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OBSERVATIONS OF BEHAVIOURAL RESPONSES OF FISH TO ENVIRONMENTAL STRESS *IN SITU*

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SUMMARY

Recovery processes operating within a stressed ecosystem are dependent in part on natural avoidance behaviour or acclimatization of organisms to otherwise unfavourable conditions. Adaptation to an altered environment can be achieved through either genetic or non-genetic means. Five case histories are presented which illustrate *in situ* behaviour of fishes to stress conditions.

INTRODUCTION

Catastrophic events such as industrial spills or sudden elimination of a thermal discharge in winter can result in temporary adverse environmental conditions which do not readily permit quantitative field sampling or adequate experimental design (Hocutt *et al.* 1976). The field ecologist is often (almost spontaneously) presented with unique conditions which he is not prepared to assess and which are unlikely to occur again. In view of the circumstances, investigators are required to improvise and make judgements based on their training, experience, assessment of the impact, equipment availability and so on. Observations so obtained, however, may prove invaluable in understanding a wide range of environmental considerations, for instance, threshold levels for particular species, ecosystem stability, or rates of recovery.

Processes involved in ecosystem vulnerability were identified by Cairns & Dickson (1977) as (1) inertia, or the ability to resist functional and structural displacement; (2) elasticity, or the ability to recover; and (3) resiliency, or the number of times that a system can recover after repeated stress. These concepts were further elaborated on by Cairns, Stauffer & Hocutt (1979), Stauffer *et al.* (1979) and Stauffer & Hocuttt (1980), with the latter two papers applying real data to the numerical system(s) proposed in Cairns & Dickson (1977). As discussed by Cairns *et al.* (1971), the rate of recovery of an ecosystem is dependent upon: (1) severity and duration of the stress; (2) numbers and kinds of associated stresses; (3) recolonization potential; and (4) residual effects on non-biological parameters, e.g. substrate. As such, natural avoidance or adaptation of organisms to stressful conditions is important to inertia and elasticity.

Three case histories which illustrate natural avoidance of fishes to stressful temperatures or oxygen regimes and two case histories which suggest that fish can adapt to artificially elevated water temperatures are presented in this paper.

CASE HISTORIES

Case I

A common by-product of fossil fuel generating stations is a warm water discharge into which fish are attracted during the winter months (Marcy 1971, 1976; Moore & Frisbie 1972). When effluent water temperatures decrease due to plant shut-down, fish acclimatized to discharge temperatures are vulnerable to cold shock. A cold-shock fish-kill occurred in February 1971 when a warm water discharge from a plant on the Susquehanna River near Harrisburg, PA, decreased from 21·1 °C to 1·1 °C in less than one hour. Dead fishes were observed along the shore and on the bottom to 30 m from the shore over a distance of 2·0 km. A pool fed predominately from groundwater was discovered while investigating the fish-kill. Water temperature in the pool was 10 °C. Over one hundred adult carp (*Cyprinus carpio*), quillback (*Carpiodes cyprinus*) and channel catfish (*Ictalurus punctatus*) were visually observed concentrated in the pool. Fishes could be driven from the pool, but they returned immediately. The thermal discharge returned to 21 °C within 24 h and no fishes were observed in the groundwater-fed pool.

Case II

Several brook trout (*Salvelinus fontinalis*) were collected during July 1977 from Riffle Creek, Randolph County, WV in a pool which had a surface water temperature of 25·5–26·1 °C. Laboratory derived final temperature preference values for brook trout range from 16 °C (Peterson 1973) to 20·3 °C (Cooper & Fuller 1945: in Coutant 1977). Careful observation and seining showed that the trout were confined to one spring-fed section of the pool where water temperature ranged between 18·9–22·2 °C. As in the above example, the fish could be driven from the preferred area, but immediately returned.

Case III

An opportunity to observe *in situ* avoidance reactions of fishes was presented in 1975 during a survey of fishes and macroinvertebrates above and below a sewerage treatment plant (STP) (Cincotta, Denoncourt & Stauffer 1976). The filamentous bacterium, *Sphaerotilus* sp., formed a solid mat across the stream for over 1500 m below the sewerage outfall on 22 August. Dissolved oxygen (DO) concentration ranged between 0·55–0·65 mg/l (5% saturation) 1265 m below the plant. Seine collections yielded *Semotilus atromaculatus* (7 specimens), *Catostomus commersoni* (1), and *Lepomis cyanellus* (2), which showed no visible signs of stress. Other fish were observed dying and DO concentrations were 0·2 mg/l (3% of saturation) 2196 m below the STP. Fishes were also dying 3765 m below the STP (DO = 0·1 mg/l, 2% saturation). No dead or stressed fishes were observed 6902 m downstream of the plant (DO = 4·15 mg/l, 46% saturation). DO concentration above the plant was 8·6 mg/l (93% saturation).

