atmospheric pressure, but also on three other factors (Owens and Edwards, 1963; Edwards, 1964). These are:—

- (a) The photosynthesis of plants which liberates oxygen into the water (though some of the oxygen may be lost to the atmosphere in bubbles),
- (b) The respiration of plants and animals (including that of microorganisms) which consumes oxygen and
- (c) The interchange of oxygen molecules between the water and the atmosphere.

Where large weed beds occur in rivers and streams the production of oxygen in photosynthesis during daylight may greatly exceed the uptake of the gas for respiratory purposes by both plants and animals and lead to marked supersaturation with respect to D.O. After nightfall, when photosynthesis ceases, a steady loss of D.O. occurs, partly to the atmosphere if conditions of supersaturation have been reached during daylight and partly to the respiration of plants and animals. Thus, marked diurnal variation of D.O. is found to occur in many streams (Butcher, Pentelow and Woodley, 1930; Schroepfer, 1942; Odum, 1956; Edwards, 1964; Owens and Edwards, 1964). The magnitude of the diurnal variation may be well over 10 p.p.m. (Owens and Edwards, 1964) and, in polluted streams with an appreciable B.O.D. content, very low concentrations of D.O. may be reached during the hours of darkness. For this reason, twenty-four continuous monitoring is necessary to determine the greatest depletion of D.O. which may occur in organically polluted streams. Gameson and Griffith (1959) concluded from their study of six months continuous records of D.O. in a polluted stream that measurements made during daytime would be an unreliable guide as to the lowest concentration of D.O. which might occur over a twenty-four hour period.

In unpolluted water the respiratory demands of plants and animals on D.O. are, normally, relatively small. The uptake of oxygen by plants for respiratory purposes is usually taken to lie between 5 and 15 per cent of the photosynthetic production of the gas, while the respiration of animals accounts for a much smaller D.O. uptake (Edwards, 1964). However, in polluted water the respiratory demands of plants and animals may be relatively large. This applies particularly to the colonies of microorganisms (bacteria, fungi and protozoa) which are present in suspension in the water or on the substratum and are engaged in breaking down the organic matter. In such conditions, huge colonies of larger animals such as Chironomids and Tubificids may develop and these, too, make appreciable demands on D.O. In grossly polluted rivers the activities of all these organisms may be sufficient to remove the D.O. entirely.

Counteracting the effects of photosynthesis and respiration is the dynamic exchange of oxygen between the water and the atmosphere. This exchange is constantly tending to equilibrium conditions (i.e. where the rate of egress of O_2 molecules is equal to the rate of ingress, and the water is then 100% saturated for the particular temperature and atmospheric pressure). Since the oxygen molecules may enter or leave the water only through the surface film the rate of compensation for gain or loss of D.O. through biological activity is relatively slow. It is slowest of all in stagnant water where the process must be one of diffusion only. However, where the water is being constantly agitated so that the surface layer, which is at all times fully saturated even when the main body of water is completely deoxygenated, is continually renewed and mixed in the lower layers, the rate of exchange of oxygen between the water and atmosphere is very much greater (Downing and Truesdale, 1956). In rivers and streams, therefore, the reaeration capacity is greatest in fast flowing shallow stretches with a high degree of turbulence and least in the deep canal-like stretches (Gameson and Truesdale, 1959).

Where it is planned to discharge an organic waste to a river or stream an estimate of the reaeration capacity of the receiving water forms a useful guide as to the likely effects of the waste on the D.O. regime. The direct measurement of the rate of exchange is lengthy and complicated (e.g. see Edwards, Owens and Gibbs, 1961); many workers have, therefore, tried to relate the reaeration rate to physical characters of the water course such as depth, current velocity or gradient. Much of this work has been carried out in the U.S.A. e.g. by Streeter and Phelps (1925), O'Connor and Dobbins (1956), Churchill, Elmore and Buckingham (1964), and Dobbins (1964) but recently Owens, Edwards and Gibbs (1964) devised an equation for English rivers relating the rate of exchange of oxygen with current and depth. The equation is:

$$f_{(20\text{ C})} = 50.8U^{0.67} H^{-0.85}$$

where U is the current velocity (cm/sec), H the depth (cm) and f the Exchange Coefficient. The latter, a mass transfer coefficient, expresses the rate of transfer of oxygen in $\mu\text{g}/\text{cm}^2$ per p.p.m. deficit per hr., which reduces to cm/hr. Gameson and Barrett (1958) point out that the Exchange Coefficient, being a fundamental unit, is a more valuable concept than the Overall Absorption Coefficient, K, which does not measure the rate of transfer of oxygen through the surface, but only the change in concentration this transfer produces. K is derived from the differential equation:

$$-\frac{dD}{dt} = KD, \text{ or, on integrating, } D = D_0 e^{-Kt}$$

wherein D is the D.O. deficit at time t and D_0 the original D.O. deficit; the equation expresses the concept of reaeration whereby the rate of the decrease in the D.O. deficit at any time t is proportional to the deficit at that time. K is related to f by the equation

$$K = \frac{f}{Z}$$

where Z is the aeration depth. In a stream of cross-sectional area A and width y , $\frac{A}{y}$ is the aeration depth. The Overall Absorption Coefficient is sometimes expressed in logs to base 10 when the symbol k_2 is used. In fast flowing streams f has values between 30 and 200 cm/hr but in slow deep rivers the value is usually less than 10 cm/hr. The rate is affected by temperature, increasing by 2% per °C above 20°C and vice versa (Gameson and Truesdale, 1959). There is also evidence (Downing, Melbourne and Bruce, 1957; Downing and Truesdale, 1955) that the value of the Exchange Coefficient is reduced by the presence in the water of surface active substances derived from detergents, e.g. alkylbenzenesulphonates.

In some rivers, it is possible, with a knowledge of f , initial B.O.D., initial D.O. deficit and of the rate of river flow, to estimate the D.O. deficit at any point below an outfall of organic waste. These data are used in the formula proposed by Streeter and Phelps (1925) to describe the variation of D.O. in a river. The "sag curve" arrived at using the formula should approximate to the observed distribution of D.O. in the river. In the equation:

$$D_t = \frac{k_1 L_o}{k_2 - k_1} \left(\frac{10^{-k_1 t}}{10} - \frac{10^{-k_2 t}}{10} \right) + D_o 10^{-k_2 t}$$

D_t is the deficit at time t , D_o the original deficit, L_o the ultimate 1st stage demand (calculated from the 5-day B.O.D.), k_2 the Absorption Coefficient to base 10 and k_1 the rate constant of oxidation. k_1 has the dimension of reciprocal time and is derived from the differential equation:

$$-\frac{dL}{dt} = K_1 L, \text{ or, on integration, } L = L_o e^{-K_1 t}$$

wherein L_o is the ultimate oxygen demand of the water, L the demand remaining at time t and K_1 the rate constant of oxidation logs base e . The equation expresses the assumption that the rate of oxidation at any time t is proportional to the amount of substrate remaining to be oxidised at that time, i.e. it is assumed that the oxidation occurs in a manner similar to a unimolecular reaction. In logs base 10 the constant (now k_1) has a value, derived from tests on sewage, in the region of 0.1 days⁻¹. The value is affected by temperature as shown by the formula derived by Streeter and Phelps (1925):

$$k_1 (T^\circ\text{C}) = k_1 (20^\circ\text{C}) \cdot 1.047^{(T-20)}$$

Other equations, based on that for D_t , allow the direct calculation of the position and extent of the maximum depletion of D.O.

The equation has been used successfully on large U.S. rivers e.g. the Ohio but has been found invalid in the case of smaller shallower English rivers, where D.O. is being consumed not only by organisms in suspension but also by those on the substratum, e.g. by sewage fungus and by bacteria and other organisms in the mud (Westlake, 1959; Owens and Edwards, 1963; Edwards, 1964). In such situations the direct application of the Streeter-Phelps equation is an oversimplification. The Water Pollution Research Laboratory in England has carried out a great deal of research into the problem of predicting D.O. variation in small, organically polluted streams and while a great deal has been learned of the basic processes involved, there is still, as Downing (1967) points out, insufficient data to allow the prediction of the effects of organic pollution with the desired precision. It now appears that the factors influencing the D.O. regime in rivers are very complex making it unlikely that very exact methods of prediction will be found in the near future. However, enough is known to allow a statistical assessment of the dangers involved in any situation and to this may be added the facts ascertained by careful observation.

METHODS AND PROCEDURE

Point sampling of the rivers in each area during daytime was carried out as often as possible during summer and autumn 1967 and 1968. In effect, each area was sampled once a week except at those times when other work intruded on this routine in which case sampling was more infrequent. A control station was worked a short distance upstream of the first outfall of waste in each area and then several points in and beyond the polluted zone until the D.O. and B.O.D. concentrations appeared to have been restored to pre-pollution levels. Stations below outfalls were placed sufficiently far downstream to allow for mixing of effluents and

river water. In most of the cases this distance was quite short (about 400 m.) since the streams are relatively narrow and shallow but at Mallow, where the Blackwater is quite wide and deep, longer distances had to be allowed below outfalls before sampling could be considered reliable.

Dissolved oxygen and biochemical oxygen demand were determined according to the methods recommended by the American Public Health Association (1965) the azide modification of the Winkler Method being used for dissolved oxygen. Ammonia was measured by Direct Nesslerization and nitrate-N by the Brucine Method. Determination of suspended solids was carried out gravimetrically using glass fibre filter paper and Hartley funnels as recommended by D.S.I.R. (1964).

The overnight surveys, carried out in July 1968, usually commenced in the evening time around 17.00 hr and finished at about 10.00 hr the following morning. Extension of sampling outside this period was considered unnecessary since the daytime levels of D.O. and B.O.D. had already been covered by the routine point sampling surveys. During the overnight surveys determinations of D.O. were made on site, a large tent being used as a field laboratory. The measurement of D.O. and B.O.D. at Mallow and all measurements of ammonia and nitrate nitrogen were carried out by the chemist at the beet sugar factory and his recordings were kindly put at the disposal of the authors.

The positions of the stations worked in daytime and overnight sampling surveys are shown on the maps in Figs. 2—5 incl.

RESULTS

(i) D.O. and B.O.D.

Rathmore

The main polluting load on the R. Blackwater at Rathmore comes from the effluent treatment plant attached to the chocolate crumb factory. B.O.D. as high as 40 p.p.m. and D.O. as low as 23% of saturation (see Fig. 6) were recorded at a point quarter of a mile (400 m.) below the outfall in the summer and autumn of 1967 and 1968, the mean value of all samples being about 17 p.p.m. for B.O.D. and 66 per cent of saturation for D.O. However, before the entry of the wastes from the factory, the river is already polluted by milk wastes and the discharge from the small sewage works about 0.7 ml (1.1 km) upstream. B.O.D. as high as 20 p.p.m. was recorded between the latter point and the factory though D.O. showed little deterioration in the stretch. An unpolluted tributary, the Awnaskirtawn, enters the main river about half a mile (0.8 km) below the factory outfall and beyond this point water quality showed a marked improvement; B.O.D. levels were found to be so markedly reduced below the confluence that the possibility of absorption of the organic matter in the water by the slime community which flourishes below the factory is suggested. Some 3 ml (5 km) below its confluence with the Awnaskirtawn the Blackwater receives another clean tributary, the Owentaraglin, but even before this point, water quality has already returned to near pre-pollution conditions.

The dilution available to the effluent of the chocolate crumb factory from the Blackwater on 209 summer and autumn days in 1967 and 1968 is indicated in Fig. 7. The flow of the effluent is about 2 million gal/day and river flow is as low as 4 million gal/day at times. Fig. 7 shows that the dilution ratio was between 5 and 20 on the majority of the days for which data are available, but on more than 40 days it was less than 5. On three days the dilution ratio was only 3 (i.e. the river flow was only twice that of the effluent). The maximum B.O.D. known to occur in the effluent is around 120 p.p.m. If this strength obtained at a time of low river flow and when the receiving water was already significantly polluted by the intermittent discharge of milk waste through the Cullavaw stream, the B.O.D. of the river below the factory would be in the region of 55 p.p.m. The maximum B.O.D. recorded below the factory was about 40 p.p.m. at which time the D.O. was only 23% of saturation. It is clear that the worst conditions which could conceivably arise at Rathmore in regard to D.O. depletion have not been encountered and fish kills, so far not noted in this area, are a probability.

Overnight surveys of the Blackwater at Rathmore (see Fig. 8), carried out in July 1968, did not reveal any marked diurnal variation in D.O. At the polluted zone station below the chocolate crumb factory, the concentration of D.O. remained more or less stable throughout the periods of sampling between 50% and 60% of saturation, while at the unpolluted and mildly polluted zone stations only small decreases in D.O. were recorded at night. At no point did the concentration fall below 50% of saturation. B.O.D. at the station below the factory showed considerable variation during both surveys, concentrations rising to over 20 p.p.m. at times. Most of this variation was probably due to washing down of plant at the factory. This, as mentioned already, occurs around midday and midnight and causes overloading of the filters.

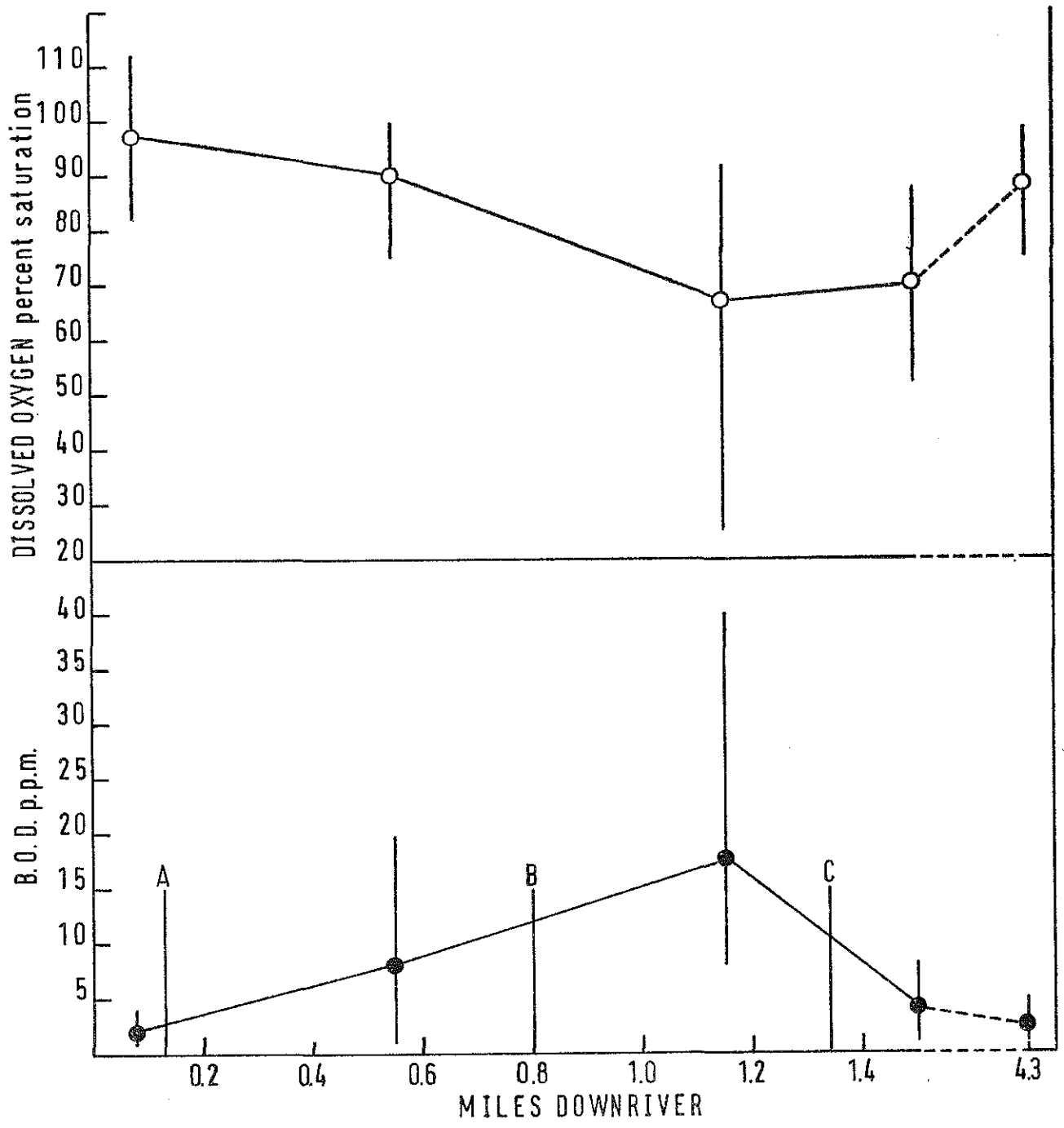


Fig. 6. Variation of dissolved oxygen and B.O.D. in the R. Blackwater at Rathmore based on the means of daytime recordings made in summer and autumn of 1967 and 1968. Vertical lines at each point indicate the ranges of the recordings. A: outfall of small sewage works and entry point of small stream polluted with creamery wastes; B: outfall of waste treatment plant at chocolate-crumb factory; C: entry point of clean tributary (Awnaskirtawn).

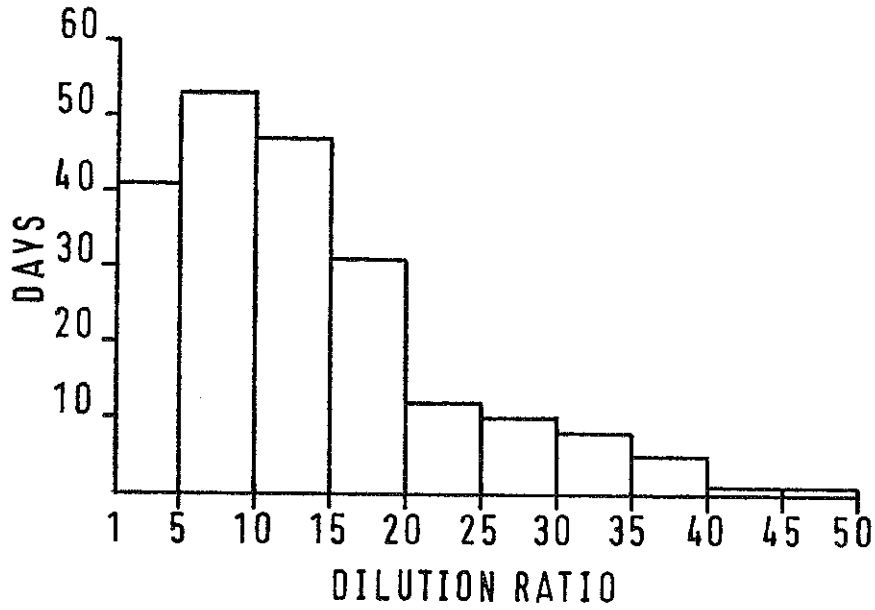


Fig. 7. Dilution of the effluent from the chocolate crumb factory at Rathmore by the R. Blackwater on 209 summer and autumn days in 1967 and 1968. The columns show the number of days on which each range of dilution ratios obtained. (Dilution ratio is the combined flow of effluent and river divided by the effluent flow).

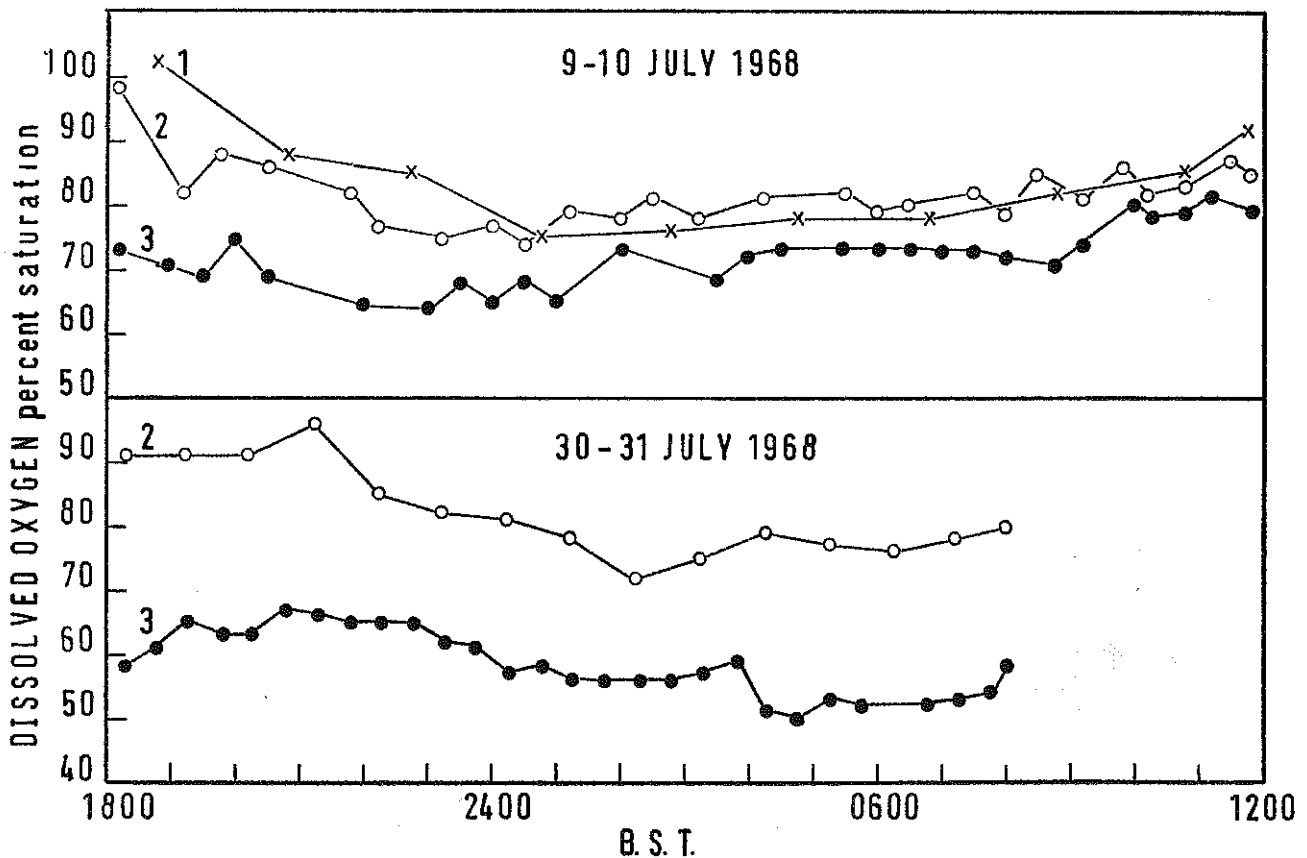


Fig. 8. Overnight variation of dissolved oxygen at three stations in the R. Blackwater at Rathmore in July 1968. 1: Unpolluted station above Rathmore; 2: Mildly polluted station below small sewage works and confluence with polluted stream; 3: Heavily polluted station below chocolate crumb factory.

Mallow

The minimum records of D.O. and the maximum records of B.O.D. (see Fig. 9) in the R. Blackwater at Mallow in the summer and autumn of 1967 and 1968 were for a point about half a mile (0.7 km) downriver of the town sewage outfall. While wastes are also discharged from the food processing plant three miles (4.8 km) upriver of the town at this time, there was, apparently, very little effect on D.O. and B.O.D. below that outfall. Nearer the town, a drop in D.O. and a rise in B.O.D. occurred below the entry point of a small stream carrying milk wastes from the creamery industries in the town, though these changes are exaggerated by the tendency of the waste to stream along the bank from which samples are taken. The same qualification must apply to recordings made at the station below the town sewage outfall, which indicated D.O. as low as 30% saturation and B.O.D. as high as 30 p.p.m. in summer and autumn of 1967 and 1968, the mean of

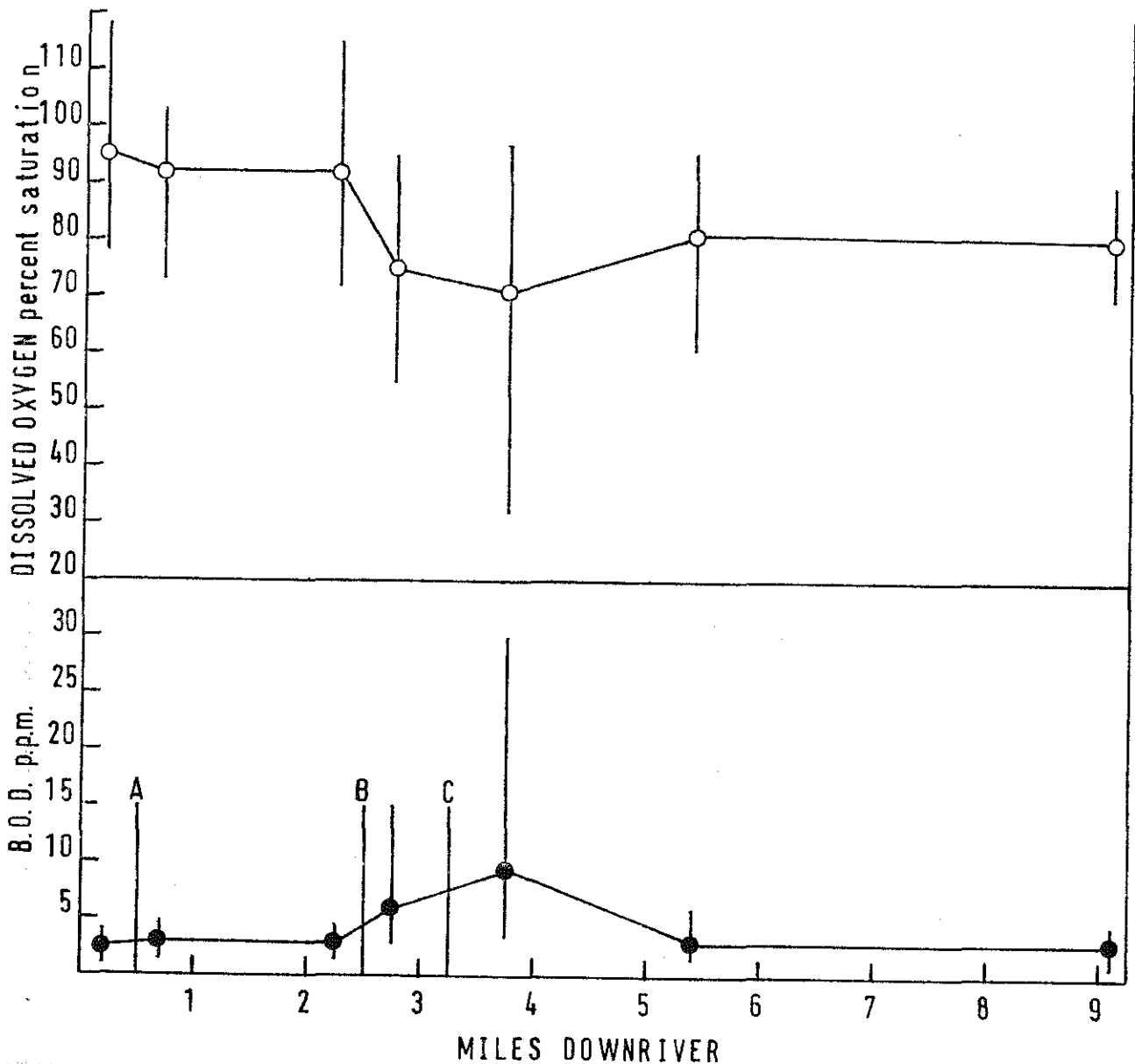


Fig. 9. Variation of dissolved oxygen and B.O.D. in the R. Blackwater at Mallow based on the means of daytime recordings made in summer and autumn of 1967 and 1968. Vertical lines at each point indicate the ranges of the recordings. A: outfall of waste from lagoons at food-processing factory; B: entry point of small stream polluted with creamery wastes; C: town sewage outfall.

recordings being 72% of saturation and 9 p.p.m. for D.O. and B.O.D. respectively. The sewage outfall is located on a fairly straight stretch of the river and discharges at the left bank; the waste can be observed streaming along this bank for some distance and it is felt that mixing is not complete at the point at which samples were taken. Recordings made at the station further down river (about 2 mls (3.2 km) below the sewage outfall) are more reliable in indicating the extent of water quality deterioration below the town and it is seen that at this point the minimum D.O. was over 60% saturation and the mean over 80% of saturation; maximum B.O.D. at this point was about 7 p.p.m. the mean about 4 p.p.m. About 4 mls (6.4 km) further downriver at Killavullen D.O. and B.O.D. ranges are similar to those recorded above the factory.

A much greater polluting load is received by the Blackwater at Mallow during the beet-sugar campaign between October and January each year. Results of analyses at several points below the outfall made during the campaigns of 1966/67, 1967/68 and 1968/69 are set out below:

Distance from beet-sugar factory (ml)	D.O.—% sat.			B.O.D.—p.p.m.		
	1966/67	1967/68	1968/69	1966/67	1967/68	1968/69
0.3 above Mean ...	96	92	87	2.0	1.7	2.2
Range ...	91—102	88—98	68—115	1.0—3.2	1.0—2.2	1.2—3.4
0.3 below Mean ...	88	91	82	7.4	3.0	3.7
Range ...	80—94	84—96	59—110	4.0—9.8	1.8—4.2	2.3—5.0
1.7 „ Mean ...	83	90	80	4.1	2.1	3.2
Range ...	78—87	84—94	62—103	3.4—4.8	1.8—2.4	2.2—4.0
4.9 „ Mean ...	78		75	3.9		2.5
Range ...	74—82		58—110	3.8—4.0		1.2—4.0
8.9 „ Mean ...	80		74	2.6		2.7
Range ...	77—82		58—103	2.4—2.8		1.4—4.4

Very few measurements are available for the campaigns of 1966/67 and 1967/68 and in the latter case none at all for the two stations furthest downriver. The measurements in 1968/69 were made weekly during the campaign (12 weeks) but in this period there was a greater frequency of floods than usual and the dilution available to the waste consequently very high. It appears, however, that D.O. would not normally be greatly depleted in the river below the beet factory during the campaign, this being due primarily to the great dilution available (see below).

