LAKE ERIE

LAKEWIDE MANAGEMENT PLAN

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Fish Tumors or Other Deformities

Paul Baumann, Victor Cairns, Bill Kurey,
Lauren Lambert, Ian Smith, Roger Thoma

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Fish Tumors or Other Deformities

Prepared for the Lake Erie LaMP
Preliminary Beneficial Use Impairment Assessment

Paul Baumann
Victor Cairns
Bill Kurey
Lauren Lambert
Ian Smith
Roger Thoma

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NOTE TO THE READER:

This technical report was prepared as one component of Stage 1, or "Problem Definition," for the Lake Erie LaMP. This report provides detailed technical and background information that provides the basis for the impairment conclusions recorded in the LaMP 2000.

This document has been extensively reviewed by the government agencies that are partnering to produce the LaMP, outside experts, and the Lake Erie LaMP Public Forum, a group of citizen volunteers. This review was designed to answer two questions:

- Is the document technically sound and defensible?
- Do the reviewers agree with the document conclusions regarding impairment?

In its present form, this report has been revised to address the comments received during that review process, and there is consensus agreement with the impairment conclusions presented.

Fish Tumors or Other Deformities

6.1 Listing Criteria

According to the IJC, a fish tumor or fish deformity impairment occurs when the incidence rates of fish tumors or other deformities exceed rates at unimpacted control sites **or** when survey data confirm the presence of neoplastic or preneoplastic liver tumors in bullheads or suckers (IJC, 1989).

6.2 Application of the Listing Criteria

The Beneficial Use Impairment Assessment Subcommittee has defined unimpacted sites as those areas where:

a) industrial or municipal pollutant discharges are not located upstream or in the immediate vicinity; and

b) surrounding land use patterns have not disrupted ecosystem function.

The IJC listing criteria require identification of fish tumor or deformity impairments:

a) regardless of whether a specific cause for the tumor has been identified;

b) regardless of whether a cause, when identified, is a chemical pollutant and/or carcinogenic;

c) regardless of whether a tumor is a carcinoma.

Currently two different assessment methods are used to evaluate the prevalence of fish tumors or deformities in Lake Erie and its tributaries (see sections 6.5 and 6.6). Although the scope of fish species evaluated and results obtained are distinct, both monitoring protocols provide information useful to assessing impairment per the IJC listing criteria. Therefore, the bench marks used in both types of studies, to determine when tumor or deformity incidence is significant, were used to develop the more detailed assessment criteria below.

Impairment determinations should be based on fish tumors or deformities that exceed rates at unimpacted sites. In the Lake Erie basin, particularly on the United States shoreline, least impacted sites are used since no completely unimpacted sites are present. Predictably tumor and deformity levels from even these less impacted locations may be somewhat elevated. Impairment occurs when:

1) *An intestinal or liver tumor prevalence of* $\geq$*5 to 7% occurs in common native nearshore species of benthic dwelling fish (the species for which we have most information in the Great Lakes are brown bullhead) or in walleye, perch or*

salmonid species offshore. Samples must consist of at least 30 fish, each of which is 250 mm or greater in length. Tumors are defined as neoplasms of either intestinal, bile duct, or liver cells as determined by histopathology.

2) *A prevalence of lip tumors $\geq$8-10% or of overall external tumors $\geq$13-15% in white sucker and brown bullhead. Tumors are defined as papillomas or other neoplasms as determined by histopathology. Samples must consist of at least 30 fish, each of which is 250 mm in length or greater.*

3) *A Deformities, Erosion, Lesions, & Tumors (DELTs) external anomaly index of > 0.5 % occurs (see sections 6.6, 6.7 and Appendix 6A). It should be noted that application of the DELTs anomaly index is not limited to the fish species listed in item 1 of the assessment criteria.*

6.3 Scope of the Assessment

The geographic scope of the Lake Erie LaMP beneficial use impairment assessment (BUIA) includes open lake waters, nearshore areas, river mouths and embayments, and the lake effect zone of Lake Erie tributaries. The lake effect zone is defined as that zone where the waters of the lake and tributary river are mixed.

The Detroit River upstream of the lake effect zone has not been included within the scope of the Lake Erie LaMP. However the water quality of the Detroit River affects western Lake Erie and the two fish communities are almost identical. Therefore tumor prevalence in fish from the Detroit River is used for comparative purposes in this report. The Buffalo River, which enters directly into Lake Erie, is within the scope of the Lake Erie LaMP. Although little mixing of Buffalo River water and eastern basin water may occur prior to discharge to the Niagara River, the three miles between the two systems still represent Lake Erie waters. In addition, fish coming from the Buffalo River and entering Lake Erie may well remain in the lake or enter the Niagara River.