Three different behavioural patterns were observed during the next 48 hours: (1) a concentration of *S. atromaculatus* and *C. commersoni* was observed at the mouth of a small tributary. Fishes were congregated in the tributary to a point where water depth prohibited further upstream migration. DO concentration was 8·25 mg/l (87% saturation) and water temperature was 18·5 °C, while the adjacent main-channel water was 24·5 °C and 3% saturated with DO. Downstream of this tributary was a mass of over 150 young and adult fishes (various species) concentrated around a small shoreline spring. The following species were collected and released: *Carassius auratus*, *Cyprinus carpio*, *Rhinichthys atratulus*, *S. atromaculatus*, *C. commersoni*, and *Ictalurus natalis*. Water temperature was 22·5 °C and DO ranged between 1·7–1·9 mg/l (18–22% saturation); (2) Small *I. natalis* and *Ictalurus nebulosus* were observed near the surface at several locations along the shoreline. They swam to deeper water when approached, but returned in 5–10 s. The fish appeared to be utilizing the higher oxygen concentrations which were apparently present at the air-water interface; (3) *I. natalis* were observed lying almost completely out of the water on top of *Elodea* sp. and *Potamogeton* sp. beds. This behaviour could possibly have been a result of either (a) higher DO concentrations at the air-water interface or (b) DO concentrations may have been slightly increased because of the photosynthetic activity of the plants.

Case IV

This case history records spawning activity of *Lepomis gibbosus* and *Lepomis cyanellus* at high temperatures (34·4–36·1 °C) influenced by the heated effluent of a fossil fuel generating station in the Schuylkill River near the Cromby Generating Station, Phoenixville, PA. Over seventy-five sunfish nests were observed in a small eddy about 45 m downstream from the effluent on 10 June 1970. The nests were on a bottom of silt, sand, and small gravel, and approximately 15 cm apart in water of 30 cm average depth. Surface water temperature in the area was 36 °C. Bottom temperature felt slightly cooler, but could not be observed with thermometers because of turbidity (a thermister was not available on this date). Some seventy-four *L. gibbosus* were taken in one haul with a 7·6 x 6·3 mm mesh bag-seine, measured (range = 68–132 mm FL; $\bar{x} = 98{\cdot}8$ mm) and released.

The area was revisited on 25 June 1970; water temperature was 35 °C from surface to bottom. An electric shocker was used to collect eighty-four *L. gibbosus* (70–140 mm FL; $\bar{x}$ = 115 mm) and seven *L. cyanellus* (90–138 mm FL; $\bar{x}$ = 118 mm). Many sunfishes were ripe and some of the larger individuals were spent. Eleven nests were randomly examined and all contained eggs. Thirteen *L. gibbosus* males ranged from 102 to 137 mm FL ($\bar{x}$ = 114 mm), and four females from 90 to 93 mm FL ($\bar{x}$ = 104 mm). Two *L. cyanellus* were ripe females (99 and 93 mm FL), and the others males (105 to 138 mm FL; $\bar{x}$ = 128 mm). Shock due to handling and capture caused a 20% mortality of fishes measured.

Nesting activity was decreased on 7 July 1970. Water temperature was 34·5 °C from surface to bottom (25 cm). Twenty-five *L. gibbosus* (95–123 mm FL; $\bar{x}$ = 102 mm) and sixteen males (99–123 mm FL; $\bar{x}$ = 108 mm) were observed.

No sunfishes or fresh nests were present on 28 June 1970. An additional nine collections made from 17 August to 15 December 1970 yielded twenty-one pumpkinseed and eighteen green sunfish, but none were young.