The dilution of the wastes from the food processing factory was calculated for the summer of 1969. The flow of waste ranges between 1 and 2 million gal/day and the mean of 73 daily recordings of river flow was 130 million gal/day. However, for most of the period between the beginning of July and mid-September, the flow was about 50 million gal/day which would have given a dilution of some 30 times to the effluent. On one day, river flow was 35 million gal/day which would have given a dilution of only 20 times. It has been calculated that at a time of river flow of 50 million gal/day the wastes, flowing at a rate of 1.5 million gal/day and at a B.O.D. of 100 p.p.m. would cause a rise of only 3 p.p.m. in the river water. As can be seen from Fig. 9 only small rises in B.O.D. were recorded below the factory in summer. The much greater increases recorded below the creamery and the town sewage outfall are, therefore, unexpected since the waste contribution from these sources is less than that from the food factory. This would support the observations made above that mixing of wastes and river water is incomplete at the stations below the creamery and below the town sewage outfall. There is another possible explanation for the relatively severe effects on D.O. below Mallow town. The full B.O.D. of the food factory waste (and the beet factory wastes in winter) may not be exerted until this waste receives an addition of domestic sewage which provides it with a proper bacterial flora for its breakdown.

The dilution of the wastes from the beet-sugar factory during the campaigns of 1967/68 and 1968/69 is represented in Fig. 10. For the greater part of both campaigns the dilution ratio was over 50 and for a considerable number of days was over 100. During floods, which were particularly frequent during 1968/69, very high dilution ratios were operating (over 300). The lowest recorded dilution received by the effluent

in 1967/68 was 40 times and in 1968/69, 47 times, the first occurring on one day the second on three days. For most of the campaign the B.O.D. of the effluent ranges between 300 and 400 p.p.m. and at dilutions of the order referred to above only small rises in this factor would be expected below the factory. For example if the dilution ratio was 100, the B.O.D. of the effluent 400 p.p.m. and that of the receiving water 3 p.p.m.,

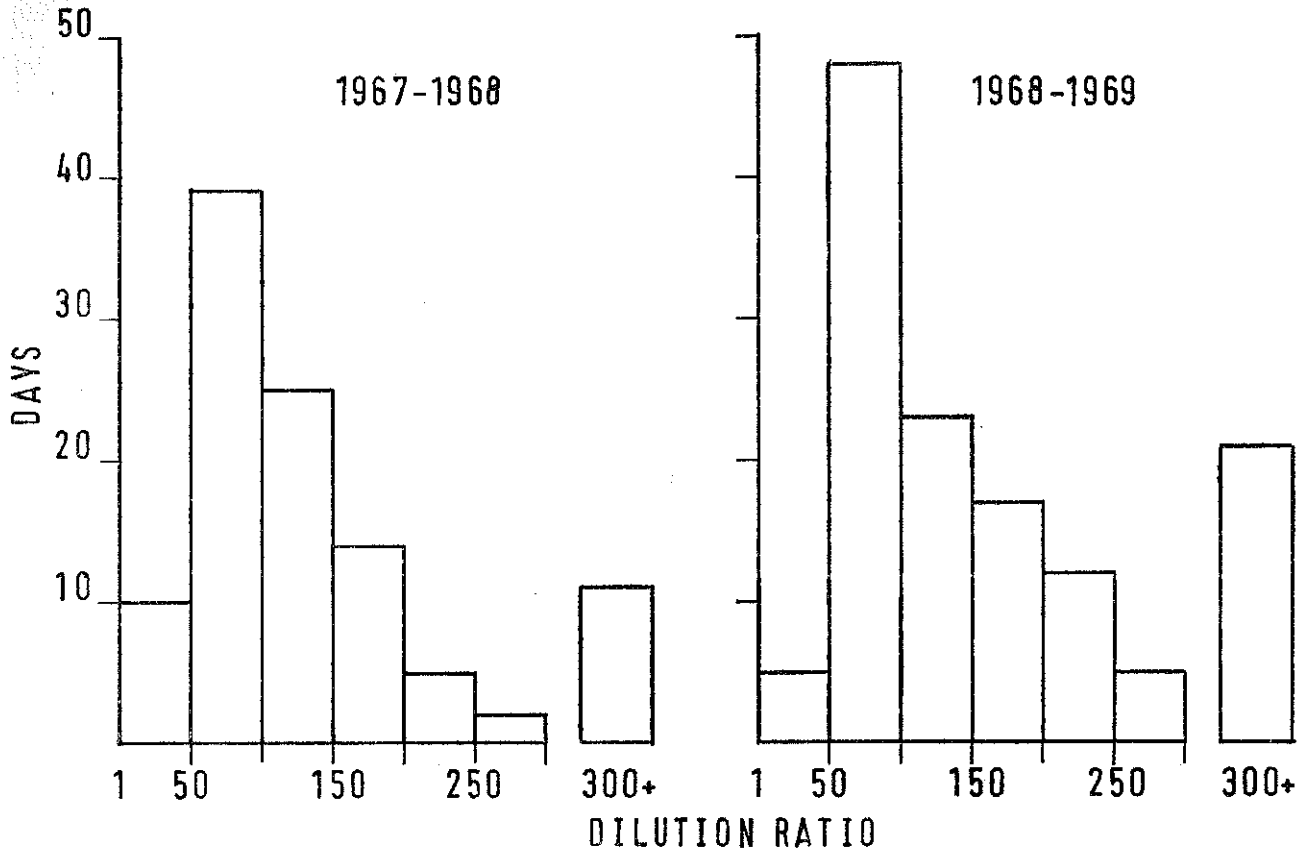


Fig. 10. Dilution of the effluent from the beet sugar factory at Mallow by the R. Blackwater during the campaigns of 1967/68 and 1968/69. Columns show the number of days on which each range of dilution ratios obtained.

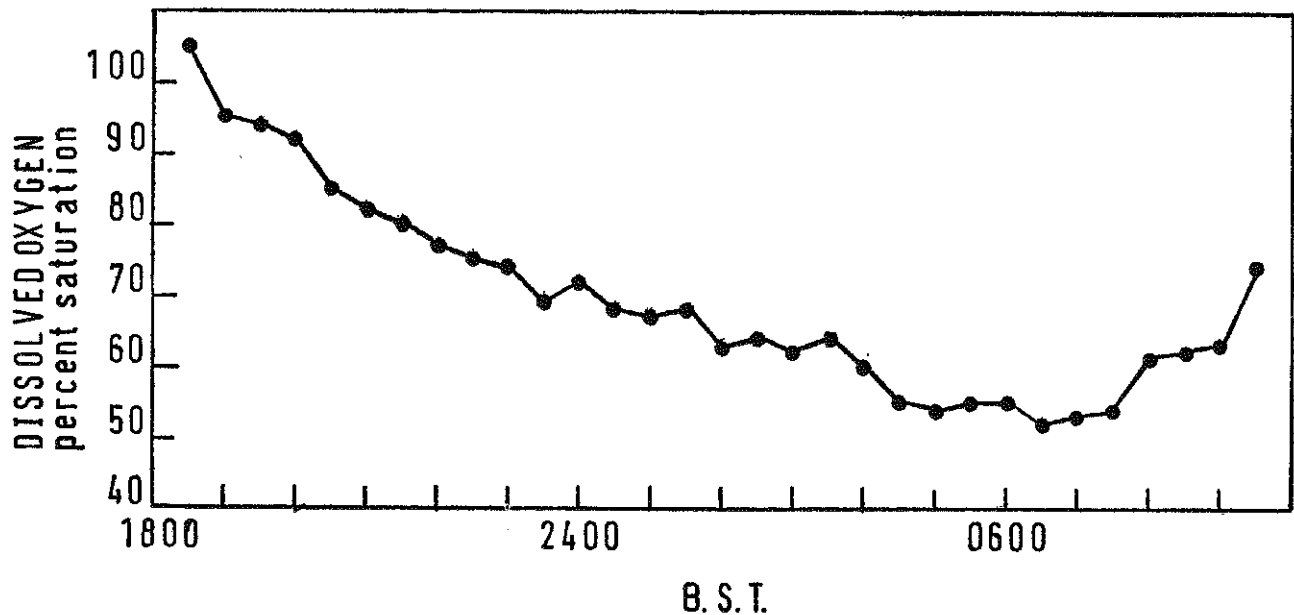


Fig. 11. Overnight variation of dissolved oxygen in the R. Blackwater at Mallow, some two miles below the town sewage outfall, on 26-27 July, 1968.

the B.O.D. of the river below the factory would not be greater than 7 p.p.m. It is clear, therefore, that the very large dilution of the wastes is mainly responsible for minimising the effects on D.O. during the campaign and that serious deoxygenation would arise where river flow was very low at the start of a campaign. This is borne out by the serious fish kills which occurred just after the commencement of the 1969/70 campaign; river flow was extremely low at the time following prolonged drought conditions in August and September, 1969.

One overnight survey was carried out on the river at Mallow in July, 1968 (see Fig. 11) the point monitored lying about 2 ml. (3 km) downriver of the town sewage outfall. A marked decrease in D.O. was recorded during this survey the concentration falling from over 100% of saturation at 18.30 hrs. to 50% of saturation at 06.00 hrs. Very little variation in B.O.D. was recorded during the period.

Mitchelstown

The Gradoge stream at Mitchelstown is grossly polluted in summer for about half-a-mile (0.8 km) above its confluence with the R. Funcheon by the effluent from the town sewage works. The latter, as explained already, is severely overloaded in summer by wastes from the milk-based industries in the town. Above the sewage works the stream also receives other, smaller discharges, mainly milk washings, so that even above the main outfall the B.O.D. of the stream was sometimes over 20 p.p.m. (see Fig 12). From the sewage works outfall to the confluence with the Funcheon, the Gradoge is little more than a sewer, with a mean B.O.D. between 40 and 50 p.p.m., while values as high as 95 p.p.m. have been recorded. D.O. is very depleted in the stretch; just above the confluence the mean of the recordings was below 10% of saturation while anaerobic conditions were detected on a few occasions.

The entry of the smaller Gradoge to the larger and unpolluted Funcheon affords the former considerable dilution and B.O.D. is greatly reduced. However, concentrations of B.O.D. as high as 20 p.p.m. were recorded just below the confluence, the mean at this point being about 10 p.p.m. D.O. in the Funcheon was found to be considerably reduced over a distance of about 4 ml (6.5 km) below the confluence, a minimum of 35% of saturation being recorded about 400 m. from the confluence and 32% of saturation at Kilee Bridge, 1.7 ml (2.7 km) from the confluence. Recovery seemed fairly rapid from this point downriver but the mean D.O. was not restored to the pre-pollution level until after the entry of the clean Sheep R. Even at this point a minimum recording of just over 60% of saturation was made.

Fig. 13a shows the variation in the dilution of the sewage works effluent at Mitchelstown by the Gradoge on 256 days in summer and autumn of 1967 and 1968. The values for the effluent flow used in calculating dilution are based on the volumes pumped into the sewage works and are, therefore, only rough estimations. The flow of the Gradoge during most of the summer of 1967 and 1968 was less than 10 million gal/day. On nearly half of the 256 days considered, the dilution ratio was between 5 and 10; ratios higher than 25 were infrequent but on occasion during floods ratios higher than 50 occurred. The dilution of the Gradoge by the Funcheon is shown in Fig. 13b. For most of the summer and autumn of 1967 and 1968 the rate of flow of the Funcheon was between 20 and 30 million gal/day and diluted the Gradoge by 3 to 7 times on most days (these data assume an addition to the flow of the Gradoge of about 1 million gal/day from the sewage works). The ameliorating effect of the clean water of the Funcheon on the heavily polluted Gradoge has been pointed out above.

Calculations show that if the minimum dilution of the sewage works effluent by the Gradoge (3 times) occurred in association with the maximum B.O.D. recorded for the effluent (280 p.p.m.) and for the receiving water (28 p.p.m.) the B.O.D. of the Gradoge below the main outfall would be in the region of 90 p.p.m. This is much the same as the maximum recorded value for the stretch (see Fig. 12). If the Gradoge entered the Funcheon with a B.O.D. of 90 p.p.m. during a period of low flow in both streams, at which time the dilution ratio between the two would be of the order of 6, the resulting B.O.D. in the Funcheon would be around 16 p.p.m. This figure is also near the maximum recorded so that it would appear that the highest levels of B.O.D. possible with current levels of pollution have been encountered in the two streams, though this

cannot be said with certainty of D.O. depletion in the Funcheon since other factors besides B.O.D. are involved in influencing the D.O. regime in this river (see below).

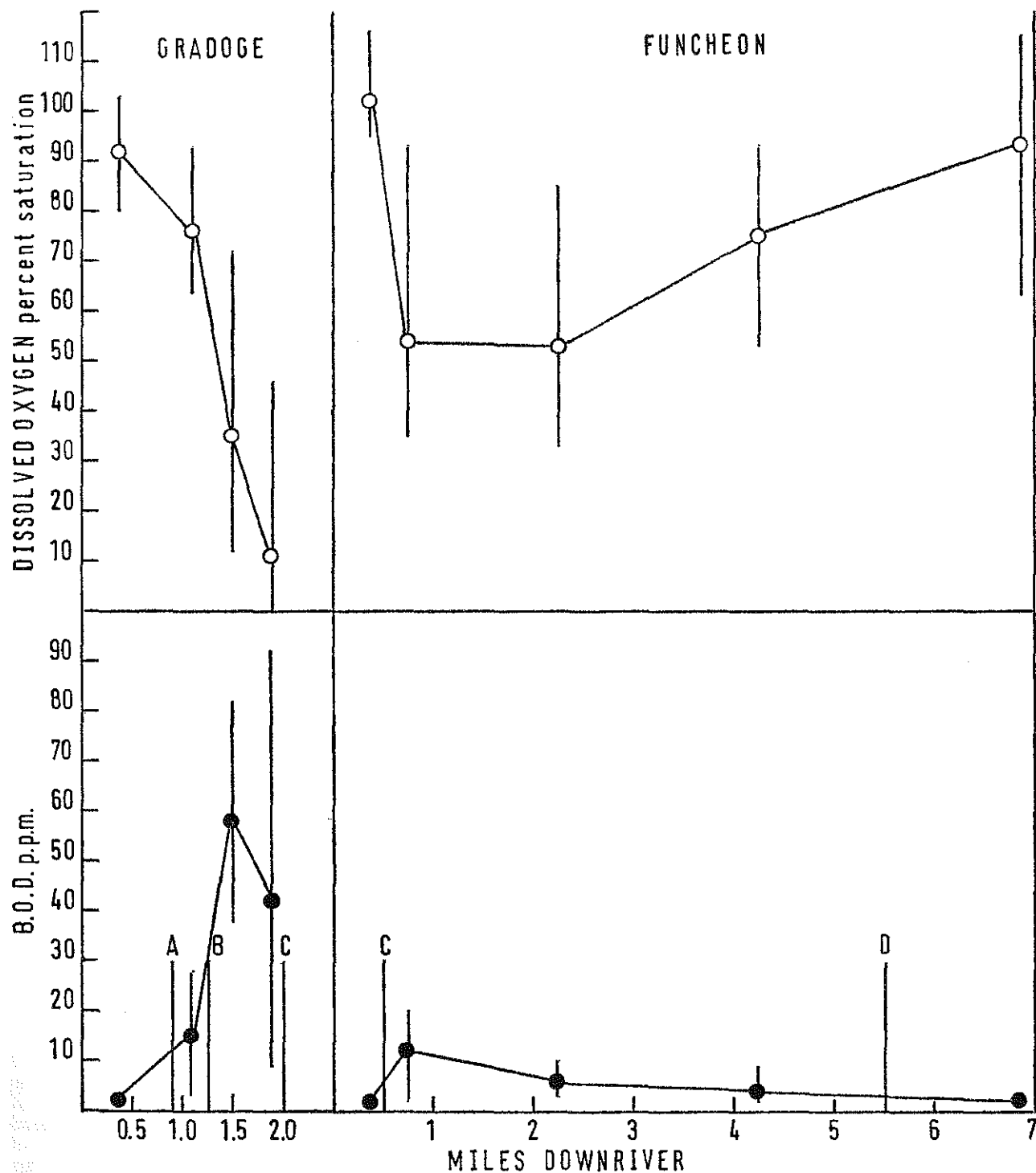


Fig. 12. Variation of dissolved oxygen and B.O.D. in the Rivers Funcheon and Gradoge at Mitchelstown based on the means of daytime recordings made in the summer and autumn of 1967 and 1968. Vertical lines at each point indicate the ranges of the recordings. A: outfall of overflow pipe through which creamery wastes are intermittently discharged; B: outfall of town sewage works; C: confluence of the Gradoge and Funcheon; D: confluence of the Funcheon and Sheep.

Two overnight surveys were carried out at Mitchelstown (see Fig. 14). Diurnal variation in D.O. was observed in the Funcheon in both polluted and unpolluted zones, a minimum value for the stretch of 16% of saturation being recorded at Kilee Bridge on the night of 19–20 July, 1968. In the polluted part of the Gradoge, D.O. remained very low in concentration throughout the whole of the period monitored and was virtually zero for some of the time. Very large fluctuations in B.O.D. occurred during these surveys and were partially responsible for the depletion in D.O. during the night. The cause of the variations has not been established; it appears however that nothing unusual occurred at the sewage works on the nights in question. The high B.O.D. levels, recorded in both the Gradoge and Funcheon, lasted for only short periods and this would seem to indicate by-passing of the treatment plant by discharge through direct outfall. Such an outfall has already been mentioned.

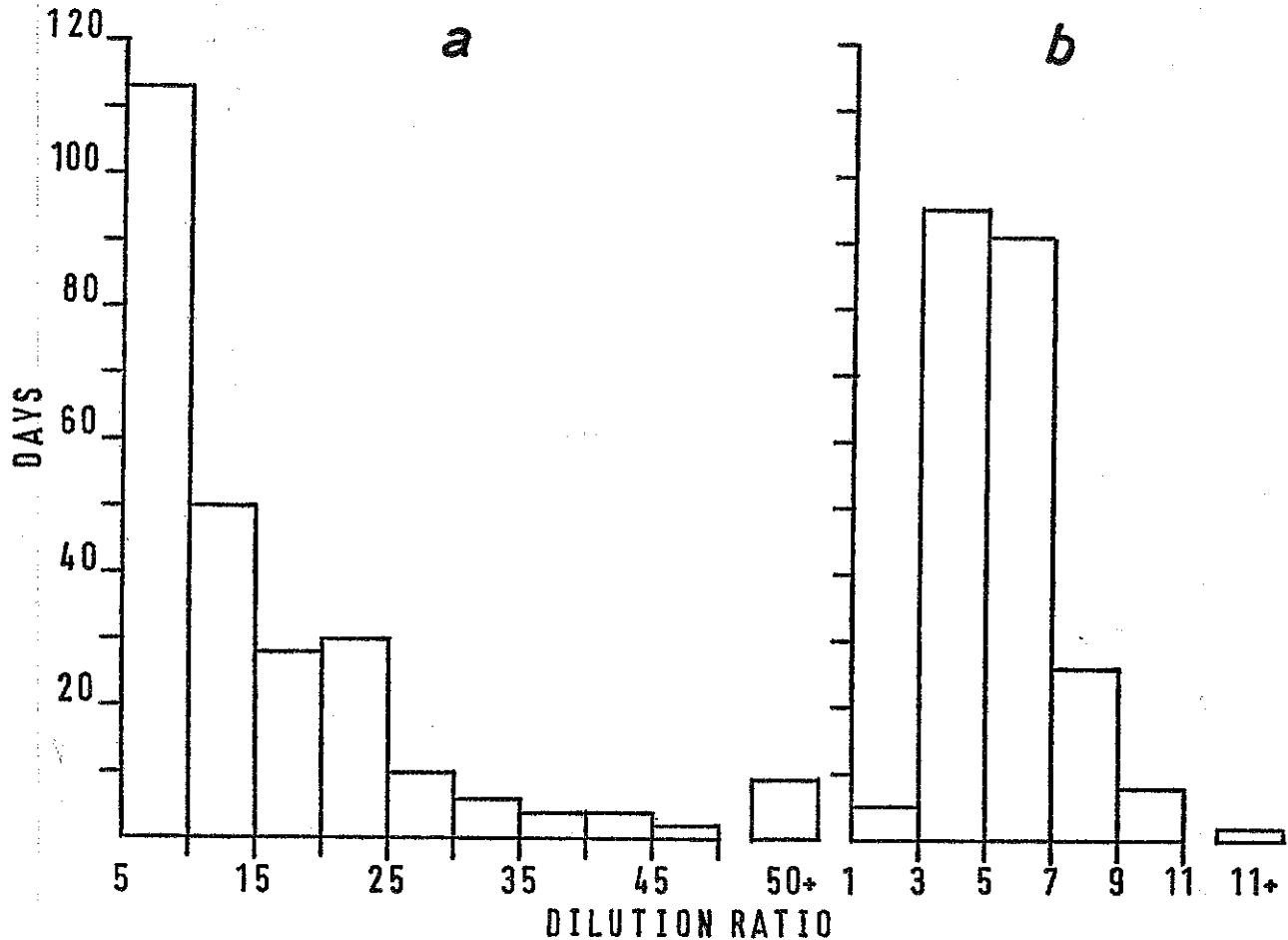


Fig. 13. Dilution of the effluent from the town sewage works by the R. Gradoge (a) and of the R. Gradoge by the R. Funcheon (b) at Mitchelstown, on 258 and 227 days, respectively, in the summer and autumn of 1967 and 1968. Columns show the number of days on which each range of dilution ratios obtained.

Rathduff

Pollution of the R. Martin at Rathduff is first encountered as the stream flows through fields on which piggery wastes are sprayed. Particularly during heavy rain, much of this material is washed into the stream, some of it entering through a small ditch (see Fig. 5). Below the latter point, a small increase in B.O.D. and reduction in D.O. were usually recorded (see Fig. 15). The deterioration in water quality was, however, much more marked below the several discharges from a creamery 400 m. downstream. At this point, D.O. as low as 28% of saturation and B.O.D. as high as 45 p.p.m. were recorded, the mean levels being 55% of saturation and 25 p.p.m., respectively. Below Rathduff the stream receives much dilution from small tributaries so that there is a rapid improvement in water quality. About 1.5 ml (2.4 km) beyond the creamery the mean D.O. recorded was over 60% of saturation while half a mile (0.8 km) further on, after the entry of a clean stream, it was nearly 80%. The mean B.O.D. at the latter point was 5 p.p.m. compared to the mean of 25 p.p.m. just below the creamery.

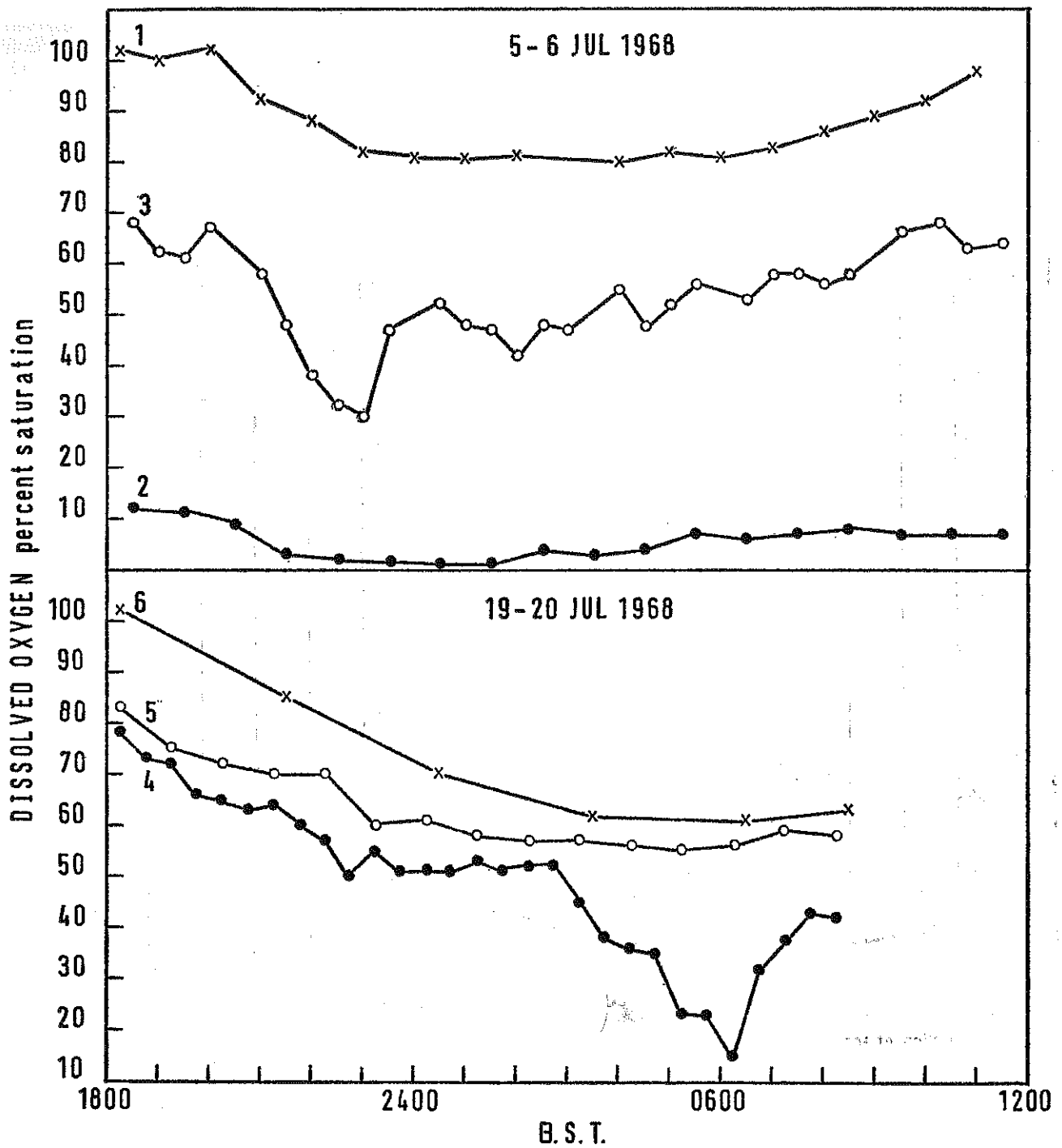


Fig. 14. Overnight variation of dissolved oxygen in the Rivers Funcheon and Gradoge at Mitchelstown in July 1968. 1: Unpolluted station on Funcheon above the confluence with the Gradoge; 2: Heavily polluted station on Gradoge just above the confluence with the Funcheon; 3: Heavily polluted station on Funcheon about 0.25 ml. below the confluence with the Gradoge; 4: heavily polluted station on Funcheon 1.7 ml. below the confluence with the Gradoge; 5: mildly polluted station on Funcheon 3.7 ml. below the confluence with the Gradoge; 6: Slightly polluted station on Funcheon 6 ml. below the confluence with the Gradoge and 1.5 ml. below that with the R. Sheep.

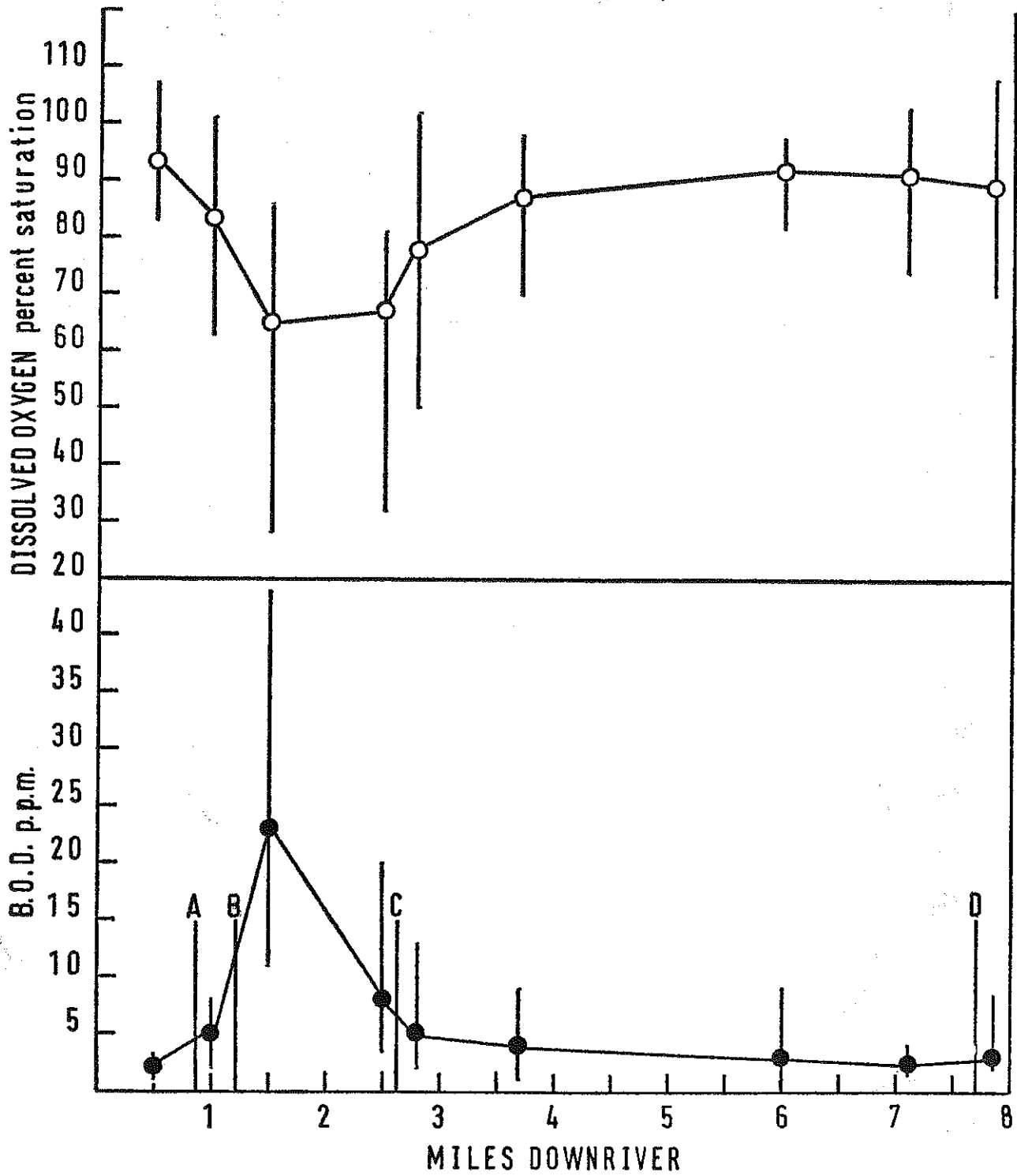


Fig. 15. Variation of dissolved oxygen and B.O.D. in the R. Martin based on the means of daytime recordings made in the summer and autumn of 1967 and 1968. Vertical lines at each point indicate the ranges of the recordings. A : entry point of ditch draining area on which piggery wastes are sprayed; B : entry point of wastes from creamery at Rathduff; C : confluence of large clean tributary with main river; D : outfall from woollen mills at Blarney.