All available fish tumor or deformity information within the geographic scope of the Lake Erie LaMP was evaluated against the bench marks outlined in Section 6.2 to determine whether impairment is occurring. Information regarding the causes of fish tumors is also included when available.

6.4 Considerations in Evaluating the Presence of Fish Tumors or Deformities

The purpose of assessing the prevalence of fish tumors and other physical abnormalities is to use these as an indicator of both environmental degradation of the aquatic ecosystem and as a measure of health impairment to fish populations (Baumann 1992, Couch and Harshbarger 1985, and Sonstegard 1977). Reports of elevated frequencies of tumors in populations of fish (epizootics) became more frequent starting in the late 1970s as research into the causes of different tumor types increased. Recently declines in tumor prevalence have also been used as an indicator of improving health in ecosystems where point sources have been eliminated or where remediation has occurred (Baumann and Harshbarger 1996). However several factors need to be considered in evaluating whether tumor prevalence is a good indicator of fish population health.

6.4.1 Internal Tumor Prevalence and Fish Age

Tumor incidence increases with age in fish exposed to carcinogens (Baumann et al. 1990). In particular fish less than three years old often do not display many tumors even in highly polluted locations, since both adequate exposure and a latent period for tumor development are needed. Thus fish which are less than three years old should not be used in surveys of internal tumors. Ages should be taken of all fish to help understand comparisons of tumor prevalence among locations. In order to minimize this problem, we have specified minimum length limits in Section 6.2, which should usually prevent sub-adult fish from entering the sample. Our tumor values for impairment were derived based on a mix of age 3 and older fish commonly found in urbanized rivers.

6.4.2 Tumor Prevalence and Old Data

Tumor frequencies change through time, particularly when point sources are being added or eliminated from a system, or when remediation has been undertaken. Since routine tumor surveys are not conducted by any government agency, data pertaining to a given system may be several or many years old. Even though logically older data cannot be a good indicator for the current status of the area in question, it must be used for impairment purposes until superseded by more recent research. An ongoing USGS survey of all of the US Lake Erie Areas of Concern began in 1998 and will conclude in 2000 with data available on all sites by 20001. This data will update the tumor incidence statistics at all of the US Lake Erie locations with prior tumor epizootics.

6.4.3 Types of Tumors Suitable as Impairment Indicators

A comprehensive review documented tumor epizootics from 41 different locations in North America (Harshbarger and Clark 1990). Additional analysis of this data indicated that 22 species of fish had populations with elevated tumor incidence associated with environmental contaminants, and that about two-thirds of these species were benthic or bottom-dwelling fishes (Baumann 1992a). A more recent review, specific to the Great Lakes, and dealing primarily with brown bullhead and white sucker, lists dozens of epizootics in both Canadian and U.S. waters (Baumann et al. 1996). Such tumors are generally categorized into three different groups by etiology: genetically induced, viral induced, and those caused by chemical carcinogens.

Genetically Induced Tumors

Some tumors have a genetic origin or etiology (Baumann 1992b). Hybrids fish species, such as platyfish/swordtail crosses, may be susceptible to tumors because of dilution of modifier genes (Anders 1967) or amplification of oncogene segments (Vielkind and Dippel 1984). Such fish exhibit a certain incidence of "spontaneous" cancers, but are also more susceptible to chemically induced cancers.

Field studies indicate that hybrids between common carp (*Cyprinus carpio*) and goldfish (*Carassius auratus*) in the Great Lakes develop gonadal tumors which appear to have a genetic basis (Harshbarger and Clark, 1990; Sonstegard 1977, Smith, 1998). Thus gonadal tumors in carp x goldfish hybrids are unsuitable for use in impairment assessments until a base incidence of "spontaneous" gonadal tumors can be determined.

There has also been a suggestion that bullhead in Great Lakes tributaries are crosses between black and brown bullheads, and thus could be more susceptible to tumors. However, genetic studies to test this hypothesis have not been conducted. Ohio EPA studies have recorded zero brown bullhead/black bullhead hybrids in Lake Erie waters or tributaries. In fact very few black bullheads have been recorded. Furthermore the differing tumor prevalence in different tributaries, and in particular the vastly differing liver tumor frequencies seen over time in single locations such as the Black River, preclude genetics as a major factor influencing tumor development in brown bullhead (Baumann, 1998).