Case V

An opportunity to examine fishes collected at unusually high temperatures occurred in the summer 1970 in the vicinity of the Barbadoes Generating Station located on the Schuylkill River near Norristown, PA (Fig. 1). Schuylkill River water, used as a coolant, was drawn from the South Channel of Barbadoes Island and the heated effluent discharged into the North Channel. An earthen dam downstream (east) of the effluent was built to aid in the construction of a railroad bridge. Outflow pipes in the coffer dam were insufficient to handle either the downstream current or the heated effluent addition. The heated waters accumulated in the temporary reservoir and a flow of warm water recirculated upstream (west) to the tip of the island. The mouth of Stoney Run on the north shore was also

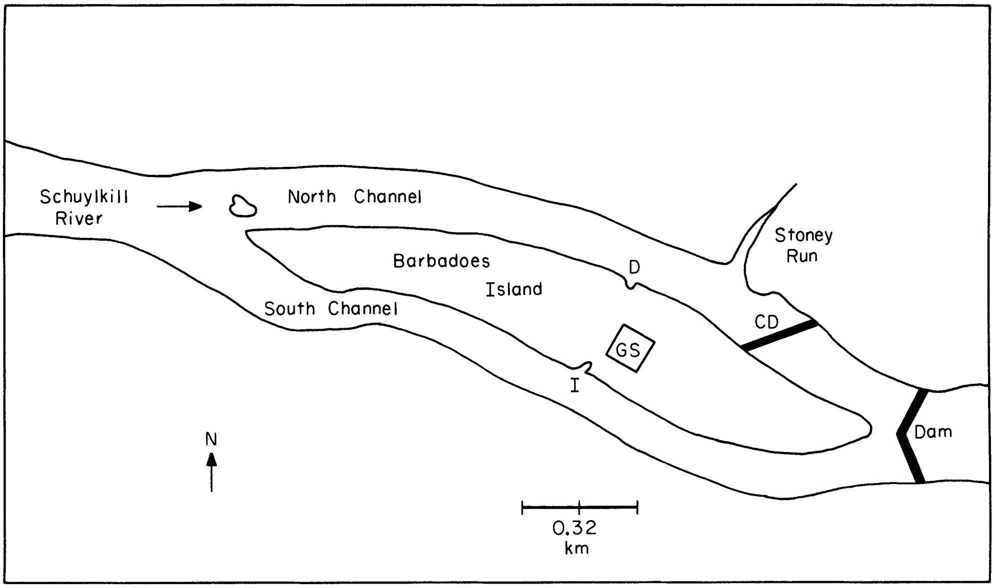

FIG. 1. Barbadoes Generating Station (GS) located on the Schuylkill River, Norristown, Pa. (CD = coffer dam; D = discharge; I = intake; arrow indicates direction of flow).

affected. Depths ranged to 2 m in the temporary main-channel reservoir and width was 75–100 m. Bottom type was primarily mud and sand with detritus and some rubble.

Fishes were sampled in Stoney Run with a 3·0 m, 6·3 mm mesh nylon seine and in the Schuylkill River with a 3·0 m otter trawl with a 12·7 mm mesh liner. Water and body temperatures were obtained immediately upon capture by forcing a physiological probe through the mouth and into the stomach.

Surface water temperatures within the affected area and Stoney Run, 28 July through 27 September, ranged from 35 to 40 °C and bottom temperatures 29–35 °C. Ambient river temperatures ranged from 28 to 30 °C. Collections of fishes were made on 28 July, 17 August and 27 September, and internal body temperatures taken; fishes were also collected on 3 August. The data indicate large populations of fishes were present and are summarized as follows:

28 July

Twelve adult specimens of four species were seined in the mouth of Stoney Run. Body temperatures of 27·8 to 31·7 °C were recorded (Table 1). Water temperatures varied from 18·9 °C on the bottom to 40 °C on the surface. Depth averaged 0·6 m.

A total of 375 specimens and ten species was taken in one trawl haul in the North Channel. Some 87% of the catch (328/375 specimens) was sunfishes, basses, and crappies. Air and surface water temperatures were 32·8 and 39·5 °C, respectively. Profiles made on other dates strongly suggest that bottom temperatures were approximately 34 °C on 28 July. Internal temperatures were recorded for *I. nebulosus, Lepomis gibbosus, Micropterus salmoides* and *Pomoxis annularis*; these ranged from 32·2 to 33·4 °C (Table 1).