It has not proved possible to measure the volume of waste entering the Martin River at Rathduff since the bulk of this is spray irrigated on surrounding fields. There is a discharge of milk waste from the creamery but this runs over the ground to the stream and not through a defined channel. However, the flow of the Martin is very small at Rathduff and serious pollution would arise in the presence of a large direct discharge. Downstream of Rathduff, the Martin is joined by several clean tributaries so that extra dilution is available within a short distance of the pollution sources.

Two overnight surveys were carried out in the Rathduff area in July 1968 (see Fig. 16). Diurnal variation did not occur in the unpolluted reaches, the D.O. remaining stable at around 100% of saturation, while in the polluted zones the D.O. showed a direct inverse relationship with B.O.D.; since the concentration of the latter was much reduced at night, D.O. tended to be higher at that time than in the daytime. The stream is so shallow at Rathduff that the effects of photosynthesis on the D.O. regime are greatly minimised by rapid reaeration.

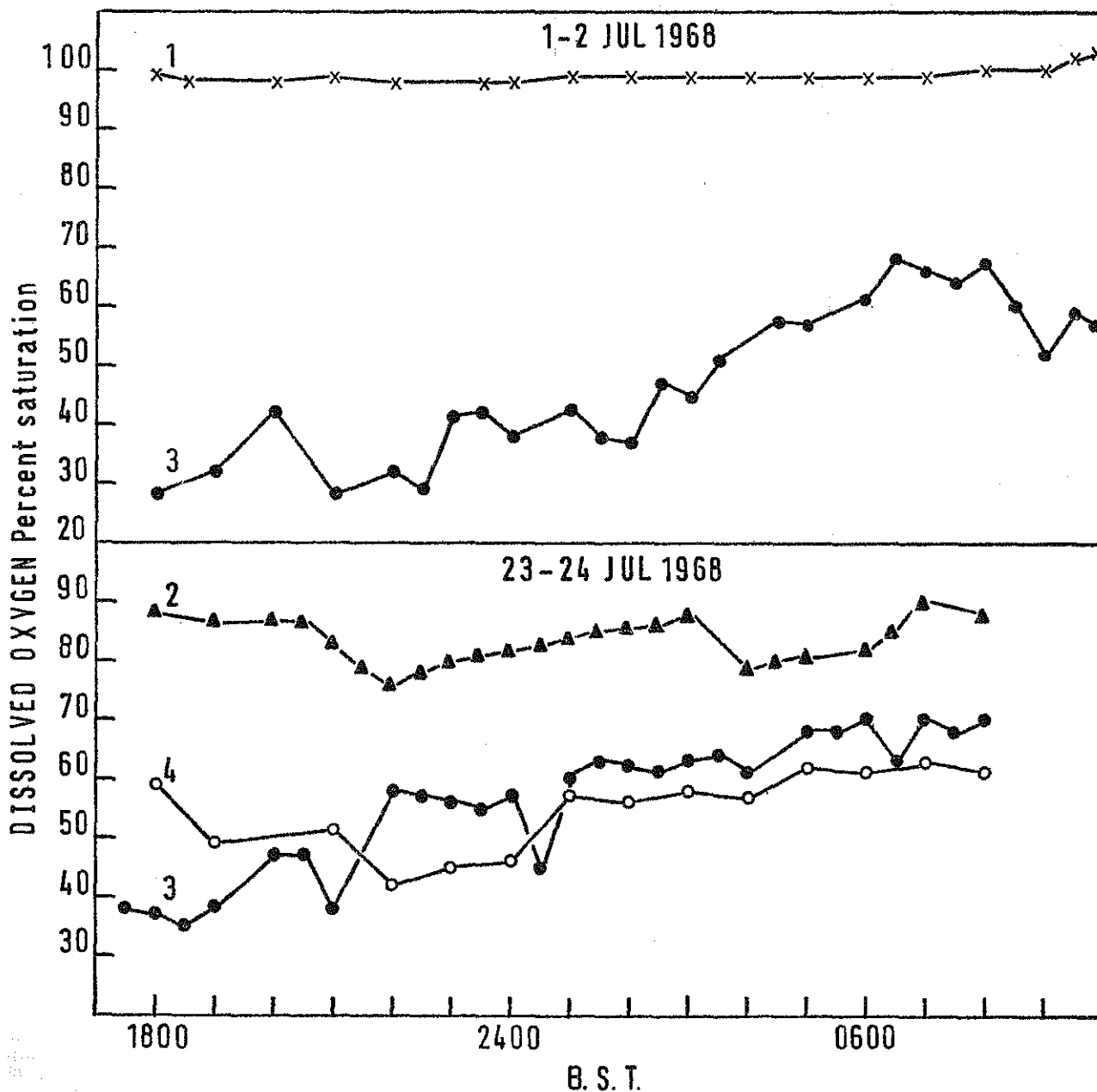


Fig. 16. Overnight variation of dissolved oxygen in the R. Martin at Rathduff in July 1968. 1: Unpolluted station above Rathduff; 2: Mildly polluted station in stretch affected by drainage from ground on which piggery wastes are sprayed; 3: heavily polluted station below outfall of wastes from creamery; 4: Recovery zone station 1.5 ml. below 3.

Blarney

The water quality of the River Martin has apparently completely recovered from the pollution at Rathduff by the time the stream enters Blarney town about six and a half ml. (10 km) below the former point. Significant changes were not recorded in D.O. or B.O.D. below the outfall of the woollen mill which contributes the only effluent to the river at this point (see Fig. 15). The sewage from Blarney is passed into drainage ditches which lie adjacent to the Blarney R. (see Fig. 5). The latter has joined with the Martin just above that point and only a small rise in B.O.D. and a small drop in D.O. were recorded down river of the drainage ditches.

It was pointed out above that the volume of waste from the woollen mill is some 80,000 gal/day, this waste being diluted about fifteen times by clean river water from above the factory before discharge. During low summer flows virtually the whole volume of the river is used to provide this preliminary dilution so that the river below the factory may consist solely of the final effluent. However analyses of this effluent show that fish would not be endangered at such times and there have been no reports of fish kills below the factory.

Generally, the measurements of D.O. showed that conditions dangerous to fish and other aquatic life were not of wide occurrence. There was only one stretch, i.e. the section of the Gradoge between the outfall of the Mitchelstown sewage works and its confluence with the R. Funcheon, where D.O. levels were probably too low at all times in the summer and autumn of 1967 and 1968 to allow of the survival of fish. This was borne out by the unsuccessful attempt to detect specimens in the reach in August 1967. The D.O. content of the R. Funcheon, below its confluence with the Gradoge, was considerably reduced over a long stretch but lethal concentrations were only detected during an overnight survey. The low level of D.O. lasted for a short period only but indicated that similar conditions may occur frequently in summer, being responsible for the fish kills which have been observed on several occasions in the stretch. Very few trout were caught in the Funcheon below the confluence with the Gradoge in the fish sampling of 1967 and 1968.

On occasion, relatively low D.O. was recorded in the Blackwater at Rathmore and Mallow and in the Martin at Rathduff; though the length of the stretch affected in each case was small (less than half a mile (0.8 km)) the low concentrations (between 25 and 30% of saturation) constitute a hazard to fish life as the safety margin is very small.

In regard to the variation in D.O. over 24 hr. periods, in most cases some diurnal variation was shown to occur. However, in only one case, that of the polluted Funcheon at Mitchelstown, was a concentration recorded during the overnight survey, which was lower than the minimum recorded for daytime sampling. On the other hand, since the minimum concentration recorded during overnight surveys was in most cases lower than the mean of the D.O. records for daytime sampling, the use of the latter alone as an indication of water quality is not to be recommended. Continuous sampling over a 24 hour period is the safest way of determining the effects of organic wastes on D.O.

Very high B.O.D. concentrations were recorded on occasion and some of the polluted stretches would not be acceptable even as sewage works effluents! The fact that the high concentrations of organic matter did not result in more marked depletion in D.O. suggested that the reaeration rates in the rivers in each area were relatively rapid. Estimates of the reaeration rates were made by using the formula proposed by Owens, Edwards and Gibbs (1964) wherein the Exchange Coefficient, f , (see above) is related to depth and current velocity as follows:

$$f_{(20^{\circ}\text{C})} = 50.4U^{0.67}H^{-0.85} \quad \begin{array}{l} U = \text{current velocity cm/sec.} \\ H = \text{depth in cm.} \end{array}$$

The formula allows a rapid estimate of f to be made since only two variables, depth and current velocity, need be measured. In 1967 and 1968 depth and velocity in measured stretches at each location were made and the values of f computed. These values were in most cases relatively high, many being over 30 cm/hr. The value for slow flowing English rivers has been given as 2-4 cm/hr. Turbulent lake-land becks have values of f lying between 30 and 200 cm/hr (Gameson and Truesdale, 1959). The estimations of f in the Blackwater and Martin showed therefore that reaeration in these rivers is in many cases quite rapid, providing an explanation for the relatively small depletions in D.O. noted in most cases. They also indicate that diurnal variation in D.O. due to photosynthesis would be greatly minimised. It can be seen from Figs. 8, 11, 14 and 16 that the degree of diurnal variation of D.O. recorded in the present survey was in most cases moderate. Where aeration is rapid the degree of supersaturation which can arise through photosynthesis is relatively small since the oxygen in excess of the saturation value is quickly lost to the atmosphere; where the reaeration rate is slow the excess oxygen is not readily shed and marked supersaturation may result. Conversely, where there is an appreciable B.O.D. the loss in D.O. will be much less if reaeration is rapid. Fig. 17 illustrates

the effect of the reaeration rate on the amplitude of the D.O. variation in a river over 24 hrs. The D.O. curves are based on the following equation, formulated by Downing and Truesdale (1956) to describe the D.O. variation in an aquarium:

$$C_t = e^{-Kt}C_o + (1 - e^{-Kt})(KC_s - K_1 - K_2 + K_3)$$

where C_t is the concentration of D.O. (p.p.m.) at any time, C_o is the original concentration of D.O., C_s the saturation concentration, K the Overall Absorption Coefficient (log base e) and K_1 , K_2 and K_3 are, respectively, the rates of respiration of animals, of plants and the production of oxygen by the latter. A theoretical day-night cycle of 16 hrs. daylight and 8 hrs. darkness has been assumed while values for K , K_2 and K_3 are taken from the literature. K_1 , the respiration rate of the animal community, has been ignored since this is usually small in rivers and streams.

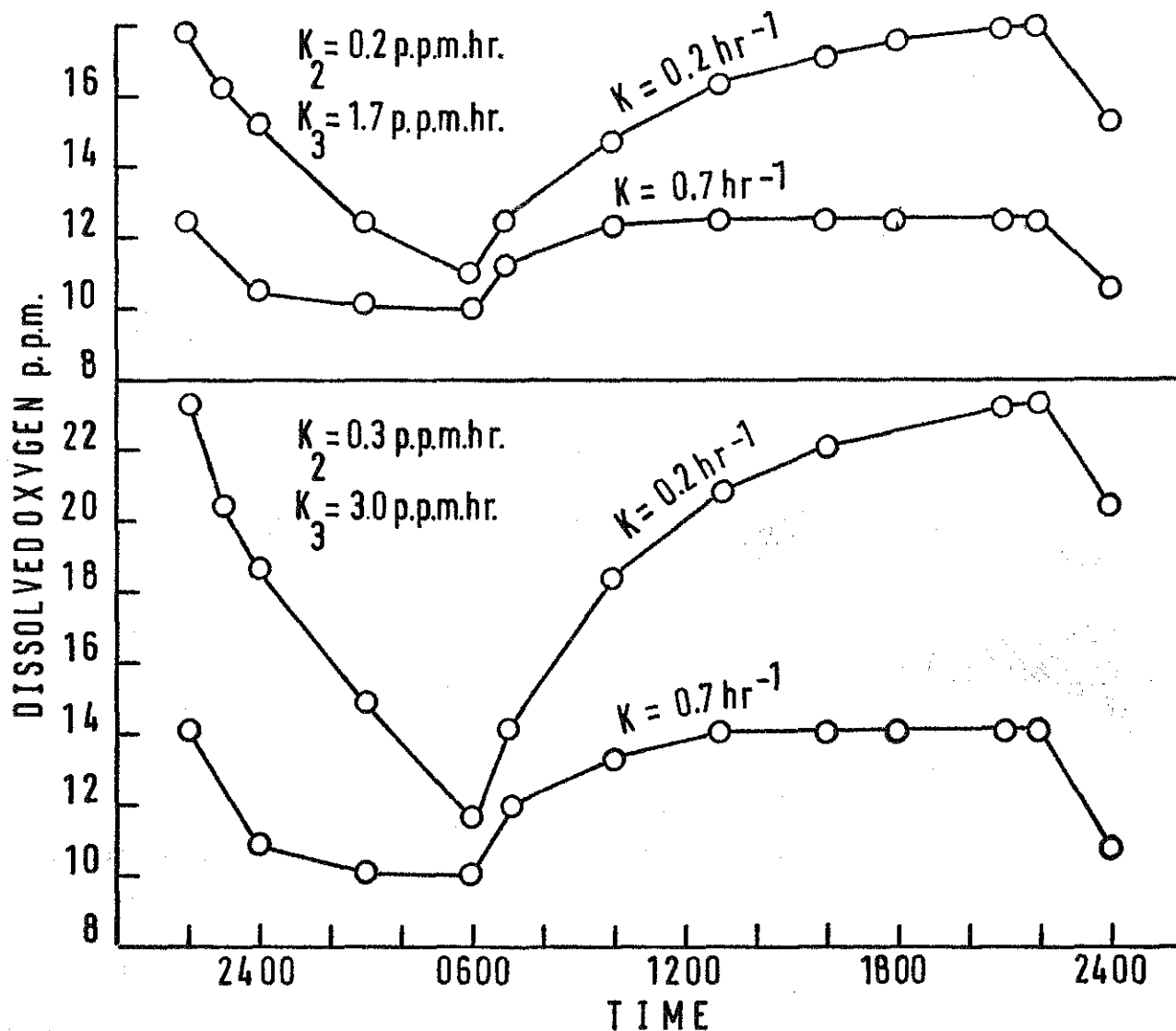


Fig. 17. Calculated diurnal variation of dissolved oxygen in a river for different values of K , the absorption coefficient, K_2 the respiration rate of plants and K_3 the rate of oxygen production of plants, using the formulae given by Downing and Truesdale (1956) to describe the variation of dissolved oxygen in aquaria.

The prediction of D.O. by the Streeter-Phelps equation was attempted on several occasions using the data from the polluted part of the R. Funcheon at Mitchelstown (see Figs. 4 and 12). This is the most convenient stretch for this type of work since a tributary of major size does not enter the main river within 5 ml. (8.0 km) of the main pollution source (in this case the Gradoge). From a large number of measurements of depth and current velocity in the reach, a mean value for f , the Exchange Coefficient, of 13 cm/hr. was calculated (this corresponds to a value of 2.2 day^{-1} for k_2 , the Overall Absorption Coefficient (log base 10), mean depth being about 60 cm). Samples for D.O. and B.O.D. determination were taken at a point 400m. below the confluence, at Kilee Bridge (1.7 ml. (2.8 km) below the confluence) and at Marshalstown Bridge (3.7 ml. (6.0 km) below the confluence), allowing for time of river flow. The values for B.O.D. and D.O. at the station below the confluence were used to predict D.O. at Kilee Bridge and those at Kilee Bridge to predict D.O. at Marshalstown Bridge. The results of these calculations are set out below :

	Station					
	Confluence		Kilee Bridge			Marshalstown Bridge
	(a)	(b)	(a)	(b)	(c)	(c)
Predicted p.p.m. ...	—	—	6.3	7.0	—	7.0
Observed p.p.m. ...	4.5	5.9	4.1	4.5	4.8	7.4

It can be seen that there was no agreement with observed values in the case of the predictions for Kilee Bridge but fairly close agreement in the case of that for Marshalstown Bridge. A similar result was obtained when predicted and observed values for Kilee and Marshalstown Bridges, based on mean B.O.D. recorded at the confluence and mean D.O. recorded there and at the two bridges over the summer and autumn of 1967 and 1968, were compared :

	Confluence	Kilee Bridge	Marshalstown Bridge
Predicted p.p.m. ...	—	6.9	8.2
Observed p.p.m. ...	5.7	5.5	7.6

Again, observed D.O. at Kilee Bridge is lower than at the confluence, whereas the predicted value for the station shows an increase over the upstream level. The observed value at Marshalstown Bridge, however, shows a significant rise over the Kilee Bridge value, as was predicted.

The results suggest that there are factors influencing the D.O. in the stretch between the Funcheon/Gradoge confluence and Kilee Bridge which are either absent or else of only small account in the downstream section. Deposits of sludge and growths of sewage fungus are common in the river between the confluence and Kilee Bridge but only sparsely developed lower down. It would appear that the lack of agreement between predicted and observed D.O. at Kilee Bridge is due to the presence of mud and sewage fungus upstream of that point; as mentioned above, in such situations a much greater demand on D.O. may exist than that indicated by the B.O.D. test and would invalidate the application of the Streeter-Phelps equation.

It is of interest to consider the value that would have to be ascribed to k_1 the rate constant of oxidation, if the predicted D.O. levels for Kilee Bridge were to agree with those observed. Fig 18 relates the differences between observed and predicted D.O. deficits for several values of k_1 . Extrapolation has been made to the k_1 axis and it can be seen that the value for the oxidation constant corresponding to a zero difference between observed and predicted D.O. deficits is, in both of the cases shown, in the region of 1.0 day^{-1} .

This is, of course, a very high value, being some ten times greater than that normally assumed for a B.O.D. test.

An alternative method which may be used to estimate the apparent value of k_1 , is to consider the reduction, with time, of B.O.D. in the stretch. On 28th August, 1968, the B.O.D. at the station near the confluence was 14.7 p.p.m. and at Kilee Bridge, 0.1 days later (i.e. time of flow between the two points), it was 6.7 p.p.m. The ultimate 1st stage demand appropriate to these two values is calculated from the relationship:

$$y = L_o (1 - 10^{-k_1 t}).$$

where y is the B.O.D. satisfied in t days, L_o the ultimate 1st stage demand and k_1 is the rate constant of oxidation. In this case since the values are from a standard B.O.D. test, the appropriate value for k_1 is 0.1 day^{-1} and for t , 5 days. Thus ultimate 1st stage demands of 21.6 p.p.m. and 10 p.p.m. are arrived at for the upper and lower stations, respectively. Subtracting the second value from the first, the actual "satisfaction" of B.O.D. in the stretch is seen to be 11.6 p.p.m. This value may now be substituted for y in the above equation, where L_o is now 21.6 p.p.m. and $t = 0.1$ days, and the relationship solved for k_1 :

$$y = L_o (1 - 10^{-k_1 t}).$$

$$\text{or } 11.6 = 21.6 (1 - 10^{-k_1 \times 0.1})$$

$$\text{so } k_1 = 3.4 \text{ day}^{-1}.$$

Data for the 6th Sept. 1968 were also used in this fashion and the value of k_1 obtained in this case was 1.8 day^{-1} .

These values do not agree very well with those obtained by extrapolation in Fig 18, but they are all of the same order of magnitude and confirm that a very high value would have to be assumed for k_1 if the mechanisms of D.O. uptake and B.O.D. satisfaction operate only in the theoretically described manner in the stretch.

It is highly unlikely that k_1 has values of this order in the present case. The estimated values are only apparent and the presence of other processes for B.O.D. removal and D.O. uptake is indicated. The factors most likely involved are the deposits of sludge on the river bed and the growths of slime organisms, especially sewage fungus communities. Velz and Gannon (1964) in the U.S.A. investigated the effects of separation and extraction from river water by slime growths of organic matter in solution and suspension and showed that this could account for the abnormal satisfaction of B.O.D. often noticed in polluted streams (e.g. the present case). The organic matter is removed from the water by a process of biophysical contact with the living floc on the substratum. It accumulates there and is oxidised over a long period of time, creating an appreciable demand on D.O. In effect, such slime growths act as an extension into the river of the percolating filter. The organisms in the sludge deposits in the slower flowing reaches are also engaged in breaking down the organic matter and consuming D.O. Owens and Edwards (1963) in comparing observed and predicted D.O. curves in a polluted English river were able to show that the big divergence between the curves, which obtained when only B.O.D. and surface reaeration rates were taken into account, was virtually eliminated when the respiration of the mud deposits was allowed for. The latter was found to be the major factor involved in the reduction of D.O. in the river investigated.

Undoubtedly, phenomena of the type described by Velz and Gannon and by Owens and Edwards are playing a major part in the D.O. regime of the polluted Funcheon and in the other polluted stretches investigated, at least near the major outfalls. This would probably apply to the polluted parts of most Irish rivers, except where these are deep and of large volume. Thus, a careful assessment of the self-purification capacity of each river, or part of a river, seems warranted. Such assessments would have to be based on

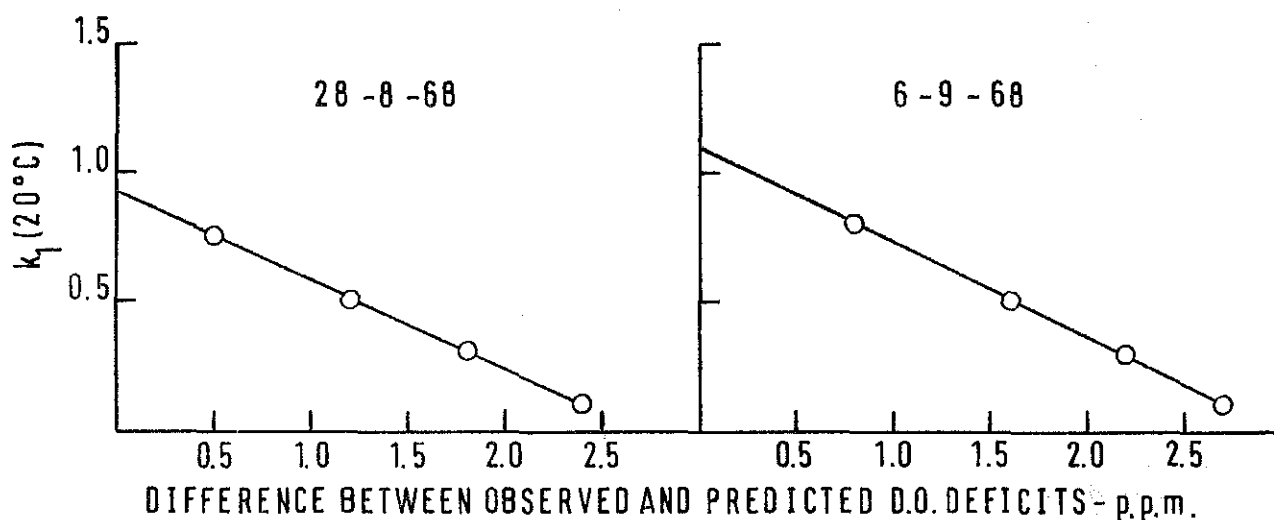


Fig. 18. Relationship between assumed values for the deoxidation constant, k_1 , and the differences between observed and predicted dissolved oxygen deficits at Kilee Bridge on the R. Funcheon at Mitchelstown, the predicted deficits being obtained using the Streeter-Phelps equation.

factors such as dilution, the rate of reaeration, the tendency for mud deposits to occur and the presence of slime growths. Several investigators (e.g. Leclerc, 1964) have suggested such assessments as a matter of course. Others, e.g. Thayer and Krutchkoff (1967), have gone further and devised procedures for obtaining probability distributions of B.O.D. and D.O. levels in rivers; this, they claim, is more useful than single, average values as provided by present methods. While it may not be possible to make such detailed studies in all cases, it seems advisable that a rough estimate, at least, should be made in the case of each effluent of significant volume of the capacity of the receiving water course to deal with the waste without a harmful loss of water quality.

(ii) Temperature, pH, Ammonia, Nitrate-Nitrogen and Suspended Solids.

Situations in which pollution caused adverse changes in the temperature or pH of the river water were not encountered in the present survey. Some of the effluents, e.g. that from the chocolate crumb factory at Rathmore, cause a rise of a few degrees in water temperature of the receiving river, but even in these cases the increased levels are well within the natural range.

Lethal concentrations of ammonia were not detected in any of the stretches under examination. In consideration of the pH and bicarbonate alkalinity ranges found in the rivers, the threshold concentration of ammonia for rainbow trout (*Salmo gairdnerii*, Richardson) in these would not be lower than about 35 p.p.m. as N. (Water Pollution Research Laboratory Nomogram for assessing the toxicity of ammonia). The highest concentration of ammonia recorded in the present case was 19.6 p.p.m. as NH_3 in the Gradoge at Mitchelstown. Elsewhere, ammonia content was not much greater than 1 p.p.m. NH_3 even in the polluted stretches. The toxicology of this compound is complex (Downing and Merckens, 1955; Lloyd and Herbert, 1960) and indicates that the soft nature of the water in the rivers would prevent the formation of the toxic species NH_3 and NH_4OH .

Nitrate levels in the rivers were not detectably increased by any of the effluents. In most cases the nitrate concentration was 1 p.p.m. as N or less, though there was a tendency for the substance to disappear, temporarily, below some outfalls. This, as Edwards (in Owens and Edwards: Discussion, 1963) points out, may be due, at least in part, to the uptake of the nitrate as a nutrient by algae.

Suspended solids were always found in very low concentrations in unpolluted parts of the rivers, the level rarely exceeding 1 p.p.m. except in floods. Marked increases in suspended solids were found in most of the polluted zones, concentrations of up to 80 p.p.m. being recorded in the Gradoge below the outfall of the Mitchelstown sewage works, up to 20 p.p.m. in the R. Martin below the creamery at Rathduff and up to 10 p.p.m. in the R. Blackwater below the outfall from the chocolate crumb factory at Rathmore. The suspended material, which is mainly of an organic nature, probably settles out quickly as in most cases pools alternate

with riffles, sludge accumulation being observed in the former below outfalls. The concentrations reached in polluted zones are well below those which are directly injurious to fish but are important from the point of view that, by increasing turbidity, they reduce photosynthesis and by virtue of their organic content create a B.O.D., when in suspension or when eventually deposited on the substratum. They may also contribute to the silting up of riffles with adverse effects on the invertebrate fauna and flora. These effects are discussed further below.

BIOLOGICAL INVESTIGATIONS

THE FLORA

The investigations of the flora of the Rivers Blackwater and Martin have been confined mainly to short qualitative surveys of the macrophytes (angiosperms, mosses and the macroscopic algae); a study of the microscopic flora was considered too specialised to be attempted in a survey of a very general nature, though a study of sewage fungus infestation was undertaken at Mallow during the beet campaign of 1968/69. Collections of the plants from riffles in the unpolluted and polluted zones were made in June 1967 and June 1968 and visual assessments of their abundance were recorded at the same time.

The effects of organic pollution on the macrophytes of rivers and streams have been described by several workers e.g. by Hawkes (1962) and by Hynes (1960). In polluted streams, the plants are subject to two main dangers; firstly, the increase in turbidity, due to solids in suspension, which curtails photosynthesis and, secondly, the increase in the silting rate which leads to changes in the nature of the substratum making this inimical to the plants of the faster flowing stretches, e.g. *Ranunculus*. There is, however, little evidence to show that low D.O. is directly injurious to macrophytes though Butcher (1933) has found indications of weakening in plants which are subject to such conditions over long periods. In addition, the presence of detergents in polluted water may be toxic to some species of plants (Roberts, 1959). Sewage fungus, which contributes to the silting up of the substratum, may also directly damage plants such as *Ranunculus* since it grows on the fronds thereby preventing photosynthesis and creating a mechanical stress on the stem which may cause the plant to break more readily in floods.

While the macrophytes are not of significant importance as food for the stream fauna they do provide substrata for a large number of microscopic organisms, mainly algae, which figure largely in the diets of many of the insect nymphs and larvae; in their turn these are important as fish food. The invertebrate fauna is usually most abundant in weed beds; Percival and Whitehead (1929) found that they could collect over half a million invertebrates per square metre in thick moss and over 200,000 per square metre in beds of pondweed (*Potamogeton* spp.). Comparable samples on different types of stony substrata, devoid of weed, yielded only between 3,000 and 4,000 animals. Furthermore, as Frost and Brown (1967) point out, the aquatic vegetation provides good lies for trout, where the fish can remain relatively undisturbed by the current and with a good food supply. Any impairment in the growth of weed in rivers is therefore likely to be detrimental to the invertebrate and vertebrate fauna.

Results :

A summary of the collections of macrophytes in unpolluted and polluted stretches in each area is set out in TABLE 1.

Angiosperms :

The most notable change in the flowering plant communities caused by pollution is the appearance of or increase in the abundance of *Potamogeton* in the riffles and the decrease in the abundance of *Ranunculus*. Such changes were shown most clearly at Rathmore, Mallow and Mitchelstown. There is a reduction in the abundance of *Ranunculus* in the polluted riffles of the R. Martin at Rathduff and Blarney, but colonisation of these by *Potamogeton* was not observed. Generally, there is a decrease in the variety and abundance of flowering plants in the polluted riffles and this appears to be a result of silting and the presence of sewage fungus. *Potamogeton* belongs to the plant community associated with the slower flowing, silted reaches and can colonise the polluted riffles as these resemble the normal habitat of the plant. The plant was found to be abundant in riffles heavily coated with slime and and seemed unaffected by the growth in contrast to *Ranunculus* the fronds of which were heavily overgrown with the slime and which in many cases was reduced to small stunted plants.