Viral and Multifactorial Tumors

Certain tumors in fish have a viral origin. The classic example is lymphoma in northern pike and muskellunge (Mulcahy and O'Leary 1979, Papas et al 1977, Sonstegard 1976). External tumors having a known viral etiology affect many species including: epidermal hyperplasia in walleye (Smith et al 1992, Martineau et al 1990, Yamamoto et al 1985) and papilloma on Atlantic salmon (Carlise and Roberts 1977), rainbow trout (Roberts and Bullock 1979), white suckers (Baumann et al 1996, Premdas and Metcalfe 1994, Smith et al 1989 a,b, Cairns and Fitzsimmons 1988, Smith and Zajdlik 1987, Sonstegard 1977) and brown bullheads (Smith et al 1989a, Baumann et al 1996).

If external tumors are due to viruses alone, the tumor rate does not increase with age and these tumors can regress spontaneously (Premdas and Metcalfe 1994, Smith and Zajdlik 1987). Since external tumors in walleye are known to have a viral origin, and since there have been no studies indicating an increased incidence in polluted waters, walleye skin tumors can not be used as indicators of impairment.

Recently scientists have succeeded in inducing lip papillomas in healthy white suckers by injecting cell-free filtrates from papilloma tissue of diseased white sucker (Premdas and Metcalfe 1994). Thus, at least some lip tumors present in white sucker have a clear cut viral etiology.

However, in other situations, pinpointing the underlying cause of a tumor as strictly viral in wild fish is not always possible. For example, with a few exceptions, prevalences of lip tumors in white sucker and brown bullhead are elevated in populations from industrialized Great Lakes areas (Baumann et al 1996 and Premdas et al), pointing to a multifactorial (chemical and viral) etiology. It is postulated that exposure to chemicals increases the incidence of tumors caused by viruses through immune suppression or enhanced viral replication. Thus, in certain situations, the presence of virally induced tumors may be an indicator of exposure to adverse levels of chemicals in the aquatic environment.

Freshwater drum from some areas in Lake Erie are known to have an increased prevalence of pigment cell tumors (chromatophoromas) (Harshbarger and Clark 1990; Baumann, Okihiro, and Kurey unpublished data). These tumors are found with increasing frequency as the length of the fish increases (Black 1983b). A lower frequency of such tumors exists in the Ohio River. At this time, no cause, either viral or carcinogen, can be assigned to these tumors. In Japanese waters (Kimura et al. 1984) similar tumors in related drum species have been correlated with chemical carcinogen exposure. However, without similar evidence for freshwater drum, such chromatophore tumors in this species cannot currently be used to assess impairment in single species studies. This species, along with all others found in the lake effect zones of Ohio tributaries and Ohio Lake Erie nearshore will be assessed as applicable in the DELTs index results (see section 6.6 and 6.7).

Chemically Induced Tumors

Tumors caused by chemical carcinogens most often affect the liver although lesions have been induced in the skin and numerous other tissues by laboratory exposure (Black, 1983; Hawkins et al. 1989). No liver tumors in any fish have ever been proven to be of viral origin. Nor are epizootics of cancer in non-hybrid, wild fish populations likely to have a purely genetic basis (Baumann 1992b). All thirteen species of benthic fish listed by Harshbarger and Clark (1990) as having had liver tumor epizootics have also had populations from unpolluted areas with documented tumor frequencies below one percent. Furthermore, in five carcinogen laboratory studies reviewed by Baumann (1992b), large numbers of control fish (of three different species) all had less than a one percent incidence of spontaneous liver tumors.

Chemical induction of liver tumors in fish has been done experimentally with a variety of carcinogens via injection, waterborne exposure, and diet (Baumann 1992b). Both skin and liver tumors were induced in brown bullhead by exposure to extracts of sediment from the Buffalo and Black Rivers which contained carcinogenic polynuclear aromatic hydrocarbons

(PAHs) (Black et al. 1983 and Black et al. 1985). Massive field studies have statistically correlated tumor frequencies in English sole with PAH in sediment in Puget Sound (Malins et al. 1984 and Myers et al. 1990). Similarly, a large number of field studies at freshwater locations have linked liver tumors in benthic fish with carcinogens, primarily PAH, in sediment (Vogelbein et al.1990, Baumann 1992a and Baumann et al. 1996). A number of laboratory experiments (Balch et al 1995, Hinton 1989, Metcalfe 1989, Metcalfe et al 1988, 1990, 1995, Hendrick 1985) clearly indicate that the chemicals have the potential to be direct acting carcinogens in fish.