Two trawl efforts in the South Channel yielded 109 specimens, 107 of which were *Notropis hudsonius*. Single specimens of *Notemigonus crysoleucas* and *L. gibbosus* were taken. Surface water temperature midstream was 35 °C, but temperature profiles showed

TABLE 1. Internal body temperatures (°C) and final preferred temperatures of fishes collected in the vicinity of Barbadoes Generating Station (an × denotes exact numbers were not recorded)

Locality	Mouth of Stoney Run						Mid-channel North of Barbadoes Generating Station											Laboratory derived final temperature preference (Coutant 1977)
Air temperature (°C)	32·8						32·2		30·6					18·9				
Water temperature (°C)																		
Surface	40·0						39·5		40·0					35·0				
Bottom	28·9						34·0		35·6					32·2				
Date	28 July						28 July		17 August					27 September				
Internal temperature (°C)	27·8	28·4	28·9	29·5	30·0	31·7	32·2	33·4	33·9	34·5	35·0	35·6	36·1	32·2	33·4	33·9	34·0	
Notemigonus crysoleucas											1		1					16·8–21·0
Ictalurus nebulosus							×	×	1	1	1	2	1				1	11·9–31
Ictalurus punctatus												1						25·2–30·5
Lepomis auritus	1	1																
Lepomis cyanellus						1												
Lepomis gibbosus			5	1	1		×	×				1	1		2	1		26–31·5
Lepomis macrochirus		1	1						1			2	1	1				27–32·3
Micropterus salmoides							×	×		1				1				26·5–32
Pomoxis annularis							×	×		1	1							10·4–19·8

a large gradient occurring from surface to bottom where temperatures were those of ambient river water. Water along the shorelines of the South Channel remained at ambient.

3 August

A single trawl collection in the North Channel yielded 1302 specimens and ten species, dominated by young *L. gibbosus* (771 specimens), *L. macrochirus* (245), and *N. hudsonius* (218). Other species present were *I. punctatus* (27), *Pomoxis nigromaculatus* (22), *P. annularis* (7), *I. nebulosus* (5), *C. carpio* (3), *Micropterus dolomieui* (3), and *M. salmoides* (1). No body temperatures were recorded. Air temperature was 32 °C; surface and bottom temperatures ranged from 35–37·8 °C, respectively.

17 August

The combined catch from two trawl hauls in the North Channel included 648 specimens and nine species. *L. gibbosus* (233 specimens) and *L. macrochirus* (265) accounted for 76% of the total catch. *N. hudsonius* (50 specimens), *P. nigromaculatus* (51), and *I. nebulosus* (32) were common. Most of the fishes were young. The air temperature was 30·6 °C, surface water temperature 40 °C, and bottom temperatures 35·6 °C. One adult *L. gibbosus* had an internal temperature of 37·8 °C. Adults were more common in the second haul and the following species were measured for internal temperature: *L. gibbosus* (2 specimens), *I. nebulosus* (6), *L. macrochirus* (4), *P. annularis* (2), *M. salmoides* (2), *N. crysoleucas* (2), and *I. punctatus* (1). Water temperatures ranged from 33·9 to 36·1 °C. The internal temperature in eleven of these specimens was 35·6 to 36·1 °C (Table 1).

27 September

Two trawl hauls in the North Channel collected 283 specimens among six species. The air temperature was 18·9 °C, surface water temperature 35 °C, and bottom temperature 32·3 °C. *L. gibbosus* (177 specimens) and *L. macrochirus* (100) were most abundant. Internal temperatures taken from *L. gibbosus* (3 specimens), *I. nebulosus* (1), and *L. macrochirus* (1), ranged from 32·2 to 34·5 °C (Table 1).

A single trawl collection in the South Channel yielded ninety-eight specimens, of which eighty-four were *N. hudsonius*. Nine *L. gibbosus*, and single specimens of *N. crysoleucas*, *I. nebulosus*, *I. punctatus*, *L. auritus*, and *Etheostoma olmstedi* were taken concurrently. Surface water temperature was 30 °C.

DISCUSSION

This manuscript presents five case histories which demonstrate *in situ* responses of fishes to unfavourable conditions. Such behaviour surely exerts selection pressure for more behaviourally responsive individuals or for those which are more resistant or adaptive to the particular stress. Preference/avoidance behaviour of fishes to temperature [summarized in Stauffer (1980)] was illustrated in case histories I–III. Case histories IV and V show adaptive responses of fishes to temperature.