Mosses

Fontinalis (probably *F. antipyretica*) occurs in all of the areas sampled. It varies in quantity from area to area but does not appear to be adversely affected by polluted conditions. *Eurynchium riparioides* occurs in the unpolluted riffles of both rivers but, with the exception of those at Blarney, is absent from the polluted riffles. This is probably due to the presence of sewage fungus. Hynes (1960) points out that *E. riparioides*

cannot tolerate the presence of the slime and only reappears in a polluted river below the active growth zone of the sewage fungus. Its presence in polluted riffles at Blarney may be explained, therefore, by the absence of sewage fungus at that point.

Algae

A number of genera have been recorded for both clean and polluted water but since the species were not distinguished, the discussion of the effects of pollution on the algal flora of the rivers is restricted. *Stigeoclonium* (probably *S. tenue*) characteristic of waters rich in nutrients (Hynes, 1960; Westlake and Edwards, 1956) occurs in the polluted zones in close association with sewage fungus in the Blackwater at Rathmore and the Funcheon at Mitchelstown but was not recorded elsewhere. The abundance of *Stigeoclonium* in organically polluted riffles has been reported by several workers in England, e.g. by Hawkes (1964), Butcher (1947) and Pentelow, Butcher and Grindley (1938). Hynes (1960) says that it is found in similar situations in America.

Sewage Fungus

The presence of sewage fungus is a marked feature of the heavily polluted parts of the rivers investigated. In most cases the infestation is confined within a short distance of the outfall though the growths, especially in the Gradoge and Funcheon at Mitchelstown, are heavy. Since, with the exception of that at Mallow, the effluent load is usually reduced or absent in winter, the growths are significant only in summer and autumn. At Mallow, however, the beet campaign of autumn and winter results in a large amount of waste entering the Blackwater which stimulates a heavy and widespread infestation of sewage fungus (known locally as "lambs' tails"). During summer, sewage fungus growths are confined to a distance of less than a quarter of a mile (0.4 km) below the outfall, even during the summer vegetable campaigns, but in winter the growth may extend for fifteen miles (24 km) downstream at times of low flow. The periodic flooding of the river in winter reduces growth by scouring the substratum, but regrowth is rapid.

It was decided to carry out an investigation of sewage fungus growths at Mallow where, in addition to the severity of the infestation, the river water is regularly analysed for D.O. and B.O.D. content by the chemist at the Beet Sugar factory; measurements of total phosphorus, soluble phosphorus and carbohydrate were also made during the period of the investigation.

The amount of slime accumulating on the undersurfaces of PVC plates (700 sq. cm) held horizontally in the water was measured in a range of current velocities at each of three sites, designated A, B and C which are 1.7, 4.8 and 8.7 ml (2.8, 7.7 and 14 km) respectively below the outfall from the beet sugar factory. Site B is 2 ml (3.2 km) below Mallow sewage outfall (see Fig. 3). The plates were cropped weekly in so far as this was possible, the collected slime being dried to constant weight at 100°C. Organic content was determined by the loss of weight on ignition at 500°C for three hours. This work was carried out during the beet campaign of 1968/69; severe flooding towards the end of the campaign restricted greatly the frequency with which the plates could be examined and the estimations of weekly crops were few in number.

A summary of the chemical conditions prevailing at each site during the period of the investigation, together with measurements made at a control station in unpolluted water above the factory, is set out below (mean of measurements with ranges in brackets):

	Control	A	B	C
B.O.D.p.p.m. ...	2.2 (1.2-3.4)	3.2 (2.2-4.0)	2.5 (1.2-4.0)	2.7 (1.4-4.4)
D.O.% sat. ...	87 (68-115)	80 (62-103)	75 (58-110)	74 (58-103)
Temp°C ...	10.6 (7.7-14.2)	10.6 (7.3-14.6)	10.6 (7.0-14.7)	10.6 (7.2-15.0)
pH ...	7.8 (7.4-8.0)	7.6 (7.3-7.9)	7.7 (7.3-8.0)	7.7 (7.3-8.0)
*Total P. p.p.m. ...	0.6 : 0.8	0.5 : 0.5	0.4 : 0.3	0.4 : 0.1
*Soluble P. p.p.m. ...	0.01 : 0.01	0.01 : 0.01	0.01 : 0.01	0.01 : 0.01
*Carbohydrate p.p.m. ...	0.2 : 0.2	0.4 : 0.3	0.2 : 0.2	0.2 : 0.1

*Two measurements only of phosphorus and carbohydrate were made and both of these are shown. On the left are those made at a time of high river flow and on the right are results of analyses made at low flow.

The data show that there is very little rise in B.O.D. at sites A, B and C compared with the control station. The gradual decrease of D.O. concentration with distance downstream shows signs of arrest at site C. Soluble and total phosphorus appear to be unaffected by the discharge, though total P decreases below the outfall, and this may indicate absorption by the slime. Carbohydrate shows a slight increase at A and declines thereafter.

Fig. 19 summarises the data obtained from the experiment. "Total crop" indicates that trapped sediment is included in the dry weight estimation. The change in species composition throughout the zone of study may, in the opinion of Dr. E. J. C. Curtis of the Water Pollution Research Laboratory, Stevenage, England, who kindly identified two sets of samples, be due to the increasing dilution of nutrients. Though not listed in the figure, a vorticellid protozoan, possibly *Carchesium spp.* was common at site C early in the investigation, disappearing from later samples. This may indicate that the area of infestation was expanding continuously as Hynes (1960) says that these forms usually occur most abundantly near the lower end of the sewage fungus zone. A cursory examination in December, 1968 did indeed show that the slime was present for up to six miles further downriver.

There is apparently no drop in total growth (Fig 19a) over the area investigated. This may be due to the addition of several organic effluents beyond Site A, which could maintain the concentration of vital nutrients, which might otherwise become limiting. The examination of the river at a point about six miles downstream of site C did indicate that the infestation was lessening at this stage. Fig. 19b indicates that the growth of the slime may be inhibited at current velocities lower than 20 cm/sec and higher than 60 cm/sec. Best growth is obtained at velocities between 30 and 50 cm/sec. The higher organic content of growths in higher current velocities (Fig 19c) is probably related to the decreasing rate of deposition and accumulation of silt.

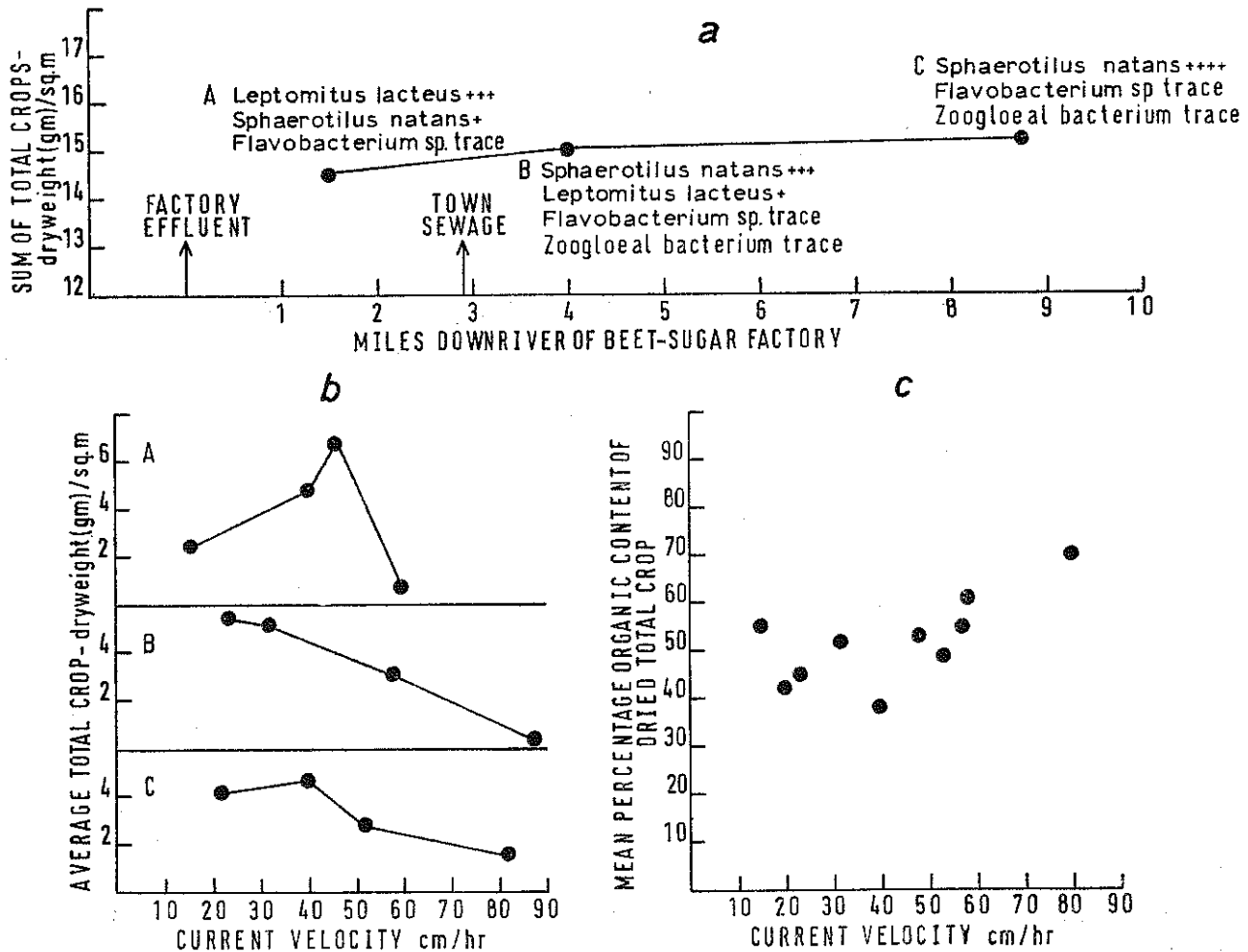


Fig. 19. Results of the measurements of the sewage fungus infestation in the R. Blackwater at Mallow during the beet-sugar campaign of 1968/69. a. Comparison of the sums of the total crops for sites A, B and C; the composition of the community at each site is indicated. b. Relationship of the average total crop to current velocity at each site. c. Relationship between the organic content of the dried total crop and current velocity

The phenomenon of slime growth response to organic pollution has been reviewed by several workers, e.g. Butcher (1932), Hynes (1960), and Curtis (1969). The community is usually composed of several species of bacteria and fungi and certain protozoa may also be present. Butcher lists the following organisms, any of which may be found in the complex:

Bacteria: <i>Sphaerotilus natans</i>	Fungi: <i>Leptomitius lacteus</i>
<i>Cladothrix dichotoma</i>	<i>Fusarium aquaeductum</i>
<i>Zoogloea ramigera</i>	<i>Penicillium fluitans</i>
<i>Beggiatoa alba</i>	
Protozoa: <i>Carchesium Lachmanni</i>	
<i>C. spectabile</i>	

Research (Bahr 1953, Pringsheim 1949) suggests that *Cladothrix dichotoma* is, in fact, a growth form of *Sphaerotilus*. It also appears that the iron bacterium, *Leptothrix ochracea*, is another form of *Sphaerotilus*.

Usually only one or two species occur in the community, and the forms most commonly met with are *Sphaerotilus natans* and *Leptomitius lacteus*. These are the two species which occurred in appreciable quantities at Mallow. Hawkes (1962) says that *Leptomitius* is not common in Britain, but it is important in continental rivers. Hynes (1960) is in agreement with this. The occurrence of the fungus at Mallow, in dominant quantities at site A, may be somewhat unusual.

The most pertinent question to be asked in regard to sewage fungus infestations is what factor, or factors, trigger them off. The obvious answer would appear to lie in increased supply of nutrients. However, the data on the factors measured in the current study, which can be taken to be connected with the food supply of the slime community, viz. B.O.D., phosphorus and carbohydrate, show little or no increase in concentration compared to areas upstream where the growths did not occur. It is, perhaps, worthy of note that Amberg and Elder (1956) record a heavy infestation in water with a B.O.D. of only 1.4 p.p.m. Wuhrmann (1954), who produced growths in artificial channels, showed that the routine B.O.D. test gave a very poor indication of the intensity of slime growth to be expected. He expressed the opinion that the type of pretreatment given to wastes had a marked bearing on their slime promoting capacities. Dissolved oxygen and temperature levels in the river are, however, consonant with good growth. The growth requirements of *Sphaerotilus natans* and *Leptomitius lacteus* have been reviewed by Harrison and Heukelekian (1958) and a pH of 7.6: at site A seems from their data to be unfavourable to the fungus. The organism was found to grow best in a slightly acid medium. Nonetheless, *Leptomitius* dominated the community at site A. Nutrients not measured in the survey were compounds of nitrogen and the necessity of organic N for the promotion of luxuriant slime growths is well founded (Hawkes 1962; Harrison and Heukelekian, 1958). It is quite likely that the beet factory effluent contains such compounds. In regard to other nutritional factors, *Sphaerotilus* does not need accessory growth factors, but does require phosphorus. The position with respect to *Leptomitius* is unclear.

In addition to chemical factors in the environment, certain physical factors may be involved in widespread outbreaks of sewage fungus, as at Mallow. It is usually noted that infestations in summer are confined to short distances. The opposite is the case in winter and since beet sugar campaigns are carried out at this time, the effects are usually most noticeable below factories of this nature. Butcher, Pentelow and Woodley (1931) quote cases of infestations covering distances of from six to twenty miles (10 to 30 km) in various rivers receiving wastes from beet sugar plants. It has already been stated that the River Blackwater is affected for up to fifteen miles (24 km) at times, during a campaign. Why outbreaks should be so widespread in winter has been speculated on by many workers. Harrison and Heukelekian (1958) conclude that increased growths in winter may be due to a better supply of D.O. and to a greater accumulation of cells, because of decreased metabolism. More relevant to the Blackwater, perhaps, they also find that if food is a limiting factor (and not D.O.—the Blackwater is usually relatively well oxygenated below the factory), then the greatest amount of growth per unit distance will be found in rivers with a lower flow. Larger flows will tend to spread the growth over long distances. In addition, because of higher water temperatures, wastes will be more quickly broken down in summer, whereas in the colder water of winter, katabolism will be retarded and nutrients will be available over a longer distance. Other possible explanations have been put forward. Amberg and Cormack (1960) showed that, in summer, *Sphaerotilus* was unable to compete with algae for phosphorus, which was a limiting factor, and growth was restricted. Hawkes (1962) suggests that at lower temperatures *Sphaerotilus* is more successful than other heterotrophic bacteria in the uptake of nutrients.

The range of current velocities may also have a bearing on the promotion of slime growths. *Sphaerotilus* grows very little below 20 cm/sec. (Hawkes, 1962) but little is known of the upper limit. From the Mallow data, it is seen that good growths were obtained at least up to 50 cm/sec.; over 60cm/sec. and below 20 cm/sec.

growth drops off. Current is important in the supply of nutrients and oxygen to the slime community—sewage fungus is not at all indicative of anaerobic conditions, as is sometimes thought. However, very fast flows scour the growths from their attachments and prevent the development of the typical tufts ("lambs' tails"). Hawkes mentions the case where good growths may be found at the banks and on larger stones, while very little growth occurs on the main substratum, due to its instability in high current speeds. This was very often found to be the case in the River Blackwater; heavy masses of slime were seen attached to flooded grass at the banks, and to fronds of *Ranunculus* in the main stream, whereas on the bed of the river very little was observed. This was especially so after a flood.

The winter of 1968/69 was, generally, unfavourable for the development of a very heavy growth of slime because of frequent floods and for much of the period the bed of the river was relatively clean. The seriousness of future infestations will probably continue to be governed by winter rainfall. No practical remedial measure would seem to be available, unless a single vital factor in nutrition can be determined and then removed from the effluent; but this seems unlikely. The measures proposed by several workers to control growth by limiting the discharge of all wastes to short periods and retaining them in reservoirs for most of the time, has been successfully carried out in the field by Amberg and Cormack (1960). Whether this would be successful in the present case, even if storage were possible, is debatable; certainly the effects on factors such as D.O. might be greatly aggravated and lead to more serious situations such as the death of fish.

Some consideration should be given to the long-term effects of these annual slime growths on the general nature of the river bed. It has been noticed that large amounts of silt are trapped by the growth and parts of the river below the factory are becoming more muddy, these conditions persisting after the infestation has disappeared. Such a situation was also found by Butcher, Pentelow and Woodley (1931) below a beet-sugar factory on the English R. Lark. The effect of mud on the D.O. regime has already been discussed while the adverse changes brought about in the invertebrate fauna in such situations are described below.

THE INVERTEBRATE FAUNA

The fact that the animal and plant communities of rivers and streams show characteristic changes in density and composition in various conditions of pollution has long been recognised. In England, the investigations on the Lark (Butcher, Pentelow and Woodley, 1931), on the Bristol Avon (Pentelow, Butcher and Grindley, 1938) and on the Tees (Butcher, Longwell and Pentelow, 1937) included detailed examinations of the manner in which the invertebrate fauna was affected by organic pollution. Many of the basic changes commonly observed in the animal communities in such conditions were codified in these and similar surveys, e.g. by Patrick (1950) and Gauhin and Tarzwell (1956) in the U.S.A., Huet (1949) in Europe and Harrison (1958) in S. Africa. One of the first studies of the connection between chemical parameters and the invertebrate faunas of polluted rivers and streams was that of Kolwitz and Marsson (1908, 1909) in devising their well known Saprobien system for the classification of polluted waters; this scheme has since been greatly extended and renewed (Sladeczek, 1965, 1967). Hynes (1960) and Hawkes (1962) have reviewed most of the major researches on the response of the invertebrate fauna to organic pollution.

The animal communities of a river or stream may be conveniently regarded as belonging to two major types. The first are those found in the parts of the river or stream where the current is fast enough to prevent silting. In this zone all the animals show some adaptation, either in structure or behaviour, by which they counteract the scouring action of the current. Thus, they may be flattened forms (e.g. the Ecdyonuridae) or possess attachment organs (e.g. *Simulium*); others, such as many of the Coleoptera, Trichoptera and Plecoptera, live between stones or among moss and other plants and are provided with strong claws and spines for clambering about in these places. The basic food for such communities is the sessile algal growth on the surfaces of the stones and plants as well as allochthonous matter such as dead leaves and other organic debris. Many of the inhabitants of this zone require a relatively high saturation of D.O. and cannot withstand great rise in temperature. Most of the insects, which make up the bulk of the fauna in streams and rivers, are in the egg stage in summer because their nymphal or larval forms cannot survive in the high water temperatures which occur at that time.

The second group of animal communities, those living in the silted reaches of the stream, are mainly of the burrowing or crawling type and feed to a great extent on the organic fraction of the material which is deposited on the substratum. Relatively low D.O. and high temperatures may occur in these reaches in summer and the animals are, therefore, relatively tolerant of such conditions. Some, such as the Tubificidae or *Chironomus*, have haemoglobin in their body fluids which allows them to live in conditions bordering on the anaerobic. Therefore, in studying the invertebrate fauna with respect to organic pollution it is less useful to consider the communities of the silted reaches since these, even under natural conditions, experience in some degree the low D.O. and silting caused by organic wastes and will not, on this account, show a marked response to such pollution. On the other hand, the animals of the faster areas (riffles) which have a much lower

tolerance of D.O. depletion and which need clean rock and plant surfaces to enable them to maintain their position are much more likely to be affected by pollution. Thus, in most investigations of the response of the invertebrate fauna to organic pollution, work is concentrated on the riffle communities (Hawkes, 1964). It should, however, be mentioned here that such an approach may not suffice in cases of pollution by toxic substances since some of the animals, e.g. the Plecoptera, which are among the more intolerant of low D.O. are yet able to withstand relatively high concentrations of, for instance, metal ions like zinc which are directly poisonous (Jones, 1940).

The realisation that the invertebrates show definite patterns of change in conditions of pollution has led to attempts by many workers to use the animals as a means of assessing the grade of pollution. While the case for an equal standing for biological with chemical and physical criteria has been advanced in the literature over the last twenty years (Butcher, 1946; Patrick, 1950; Gaufrin and Tarzwell, 1952; Hynes, 1959, 1960; Hawkes, 1964) the subject is still a somewhat controversial one; even amongst biologists themselves there is disagreement concerning the manner in which biological data should be presented. On the one hand there are those (e.g. Beck, 1955, 1957; Burlington, 1962; King and Ball, 1964) who prefer to present the data on the fauna of polluted zones in the terms of reference of that of the unpolluted river, either graphically, or numerically; on the other hand several workers, more notably Hynes (1960) and Brinkhurst (1966), have severely criticised such procedures, regarding them as over-simplifications of very complex situations; they recommend the use of straightforward species lists for each station worked. The former methods are most commonly used in the U.S.A. and on the European continent, the Saprobien system being the basis for these in the latter area. Most English workers have preferred the straightforward listing of species though there are exceptions, notably the Trent River Authority, whose biologists use a Biotic Index System (Woodiwiss, 1964) to present the data arising from biological investigations in the rivers of the Trent system.

Whatever the manner in which the results of biological surveys of polluted rivers are presented, there is no doubt that they form a very valuable tool in such surveys. Basically, the contrasting of biological and chemical approaches to pollution detection and assessment is invalid since the two are complementary. Neither is capable, on its own, of giving a full description of the conditions. While chemical tests are far more precise, biological data can show more reliably the general state of and past history of pollution in a river since the animals, individually, spend relatively long periods there; chemical samples, on the other hand, are taken only at single points in time. There is evidence also that the stream invertebrates may be more sensitive to very mild pollution than are chemical tests (Hynes, 1965) while, with an adequate knowledge, the sampling and working up of biological samples is no more time-consuming than standard chemical procedures especially the B.O.D. test. It should be mentioned here that it is the larger forms of the invertebrate fauna, "the macroinvertebrates", which are normally considered in biological surveys; these are more easily sampled and identified than groups such as the Protozoa and Rotifera, though the latter have also been used extensively. With an increase in the understanding of the biotic requirements of each species the value of the biological methods of pollution assessment will become greater and perhaps help to clarify some of the chemical phenomena involved.

Methods

Two surveys of the invertebrate fauna were carried out during the investigations, the first between August 1966 and April 1967, the second between June 1968 and March 1969 (Blackwater and Funcheon only). Sampling was confined to riffles and several stations were worked in the unpolluted and each of the polluted zones (see below).

In the earlier survey, sampling was of a qualitative nature, a pond net (10 meshes/cm) being used to collect animals over a wide area of the stream bed at each point. The net was held vertically against the substratum with the mouth pointing upstream and material, dislodged by kicking with the boot, allowed to drift in. Samples from different stations were made roughly comparable by limiting the collecting time to 10 minutes. This method of sampling has been recommended by several workers e.g. Morgan and Egglisshaw (1965), Hynes (1960) and Macan (1958) as being more useful than the area density methods (grabs, frames and scoops) when sampling stony substrata. Animals living in such conditions are not randomly distributed and are unlikely, therefore, to be sampled adequately when only limited areas are covered. Needham and Usinger (1956) found that a very large number of samples had to be taken with a Surber frame in riffles in order to obtain a statistically valid mean for the numbers of animals on the substratum. By ranging over a wide area at each station with the pond net, the non-random distribution of the animals is compensated for and, in addition, as most of the micro-habitats are sampled, the list of species obtained should be reasonably complete.

In the 1968/69 survey an attempt was made to obtain an estimate of the absolute numbers of animals present per unit area, using a Surber sampler. Sampling was carried out separately on weed and on stones and usually three samples were taken in each case.

Identification of the organisms taken in these surveys was made from the following volumes:

Platyhelminthes	Tricladida	Reynoldson 1967
Annelida	Oligochaeta	Brinkhurst 1963
	Hirudinea	Mann 1964
Crustacea	Malacostraca	Hynes, Macan and Williams 1960
Mollusca	Gastropoda	Macan 1960
	Lamellibranchiata	Ellis 1962
Arachnida	Hydrachnellae	Soar and Williamson, 1925, 1927, 1929
Insecta	Ephemeroptera	Macan 1961
	Coleoptera	Balfour-Browne, 1940, 1950, 1958
		Joy 1932
	Trichoptera	Hickin 1967
	Plecoptera	Hynes 1958
	Diptera	Macan 1959

Results

The composition of the various samples taken throughout the investigations is set out in Tables 2—14.

In order to simplify the presentation of the data, the organisms comprising the samples in each case have been classified in sixteen groups. Fifteen of these are taxonomic divisions, the last being a miscellaneous group. The taxonomic divisions were chosen so that the numbers of specimens involved in each would be sufficiently large to show significant differences between samples from unpolluted and polluted water, where such existed, and that they would be sufficiently small to show the effects on different types of organisms. Thus, it was possible to divide up the order Ephemeroptera into two families and one genus since the number of each sub group was in most samples relatively large. On the other hand the Plecoptera had to be grouped at order level since the numbers in lower taxonomic divisions were, in most cases, very small.

In describing the composition of the fauna in unpolluted and polluted parts of the river a scheme of zonation has been adopted to distinguish between the various grades of pollution in which the samples were taken. These zones are designated 0, 1, 2, 3 and 4 the numbers indicating the degree of pollution at the points at which samples were taken, as follows:

- 0: The unpolluted zone; high saturations of D.O. (80—120 per cent) and low B.O.D. (less than 3 p.p.m.); stones and weeds clean.
- 1: The mildly polluted zone; the stretch of a river below an outfall of effluent of relatively small volume, in which D.O. is not seriously affected (usually greater than 70 per cent of saturation) though B.O.D. may be as high as 10 p.p.m. Sewage fungus sparsely developed or absent but algae usually make stones and weed slimy.
- 2: The recovery zone; stretch of river some distance below a major outfall of waste having immediate severe effects on water quality, in which conditions are improving again; resembles Zone 1 but D.O. usually lower (less than 70 per cent saturation); B.O.D. usually less than 5 p.p.m.; Sewage fungus may be present but is usually near the end of its strongly growing zone; algae usually abundant. Conditions in this zone will vary with the distance from the main outfall.
- 3: The post-dilution zone; stretch of a polluted river below the entry point of a clean tributary; conditions in this zone will vary depending on the stage at which the tributary enters the main river, i.e. either into Zone 4 or Zone 2 of the latter; water quality may be similar, therefore, to Zone 0, 1, or even 2; algae usually abundant, sewage fungus usually absent.
- 4: The heavily polluted zone; the stretch of a river immediately below a major waste outfall where D.O. may be severely depleted, sometimes zero, and rarely higher than 60 per cent in summer; B.O.D. usually very high (up to 90 p.p.m.) and not normally lower than 10 p.p.m. on average. Sewage fungus and algae abundant.

These zones are based on summer conditions, except in the case of the Blackwater at Mallow (see later). Due to lessening in effluent flow and increase in river discharge, marked improvement in water quality occurs in polluted zones in winter and spring so that, on the above classification, points regarded as being in a particular zone in summer were usually not such in winter and spring. However, for convenience and clarity it was considered preferable in most cases to retain the designations of summer for the whole year.

Zone 0 in each case is the stretch immediately upstream of the first source of pollution. The mildly polluted zone of the Blackwater at Rathmore is the stretch between the entry points of the effluent from the small sewage works and of the stream carrying milk wastes and the outfall of the chocolate crumb factory (see Fig. 2). Between the latter point and the confluence with the clean Awnaskirtawn tributary is the heavily polluted zone, while Zone 3 lies below the confluence. In autumn 1966 and spring 1967 the station in the latter zone was located about quarter of a mile below the confluence but in winter 1966 it was located three miles further downriver just above the entry point of another clean tributary, the Owentaraglin. The mildly polluted zone in the R. Blackwater at Mallow is, in spring and summer, the stretch between the outfall of the beet sugar/food processing plant and the town sewage outfall (see Fig. 3). However, in autumn and winter this stretch, along with that immediately below the town, which is always heavily polluted, must be regarded as Zone 4, because of the entry during that period of large amounts of waste from the beet sugar factory. Recovery zone stations are at 2 and 6 miles below the town in summer and spring but in autumn and winter the upriver station is in Zone 4, while recovery stations are then at 6 and 9 miles below the town.

The stretch of the Gradoge stream between the outfall of the Mitchelstown sewage works and the confluence of that stream with the Funcheon and the stretch of the Funcheon itself between the confluence and Kilee Bridge is all regarded as Zone 4 (see Fig. 4). Between Kilee Bridge and Marshalstown Bridge the river may be regarded as mildly polluted (Zone 2) while beyond its confluence with the clean Sheep R. is Zone 3 of the Funcheon.

A mildly polluted zone is recognised in the Martin R. at Rathduff in the vicinity of the point at which the stream becomes polluted by sprayed piggery wastes and a heavily polluted zone immediately downstream of the creamery (see Fig. 5). Tributaries enter the Martin almost immediately below the latter point and stations further downstream are therefore regarded as being in Zone 3. Below Blarney the water quality of the Martin is only slightly affected and the stretch is regarded as Zone 1.

The composition of the samples in the 1966/67 collections (TABLES 2 to 10 incl.) is given in the form of percentages. This has the advantage of allowing rapid comparison between the essential features of the faunas of different zones. The presence, however, of very large numbers of one group of organisms in samples, where these do not appear to be directly related to pollution, is likely to bias the percentage composition of other groups, making comparison difficult. In some of these cases, therefore, e.g. the Simuliidae at Mitchelstown, the abundant groups have not been considered when calculating percentages, the actual numbers being given instead. Actual numbers, only, have been given in the case of the 1968/69 collections (Tables 11—14 incl.) as in most cases these were relatively small. In the latter survey only two stations, one in the unpolluted and the other in the heavily polluted zone, were worked, except at Mallow where the stretch between the beet sugar factory and the town was sampled as a heavily polluted zone in autumn and winter, 1968, and as a mildly polluted zone in summer 1968 and spring 1969.

The main changes which occur in the composition of the invertebrate fauna in the polluted reaches are readily seen from a perusal of TABLES 2 to 14 incl. While it is not felt necessary, therefore, to describe these in detail for each location, the salient features of the distribution between unpolluted and polluted zones for each faunal group in turn will be considered briefly. A list of the animals collected in each area is set out in Appendix B.