One long-term series of studies in the Black River, Ohio has demonstrated a decline in liver tumors in brown bullhead following a decline in PAH in the river sediment (Baumann and Harshbarger, 1995). After remedial dredging in 1990, buried PAH contaminated sediment was re-exposed and liver tumor prevalence again increased dramatically (Baumann and Harshbarger 1998). Such fluctuations in an effect which tracks similar fluctuations in the purported cause is one of the strongest epizootiological arguments for a cause and effect relationship.

The most recent literature review on Great Lakes tumor data states that there is sufficient data to warrant the conclusion that high tumor prevalences in suckers and bullheads from the Great Lakes are associated with exposure to chemical contaminants (Baumann et al. 1996). Suckers and bullheads are inshore species that do not migrate extensively. Therefore, the health of these species reflect the impacts of localized aquatic environment conditions on fish health.

6.5 Status Of Lake Erie Fish Tumor or Deformity Prevalence - Individual Species Studies

Background

White sucker and brown bullhead are the benthic species most commonly used for monitoring tumor prevalences in the Great Lakes. Individual species studies are typically limited to evaluation of tumors (versus other types of deformities) on mature fish and focus on the potential for links between the presence of tumors and chemical carcinogens. Both external and internal tumors are usually evaluated and histopathological analysis of tumors is usual.

This section summarizes available data on fish tumor or deformity prevalence in individual Lake Erie fish species.

Brown Bullhead (*Ameiurus nebulosus*)

Tumors are most often found in the skin, mouth area, and liver in brown bullhead. Studies of tumors in brown bullhead from Lake Erie and its tributaries have occurred in the Detroit River (Michigan), Old Woman Creek and the Huron, Black, Cuyahoga and Ashtabula Rivers (Ohio), Presque Isle Bay (Pennsylvania), Buffalo River (New York), and Long Point Bay (Ontario). Old

Woman Creek, the Huron River, and Long Point Bay are reference sites (= least impacted) but not control sites. While none of these sites has industrial point sources of carcinogens, Old Woman Creek contains elevated PAH levels in sediment near a railroad bridge and a highway bridge (Johnston and Baumann 1989). Long Point Bay is just west of the industrialized Nanticoke area where there is PAH input to sediment.

A summary of historical study results is shown in Tables 6.1 and 6.2. An ongoing study by the USGS will provide new data for all U.S. Lake Erie Areas of Concern by 2002.

Table 6.1. Prevalence (to nearest 0.5%) of external tumors in brown bullhead by location and date; (Baumann et al. 1996; Smith et al. 1989a).

Location	Date	N	%	Reference
Detroit River, MI**	1985-87	449	10	Maccubbin & Ersing 1991
(Trenton/Amherstburg)	1993	48	21	Leadley et al. 1997
Black River, OH	1980	86	35	Baumann et al. 1987
	1993	104	25	Baumann, unpublished
Presque Isle Bay, PA	1992	102	56	Obert, 1994
	1995	69	27.5	Obert, 1997
	1997	63	11	Obert, 1998
Buffalo River, NY	1983	30	23	Baumann, unpublished
	1988	100	23	Baumann, unpublished
Ashtabula River, OH	1991	98	16	Mueller and Mac, 1994
Cuyahoga River, OH	1984	90	9	Baumann, et al. 1991
	1987	41	19.5	Baumann, unpublished
Detroit R (Peche Isl.*)	1993	27	7.5	Leadley et al. 1997
Old Woman Creek*	1984-85	120	2.5	Baumann, unpublished
Huron River*	1986-87	282	6.5	Smith et al. 1994
Long Point Bay, Ont. *	1985	53	15	Smith et al. 1989a

** reference (=least impacted) sites.*

*** Because the Detroit River is the major source of water inflow to Lake Erie study results showing high tumor incidence in the Detroit River are included here. Given the relationship of Detroit River flow to Lake Erie, **causes** of tumor incidence in the Detroit River may also be affecting the western basin of Lake Erie.*

Table 6.2. Prevalence (to nearest 0.5%) of liver tumors (neoplasms) in brown bullhead by location and date; (Baumann et al. 1996; Smith et al. 1989a).