In case histories II and III, DO concentrations may have been the directive factor (Fry 1947) which caused the fish aggregations. No doubt, once in areas of higher oxygen concentrations, the fishes remained there. However, it may be that at least in case history II that fish oriented to a temperature gradient. Regardless of the mechanism involved, orientation to a cold spring would have two desirable results: (1) fishes would be in areas of higher DO and (2) basal metabolic rates would be lowered in the cooler water. In any event, orientation to either temperature or a dissolved oxygen gradient is a proximate factor with energy conservation being the ultimate benefit.

In case histories IV and V, it is doubtful that the adaptation exhibited was entirely caused by past thermal history (individual acclimatization) even though this is an important factor influencing the final preferendum of fishes either in the laboratory or *in situ*. It is more probable that the development of resistant populations is a form of evolutionary adaptation, with the artificial stress acting as the selecting mechanism or evolutionary force. Ferguson (1968) stated that historically it has been thought that natural vertebrate populations were unlikely candidates to elicit a genetic response to an artificial stress due to their relatively slow reproduction rate. However, several authors have shown that vertebrate populations develop resistance to pesticides in a few generations (Vinson, Boyd & Ferguson 1963; Nagvi & Ferguson 1970; Boyd & Ferguson 1964a, b).

Case history IV exemplifies the response of individuals to conditions that are considered intolerable. Hunter (1963) reported multiple spawns of *L. cyanellus* in ponds in Wisconsin from mid-May to early August at temperatures from 20–28 °C. The final preferred temperature for *L. cyanellus* is 27·3 °C (Jones & Irwin 1965: in Coutant 1977). *L. gibbosus* exhibits similar nesting behaviour (Breder & Rosen 1966). Cincotta (1980) reported a final preferred temperature of 31 °C for *L. gibbosus*. The fact that elevated temperatures did not disrupt normal reproductive behaviour nor the physical act of spawning should not be taken lightly, for this is the critical essence of the success of any species. It can be conjectured that the steam electric plant's discharge had operated as a selective mechanism on the local deme since it became operational in the 1920s, and that a distinct preference for spawning at elevated temperature regimes evolved. Conditions prevented anything other than a field reconnaisance of the situation, but imagine the importance if the upper temperature for the successful development of eggs and larvae had increased by 2 or 3 °C as a result of 50 yr of artificial selection.

A comparison of internal body temperatures of fishes collected in Case History V and their final preferred temperature (Table 1) suggests two phenomena. First, fishes collected at the mouth of Stoney Run apparently actively avoided surface water temperatures as indicated by internal body measurements. Secondly, certain species may have adapted to the artificial conditions created by the plant either through genetic avenues (i.e. selection for heat resistant individuals) or through non-genetic ones (i.e. individual acclimatization). With regards to the latter, this would correlate well with the model presented above for Case History IV regarding selective mechanisms. It is likely that species which are *r*-strategists would use genetic avenues to either tolerate or repopulate areas deleteriously influenced by a stress. Conversely, *k*-strategists would by their nature utilize non-genetic means such as individual acclimatization or active-preference/avoidance behaviour to either assure their position within a stressed ecosystem or to facilitate their reinvasion. As summarized by Smit (1980), phenotypic adaptation is the acclimation process by which individuals can maintain their '... metabolism and activity in such a way that survival in an altered environment is secured. It is realized that the limits of this phenotypic variation are genetically fixed and ... the organism may fail to adapt.'

Two final points may be made. First, aquatic organisms do show a rather startling ability to adapt to natural and man-related stresses. The case histories presented herein represent examples of an increasing burden on aquatic ecosystems in general. Since it has been demonstrated that community components can adapt to altered environmental conditions, then it is reasonable to expect that as more is learned about assimilative capacity in ecosystems it will be found that whole communities can adapt through homeostatic mechanisms to maintain functional and structural integrity (Cairns 1977).

Secondly, the phenomena discussed above have wide-reaching management implications. Since (1) fish are mobile and sensitive to various pollutants, thus, actively preferring and avoiding environmental disturbances, and (2) there is a legal mandate in most countries to maintain water quality to assure recreational and commercial fisheries, it is advisable that planning for mitigation of future industrial and municipal plants includes designs for natural and artificial refugia for fishes. Such management plans would minimize the impact of a catastrophic event on local populations and facilitate recovery. In this regard, the response of fish communities to artificial stimuli must be evaluated in light of: (1) the duration of the stress; (2) the intensity and constancy of the stress; (3) the ability of individual organisms to acclimate to the artificial conditions; and (4) the evolutionary plasticity of the affected populations.

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