Oligochaeta

The oligochaete worms were not found to be a very important group in the unpolluted reaches, 6.9 per cent of the total numbers taken in the Martin R. at Blarney in winter 1966 being their greatest expression in these. Marked increases in density were, however, always recorded in the polluted zones, especially in Zone 4 of the Gradoge, Funcheon and Martin R. at Rathduff; in these reaches the Oligochaetes accounted for up to 60 per cent of the total numbers taken in samples. Their abundance usually appeared to fall rapidly in the recovery zones. While increases in the density of Oligochaetes were recorded in the polluted zones of the Blackwater at Rathmore and Mallow these were of a much lower order than those at the other locations. Most of the specimens taken in polluted zones were Lumbriculidae and Tubificidae.

Hirudinea

The leeches as a group were, like the Oligochaetes, an important part of the fauna in the polluted zones, though at two locations only, Rathmore and Mallow. At the former, the leeches accounted for 21.5 per cent of the numbers in the samples from Zone 4 in winter 1966, while they accounted for 45.9 per cent of a Zone 4 sample at Mallow in autumn 1966. Most of the specimens were *Erpobdella octoculata* and, at Rathmore particularly, *Helobdella stagnalis*. It is significant that leeches were numerous at those locations where Oligochaetes were not markedly abundant. There is usually found to be an inverse relationship between the density of the two groups in polluted water because of the predatory activities of the leeches. (Brinkhurst, 1966).

Gammarus

The Amphipod *Gammarus duebeni* was an important constituent of the unpolluted zone samples at all locations, being particularly numerous in those from the Gradoge and Funcheon at Mitchelstown. However, it appeared to be severely affected by pollution, being found in very small numbers in mildly polluted and often not at all in the heavily polluted zones. A gradual increase in numbers was usually noted at recovery zone stations.

Asellus

The Isopod, *Asellus aquaticus*, was not taken in collections from unpolluted water but appeared in those from the polluted zones of the Blackwater at Mallow and Funcheon at Mitchelstown. This species is a member of the silted river community and its invasion of riffles in polluted conditions is a well known phenomenon (Hynes, 1960).

Baetidae

The ephemeropteran family, Baetidae, was one of the most important groups in the samples from the unpolluted reaches of all areas. Three species, *Baetis rhodani*, *B. pumilus* and *B. scambus* were present, the first of these being by far the most numerous, while the last, a summer growing form, was only taken in summer and autumn samples. The Baetidae, while usually scarce or absent in samples from Zone 4, were often present in very large numbers in those from Zones 1 and 2. However, in the latter samples nearly all specimens were *B. rhodani*. The unusual tolerance of this species to organic pollution is well founded (Hynes, 1960; Woodiwiss, 1964).

Ecdyonuridae

The flattened nymphs of the ephemeropteran family, Ecdyonuridae, were an important group in the samples from unpolluted reaches in winter and spring, being represented in these by three species, *Ecdyonurus venosus*, *Heptagenia sulphurea* and *Rhithrogena semicolorata*. The last was particularly numerous at Mallow in spring 1967. These forms were found to be severely affected by pollution being, in most cases, absent from Zone 4 and very scarce in Zones 1 and 2.

Ephemerella

The ephemeropteran family, Ephemerellidae, was represented in the samples by one species, *Ephemerella ignita*, which appeared to be very common in summer and autumn in unpolluted water. Very large numbers were taken in the Funcheon and Gradoge. The nymphs were usually absent from Zone 4 samples and greatly reduced in abundance in Zones 1 and 2 samples.

Plecoptera

While the stonefly nymphs were, in summer particularly, only a relatively minor group of the fauna of unpolluted reaches, they demonstrated the most marked reaction to pollution. They were usually found to be very scarce, or absent entirely, from the whole of the polluted reach, only reappearing in pre-pollution numbers in some of the Zone 3 samples. Eleven species were recorded but of these only *Leuctra fusca* in summer and autumn and *L. hippopus* and *Protonemura meyeri* in winter and spring, were at all numerous.

Trichoptera-free

The uncased caddis larvae of the families Hydropsychidae, Polycentropidae, Rhyacophilidae and Philopotamidae were relatively numerous in collections from unpolluted water especially in the Blackwater at Rathmore and Mallow. These organisms were usually scarce or absent in samples from Zone 4 at each location, but were often found in large numbers in Zones 1 and 2. This applies particularly to *Hydropsyche* spp. in the Blackwater at Mallow, where high densities of these forms were taken in the recovery zones.

Trichoptera-cased

The case-bearing caddis larvae, represented in the collections chiefly by the families Glossosomatidae, Limnephilidae and Sericostomatidae, were only a small element of most of the collections from unpolluted water. An exception was the Glossosomatid, *Agapetus fuscipes*, which was found in very large numbers in the Funcheon in winter and spring. In polluted water these forms were always found to be severely restricted or absent.

Coleoptera

The water beetles in the collection were represented mainly by the larvae and adults of three species of the Helmididae, *Latelmis volkmari*, *Esolus parallelipedus* and *Limnius tuberculatus*. These small beetles were numerous in most of the collections from unpolluted water, particularly those from the Gradoge at Mitchelstown. In the polluted zones the densities of both adults and larvae were in all cases markedly reduced.

Chironomidae

Time did not permit the identification of the species comprising this group of organisms in the collections; as is, unfortunately, inevitable in most surveys of the invertebrate fauna of streams, they had to be treated as a group. The Chironomids were one of the most numerous groups in both unpolluted and polluted zone samples; in the autumn 1966 collections from the Blackwater at Rathmore, the group accounted for 44 per cent of the total numbers in the unpolluted zone samples and 84 per cent in the Zone 4 samples. In most of the samples taken in the latter zones the Chironomids were the main element, the only other group to rival them in abundance in these reaches being the Oligochaeta. They were also usually the most numerous forms in Zone 2 samples.

Simuliidae

The Simuliidae were numerous in most samples taken in unpolluted zones but particularly so in the Gradoge and Funcheon at Mitchelstown where huge colonies of the larvae and pupae were present on weed such as *Ranunculus*. The group did not appear to be adversely affected by pollution being taken in large numbers on several occasions in Zones 4 and 2 in the Funcheon. It is possible that the abundance of the Simuliidae is more connected with weed density than pollution, the scarcity of these forms in some of the polluted zones being due to the destruction of the weed by sewage fungus.

Other Diptera

Small numbers of the larvae of Tipulidae, Ceratopogonidae and Anthomyiidae occurred in collections from unpolluted and polluted zones. The numbers taken were rather small so that indications of changes in density due to pollution were not marked. There was, however, a definite tendency for the Tipulids *Dicranota* spp. to be absent from polluted zone samples.

Mollusca

The molluscs were not particularly numerous in collections from unpolluted zones. The most commonly occurring forms in these areas were the small limpet-like *Ancylastrum fluviatile* and the snails *Potamopyrgus jenkinsi*, *Limnaea pereger* and *Physa fontinalis*. The group appeared to be relatively tolerant of pollution, being taken in small numbers in most of the Zone 4 samples, while large numbers of *A. fluviatile* were often recorded in Zones 1 and 2. The astronomical numbers of *P. jenkinsi* taken in samples from the R. Martin below Blarney call for some comment. Very little deterioration in water quality is noticeable below Blarney though there are abundant growths of algae in that reach compared to very little in the river above the town. Whether the huge densities of the snail were due to pollution is hard to say but it may be significant that this was the only point investigated at which an effluent containing other than animal and plant wastes is discharged. The composition of the wastes from the woollen mill at Blarney has been described above.

Others

Placed together in this group are water mites (Hydracarina), flat worms (Tricladida) and the small may flies (*Caenis* spp.). These forms showed a rather erratic distribution in each area which could not be directly related to pollution. The occurrence of large numbers of *Caenis rivulorum* in the recovery zones of the Blackwater at Mallow in spring 1967 may have been due to the silted conditions brought about by the beet sugar factory effluent. The nymphs thrive in such conditions.

It is clear from the above remarks and from the data given in TABLES 2 to 14 that there are differences both in composition and abundance between the invertebrate faunas of the unpolluted and polluted zones of the rivers in each area. In the unpolluted reaches the fauna is dominated by groups such as the Baetidae, *Gammarus*, Coleoptera and Trichoptera, which are important at all times and by other groups which are particularly abundant at certain periods only in the year, e.g. the Chironomidae and *Ephemerella* in summer and autumn and Ecdyonuridae and Plecoptera in winter and spring. In the polluted zones, however, the fauna is at all times numerically dominated by the Oligochaeta, Chironomidae, Hirudinea or Mollusca. The common and numerous animals of the unpolluted reaches are very scarce in or even absent from the heavily polluted zones and most of them are also reduced in number in the mildly polluted and recovery zones. There are exceptions, e.g. *Baetis rhodani* and *Hydropsyche* spp. which appear to tolerate mildly polluted conditions often reaching very high densities in such zones, either due to an increased food supply or lack of competition; however, even these cannot withstand the conditions of the heavily polluted zones, at least in summer and autumn.

Not only is the composition of the invertebrate community changed in polluted conditions but the density is usually very much greater there than in the unpolluted reaches of the river. For instance, 4,673 animals were taken in the sample in the heavily polluted reach of the R. Blackwater at Rathmore in Autumn 1966 compared to 1,476 in the unpolluted reach. The difference between clean and polluted water samples was even more marked in the Martin R. at Rathduff at the same period. The increased numbers of animals in polluted zones is usually due to the very high densities of Chironomidae or Oligochaeta in these places, but of interest are the very large numbers of *Baetis rhodani* which occurred, especially in spring, in samples from mildly polluted and recovery zones.

Generally there is a steady improvement in faunal diversity throughout the polluted zones and some of the TABLES show the complete sequence from the most severe effects to complete recovery. For the most part the recovery pattern exhibits in reverse the deterioration recorded in mildly polluted zones, which are present at Rathmore and Mallow (in summer and spring) on the Blackwater and at Rathduff and Blarney on the Martin R. Thus the first of the normal riffle animals to reappear in large numbers following severe pollution are relatively tolerant forms such as Baetidae and *Hydropsyche* spp. and these are followed at later stages by more sensitive types such as *Gammarus* and *Ephemerella* and lastly by the forms most affected by pollution, the Ecdyonuridae and Plecoptera. The recovery of the last two groups was not always covered in the sampling surveys, since it is not usually accomplished in a short distance (although Zone 3 stations are an exception—the rapid recovery of the fauna due to dilution of the polluted main river by a clean tributary is well demonstrated by the data for Rathmore in autumn 1966 and spring 1967—TABLES 2 and 8).

In addition to recovery with distance downstream it was also noticed that some improvement in faunal quality occurred in the polluted zones between autumn and spring in most cases. The recovery was indicated by the presence in winter and spring samples from these zones of clean water forms which appeared to have been absent from samples taken there in summer and autumn. In addition, the density of some groups, which was very small in summer and autumn samples, increased in the samples of winter and spring. This improvement is probably due to the reduction in effluent flow and increase in river flow in winter, which leads to better water quality and less impairment of the substratum. Recovery of this nature in faunal quality is different in its procedure to that observed at increasing distances downstream of an outfall and may be much more rapid due to the immigration of clean water forms from tributaries, or from upriver unpolluted reaches (Brinkhurst, 1965). The position in the Blackwater at Mallow is an exception, however, since here large volumes of waste are discharged between October and January each year, during the beet campaign. Sewage fungus carpets the bed of the river for distances up to fifteen miles below the beet factory at this time and samples of the fauna taken throughout the campaign of 1966/67 showed that the number and diversity of animals were greatly reduced for a similar distance; most specimens were covered with filaments of *Sphaerotilus*, many being apparently dead on capture. However, rapid recovery occurs after the termination of the campaign.

It is worth pointing out, in connection with the surveys of 1968/69, that in most cases the fauna of the unpolluted reaches and of the polluted reaches was found to be far more abundant in the weed beds, though there were animals, e.g. the Ecdyonuridae, which were mainly confined to stones. This may explain why, in the 1966/67 survey, very low numbers of organisms were taken in the Blackwater at Mallow in winter. A combination of sewage fungus and flooding destroys much of the *Ranunculus* beds in this stretch in winter, thereby reducing the overall abundance of the fauna.

Comparison of the numbers of animals taken in the 1966/67 and 1968/69 surveys shows that the latter were much smaller than the former. This results from the restricted area of the substratum which is sampled when using a Surber frame (as in 1968/69) compared to that covered when sampling with the pond net (as in 1966/67). The small size of the samples in 1968/69 led to the failure to take some of the less numerous species (especially of the Plecoptera) which had been recorded in 1966/67. In addition, the presence of small numbers of clean water forms in the polluted reaches was not shown as clearly in 1968/69 as it had been

earlier. While these omissions were not serious enough to prevent the main features of the fauna in each zone being recognised in the 1968/69 survey, it is felt that the procedures used in 1966/67 are preferable as some of the less numerous organisms, e.g. the Plecoptera, are among the more intolerant of pollution and, therefore, useful in indicating mild levels of these conditions.

The pattern of response to organic pollution, shown by the invertebrate communities of the riffles in the Blackwater and Martin, parallels in most respects that described for other rivers by workers such as Hynes (1960) and Hawkes (1962, 1964). The exact reason for these patterns has only been speculated upon and little research has been carried out to determine what particular change or changes in the biotope induced by the polluting matter makes this inimicable to most of its usual inhabitants. Superficially, organic pollution has two main effects on the riffle environment, viz. the lowering of the D.O. content of the water and the impairment of the substratum by the growths of sewage fungus and algae. The majority of the riffle animals require relatively high saturations of D.O. and, being lithophiles, clean surfaces to enable them to grip the substratum with their claws. Some of these animals live in the dead water spaces between or behind stones and among vegetation, while others live in more exposed situations such as on the tops and sides of stones, in a thin, near stagnant layer (Prandtl's layer) which exists just above the substratum in all flowing systems (Ambühl, 1962; Jaag and Ambühl, 1964; Ruttner, 1963). The D.O. supply of animals in riffles is not obtained, therefore, from the main water body, but from a non-flowing layer which surrounds their bodies, the thickness of which depends on the degree of exposure to and the speed of the main current. The diffusion of oxygen into these layers is helped not only by the continuous renewal of surface contact between the latter and the main water body but also by the bodily undulations of the organisms themselves which help to keep the water in the layers circulating. The former mechanism is more important to those organisms, such as *Rhithrogena*, which live in the most exposed habitats and which cannot circulate water over their bodies, while the latter is found in those organisms living in more sheltered regions where the non-flowing layer is relatively thick but is kept circulating by the movements of the animal itself.

It is easy to see that in polluted conditions these delicate relationships will not function. Since the D.O. of the main water body is usually depleted, proportionally less will be available within the immediate environment of the individual animal. In addition, sewage fungus will clog up crevices between stones and foul the surfaces of the latter and of plants thereby destroying the main microhabitats of the riffles. There is also the likelihood that, even if the animals could contend with the physical handicap of the slime growth, they would be unable to survive in the very low concentrations of D.O. which are reported to exist in the immediate vicinity of these growths. However, animals which, because of their general morphology, are adapted to crawling or burrowing do not appear to be adversely affected in polluted riffles. The Oligochaeta, Chironomidae and Hirudinea are of this type but the high densities of these often found in polluted riffles may be as much the result of reduced competition as their ability to survive the physical and chemical changes in the environment. In addition, as Hynes (1960) points out, most of the clean water forms become over-grown with sewage fungus in polluted riffles, a development which, on mechanical grounds alone, would appear to militate against their survival. Chironomids and Oligochaetes, however, do not appear to be susceptible to this hazard.

Whatever the exact reasons for the failure of the normal riffle communities to maintain themselves in polluted conditions the fact that they exhibit a change in such circumstances makes them extremely useful in pollution assessment and control. In the present investigation they showed close correlation in their response to pollution with physical and chemical parameters of water quality; indeed even when D.O. and B.O.D. indicated that a complete recovery of water quality had taken place at a particular position below an outfall, slight differences between the fauna there and in unpolluted reaches were often still present. This may indicate the inability of chemical methods, particularly the measurement of B.O.D., to give a reliable account of pollution effects, at least those arising from organic wastes, and suggests that the invertebrate fauna, with closer attention, would serve better as the main criterion of water quality in rivers. At least it should be conceded that, as Hawkes (1964) says, "To disregard biological methods of detection and assessment is to neglect the use of a most useful tool in pollution control work."

FISH

Fish represent the most important product of the biological processes in a river or stream and from an ecological standpoint are usually found near the end points of the food chains and webs. The fish stocks of the Blackwater, in common with those of many other Irish rivers, comprise not only salmon, of great commercial and sporting value, but also brown trout and coarse fish which are of increasing importance in view of the great upsurge of interest in this country by foreign anglers. The welfare of the fish stocks is, therefore, of paramount concern and in an investigation such as that being described must be the prime consideration.

A river system may be classified as "good" or "bad" from the point of view of water quality on the bases of the size and diversity of the fish stocks it is known to contain (Pentelow, 1955), but, as Hynes (1960) points out, fish, by virtue of their mobility, are less useful indicators of water quality in the case of localised pollution since they may be only temporary residents of the stretch under observation. However, the welfare of fish in a river depends on a complex web of chemical, physical and biological factors, so that changes in any of these, arising from pollution, even if not of immediate danger to individual fish, may over a long period have detrimental effects on the stock as a whole.

A great deal of research has been carried out into the effects of various pollutants on fish. Most of this work has been of an experimental nature under controlled conditions in a laboratory and has been aimed at the determination of the maximum concentrations of various poisons which allow the survival of fish in the laboratory aquaria. Herbert (1965) and Lloyd (1965) have reviewed the work of this nature carried out at the Water Pollution Research Laboratory in England while similar work in the U.S.A. has been reviewed by Doudoroff and Katz (1950, 1953). The relationship between D.O. and fish survival has also been studied in the laboratory e.g. by Downing and Merckens (1957) and Alabaster, Herbert and Hemens (1957) and while a good deal of information is now available on the lowest D.O. concentrations at which different species of fish can live there is still a lack of field observation on the overall effects of sub-lethal D.O. deficiency on the natural populations of fish. Doudoroff (1968) and Tarzwell (1958) have stressed the need for this sort of information while some attempts have been made to obtain it e.g. by Doudoroff and Warren (1965).

The significance of the D.O. requirements of natural fish populations was clearly demonstrated by Ellis (1937) working in the U.S.A. He investigated the fish fauna and chemical characteristics of a very large number of rivers and streams and carried out nearly 6,000 estimations of D.O. The results showed that the vast majority of waters holding a good varied fish fauna had a mean D.O. concentration of at least 5 p.p.m. This concentration is much higher than that found adequate to ensure the survival of fish for short periods in experimental laboratory aquaria. While even in the field fish may be found living in highly polluted water (Allan, Herbert and Alabaster, 1958; Alabaster, 1959), it is clear that the best expression of fish stocks occurs in those stretches which are normally well aerated. This applies particularly to salmonids which are less tolerant of low concentrations of D.O. than the coarse fishes (Cyprinidae) and are typically found to inhabit the upper, faster flowing parts of river systems.

Besides the direct effect of organic pollution on fish, through dissolved oxygen depletion, there are also indirect effects, e.g. the destruction of the invertebrate fauna which forms the food of many species, or of weed which provides them with cover and shelter. The impairment of the substratum by silting or by the growth of sewage fungus may have detrimental effects on the spawning of salmonids and thus have very serious consequences in regard to the long term survival of the stock.

Investigations of the effects of pollution on fish must be concerned, therefore, not only with the capacity of the polluted stretches to support living fish but must cover all aspects of fish biology, especially growth, feeding and reproduction. Such an investigation has been attempted in the present case and is described below.

Methods of Sampling and Procedure of Laboratory Examination.

The main investigations of the fish stocks were carried out in August 1967 and 1968, with the cooperation of the Inland Fisheries Trust Inc. The time available did not permit large scale sampling more than once in each year and it was decided that this would be best undertaken in the month of August when water quality would be most affected in the polluted stretches and when salmonids hatched in the previous winter and spring would be of catchable size.

Measured stretches (between 50 and 80 m. in length) of physically similar characteristics (current speed, depth and substratum composition) were selected in the unpolluted and heavily polluted reaches in each area and the entire fish stock removed in so far as this was possible by electro-fishing (petrol-driven Onan a/c fishing units). The Removal Method was employed, wherein each stretch is fished several times, usually three, the fishing effort being standardised as far as possible. The catches for each successive effort are kept separate and the regression of the catch per unit effort on the cumulative catch up to that point should on extrapolation give the total population. This system of quantitative sampling of animal populations was first used on rats (Leslie and Davis, 1939) but has been used extensively on fish since that time e.g. by Libosvsky (1966) and Johnson (1965).

During fishing the selected stretches were blocked off at each end with quarter-inch stop nets anchored to the bottom with stones and held upright by three or four helpers. In some stretches weed was very abundant and had to be removed before fishing commenced. The catches were placed in plastic sacks and stored in dilute formalin (4%) prior to examination.

The Removal Method was not feasible at Mallow because the width and flow of the river at that point precludes the blocking off of stretches. Samples were taken by electro-fishing from a boat in 1967 and by gill netting in 1968. However, neither of these methods proved very successful, smaller fish, especially, being very few in the samples.

In March, 1968, smaller qualitative samples were taken in each area, except Mallow, to determine the distribution of the fish, and their feeding habits, at the time of year when pollution is much reduced.

The catches of non-salmonid fish are not as reliable as those of salmon and trout in indicating the total numbers in any stretch because of the tendency of helpers to take the salmonids preferentially. However, the catches are thought to be reliable for comparative purposes.

The routine laboratory examination of the catches included weighing, measuring, removal of the gut for stomach content analysis and, in the case of salmon and trout, of scales for age determination. The determination of age in the case of other species was not attempted.

Results.

A general idea of the effects of pollution on the density of the fish stocks in the stretches immediately below the major outfall in each area may be gained from a comparison of the total numbers of specimens of salmonid and non-salmonid fish taken in sampling these and the non-polluted areas upriver in August 1967 and 1968 (1967 data only for Rathduff and Blarney; Gradoge not sampled in 1968).

	Rathmore (1967+1968)		Mallow (1967+1968)		Mitchelstown				Rathduff (1967)		Blarney (1967)	
	C	P	C	P	Gradoge (1967)		Funcheon (1967+1968)		C	P	C	P
Salmonid	372	140	52	23	111	Nil	498	36	94	19	810	221
Non-salmonid	496	605	76	91	64	Nil	183	450	6	29	238	501
Totals	868	745	128	114	175	Nil	681	486	100	48	1048	722

C=Clean water. P=Polluted water.

Since the effort involved in clean and polluted water stretches was roughly similar in each area the numbers caught may be regarded as a rough index of the abundance of fish for comparison of these stretches.

The figures show that there was an appreciable drop in the numbers of fish in samples from polluted water compared to those from unpolluted water. This was, however, entirely due to the relative scarcity of the salmonid fish in polluted water, especially at Mitchelstown and Rathduff; the catches of non-salmonid fish were, in contrast, appreciably greater in polluted water compared to unpolluted and, because of this, the difference in the overall density of fish between the two zones is, in most of the cases, not very marked.

Trout and Salmon

Occurrence—The total numbers of salmon and trout taken in the various samples are shown below (1967 and 1968 data combined for Blackwater at Rathmore and Mallow and Funcheon at Mitchelstown, 1967 data only for Martin at Rathduff and Blarney; Gradoge not fished in 1968):

	Rathmore (1967+1968)		Mallow (1967+1968)		Mitchelstown				Rathduff (1967)		Blarney (1967)	
	C	P	C	P	Gradoge (1967)		Funcheon (1967+1968)		C	P	C	P
Trout	108	103	21	20	111	Nil	204	36	94	19	398	113
Salmon	264	37	31	3	Nil	Nil	294	Nil	Nil	Nil	412	108

C=Clean Water. P=Polluted Water.

Salmon were not present in samples from either clean or polluted water stretches of the Gradoge at Mitchelstown in August 1967 and Martin at Rathduff in August 1967 and 1968 and the species is probably non-resident at those points. Trout were numerous in all of the clean water reaches sampled.

The greatest difference observed between clean and polluted water stretches in regard to salmonid stocks was in the Gradoge at Mitchelstown where in August 1967 trout appeared to be absent from the polluted zone. This is the most heavily polluted reach encountered during the survey and the dissolved oxygen content would in summer and autumn be insufficient under normal circumstances to support fish life. However, in March 1968, trout were present in the lower part of the Gradoge, along with some salmon parr, and it is probable that both species move into the polluted reach in winter and spring from the Funcheon. A reduction in effluent flow and increase in river flow lead to a marked improvement in the water quality of the stream at those times over the conditions of summer and autumn and dissolved oxygen is usually over 70% of saturation.

Very small numbers of salmonids were taken in samples from the polluted reaches of the Funcheon at Mitchelstown and Martin at Rathduff. In the polluted Funcheon salmon were not found at all, though occurring abundantly in the clean water reaches above the confluence of the river with the grossly polluted Gradoge. Trout, also numerous above the confluence, appeared to be present only in very small numbers at Kilee and Marshalstown Bridges, 1.7 ml. (2.8 km) and 3.7 ml. (6.0 km) below the confluence respectively (see Fig. 4); it is possible that the trout captured in this stretch were only temporary residents, having moved in from tributaries or from cleaner areas downriver. Fish kills occurred at several times in this reach of the Funcheon during the course of the investigations and it is significant that dissolved oxygen is likely to reach very low levels over 24 hour periods here in summer. Exploratory fishing at several points in the stretch below Marshalstown Bridge from a moving boat in August 1967 indicated that the trout population is very restricted until after the confluence of the Funcheon with the clean Sheep R. (see Fig 4) which affords considerable dilution to the main river.

In the R. Martin at Rathduff only a few trout were taken in sampling the stretch below the cheese factory and creamery in August 1967 and none at all in August 1968. However, it is unlikely that the fish population is affected for more than a small distance in this area as the main stream receives several clean tributaries below Rathduff and a rapid improvement in water quality takes place. It is probable that the trout move only temporarily into pools below the outfalls to feed—there have not been any reports of fish kills at this point.

In the case of the Blackwater at Rathmore, trout appeared to be as numerous in the polluted water reaches as in the clean water but young salmon showed a great decrease in density between the two zones. The catches of salmonids in the Blackwater at Mallow which, as mentioned above, were of a qualitative nature, are too small to be relied on as indications of the abundance of the fish in the unpolluted and polluted zones but they show that both trout and salmon were present in the latter at the time of sampling. There were large reductions in the numbers of trout and salmon caught in the polluted zone at Blarney compared to those taken upriver but it is probable that this is mainly due to changes in the physical nature of the river between the points of sampling. The river in the unpolluted area is relatively shallow and fast flowing while in the polluted area it is somewhat deeper and slower flowing.

Age and Growth—Fig 20 shows the age frequency in the combined samples of trout and salmon take in August 1967 and 1968 in each area (Mallow being excepted as the samples here were very small in size). Except in the case of trout at Rathmore, there appears to be a difference in the age composition of the stocks in polluted water compared to those in unpolluted water, a greater proportion of older fish being present in the former zone. This is most marked in the case of salmon at Rathmore and trout at Rathduff where 1+ fish dominate the sample from polluted water and 0+ fish that from unpolluted water. The samples of trout from polluted water at Rathmore, however, showed exactly the same age composition as that of the samples from unpolluted water. Generally, there were very small numbers of 0+ fish in the polluted zone samples in each area and this may indicate that these are less tolerant of pollution than the older age groups. Since very few 0+ trout were present in the samples from unpolluted water at Rathmore, the age composition of the trout population in that zone resembles that of the fish from polluted water.

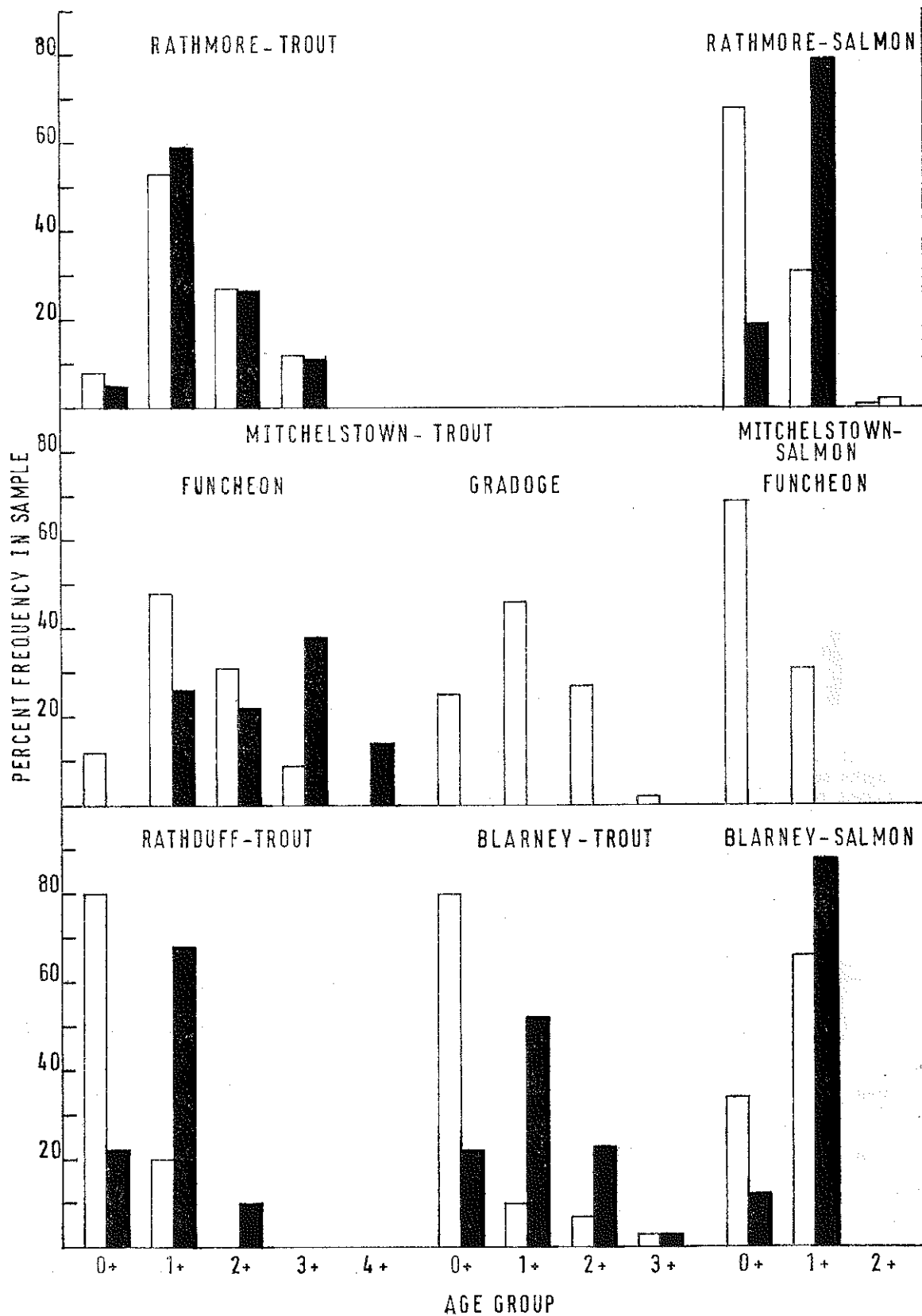


Fig. 20. Age frequency in samples of trout and young salmon at Rathmore, the Rivers Funcheon and Gradoge at Mitchelstown and the R. Martin at Rathduff and Blarney, taken in August 1967 and 1968. White columns: unpolluted water; black columns: polluted water.

The length distribution in the samples, shown in Figs. 21 and 22, reflects the differences in age distribution between fish of polluted and unpolluted stretches, mentioned above. Thus, the salmon and trout of the polluted zones are larger fish than those of the unpolluted and even at Rathmore where trout stocks showed the same age composition in the two zones, the trout from polluted water were somewhat larger on average than those from unpolluted water. This latter tendency was, in fact, noted in each area, fish of the same year class being slightly larger in polluted water than in unpolluted. This is shown below for trout at Rathmore and Mitchelstown (Funcheon) the mean length at capture of fish of each age class from unpolluted and polluted water being given in cm, with the range in brackets:

Age Class	Year	Rathmore		Mitchelstown	
		C	P	C	P
0+	1967	6.4 (one only)	7.0 (6.9-7.2)	8.1 (6.6-9.1)	N.P.
	1968	7.8 (6.5-8.9)	8.8 (one only)	8.4 (7.9-8.8)	N.P.
1+	1967	14.4 (11.9-17.0)	16.7 (14.0-20.5)	14.8 (12.2-16.6)	14.8 (14.3-15.7)
	1968	15.1 (13.2-17.2)	17.4 (14.9-20.1)	14.6 (12.3-17.1)	14.9 (13.7-16.4)
2+	1967	17.5 (15.7-19.2)	19.7 (17.9-23.2)	17.7 (14.3-20.9)	24.9 (22.8-27.3)
	1968	18.3 (14.8-21.0)	20.1 (17.5-23.0)	17.6 (14.2-21.0)	20.0 (18.3-21.7)
3+	1967	19.7 (16.4-22.3)	26.0 (22.0-29.5)	22.3 (18.8-26.4)	27.2 (22.3-35.2)
	1968	18.8 (18.6-19.0)	24.5 (20.6-29.6)	22.7 (19.4-28.2)	29.9 (26.0-33.7)

N.P. not present in sample.
C=Clean water. P=Polluted water.

The difference in growth rate between fish from unpolluted and polluted water is also shown by a comparison of the lengths at the end of each year of life of fish of all age classes from the two zones. These lengths have been obtained by back calculation of the scale/body length ratios and are set out below (cm):

	TROUT								SALMON			
	L1		L2		L3		L4		L1		L2	
	C.	P.	C.	P.	C.	P.	C.	P.	C.	P.	C.	P.
Blackwater : Rathmore	7.4	7.0	14.0	15.5	17.4	20.6	19.7	26.0	6.4	5.9	11.4	13.0
Gradoge : Mitchelstown	7.0	*	14.0	*	18.5	*	*	*	*	*	*	*
Funcheon : Mitchelstown	6.7	8.4	13.6	16.7	18.0	23.2	22.3	27.6	6.6	*	12.8	*
Martin : Rathduff	7.1	9.1	13.9	12.8	*	*	*	*	*	*	*	*
Martin : Blarney	6.8	7.5	14.0	15.9	15.0	17.4	*	*	4.8	5.0	10.5	10.4

* Fish of this age class not present in the sample.
C=Clean water. P=Polluted water.

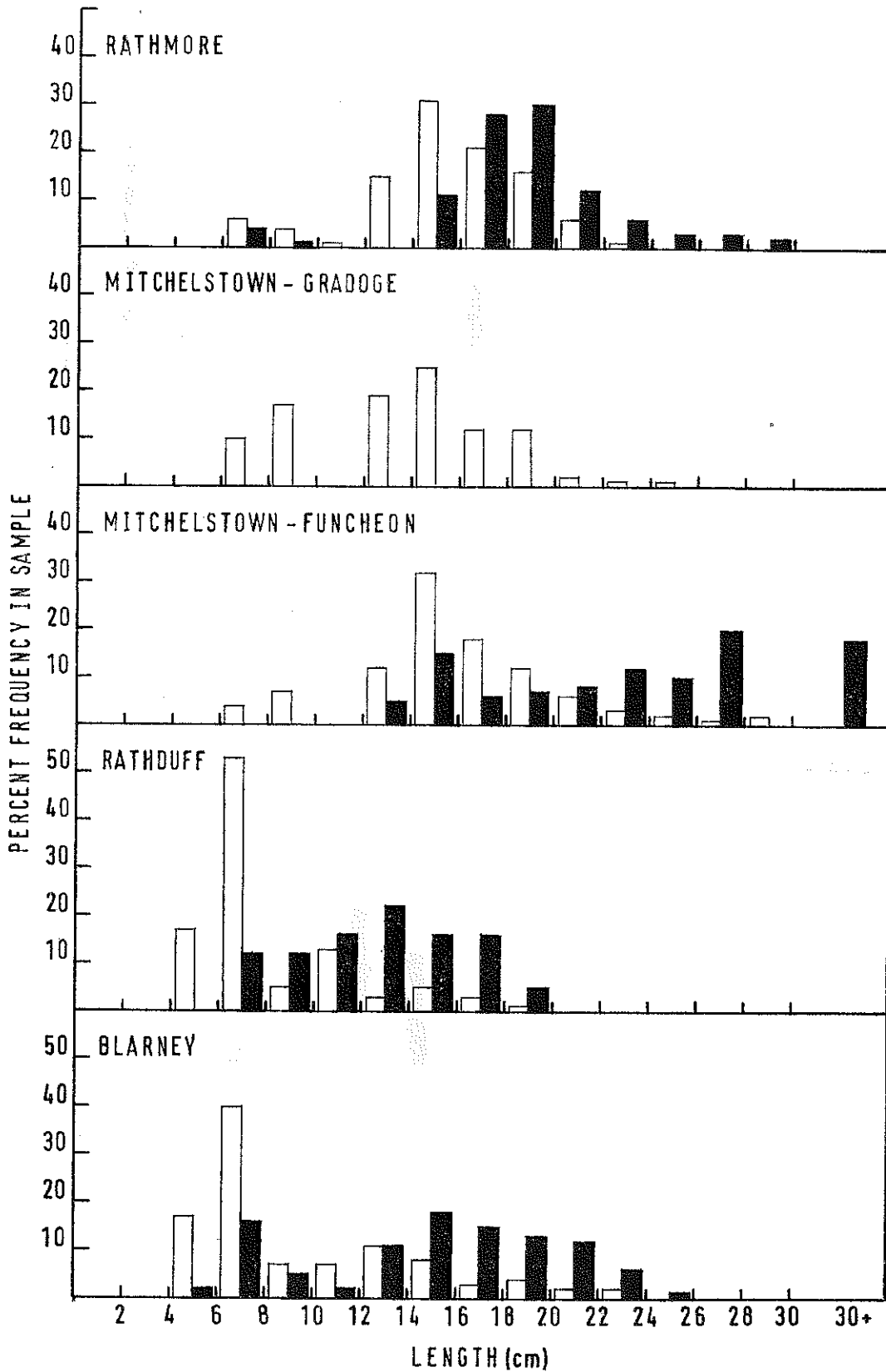


Fig. 21. Length frequency in samples of trout from the R. Blackwater at Rathmore, the Rivers Funcheon and Gradoge at Mitchelstown and the R. Martin at Rathduff and Blarney, taken in August 1967 and 1968. White columns: unpolluted water; black columns: polluted water.

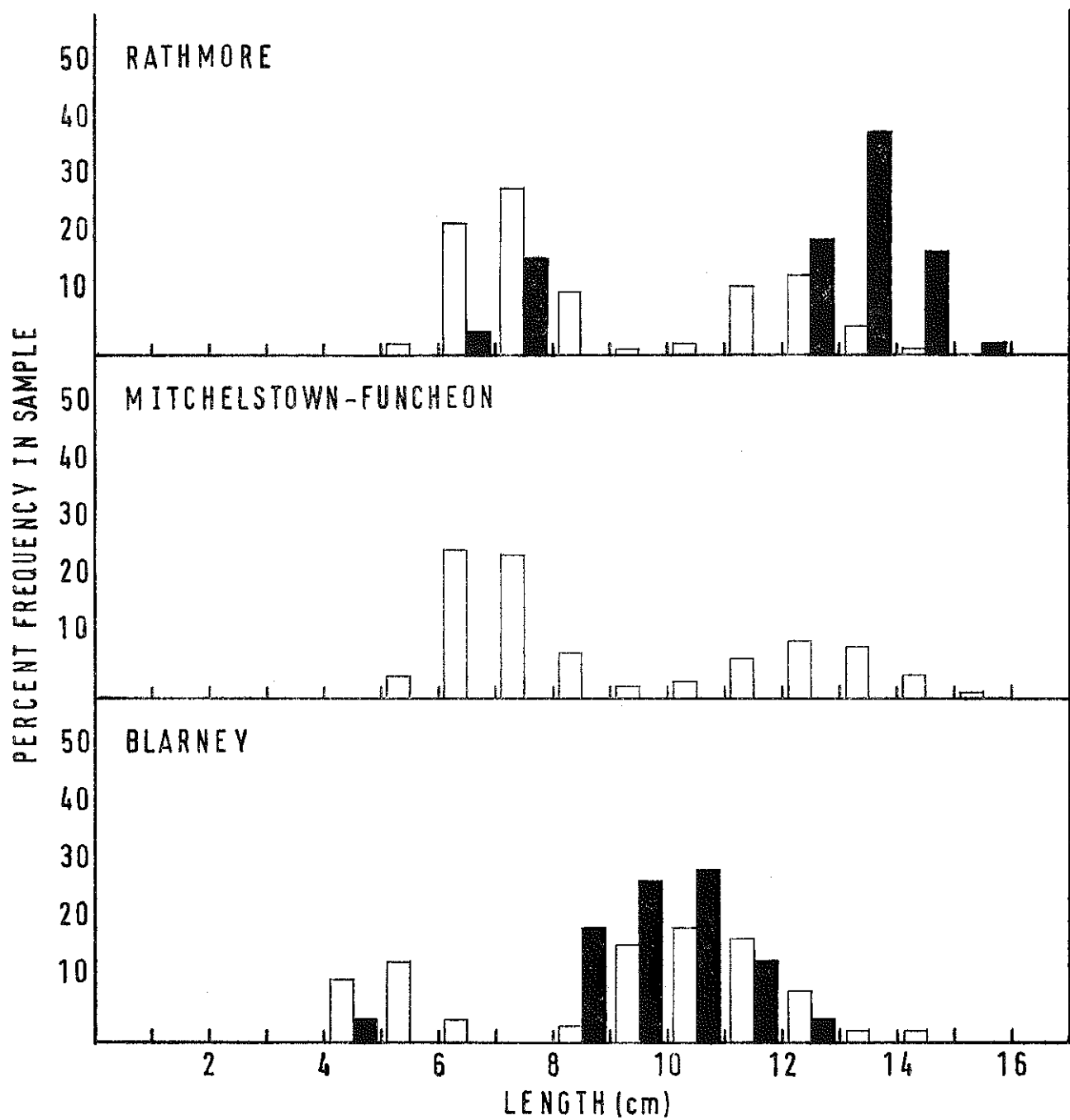


Fig. 22. Length frequency in samples of young salmon from the R. Blackwater at Rathmore, the R. Funcheon at Mitchelstown and the R. Martin at Blarney, taken in August 1967 and 1968. White columns: unpolluted water; black columns: polluted water.

There is a tendency for the difference in length between clean and polluted water fish to increase with age and the greatest difference is found at Rathmore where trout in polluted water are, at the end of their fourth year of life, 6 cm longer, on average, than fish of the same age in unpolluted water. The average weight of fish of each age class was correspondingly greater than comparable fish in clean water and at Rathmore, where the age composition of the trout stocks in clean and polluted water was identical, the mean weight of individual fish in polluted water was twice that in the unpolluted. This large difference in weight is thought to be partly due to fat deposits in the polluted water fish (see below).

Food—The food eaten by salmon and trout in each stretch is set out in TABLE 15. This TABLE gives the proportions of the stomachs examined in which each type of food occurred. These data are considered by the authors to be more useful indicators of the general feeding habits of the fish than are the proportions of all food organisms eaten represented by each food group, since in the latter case one or only a few fish may account for all or most of one food organism type eaten. Furthermore, the numbers of different organisms eaten does not take account of the size of these animals and in TABLE 16, therefore, the dominant items in the food are indicated. A food organism type was considered dominant in any stomach if it occupied more than 50% of the volume of the stomach when the latter was half full or fuller. Hynes (1950) has proposed the recording of fish stomach contents on similar lines.

In TABLES 15 and 16 the food organisms are grouped in the same categories used in the section on the invertebrate fauna with the addition of two groups not covered by those categories, viz. "Terrestrial Organisms" and "Trichopteran sub-imagos". Oligochaeta and Hirudinea are grouped together in the Annelida as the number of organisms of this type eaten was very small. Since the fish samples were taken in August 1967 and 1968, the stomach contents are best compared with the invertebrate fauna collection of August 1966 (TABLES 2, 3 and 4).

Generally the stomach contents reflect the composition of the invertebrate fauna and, as TABLE 16 shows, the organisms which appear as dominant items in the stomach are also those which are taken by most of the fish. Furthermore, it is clear that the changes in the fauna in polluted conditions do not affect the feeding of the salmon or trout; chironomid larvae, which become very numerous in polluted conditions, were eaten by the great majority of salmon and trout in these zones. However, the large populations of Oligochaetes which were present in some polluted stretches, e.g. in the R. Martin at Rathduff, appeared to be inaccessible as food to the trout and salmon and were rarely detected in the stomach contents. The worms may not be easily taken by the fish because of their habit of burrowing though Nikolsky (1963) argues that due to rapid disintegration in the fish stomachs, the importance of Oligochaetes as food may be underrated. The food eaten by the fish in the unpolluted stretches is generally more diverse than that eaten by the polluted water fish and this is a reflection of the changes produced by pollution. The trout in both unpolluted and polluted water feed to a large extent on "Terrestrial Organisms" (adult Diptera, terrestrial beetles, aphids and land bugs) but the young salmon show a much smaller tendency to do so; a similar difference was noted between trout and young salmon in the R. Liffey by Frost and Went (1940). In the case of Rathmore, the "Terrestrial Organisms" eaten by the fish in the polluted zones consisted for the most part of Psychodid larvae and pupae. These forms are not typical of running water and it appears that they are brought into the stream in the effluent from the nearby waste treatment plant attached to a chocolate crumb factory. Tomlinson (1946) points out that the Psychodidae flies are the most commonly found insects of percolating filters and that they produce a new generation every 60 to 70 days. The group is very important in the workings of the filters as the larvae constantly crop the bacterial film and thus prevent the excessive growths which lead to clogging (Williams and Taylor, 1968.) Psychodid larvae and pupae were observed on numerous occasions in the effluent from the treatment plant.

Trout at Rathmore showed distinctly greater growth in polluted water than in unpolluted and also had high Condition Coefficients and fat contents (see below). It appears that this may be due to a greater food supply, both in the form of the invertebrate fauna in the stream and that brought in with the effluent. It is probably significant that while most of the stomachs of trout in polluted waters were found to be more than one-half full on capture, those of fish from the clean water reaches contained only small amounts of food, many being nearly empty. A similar pattern was noted in other areas and it would appear that where they can survive in organically polluted reaches trout and salmon may find a greater source of food than in upstream reaches and thereby make better growth. The experimental study of Warren, Wales, Davies and Doudoroff (1964), in which sucrose introduced into a small stream caused a growth of sewage fungus and associated chironomid larvae, led to a greatly increased production of trout in the stretch. However, the conditions of water quality under which the food supply of fish is increased are unsatisfactory from the point of view of dissolved oxygen and in such situations fish mortalities are likely to occur periodically, e.g. as in the R. Funcheon at Mitchelstown.

Condition of trout—Condition Coefficients of trout were calculated using the formula devised by Fulton (1902):

$$K = \frac{100 W \text{ (gm)}}{L^3 \text{ (cm)}}$$

Fig. 23 shows the Condition Coefficient frequency of trout from clean and polluted water stretches of the R. Blackwater at Rathmore and Mallow, the R. Funcheon at Mitchelstown and the R. Martin at Blarney. With the exception of that for Rathmore, the distribution of the K values is much the same for clean water as it is for polluted water fish. At Rathmore, the trout had an average K of 1.44 in polluted water and of 1.24 in clean water. As mentioned above, the average weight of trout in polluted water in this area was about twice that of trout in clean water.

Water, Protein and Fat Content of Trout—Because of the significantly better conditions of trout from polluted water at Rathmore compared to those from unpolluted water it was decided to analyse the muscle tissue to determine whether the edible portion of the fish was affected by this difference. Heavy deposits of fat had already been noted lining the guts of the polluted zone fish. The results of the analyses are shown below:

Sample	No. of fish	Mean percentage of fresh muscle weight.			Mean K
		Water	Protein	Fat	
Unpolluted Water ...	11	79.0	18.3	1.5	1.34
Polluted Water ...	9	74.4	18.7	5.9	1.48

The fat content of the muscle of the trout from polluted water is four times greater than that of fish from clean water. There is virtually no difference in protein content but the water content of the muscle of polluted zone fish is slightly less than that in clean water fish.

An attempt was made to assess the palatability of trout from clean and polluted water at Rathmore and is described in Appendix C.

Salmonid Spawning and Sewage Fungus—The danger to the eggs of salmon and trout where these are laid in stretches of the river subject to sewage fungus infestation should be mentioned at this stage. Severe flooding prevented any investigation of this at Mallow, but from the previous experience of the fishery inspector in the area, it is known that salmon construct redds in the zone of the river affected by sewage fungus and have, indeed, been observed to do so while the slime was present. The fate of the eggs in these cases is unknown, but there is much evidence that the covering up of salmonid redds by materials such as silt, causes mortalities in the eggs and developing larvae (Coble, 1961; Peters, 1965). The maintenance of a current of water through the redd is necessary for the supply of adequate D.O. to the eggs. Stuart (1953) showed how the brown trout (*Salmo trutta* L.) constructed its redd in a manner which allowed a continuous current of water to pass through the gravel in which the eggs lay. It is possible that the rate of flow of water through the redd is equal in importance to the D.O. concentration, since even if the stream above is well aerated, a very slow flow inside the redd might well lead to local desaturation in the micro-environment of the egg. Peters (1965), investigating the effects of sediment in artificial redds, found a correlation between low intragravel velocities and egg mortalities, but very little change in D.O. of water inside the redd. The reason may be as above, but could also have been due to an accumulation of metabolic products.

The investigations of several workers (Silver, Warren and Doudoroff, 1963; Alderdice, Wickett and Brett, 1958) have dealt with the effects of low D.O. and current velocities on the development of salmonid eggs. It seems that in some cases critical levels of D.O. may be as high as 7 p.p.m., especially just prior to hatching. Intragravel water velocity must be high enough to bring D.O. in sufficient quantities, not only to the redd as a whole, but also to the chorionic surfaces of the individual eggs. Furthermore, size at hatching was found to be dependent on current velocity and D.O. content, even at relatively high levels of these factors.

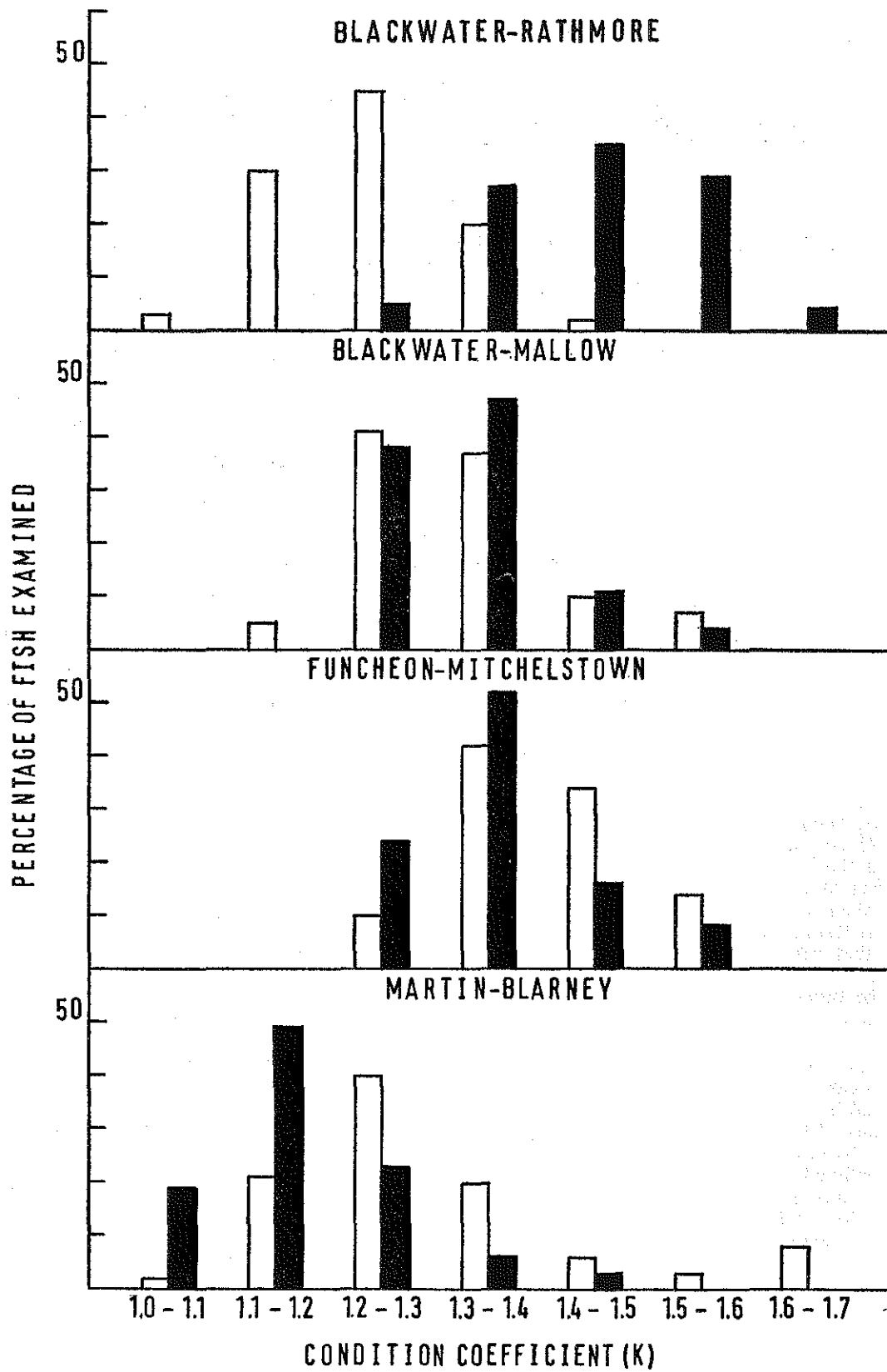


Fig. 23. Condition coefficients of trout in samples from the R. Blackwater at Rathmore and Mallow, the R. Funcheon at Mitchelstown and the R. Martin at Blarney. White columns: unpolluted water; black columns: polluted water.

It is almost certain that sewage fungus growing on the tops of redds will impede the flow of water through the gravel underneath and cause undesirable effects of the type mentioned above. The zone of the river affected by the growths has, as mentioned above, several salmon spawning areas and in winters when sewage fungus takes a firm hold, high mortalities in the redds seem to be likely. Rasmussen (1955) has shown that this happens in the case of slime growing on top of trout redds. Winters like that of 1968/69 may, however, result in little damage, since the growths are continually removed by flooding.

Other Fish

The numbers of each species of non-salmonid fish taken in the samples of August 1967 and 1968 are set out below (1967 and 1968 data combined for Blackwater at Rathmore and Mallow and Funcheon at Mitchelstown, 1967 data only for Martin at Rathduff and Blarney; Gradoge not fished in 1968):

	Rathmore		Mallow		Mitchelstown				Rathduff		Blarney	
	C	P	C	P	Gradoge		Funcheon		C	P	C	P
					C	P	C	P				
Eel ...	56	233	23	24	24	Nil	84	101	1	8	77	85
Stoneloach ...	277	57	7	Nil	22	Nil	51	7	1	Nil	89	42
Minnow ...	153	172	19	15	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Gudgeon ...	2	80	Nil	6	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Dace ...	Nil	Nil	25	44	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Roach ...	2	40	1	1	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Stickleback ...	Nil	Nil	Nil	Nil	4	Nil	2	2	2	4	27	265
Lamprey ...	6	23	1	1	14	Nil	46	340	2	17	45	109

C=Clean Water.

P=Polluted Water.

The eel, stoneloach and lamprey (probably Brook Lamprey) appear to be the commonest non-salmonid fish in the rivers, being taken in the clean water stretches in each area, and in relatively large numbers except at Rathduff. Minnow were found in large numbers in the Blackwater at Rathmore and Mallow but are, apparently, absent from the Funcheon and Gradoge at Mitchelstown and from the R. Martin. Dace are numerous in the Blackwater at Mallow and roach are present there also. The two species are recent introductions to the river system and their range is expanding continuously (Went, 1946, 1950). However, only roach were found upriver of Mallow at Rathmore and neither in the Funcheon at Mitchelstown, though both are resident in the lower reaches of that tributary (Healy, 1956). Gudgeon appear to be numerous at Mallow and Rathmore but absent from the other locations. One specimen of the rudd was taken at Mallow but it is unlikely that this species occurs at the other points investigated. The 3-spined stickleback was found only in samples from the streams at Mitchelstown and from the two sites in the Martin, being particularly numerous at Blarney.

With the exception of the stoneloach, these fish seem quite unaffected by the degree of pollution in all but one of the areas investigated. The low D.O. obtaining in the Gradoge at Mitchelstown in summer cannot be tolerated even by eels, a species more resistant to deoxygenation than most fish (Degens, Van Der Zee, Kommer and Kamphuis, 1950), and this zone is apparently fishless at that time of year. Elsewhere, only the stoneloach appeared to be adversely affected in polluted stretches, being taken in very small numbers there compared to upriver unpolluted zones. It is unlikely that this is due to lack of sufficient D.O. since the species is capable of taking air through the mouth at the water surface (Marshall, 1965) and Smyly (1955) concludes that these fish are relatively tolerant of organic pollution. However, this species is lithophilic in behaviour, living under stones during daytime, so that it is likely that in polluted conditions, where the substratum is covered with growths of slime and with silt, the fish would be faced with a restriction in the number of suitable habitats.

In most cases the other non-salmonid fish appeared to be somewhat more numerous in polluted water than in clean water. This was especially marked in the case of the lamprey, very large numbers of ammocoete larvae being taken in the polluted water samples. This may be due to accumulation of mud in the polluted reaches; though hatching in nests made in clean gravel, the larvae drift downstream to burrow in muddy banks where several years may be spent before metamorphosis occurs.

The roach and gudgeon catches in the Blackwater at Rathmore in August 1968 were much greater in polluted than in unpolluted water; though this may represent a migration into the area, since roach were absent and gudgeon very scarce in the 1967 samples, the ability of these species to thrive in the polluted reaches is obvious. This applies equally well to the eel so that generally the situation at Rathmore would seem to bear out the observation of Sawyer (in Frost and Brown, 1967) that any increase in the silting of trout streams leads to an increase in the number of coarse fish such as dace and roach, and of eel and lamprey and to a reduction in the density of small fish such as stone loach. This pattern is not so clear in the other areas investigated but it would appear that the tendency for coarse fish or eels to increase in numbers in trout streams under polluted conditions is likely to lead to serious competition for the salmonids and ultimately to their elimination.

DISCUSSION AND CONCLUSIONS

In this survey of the Rivers Blackwater and Martin, ample evidence has been accumulated to show that the discharge of waste to these rivers causes deteriorations in water quality ranging in degree from mild to severe and of variable extent below the point of discharge. In regard to the degree of pollution there are the contrasting cases of the Gradoge at Mitchelstown and the Martin at Blarney; in the polluted section of the Gradoge, very low D.O., abundant sewage fungus and an apparent absence of fish and of the normal invertebrate fauna have been recorded throughout the summers of 1967 and 1968, but in the Martin below Blarney town very little change in respect of normal chemical or biological features seemed to have been caused by the effluent from a woollen mill. In regard to the extent of pollution, the Blackwater at Mallow is infested by sewage fungus for distances up to fifteen miles during the beet sugar campaign but, in the same river at Rathmore, where a clean tributary enters just below the main waste outfall, the severe effects of pollution are restricted to half a mile of the main river.

The bulk of the waste material discharged to the Blackwater and Martin is of an organic nature, arising from milk-based industries at Rathmore, Mallow, Mitchelstown and Rathduff and from beet-sugar and food processing industries at Mallow. Such industries operate mainly on a seasonal basis so that significant volumes of waste are discharged during part of the year only in each case, e.g. during late autumn and winter in the case of the beet-sugar factory at Mallow. Domestic sewage, though arising from relatively small communities, is the most commonly encountered and persistent source of pollution of the rivers and in several cases is discharged untreated.

The magnitude of an organic trade waste as a polluting source is best expressed in terms of its population equivalent. This equivalent is calculated using the statistic which shows that the sewage of one person per day in a modern urban community exerts a B.O.D. of 0.12 lb. (Southgate, 1948). Thus if the strength (B.O.D.) and volume of the trade waste are known it is possible to calculate the size of the human population which would contribute a similar amount of waste. It has been calculated that the amount of trade waste discharged per day in summer and autumn to the Blackwater at Rathmore is equivalent to the sewage of some 7,000 persons and at Mallow to that of about 20,000 persons. During the beet campaign in winter at Mallow, trade wastes entering the river have a population equivalent of nearly 175,000. Trade and domestic wastes are treated together at Mitchelstown so that it is not possible to gauge the strength and volume of trade wastes entering the River Gradoge; however, prior to treatment, trade wastes arising in Mitchelstown have a population equivalent of nearly 140,000. The only waste investigated which has a relatively small organic content is that from a woollen mill at Blarney.

The pollution potential of the waste discharges from Rathmore, Mallow, Mitchelstown and Rathduff is offset by several factors, the more important of which are the generally unpolluted nature of the receiving water, the dilution afforded by the latter and the relatively high rates of reaeration which obtain in most stretches and which help to reduce the extent of D.O. depletion. There is no doubt, however, that in slow flowing rivers B.O.D. of the order recorded in some stretches of the Blackwater would result in anaerobic conditions. Continuous low D.O. was not observed in any of the areas under investigation and only one of these, the polluted part of the Gradoge at Mitchelstown, was subject to such conditions for long periods. However, depletions in D.O., sometimes great enough to be of danger to fish, were recorded on occasion in each area except Blarney. In the Funcheon at Mitchelstown, below the confluence with the polluted Gradoge, trout are known to be killed periodically in summer months. Diurnal variation in D.O., while reduced by high reaeration rates, is marked enough to warrant continuous twenty-four hour sampling in any part of the river to judge the suitability of the conditions for fish.

More obvious and, perhaps, more damaging than the depletion of D.O. in polluted conditions is the stimulation of the growths of slime and algae. Such growths occur, particularly in summer, at Rathmore, Mallow, Mitchelstown (Gradoge and Funcheon) and Rathduff, but are very widespread at Mallow in autumn and

winter. The sewage fungus is found not only in those reaches where D.O. is very depleted but also where the water is well aerated and is particularly heavily developed in the faster areas of the rivers, i.e. in the riffles. The effect of the slime in the latter reaches is to bring about a complete change in the plant and animal biocoenoses, with the elimination of those organisms normally numerous in riffles and their replacement by organisms which are usually most numerous in silted parts of the rivers. The most obvious examples of this phenomenon are the presence of pondweed, *Potamogeton*, and of the water hog louse *Asellus* in most of the polluted riffles. The worst effects of pollution on the plant and animal communities were always found in the stretches infested with sewage fungus but even where the latter had died down well below an outfall, the fauna and flora still showed some impairment compared to the naturally occurring communities. In this case silting and the presence of algae are probably responsible for the absence or sparseness of some clean water organisms. Such effects were in some cases observed to persist over long distances e.g. nine miles at Mallow in winter and five miles in the Funcheon at Mitchelstown in summer, but in others were confined to short distances, e.g. half a mile at Rathmore and one mile at Rathduff. In the latter cases the entry of clean tributaries leads to a quick recovery of water quality. The impairment of the flora and fauna in polluted stretches is to some extent reduced in winter and spring when effluents are small in volume and river discharge increased; the main reason for the partial restoration in faunal quality at these times appears to be the absence of sewage fungus.

While fish are relatively mobile and, therefore, not the most reliable indicators of pollution, in the present case several differences were apparent between samples taken in unpolluted and polluted reaches. For example, trout, especially at Rathmore, showed a greater growth rate in polluted water than in clean water and, in addition, had greater fat deposits in their tissues. These differences are probably due to the greater amount of food, in the form of the invertebrate fauna, available in polluted compared to unpolluted reaches, but at Rathmore a supply of extraneous food also seems to be responsible. Salmon were usually found in smaller numbers in polluted water compared to clean water samples, being absent altogether from some of the former, and appear to be less tolerant of pollution than trout. This difference may however be connected with fish size; very few 0+ trout were taken in samples whereas most of the salmon catches were of 0+ fish. Both of the salmonid species appeared to be less tolerant of pollution than other fish such as eel, lamprey and the coarse fishes. However, it appears that all fish are unable to survive in the polluted Gradoge in summer and while trout were found in the polluted part of the Funcheon, their existence in that reach is precarious. It is worthy of note that non-salmonid fishes were usually taken in larger numbers in polluted compared to unpolluted reaches this being especially the case at Rathmore. While this may, in part, be due to physical changes in the rivers it has already been pointed out that an increase in the silting rate in trout streams leads to a change in the fish fauna, species such as roach, dace and lamprey increasing in number at the expense of the stone loach and salmonids. Such a change seems to be occurring at Rathmore where between 1967 and 1968 there was an increase in the numbers of gudgeon and roach in the catches from polluted water.

The effects on the fish stocks are very localised but it must be stressed that their nature in each area cannot be regarded as permanent and all of the effects encountered, from the minimal to the most severe, may be expected to follow each other in time at any one point if pollution increases. Thus an extension of the fishless zones of the Gradoge/Funcheon system and the rendering fishless of the most polluted stretches in other areas may be the next development. Such changes will be unavoidable if pollution increases, unchecked. While the overall fish productivity of the rivers is probably not significantly influenced by pollution at this stage, there are no grounds for complacency.

Salmon are the most valuable fish species in the Irish rivers and their continued existence as such depends on two conditions, firstly, the health of estuaries through which the adults must ascend to spawn and the young reach the sea and, secondly, the suitability of the upper reaches of the river for spawning and parr survival. In regard to estuaries there seems little danger at the moment in that respect as far as the Blackwater is concerned though the Lee estuary, through which the salmon of the Martin River must pass, is at times grossly polluted and may be nearing the danger point for the fish. In the upper reaches of the rivers there are two dangers to salmon arising from pollution. One of these is the presence of sewage fungus in the spawning areas, and the danger to salmon eggs in such situations has already been mentioned. In addition to the danger from sewage fungus, low D.O. in parts of the rivers in summer is a hazard to young salmon which appear to be more susceptible to this than trout. They may be killed or else prevented from making the downstream migration. The angler must also be considered and local opinion in Mallow is that salmon fishing has deteriorated considerably in the reach below the town which is at all times polluted by crude sewage. It is possible that the adult fish are not inclined to hold station there for very long because of the water conditions. However, the whole position of salmon vis-à-vis pollution has been complicated by the presence of the U.D.N. disease and it would be impossible at this stage to say anything definite regarding the effects of pollution on salmon in the Blackwater. Certainly, records for the period up to 1964, the year in which the disease first became prevalent, did not show any evidence of a decline in the catches of the fish.

It is considered that the major sources of pollution on the Blackwater and Martin systems have been at least detected if not examined in detail during this survey. However, some consideration should be given here to other sources of polluting material which may exist. The most obvious of these, other than those of a domestic or industrial nature, are farm wastes. Situations involving pollution by farm wastes have not been detected in this survey and, in the experience of the Fishery Inspectors for the rivers, there are probably none at the moment. However, with the increasing emphasis on the intense rearing of cattle and other stock it is not unlikely that farms may become important in the water pollution field and in England, for instance, much attention has been given to the disposal of wastes arising from that source (Quick, 1968; Soutar and Baxter, 1968; Wheatland and Borne, 1964). Of particular concern in relation to the pollution potential of farming are the waste liquors which arise from the making of silage. Silage effluents vary in volume depending on the condition of the grass ensiled, being smaller in volume where the dry matter content is high, but the strength of such effluents, in terms of B.O.D., is enormous. Jones (1954) carried out analyses on effluents from various types of concrete silos and found an average B.O.D. for these of over 54,000 p.p.m. This concentration, as he points out, is about 220 times as strong as that of settled domestic sewage. The effluent from one ton of greenstuff containing 17.8 per cent dry matter was equivalent to 12,000 gals. of sewage but when the dry matter content was 23.4 per cent the equivalent was only 4,000 gals. Wilting of the grass in fields after cutting, prior to ensilage, is an effective way of reducing the amount of waste liquor. The use of silage for cattle feeding is being strongly recommended, officially, in this country at present and it is likely that, unless controlled, the polluting matter from this source may become one of the major threats to water quality in Irish rivers. (The Department of Agriculture and Fisheries has issued several leaflets which point out the necessity for controlling and safely disposing of the effluents from silage making units). The safe disposal of such wastes and, indeed, of all farm wastes is difficult since, as Fish (1967) says, the scaling down of urban notions of sewage disposal may not be wholly appropriate. Wheatland and Borne (1964) maintain that the best way to dispose of farm wastes is either to spread them directly on land or else to pump them to large storage ponds from which water is drawn for irrigation purposes.

The use of chemicals as insecticides, herbicides and as fertilisers is currently emerging as a major threat to surface water quality. Holden (1964) has reviewed the position regarding the effects on aquatic life of the use of substances like D.D.T., dieldrin and heptachlor in agriculture and forestry and quotes cases of fish and insect mortalities in streams in the U.S.A. and in Scotland which resulted from the treatment of the surrounding land with such substances. Klein (1962) also points out the dangers to aquatic life arising from such chemicals. In connection with the present survey, Timpson (unpublished) has shown that relatively high levels of dieldrin occur in both the river water and the fish of the Martin River at Blarney.

The effects of eutrophication of inland waters due to increases in the concentrations of nitrogen and phosphorus are well known in regard to lakes but are not so marked in the case of flowing waters since planktonic algae cannot normally multiply there and bottom sediments, which in lakes serve as a reservoir of inorganic nutrients, are usually regularly scoured in rivers (Owens and Wood, 1968). However, in rivers, growths of attached filamentous algae such as *Cladophora* may be stimulated by increased nitrate and phosphate levels in the water (Ministry of Technology, 1968) and the occurrence of water weeds such as *Potamogeton* and *Ranunculus* may also be increased. Such changes, besides being of nuisance value, may also, in the long term, change the nature of a river since they encourage silting by reducing current velocity. Much of the nitrogen increase in rivers in England is due to the run-off from agricultural land where the use of artificial fertilisers has doubled in the last decade (Lund, 1967). Phosphate in river water has been greatly augmented by that entering in domestic sewage and in industrial effluents. Owens and Woods (1968) calculated that, in effluents from English sewage treatment plants, 50 per cent of the phosphate content is derived from detergents. The current problem of eutrophication in Lough Neagh is thought to be due to the large amount of phosphate entering the water in sewage effluents and methods for removing the substance from the wastes are being considered.

Such sources of pollution, while existing in some measure in the case of the Blackwater and Martin rivers, have not as yet caused any major changes in water quality. It is not unlikely, however, that they will do so in the future.

SUMMARY

1. An investigation has been carried out on the Rivers Blackwater and Martin, Co. Cork, to determine the effects of pollution on the water quality of these rivers with particular reference to their fish stocks.
2. Investigations commenced in June, 1966 and were terminated in July, 1969. Laboratory work was carried out at the Zoology Department, University College, Cork.

3. Investigations were concentrated at Rathmore and Mallow on the main Blackwater, at Mitchelstown on the Funcheon, a tributary of the Blackwater, and at Rathduff and Blarney on the Martin. These locations were chosen as the bulk of the waste material is discharged to the rivers at these points. Other points on the main Blackwater and on its tributaries were examined in less detail.
4. Information on waste discharges in regard to their composition and volume led to the conclusion that the wastes are almost exclusively of an organic nature and that the bulk is derived from industries processing milk and agricultural products.
5. Weekly daytime measurements of D.O., B.O.D., suspended solids, pH and temperature were made in each area of investigation in the summers of 1967 and 1968 and, in addition, of ammonia and nitrate-nitrogen in summer, 1967. Depletion in D.O. and increases in B.O.D. and suspended solids were noted in varying degrees below each effluent. However, in only one case (the Gradoge at Mitchelstown) were such conditions severe enough at the time of measurement to be lethal for fish. Diurnal variation in D.O. was also investigated in unpolluted and polluted reaches at each location in July 1968 and was found to be generally of small magnitude, except in the case of the Funcheon at Mitchelstown where markedly lower D.O. concentrations than those occurring during day time, were recorded overnight. The relatively small D.O. depletion, which accompanied the large B.O.D. concentrations recorded on occasion, seemed to be due to the high rates of reaeration produced by river flow characteristics. However, the presence of sewage fungus and muds complicates the position with regard to the prediction of the effects of wastes on D.O. and the classical Streeter-Phelps equation is probably not directly applicable in the case of most Irish rivers. Lethal levels of ammonia were not detected in the rivers. Suspended solids, while never nearing directly lethal levels, were found to settle out quickly in pools between riffles where, in the form of sludge and mud, they represent a drain on D.O.
6. The macrophytes, mosses and algae were examined in unpolluted and polluted riffles in each area in June 1967 and 1968. The most notable effects of pollution on the flora are the replacement of *Ranunculus*, the most commonly occurring plant in the unpolluted riffles, by pondweed, *Potamogeton* and the stimulation of the sewage fungus community as well as algae, particularly *Stigeoclonium* spp. A quantitative study of the sewage fungus infestation in the Blackwater at Mallow during the beet-sugar campaign of 1968/69 proved inconclusive but it appears that periodic flooding in the river at this point is the main factor governing the extent of the infestation.
7. The macroinvertebrate fauna of unpolluted and polluted riffles in each area was examined in two surveys, one in 1966/67, the other in 1968/69. Various degrees of impairment of the normal fauna were observed in the polluted riffles, the basic change always being of the same type i.e. a reduction in the diversity and density of most of the clean water forms and a marked increase in the numbers of organisms such as Oligochaetes, Chironomids and leeches. These changes in the macroinvertebrate fauna in polluted conditions were related generally to the degree of deterioration in water quality as indicated by depletion of D.O. and increase in B.O.D. but more directly to the intensity of sewage fungus infestation and silt deposition on the substratum.
8. Fish populations in unpolluted and polluted reaches at each location were compared. Several differences were noted, among which was the apparently better growth rate of trout in polluted water, at Rathmore particularly. Complete elimination of fish by pollution was detected in only one stretch and in all others trout, at least in small numbers, and other fish were caught. Young salmon were, however, absent from some of the latter and seem to be the least resistant species. For fish, the depletion of D.O. is the main danger from the pollution observed in the Blackwater and Martin. Since the extent of depletion is greatly curtailed by factors such as rapid reaeration the value of fish as indicators of pollution is not as great as is that of the invertebrate fauna.
9. It is concluded that the Blackwater and Martin were not seriously polluted in the period during which the investigations were carried out and that the overall productivity of fish was not significantly affected by the pollution up to the point at which the investigations were terminated. This state of affairs may not remain permanent and strict control of waste discharges is necessary if serious deterioration of these and other Irish rivers is to be prevented.

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APPENDIX A

INVESTIGATIONS OF THE ESTUARY OF THE BLACKWATER.

Measurements of D.O., salinity and temperature were made at several points above the estuary mouth in August 1967 and again in August 1968. Suspended solids were also measured in 1968. Samples were taken, using a "Casella" bottle, from a boat moving upstream at half-tide and downstream at full-tide. In 1967 only five stations were worked, samples being taken at right and left banks and at midstream from the bottom, midwater and surface at each station. In 1968, 21 stations were worked at approximately half mile (0.8 km) intervals between the mouth at Youghal and the top at Cappoquin, but only one sample, from 2-3m. depth, in midstream, was taken at each station.

The most notable finding of these surveys was the depletion of D.O. in the stretch in 1967, a minimum of 70% of saturation being recorded about 9 miles above the mouth (Fig. 24a). Despite the much greater number of stations worked in the 1968 survey, marked depletion of D.O. was not found at any point. Suspended solids (see Fig. 24b), measured in 1968, showed a gradual increase in concentration from the top of the estuary, where the concentration was almost undetectable, to the mouth at Youghal where 400 p.p.m. were recorded. This is well within the normal range for estuaries.

The depletion in D.O. in August 1967 is surprising in consideration of the amount of waste entering the estuary. The towns of Cappoquin and Lismore at the upriver end have each populations less than 1,000 and the domestic sewage, together with effluents from a small bacon factory in Cappoquin, receives great dilution in the estuary. The domestic sewage of Youghal (population 5,000) is discharged, untreated, into the mouth of the estuary, but the salinity data (Fig. 24a) indicate that this waste would not be carried very far above the estuary mouth by tidal action, certainly not as far as the reach where low D.O. was recorded in August 1967. There are extensive mud deposits in the Blackwater estuary, but these have arisen through natural agencies and are mainly inorganic in nature. However, even a small amount of organic matter, waste or otherwise, discharged into the estuarine reaches might, through tidal action, accumulate in certain regions and lead to low D.O. as recorded in August 1967. The need for a regular check on the D.O. concentration in this and other Irish estuaries is clear.

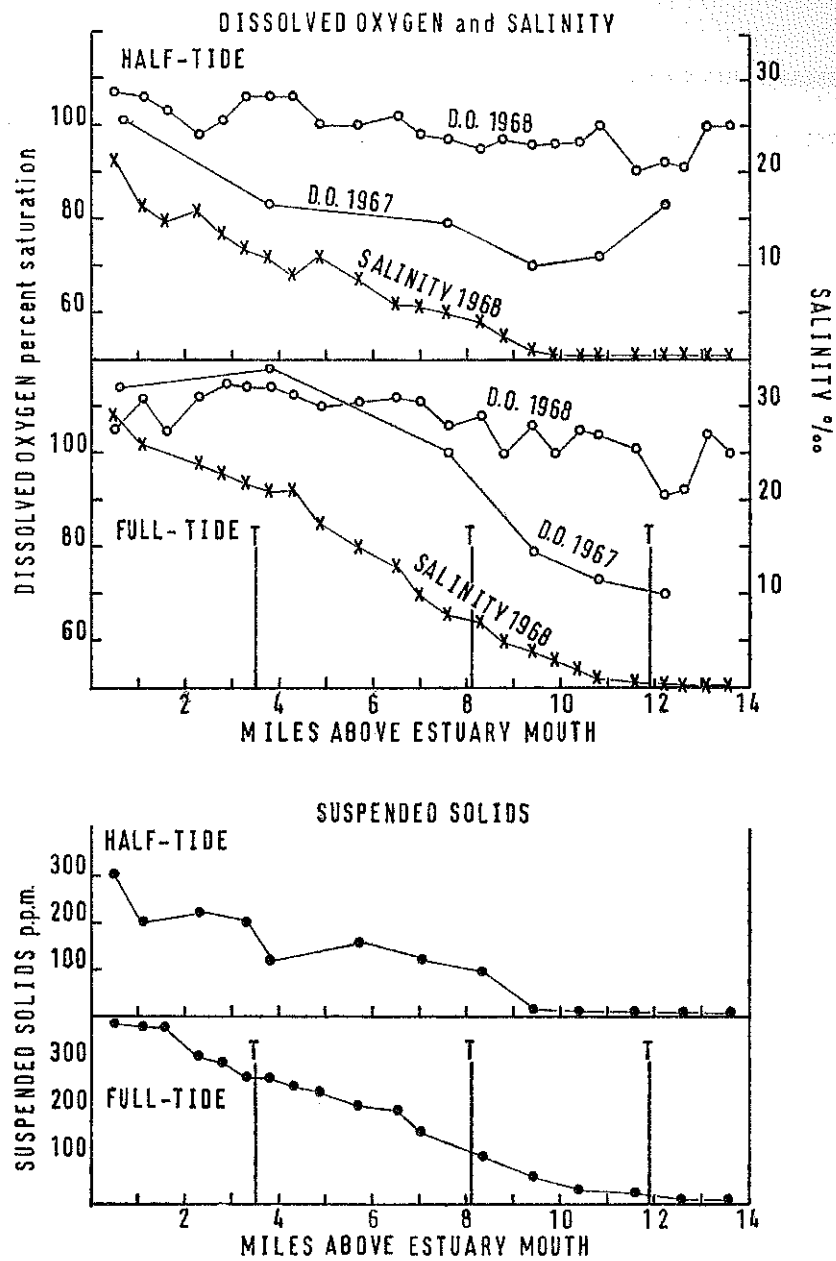


Fig. 24. Recordings of dissolved oxygen, salinity and suspended solids at a series of stations above the mouth of the Black-water estuary at two tidal positions in August 1968. Recordings of dissolved oxygen made in August 1967 are also shown. T indicates the entry points of tributaries.

APPENDIX B

A LIST OF ANIMALS RECORDED IN EACH AREA.

R=Rathmore; M=Mallow; F=Fermoy; MIT=Mitchelstown; RD=Rathduff; B=Blarney.

PLATYHELMINTHES

Tricladida

Dugesia sp. M, MIT.

Polycelis spp. M, F, RD, B.

ANNELIDA

Oligochaeta

Limnodrilus hoffmeisteri Clap. R, M, MIT.

Limnodrilus udekemianus Clap. MIT.

Rhyacodrilus coccineus (Vej.) R, M, MIT.

Aulodrilus pluriseta (Piguet) M.

Psammorectes barbatus (Grube) M, F.

Pelosclex ferox (Eisen) MIT.

Tubifex tubifex (Müller) R, M, F, MIT.

Tubifex ignotus (Stolc) R, M, MIT.

Tubificidae indet R, M, F, MIT, RD, B.

Nais spp. MIT.

Naididae indet. R, MIT, RD, B.

Enchytraeidae indet. R, M, F, MIT, RD, B.

Lumbricalus sp. R, F, MIT, RD, B.

Stylodrilus heringianus Clap. R, M, F, MIT, RD, B.

Eiseniella tetraedra (Savigny) R, M, F, MIT, B.

Hirudinea.

Erpobdella octoculata (L.) R, M, F, MIT, B.

Glossiphonia complanata (L.) R, M, F, MIT, RD, B.

Helobdella stagnalis (L.) R, M, F, MIT, RD, B.

Piscicola geometra (L.) R, M, MIT, RD, B.

Hemiclepsis marginata (Müll.) M, MIT.

Theromyzon tessulatum (Müll.) M.

ARTHROPODA—CRUSTACEA

Amphipoda

Gammarus duebeni Lillj. R, M, F, MIT, RD, B.

Isopoda

Asellus aquaticus L. M, F, MIT.

ARTHROPODA—INSECTA

Plecoptera

Protonemura meyeri (Pict.) R, M, F, MIT, RD, B.

Amphinemura sulcicollis Steph. R, M, MIT.

Nemurella picteti Klap. MIT.

Brachyptera risi (Mort.) M, MIT, B.

Leuctra fusca L. R, M, F, MIT, RD, B.

Leuctra hippopus Kemp. R, M, F, MIT, RD, B.

Perla bipunctata Pict. R, M, F, MIT, B.

Isoperla grammatica (Poda) R, M, F, MIT, RD, B.

Chloroperla torrentium (Pict.) R, M, F, MIT, RD, B.

Capnia bifrons (Newm.) M, F, RD.

Ephemeroptera

Baetis rhodani (Pict.) R, M, F, MIT, RD, B.

Baetis pumilus (Burmeister) R, M, F, MIT, RD, B.

Baetis scambus Eaton R, M, F, MIT, RD, B.

Ephemerella ignita (Poda) R, M, F, MIT, RD, B.

Ecdyonurus venosus (Fabr.) R, M, F, MIT, RD, B.

Heptagenia sulphurea (Müll.) R, M, F, MIT, RD, B.

Rhithrogena semicolorata (Curtis) R, M, F, MIT, RD, B.

Caenis rivulorum Eaton. R, M, F, MIT, B.

Paraleptophlebia submarginata (Steph.) R.

Trichoptera

Rhyacophila dorsalis Curt. R, M, F, MIT, RD, B.

Rhyacophila munda McLachlan. R, M, F, MIT, RD, B.

Hydropsyche instabilis Curt. R, M, F, MIT.

Hydropsyche spp. R, M, F, MIT, RD, B.

Polycentropus flavomaculatus (Pict.) R, M, F, MIT, RD, B

Philopotamus montanus (Donovan) M, F, RD, B.

Psychomyia pusilla (Fabr.) R, M, F, MIT.

Glossosoma boltoni Curt. R, M, F, MIT.

Agapetus fuscipes Curt. R, M, F, MIT, RD, B.

Silo pallipes Fabr. R, M, F, MIT, RD, B.

Lepidostoma hirtum (Fabr.) R, M, F, MIT.

Athripsodes spp. R, M, F, MIT.

Leptoceridae indet. R, M, F, MIT, RD, B.

Notidobia ciliaris (L.) R, M, F, MIT.

Anabolia nervosa (Curt.) F, MIT.

Limnephilidae indet. R, M, F, MIT, RD, B.

Odontocerum albicorne (Scopoli) M, F, MIT, RD, B.

Hydroptilidae indet. R, M, F, MIT.

Coleoptera

Latelmis volkmari Panzer R, M, F, MIT, RD, B.

Limnius tuberculatus Müll. R, M, F, MIT, B.

Esolus parallelipedus Müll. R, M, F, MIT, RD, B.

Brychius elevatus Panzer. R, M, MIT.

Gyrinus spp. R, M, F, MIT.

Hydrophilidae indet. R, M, MIT, RD, B.

Dytiscinae indet. R, M, MIT, RD.

Diptera

Chironomidae indet. R, M, F, MIT, RD, B.

Simuliidae indet. R, M, F, MIT, RD, B.

Ceratopogonidae indet. R, M, F.

Anthomyiidae indet. R, M, F, MIT, RD.

Dicranota spp. R, M, F, MIT, RD, B.

Pedicia spp. R, M.

Tipulidae indet. R, M, F, MIT, RD, B.

ARTHROPODA—ARACHNIDA

Hydracarina

Megapus spp. R, M, F, MIT, RD.

Sphercon spp. R, M, MIT, B.

Lebertia spp. R, M, MIT, RD, B.

Hygrobates spp. R, M, F, MIT, RD, B.

Aturus spp. M, F, B.

Atractides spp. F.

MOLLUSCA

Gastropoda

Ancylus fluviatile (Müll.) R, M, F, MIT, RD, B.

Potamopyrgus jenkinsi (Smith) R, M, F, MIT, RD, B.

Lymnaea peregra (Müll.) R, M, F, MIT, RD, B.

Physa fontinalis (L.) M, F, MIT.

Bithynia tentaculata (L.) M, F.

Planorbis contortus (L.) M, F, MIT.

Planorbis albus (Müll.) M, F.

Segmentina complanata (Linn.) M, F.

Planorbis laevis Alder M, F.

Valvata piscinalis (Müll.) M, F.

Theodoxus fluviatilis (L.) F.

Lamellibranchiata

Sphaerium corneum (L.) R, M, F, MIT, RD, B.

Pisidium subtruncatum Malm. R, M, F, MIT.

VERTEBRATA (no data for Fermoy).

Marsipobranchii

Lampetra spp. R, M, MIT, RD, B.

Pisces

Salmo salar L. R, M, MIT, B.

Salmo trutta L. R, M, MIT, RD, B.

Anguilla anguilla (L.) R, M, MIT, RD, B.

Nemacheilus barbatula (L.) R, M, MIT, RD, B.

Phoxinus phoxinus (L.) R, M.

Gobio gobio (L.) R, M.

Leuciscus leuciscus (L.) M.

Rutilus rutilus (L.) R, M.

Scardinius erythrophthalmus (L.) M.

Gasterosteus aculeatus L. MIT, RD, B.

APPENDIX C

PALATABILITY OF TROUT FROM UNPOLLUTED AND POLLUTED WATER OF THE R. BLACKWATER AT RATHMORE.

Since tests had shown that the edible portions of brown trout in clean and polluted water at Rathmore were significantly different in composition it was decided to augment these data by comparing the palatability of the two types of fish. Samples of trout were sent live in tanks to the Research and Development Department of the Irish Sugar Co. at Carlow where a taste panel is maintained in connection with the testing of the company's food products.

The Triangular (Duo-Trio) test was used wherein each panel member is presented with three specimens, two of which are from the same sample and the third from the other sample, and is asked to state, firstly, which is the "odd man out" and, secondly, which fish type is preferred. The results showed that a significant difference in taste was only present in the case where the large fish of the polluted water were given with unpolluted water fish. In this case, 9 out of 12 members of the panel successfully picked out the odd specimen and of these 6 preferred the clean water fish and 3 the polluted water fish. Fish do not grow as large in unpolluted water at Rathmore as in polluted water and for this reason it is not possible to dissociate the significant taste difference from size.

TABLE 1. A Summary of the combined collections of June, 1967 and 1968 of angiosperms, mosses and macroscopic algae from unpolluted and polluted riffles of the R. Blackwater at Rathmore and Mallow, the R. Funcheon at Mitchelstown and the R. Martin at Rathduff and Blarney.

1: present 2: sparse 3: moderate amount 4: abundant

Location	Angiosperms		Mosses		Algae	
	Unpolluted	Polluted	Unpolluted	Polluted	Unpolluted	Polluted
Rathmore (Blackwater)	Ranunculus aquatilis 4 Myriophyllum sp 2 Potamogeton sp 1	Potamogeton sp 3 Ranunculus aquatilis 1	Eurynchium riparioides 4 Fontinalis sp 3	Fontinalis sp 3	Ulothrix sp 3 Mougeotia sp 3 Oedogonium sp 3 Lemanea sp 2 Vaucheria sp 2 Spirogyra sp 1	Stigeoclonium sp 4 Vaucheria sp 4 Spirogyra sp 2 Ulothrix sp 2 Mougeotia sp 1
Mallow (Blackwater)	Ranunculus aquatilis 4 Callitriche hermaphrodita 2 Potamogeton crispus 2 Potamogeton sp 2 Myriophyllum sp 1 Berula sp 1	Ranunculus aquatilis 1 Potamogeton crispus 1 Callitriche stagnalis 1	Fontinalis sp 2 Eurynchium riparioides 1	Fontinalis sp 1	Spirogyra sp 3 Oedogonium sp 3	Oedogonium sp 3 Cladophora sp 2 Ulothrix sp 2
Mitchelstown (Funcheon)	Ranunculus aquatilis 4	Ranunculus aquatilis 4 Potamogeton natans 3 Potamogeton crispus 3	Fontinalis sp 4 Eurynchium riparioides 2	Fontinalis sp 3	Cladophora sp 2	Stigeoclonium sp 4 Vaucheria sp 3 Spirogyra sp 1
Rathduff (Martin)	Ranunculus aquatilis 4 Rorippa nasturtium-aquaticum 3 Callitriche stagnalis 2 Myriophyllum sp 1 Veronica beccagunga 1 Myosotis secunda 1	Ranunculus aquatilis 2	Fontinalis sp 3 Eurynchium riparioides 1	Fontinalis sp 1	Nostoc sp 3 Tetraspora sp 1 Mougeotia sp 1 Cladophora sp 1	Vaucheria sp. 4 Ulothrix sp 4 Cladophora sp 1
Blarney (Martin)	Ranunculus aquatilis 3 Myriophyllum sp 1 Potamogeton pectinatus 1 Berula sp 1	Ranunculus aquatilis 3	Fontinalis sp 2 Eurynchium riparioides 1	Fontinalis sp 1 Eurynchium riparioides 1	Lemanea sp 1 Cladophora sp 1	Oedogonium sp 4 Ulothrix sp 2 Spirogyra sp 2 Vaucheria sp 1 Lemanea sp 1

TABLE 2. Percentage composition of samples of the invertebrate fauna from unpolluted and various polluted zones of the R. Blackwater at Rathmore and Malloy, autumn 1966. The zones, shown in the TABLE in the actual sequence encountered when proceeding downstream, reading from left to right are, O: unpolluted; 1: mildly polluted; 2: recovery; 3: post dilution; 4: heavily polluted. * less than 0.5 per cent.

Faunal Group	Rathmore				Malloy				
	0	1	4	3	0	1	4	2	2
Oligochaeta ...	*	*	3.8	*	*	*	0.5	1.5	1.8
Hirudinea ...	—	0.8	1.4	4.9	0.8	*	45.9	11.9	10.2
Gammarus ...	5.2	0.9	*	*	20.4	2.2	0.7	4.3	3.1
Asellus ...	—	—	—	—	—	*	3.3	4.2	7.7
Baetidae ...	14.6	30.0	1.4	7.8	25.7	11.6	1.7	15.5	27.4
Ecdyonuridae ...	0.8	1.6	—	*	10.4	2.6	—	1.0	1.1
Ephemera ...	0.6	0.9	*	*	2.0	3.4	1.7	15.8	7.3
Plecoptera ...	2.4	1.5	*	*	7.1	2.8	1.4	2.4	0.8
Trichoptera-free ...	9.9	3.3	*	1.2	6.7	4.5	1.7	8.0	9.7
Trichoptera-cased ...	0.5	*	—	—	2.0	*	—	0.5	*
Coleoptera ...	6.1	7.9	*	1.5	8.7	2.5	*	2.9	3.1
Chironomidae ...	44.0	36.5	84.3	59.3	7.1	33.7	6.9	20.6	12.2
Simuliidae ...	6.1	7.0	7.3	19.3	4.6	28.8	*	4.2	6.7
Other Diptera ...	—	*	*	*	*	*	—	0.8	—
Mollusca ...	3.5	3.3	1.0	4.9	3.6	6.8	30.8	3.3	3.6
Others ...	6.1	5.4	*	*	0.6	*	5.0	3.2	5.1
Total numbers in samples ...	1,476	1,838	4,673	2,695	2,040	3,627	578	1,385	2,669

TABLE 3. Percentage composition of samples of the invertebrate fauna from unpolluted and various polluted zones of the Rivers Funcheon and Gradoge at Mitchelstown, autumn 1966. See TABLE 2 for explanation of symbols.

Faunal Group	Gradoge		Funcheon			
	0	4	0	4	2	3
Oligochaeta ...	1.6	42.3	0.7	22.0	2.8	3.7
Hirudinea ...	—	—	—	0.5	*	—
Gammarus ...	17.7	—	21.0	8.3	7.6	7.3
Asellus ...	—	—	—	8.1	1.0	—
Baetidae ...	22.7	*	34.1	5.6	44.6	36.6
Ecdyonuridae ...	*	—	1.4	—	*	—
Ephemera ...	6.8	—	5.6	—	4.1	8.1
Plecoptera ...	*	—	1.3	*	*	1.4
Trichoptera-free ...	1.0	—	1.9	1.4	1.1	1.8
Trichoptera-cased ...	0.5	—	*	—	*	*
Coleoptera ...	31.2	—	9.5	4.8	1.7	24.8
Chironomidae ...	12.1	56.4	20.5	44.9	35.0	10.6
Simuliidae ...	(4114)	(2)	(8434)	(2)	(3820)	(5636)
Other Diptera ...	1.5	—	*	*	0.8	—
Mollusca ...	0.5	0.9	1.2	3.4	—	2.4
Others ...	3.9	—	2.2	*	0.8	3.1
Total numbers in samples† ...	1,814	426	1,807	746	1,056	1,611

† Excluding catches of Simuliidae—numbers of these in each sample given in brackets.

TABLE 4. Percentage composition of samples of the invertebrate fauna from unpolluted and various polluted zones of the R. Martin at Rathduff and Blarney, autumn 1966. See TABLE 2 for explanation of symbols.

Faunal Group	Rathduff				Blarney	
	0	1	4	3	0	1
Oligochaeta ...	0.6	0.6	60.7	5.5	2.2	11.4
Hirudinea ...	—	*	—	*	*	*
Gammarus ...	11.6	12.2	*	5.0	23.7	25.0
Asellus ...	—	—	—	—	—	—
Baetidae ...	58.7	38.1	4.9	11.3	49.9	42.6
Ecdyonuridae ...	2.4	—	—	—	1.0	—
Ephemera ...	*	*	—	—	0.4	*
Plecoptera ...	1.8	0.7	—	*	0.8	—
Trichoptera-free ...	*	0.5	—	1.1	5.4	*
Trichoptera-cased ...	*	—	—	—	*	*
Coleoptera ...	1.1	*	*	0.6	4.7	9.9
Chironomidae ...	2.3	2.5	30.9	17.2	5.5	5.9
Simuliidae ...	16.4	43.5	3.3	58.2	2.1	0.7
Other Diptera ...	2.0	*	—	*	2.3	*
Mollusca ...	*	*	—	0.5	1.2	2.6†
Others ...	2.0	0.9	*	—	0.7	1.1
Total numbers in samples ...	2,276	1,607	12,353	5,498	2,254	1,778†

†Very high catch of *Potamopyrgus jenkinsi* (31,500) excluded.

TABLE 5. Percentage composition of samples of the invertebrate fauna from unpolluted and various polluted zones of the R. Blackwater at Rathmore and Mallow, winter 1966. See TABLE 2 for explanation of symbols.

Faunal Group	Rathmore				Mallow				
	0	1	4	3	0	4	4	2	2
Oligochaeta ...	1.9	2.8	2.9	*	—	2.5	3.7	0.8	*
Hirudinea ...	*	1.4	21.5	0.5	0.5	4.1	17.8	1.9	1.6
Gammarus ...	6.0	1.4	*	2.6	32.2	53.5	14.0	2.5	11.5
Asellus ...	—	—	—	—	*	0.8	1.9	12.6	—
Baetidae ...	13.9	41.0	7.1	10.8	23.1	4.9	7.5	7.3	37.4
Ecdyonuridae ...	17.9	16.1	*	2.0	16.0	*	—	5.9	8.0
Ephemera ...	—	—	*	*	*	—	—	—	*
Plecoptera ...	8.2	6.7	*	3.3	1.9	—	—	—	*
Trichoptera-free ...	14.5	9.7	4.8	9.4	12.8	5.3	1.0	3.1	8.3
Trichoptera-cased ...	4.9	0.8	0.4	0.9	1.0	2.3	1.0	1.3	0.8
Coleoptera ...	24.5	11.4	0.8	6.5	1.4	4.9	1.9	*	3.8
Chironomidae ...	3.3	5.0	51.6	31.2	3.7	14.8	7.5	58.6	18.7
Simuliidae ...	1.0	1.4	0.8	6.9	—	—	—	0.8	3.8
Other Diptera ...	0.6	0.6	1.0	*	*	2.1	—	*	—
Mollusca ...	2.9	1.6	5.2	14.9	6.7	5.4	43.9	4.8	5.8
Others ...	*	*	3.4	10.0	*	—	—	—	—
Total numbers in samples ...	955	361	1,189	2,404	627	243	107	478	1,041

TABLE 6. Percentage composition of samples of the invertebrate fauna from unpolluted and various polluted zones of the Rivers Funcheon and Gradoge at Mitchelstown, winter 1966. See TABLE 2 for explanation of symbols.

Faunal Group	Gradoge		Funcheon			
	0	4	0	4	2	2
Oligochaeta ...	2.0	33.9	*	5.3	8.1	9.5
Hirudinea ...	*	—	*	*	*	*
Gammarus ...	33.5	—	29.5	1.4	3.7	27.7
Asellus ...	—	—	—	11.6	*	—
Baetidae ...	13.2	*	27.1	17.9	15.2	22.9
Ecdyonuridae ...	7.5	—	8.7	*	0.7	1.9
Ephemerella ...	*	—	*	—	*	*
Plecoptera ...	3.3	*	3.5	—	—	0.9
Trichoptera-free ...	4.5	*	2.4	*	*	7.5
Trichoptera-cased ...	0.7	*	12.8	*	*	1.0
Coleoptera ...	27.7	*	9.7	0.8	*	19.4
Chironomidae ...	1.4	64.7	3.8	60.8	69.4	3.5
Simuliidae ...	(383)	(156)	(33)	(3,200)	(3,440)	(231)
Other Diptera ...	1.7	*	*	*	*	0.9
Mollusca ...	2.0	—	*	1.0	*	4.3
Others ...	1.7	0.9	1.1	0.9	*	*
Total numbers in samples† ...	1,777	5,491	2,341	2,900	1,903	1,524

† Excluding catches of Simuliidae—numbers of these in each sample given in brackets.

TABLE 7. Percentage composition of samples of the invertebrate fauna from unpolluted and various polluted zones of the R. Martin at Rathduff and Blarney, winter 1966. See TABLE 2 for explanation of symbols.

Faunal Group	Rathduff				Blarney	
	0	1	4	3	0	1
Oligochaeta ...	1.8	12.8	63.6	7.2	6.9	2.0
Hirudinea ...	*	*	0.9	0.9	*	1.7
Gammarus ...	6.7	*	*	7.6	20.1	34.3
Asellus ...	—	—	—	—	—	—
Baetidae ...	65.2	27.8	2.5	21.1	22.3	7.2
Ecdyonuridae ...	11.0	*	—	*	11.2	*
Ephemerella ...	—	—	—	—	—	*
Plecoptera ...	4.1	*	*	4.6	4.4	*
Trichoptera-free ...	1.5	*	*	1.5	3.7	0.6
Trichoptera-cased ...	0.7	—	—	—	1.6	*
Coleoptera ...	0.8	*	*	*	1.6	9.9
Chironomidae ...	4.0	38.5	10.5	44.2	16.9	18.4
Simuliidae ...	2.8	20.0	21.5	6.0	5.0	1.8
Other Diptera ...	1.2	*	*	2.4	2.9	0.6
Mollusca ...	*	*	0.5	3.7	2.6	18.6†
Others ...	—	*	*	—	*	4.2
Total numbers in samples ...	3,149	6,252	14,869	2,233	1,837	1,272†

† Excluding *Potamopyrgus jenkinsi* (40,500).

TABLE 8. Percentage composition of samples of the invertebrate fauna from unpolluted and various polluted zones of the R. Blackwater at Rathmore and Mallow, spring 1967. See TABLE 2 for explanation of symbols.

Faunal Group	Rathmore				Mallow				
	0	1	4	3	0	1	4	2	2
Oligochaeta ...	3.1	0.7	0.8	*	*	2.8	—	5.6	0.5
Hirudinea ...	*	0.8	5.9	1.3	*	0.6	0.7	6.2	2.4
Gammarus ...	1.1	*	—	—	6.0	2.1	0.7	1.7	1.9
Asellus ...	—	—	—	—	—	*	—	3.5	4.1
Baetidae ...	15.9	46.8	34.0	34.8	15.8	34.5	40.9	8.8	17.3
Ecdyonuridae ...	24.1	5.6	6.0	3.7	53.5	9.5	6.0	0.6	2.6
Ephemera ...	—	—	—	—	—	—	—	—	—
Plecoptera ...	4.3	0.9	1.5	3.9	2.8	1.7	0.7	0.6	1.1
Trichoptera-free ...	9.0	2.0	2.4	1.5	5.5	2.1	1.0	1.7	7.4
Trichoptera-cased ...	4.7	0.5	*	*	2.3	1.8	—	0.6	—
Coleoptera ...	20.2	6.9	0.8	2.9	3.4	4.6	—	0.8	3.9
Chironomidae ...	6.2	29.9	44.4	38.8	2.2	15.7	48.1	29.4	27.7
Simuliidae ...	8.8	*	—	*	3.4	5.3	—	7.3	28.2
Other Diptera ...	*	*	1.8	4.4	*	2.7	1.3	3.3	0.7
Mollusca ...	0.7	0.8	2.5	*	0.9	11.0	1.3	4.7	—
Others ...	1.5	4.9	—	7.7	3.1	5.1	—	25.1	2.1†
Total numbers in samples ...	1,261	2,400	1,443	3,740	3,413	3,199	831	2,289	2,315†

† Excluding catch of *Caenis rivulorum* (3,830).

TABLE 9. Percentage composition of samples of the invertebrate fauna from unpolluted and various polluted zones of the Rivers Funcheon and Gradoge at Mitchelstown, spring 1967. See TABLE 2 for explanation of symbols.

Faunal Group	Gradoge		Funcheon		
	0	4	0	4	2
Oligochaeta ...	0.8	33.3	0.8	1.4	0.5
Hirudinea ...	*	—	—	*	*
Gammarus ...	10.1	—	4.2	*	3.0
Asellus ...	—	—	—	1.1	*
Baetidae ...	32.5	—	11.8	11.6	50.8
Ecdyonuridae ...	6.6	—	7.6	0.6	1.6
Ephemera ...	*	—	—	*	—
Plecoptera ...	1.3	—	2.6	*	0.9
Trichoptera-free ...	3.6	—	3.7	*	1.0
Trichoptera cased ...	1.7	—	32.7	*	*
Coleoptera ...	36.5	—	9.2	*	1.2
Chironomidae ...	3.2	66.6	27.1	83.3	39.4
Simuliidae ...	(440)	(—)	(2,500)	(4,600)	(820)
Other Diptera ...	*	—	*	*	*
Mollusca ...	1.3	—	*	*	*
Others ...	2.3	—	*	*	*
Total numbers in samples†	2,875	3,600	2,782	5,905	3,555

† Excluding catches of Simuliidae—numbers of these in each sample given in brackets.

TABLE 10. Percentage composition of samples of the invertebrate fauna from unpolluted and various polluted zones of the R. Martin at Rathduff and Blarney, spring 1967. See TABLE 2 for explanation of symbols.

Faunal Group	Rathduff		Blarney	
	0	4	0	1
Oligochaeta ...	1.1	34.4	5.5	3.3
Hirudinea ...	*	*	*	0.6
Gammarus ...	2.8	*	1.8	7.1
Asellus ...	—	—	—	*
Baetidae ...	7.3	1.8	7.8	1.4
Ecdyonuridae ...	*	*	2.3	*
Ephemerella ...	—	—	—	—
Plecoptera ...	*	*	0.7	*
Trichoptera-free ...	3.0	*	0.8	*
Trichoptera-cased ...	4.8	—	1.0	*
Coleoptera ...	0.7	—	2.4	0.5
Chironomidae ...	69.5	58.3	55.2	55.0
Simuliidae ...	3.8	3.2	0.6	1.4
Other Diptera ...	*	*	*	*
Mollusca ...	1.4	*	19.8	28.8
Others ...	4.8	*	1.6	*
Total numbers in samples ...	4,375	3,430	5,436	5,455

TABLE 11. Average numbers of each group of the invertebrate fauna in samples taken with a Surber apparatus (frame size 1/17 sq. metre) in unpolluted (0) and heavily polluted (4) zones of the R. Blackwater at Rathmore and Mallow and R. Funcheon at Mitchelstown in summer 1968. The mildly polluted zone (1) of the Blackwater at Mallow, which is classified as heavily polluted during autumn and winter, was also sampled at this time and the data are given for comparison with those in TABLES 12 and 13. Numbers taken on stones and on weed are shown separately.

Faunal Group	Blackwater—Rathmore				Blackwater—Mallow						Funcheon			
	0		4		0		1		4		0		4	
	Stone	Weed	Stone	Weed†	Stone	Weed	Stone	Weed	Stone	Weed	Stone	Weed	Stone	Weed
Oligochaeta	3	—	7	—	—	10	—	4	1	—	7	2	50	600
Hirudinea	1	1	33	—	—	—	—	4	19	7	1	1	—	—
Gammarus	—	5	—	—	10	3	—	—	—	—	6	40	1	1
Asellus	—	—	—	—	—	—	—	—	2	2	—	—	—	—
Baetidae	17	38	—	—	4	5	8	—	—	—	2	53	—	—
Ecdyonuridae	12	3	—	—	21	3	6	—	—	—	21	1	—	—
Ephemerella	8	71	—	—	25	150	24	25	7	35	9	110	—	—
Plecoptera	6	3	—	—	3	3	1	—	—	—	10	5	—	—
Trichoptera-free	17	33	1	—	24	14	—	1	—	1	11	15	—	—
Trichoptera-cased	—	8	—	—	6	2	—	—	2	6	50	5	—	—
Coleoptera	9	7	—	—	3	1	—	—	—	—	18	4	—	—
Chironomidae	72	128	115	—	26	134	63	295	110	1,040	65	470	185	250
Simuliidae	4	47	—	—	2	260	4	1,500	6	80	3	150	—	100
Other Diptera	—	—	2	—	—	1	—	—	—	—	2	—	—	—
Mollusca	1	1	1	—	14	6	1	—	7	8	21	4	1	2
Others	17	18	50	—	3	7	3	170	3	5	—	8	—	—
Total No. per Sample	167	363	209	—	141	599	110	1,909	157	1,184	226	868	237	953
Total No. per Sq. M.	2,839	6,171	3,553	—	2,397	10,183	1,870	32,453	2,669	20,128	3,842	14,756	4,029	16,201

† Not enough weed growth in zone to permit sampling.

TABLE 12. Average numbers of each group of the invertebrate fauna in samples taken with a Surber apparatus (frame size 1/17 sq. metre) in unpolluted (0) and heavily polluted (4) zones of the R. Blackwater at Rathmore and Mallow and the R. Funcheon at Mitchelstown in autumn 1968. Numbers taken on stones and on weeds are shown separately.

Faunal Group	Blackwater—Rathmore				Blackwater—Mallow						Funcheon			
	0		4		0		4		4		0		4	
	Stone	Weed	Stone	Weed	Stone	Weed	Stone	Weed	Stone	Weed†	Stone	Weed	Stone	Weed
Oligochaeta	1	1	6	40	2	2	—	—	3	—	2	2	1,000	250
Hirudinea	1	—	3	41	3	6	15	100	3	—	—	1	—	—
Gammarus	1	1	—	—	4	12	2	10	1	—	12	45	—	—
Asellus	—	—	—	—	1	—	1	—	8	—	—	—	—	—
Baetidae	6	8	20	3	12	10	5	—	—	—	14	42	—	—
Ecdyonuridae	13	3	1	1	1	3	—	—	—	—	—	—	—	—
Ephemerella	—	—	—	—	—	—	—	—	—	—	2	26	—	—
Plecoptera	—	2	—	—	1	1	—	—	—	—	4	3	—	—
Trichoptera-free	7	29	1	—	9	14	3	10	1	—	5	6	—	—
Trichoptera-cased	—	1	—	—	1	—	—	—	—	—	10	1	—	—
Coleoptera	6	23	2	—	4	5	9	5	—	—	12	16	—	—
Chironomidae	6	23	53	69	20	17	12	10	10	—	4	79	275	250
Simuliidae	1	1	—	30	13	35	1	100	—	—	10	103	—	—
Other Diptera	—	2	—	—	—	1	—	—	3	—	1	—	—	—
Mollusca	12	8	—	—	10	89	52	55	3	—	21	6	—	—
Others	—	1	10	—	2	1	37	25	16	—	—	2	—	—
Total No. per Sample	54	103	96	184	83	196	137	315	48	—	97	332	1,275	500
Total No. per Sq. M.	918	1,751	1,632	3,128	1,411	3,332	2,329	5,355	816	—	1,649	5,644	21,675	8,500

† Not enough weed growth in zone to permit sampling.

TABLE 13. Average numbers of each group of the invertebrate fauna in samples taken with a Surber apparatus (frame size 1/17 sq. metre) in unpolluted (0) and heavily polluted (4) zones of the R. Blackwater at Rathmore and Mallow and the R. Funcheon at Mitchelstown in winter 1968. Numbers taken on stones and on weed are shown separately.

Faunal Group	Blackwater—Rathmore				Blackwater—Mallow						Funcheon			
	0		4		0		4		4		0		4	
	Stone	Weed	Stone	Weed	Stone	Weed	Stone	Weed	Stone	Weed†	Stone	Weed	Stone	Weed
Oligochaeta	—	1	6	3	3	1	1	1	—	—	3	2	1,000	400
Hirudinea	—	—	1	11	1	1	15	31	2	—	—	2	5	3
Gammarus	1	3	—	—	6	3	1	1	—	—	2	25	3	2
Asellus	—	—	—	—	—	1	2	2	10	—	—	—	—	—
Baetidae	19	7	10	10	12	4	1	1	2	—	20	11	1	2
Ecdyonuridae	17	6	1	—	25	8	—	—	—	—	7	—	—	—
Ephemera	—	—	—	—	—	—	—	—	—	—	—	1	—	—
Plecoptera	—	—	—	—	—	—	—	—	—	—	1	4	—	—
Trichoptera-free	6	11	3	4	7	15	—	2	2	—	3	4	2	1
Trichoptera-cased	3	5	—	—	6	4	2	—	—	—	2	8	—	4
Coleoptera	5	16	2	—	5	10	4	1	—	—	4	16	3	2
Chironomidae	6	6	53	410	15	10	2	128	3	—	1	3	5	16
Simuliidae	4	6	—	15	25	2,300	—	1,800	10	—	2	3	—	—
Other Diptera	—	—	4	15	1	1	1	—	3	—	—	1	—	—
Mollusca	1	16	1	—	17	29	27	21	—	—	1	16	1	3
Others	2	11	1	1	8	70	3	12	7	—	—	—	—	—
Total No. per Sample	64	88	82	469	131	2,457	59	2,000	39	—	46	96	1,020	433
Total No. per Sq. M.	1,088	1,496	1,394	7,973	2,227	41,769	1,003	34,000	663	—	782	1,632	17,340	7,361

† Not enough weed growth in zone to permit sampling.

TABLE 14. Average numbers of each group of the invertebrate fauna in samples taken with a Surber apparatus (frame size 1/17 sq. metre) in unpolluted (0) and heavily polluted (4) zones of the R. Blackwater at Rathmore and Mallow and the R. Funcheon at Mitchelstown, spring 1969. The mildly polluted zone (1) of the R. Blackwater at Mallow, which is classified as heavily polluted during autumn and winter, was also sampled at this time and the data are given for comparison with those in TABLES 12 and 13. Numbers taken on stones and on weed are shown separately.

Faunal Group	Blackwater—Rathmore				Blackwater—Mallow						Funcheon			
	0		4		0		1		4		0		4	
	Stone	Weed	Stone	Weed†	Stone	Weed†	Stone	Weed†	Stone	Weed†	Stone	Weed	Stone	Weed
Oligochaeta	—	3	20		1		3		—		3	3	300	350
Hirudinea	—	—	19		1		16		15		1	1	—	2
Gammarus	1	1	—		2		—		—		1	5	—	—
Asellus	—	—	—		—		—		1		—	—	—	—
Baetidae	28	21	20		2		10		10		26	11	12	19
Ecdyonuridae	11	3	1		30		2		1		2	—	1	—
Ephemerella	—	—	—		—		—		—		—	—	—	—
Plecoptera	1	5	—		2		—		—		4	6	1	—
Trichoptera-free	8	12	1		7		1		1		2	3	1	4
Trichoptera-cased	3	53	—		3		—		—		2	5	4	12
Coleoptera	4	8	—		2		1		—		4	16	2	1
Chironomidae	35	75	75		10		20		35		50	7	130	135
Simuliidae	15	25	1		1		—		—		—	1	1	—
Other Diptera	—	—	1		1		5		2		—	2	—	—
Mollusca	1	10	1		3		—		—		1	2	1	—
Others	—	5	1		3		—		—		—	2	1	—
Total No. per Sample	107	221	140		68		58		65		96	64	454	523
Total No. per Sq. M.	1,819	3,757	2,380		1,156		986		1,105		1,632	1,088	7,718	8,891

† Not enough weed growth in zone to permit sampling.

TABLE 15. Percentage occurrence of each group of food organisms in the stomachs of trout and young salmon from the combined samples of August 1967 and 1968 taken in unpolluted and polluted stretches of the River Blackwater at Rathmore, the Rivers Funcheon and Gradoge at Mitchelstown and the River Martin at Rathduff and Blarney. C=Clean water P=Polluted water.

Food Group	Rathmore				Mitchelstown				Blarney				Rathduff	
	Trout		Salmon		Trout (Gradoge)	Trout (Funcheon)		Salmon (Funcheon)	Trout		Salmon		Trout	
	C	P	C	P	C	C	P	C	C	P	C	P	C	P
Annelida	2.5	—	3.0	—	2.2	—	—	—	4.6	4.0	7.3	17.6	—	—
Gammarus	8.9	—	1.9	—	43.8	58.4	8.3	3.3	43.3	30.0	6.8	2.9	37.0	—
Asellus	—	—	—	—	—	—	25.0	—	—	—	—	—	—	—
Baetidae	43.2	17.1	85.7	54.6	21.4	48.9	8.3	72.9	32.2	10.0	37.5	30.0	43.0	21.0
Ecdyonuridae	7.4	—	9.5	—	5.6	1.8	—	2.5	0.6	—	0.5	—	14.6	21.0
Ephemera	3.0	2.1	26.7	10.0	34.8	79.2	—	89.4	13.3	2.0	17.0	—	5.9	—
Plecoptera	1.9	—	8.0	—	2.2	3.2	—	4.3	1.8	—	7.6	—	—	—
Trichoptera-free	33.1	4.3	60.4	5.0	13.5	12.3	—	25.1	9.2	2.0	28.0	—	8.5	—
Trichoptera-cased	37.1	—	12.0	—	22.5	36.1	—	11.5	—	—	—	—	—	—
Coleoptera	14.4	—	5.7	—	12.4	2.5	—	1.7	5.8	6.0	3.5	2.9	5.2	—
Chironomidae	23.8	95.8	46.3	100.0	38.2	40.6	91.7	42.3	41.4	40.0	50.5	67.6	46.5	90.0
Simuliidae	35.0	—	38.1	5.0	28.1	58.8	41.7	67.7	35.2	4.0	66.0	5.9	35.5	10.0
Other Diptera	8.0	2.1	4.6	—	18.0	9.0	8.3	11.7	3.4	—	6.5	2.9	1.0	—
Trichopteran subimagos	37.7	2.0	11.2	—	6.7	9.0	—	4.7	11.4	24.0	13.5	—	—	—
Mollusca	26.3	4.3	8.8	10.0	24.7	55.5	—	9.9	22.7	38.0	33.0	11.8	18.0	—
Terrestrial Organisms	82.4	85.2	33.3	59.1	27.0	46.0	—	9.2	25.0	22.0	18.5	5.9	32.5	26.3

TABLE 16. Dominant foods in the stomachs of trout and young salmon from clean (C) and polluted (P) stretches of the R. Blackwater at Rathmore, the Rivers Funcheon and Gradoge at Mitchelstown and the R. Martin at Rathduff and Blarney. Figures show the percentage of fish in the combined samples of 1967 and 1968 in which each food group was dominant, i.e. represented 50% or more by volume of the stomach contents.

Food Group	Rathmore				Mitchelstown					Blarney				Rathduff	
	Trout		Salmon		Trout (Gradoge)	Trout (Funcheon)		Salmon (Funcheon)	Trout		Salmon		Trout		
	C	P	C	P	C	C	P	C	C	P	C	P	C	P	
Annelida	—	—	1.2	—	—	—	—	—	—	—	1.0	14.7	—	—	
Gammarus	—	—	—	—	10.1	20.2	—	—	36.1	20.0	—	—	10.4	—	
Asellus	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
Baetidae	1.5	—	10.9	—	—	1.9	—	1.8	2.3	2.0	8.0	5.9	18.8	5.3	
Ecdyonuridae	—	—	7.3	—	1.1	—	—	—	—	—	—	—	—	—	
Ephemera	—	—	1.3	—	2.3	12.3	—	38.0	—	—	—	—	—	—	
Plecoptera	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
Trichoptera-free	1.9	—	12.5	—	—	—	—	1.8	2.3	—	1.0	—	—	—	
Trichoptera-cased	7.6	—	—	—	1.1	2.2	—	—	—	—	—	—	—	—	
Coleoptera	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
Chironomidae	—	36.2	1.2	63.6	1.1	—	88.3	1.8	1.2	8.0	—	26.5	2.1	78.9	
Simuliidae	—	—	6.3	—	—	7.3	—	23.7	1.2	—	14.0	2.9	6.2	10.5	
Other Diptera	1.9	—	0.6	—	—	—	—	—	—	—	—	—	—	—	
Trichopteran subimagos	5.7	—	1.5	—	—	—	—	—	—	—	—	—	—	—	
Mollusca	—	—	—	—	3.4	13.3	—	2.6	1.2	8.0	12.0	—	—	—	
Terrestrial Organisms	22.6	34.1	2.3	22.7	6.8	9.7	—	0.8	9.3	24.0	6.0	2.9	8.3	—	