Location	Date	N	%	Reference
Detroit R., MI**	1985-87	306	9	Maccubbin & Ersing 1991
(Trenton/Amherstburg)	1993	48	16.5	Leadley et al. 1997
Black River, OH	1982	124	60	Baumann et al. 1990
	1987	80	32.5	Baumann & Harshbarger 1995
	1992	97	58	Baumann & Harshbarger 1998
	1995-96	49	12	Baumann unpublished
	1998	45	6.5	Baumann unpublished
Ashtabula River, OH	1991	98	7	Mueller & Mac 1994
Cuyahoga River, OH	1984	85	9.5***	Baumann et al. 1991
	1987	71	19.5	Baumann unpublished
Presque Isle Bay, PA	1992	102	22	Obert 1994
	1995	69	11.5	Obert 1997
	1997	63	3	Obert 1998
Buffalo River, NY	1983	30	26.5	Baumann unpublished
	1988	100	19	Baumann unpublished
Detroit R (Peche Isl.)*	1993	27	3.5	Leadley et al. 1997
Old Woman Creek, OH*	1992-93	120	5.5	Baumann unpublished
Huron River, OH*	1986-87	282	1	Smith et al. 1994
	1998	30	6.5	Baumann unpublished
Long Point Bay, Ont.*	1985	53	0-8	Smith & Ferguson 1986

** reference (=least impacted) sites.*

*** Because the Detroit River is the major source of water inflow to Lake Erie study results showing high tumor incidence in the Detroit River are included here. Given the relationship of Detroit River flow to Lake Erie, **causes** of tumor incidence in the Detroit River may also be affection the western basin of Lake Erie.*

**** Conservative value based on a combination of gross observations and a limited histopathological survey.*

Liver Tumors in Brown Bullhead

A total of 10 sites (4 reference sites) have been investigated for bullhead liver tumors in the Lake Erie region. Tumors were most abundant in the Black River, particularly in the early 1980s and 1990s (50-60%). Other systems including the Buffalo River, Presque Isle Bay, the Cuyahoga River, and the Detroit River also had bullheads with a liver tumor prevalence in double digits at some time in their history. The Ashtabula River had an intermediate tumor prevalence of 7% in 1991. All of these sites were known to be contaminated with carcinogens at the time of the referenced study (Baumann et al. 1996).

Tumor prevalence at least impacted (reference) locations ranges from 0% in Long Point Bay to 6.5 % in the Huron River.

There are some considerations at these sites that blur the line between impaired and reference sites, and point out the difficulty in finding an unimpacted reference location against which to assess impairment. This is the reason for choosing ranges in the assessment criteria benchmarks, rather than a single threshold number.

- Some fish in Long Point Bay that had visual abnormalities were not subjected to histopathology. If all such fish had actual liver neoplasms, the prevalence there would be 8%. However all fish with visual abnormalities that were examined by histopathology were found not to have neoplasms.

- The Old Woman Creek samples included a high percentage of older fish, and thus may not be directly comparable to the other sites (see Section 6.4.1).

- Given the fact that none of these locations is both pristine and isolated from nearby contaminated locations, such values should be viewed as elevated above a pre-industrial background level.

Evidence exists for the presence of, exposure to, and metabolism of PAHs by bullheads in the Black and Buffalo Rivers (Baumann et al 1987, 1988, 1990, Fabacher et al 1988, Black et al 1985, Black 1983a). The Black and Buffalo Rivers both contained high levels of PAHs in the sediments at the time of the studies. Contaminated sediments in the Black River were dredged in 1990, and after a short term spike in tumor incidence, reduced rates of tumor incidence have resulted.

Sediment analysis in Presque Isle Bay documented variable levels of carcinogenic PAHs. PAHs also occur in the Ashtabula, Detroit and Cuyahoga River sampling locations, making a chemical etiology plausible at all of these sites.

In summary, the historical liver tumor incidence rates in brown bullhead from the Black, Buffalo, Detroit and Cuyahoga Rivers and Presque Isle Bay clearly exceeded both the 5-7% assessment criteria benchmark and incidence rates at least impacted (reference) sites. Recent surveys indicate a decline in the liver tumor prevalences in bullhead from Presque Isle Bay and the Black River to below, and just at the threshold of, the assessment criteria benchmark for impairment, respectively.

External Tumors in Brown Bullhead

Brown bullheads from contaminated areas often have tumors of the skin and oral cavity. In other species of fish, skin tumors have been shown to be caused by viruses, either alone, or exacerbated by the simultaneous presence of chemical carcinogens. However, virus has not been demonstrated to be a cause of brown bullhead cutaneous lesions (Baumann et al, 1996), and bullheads (as well as mice) developed skin tumors when painted with river sediment extract containing PAHs (Black 1983).

A summary of external tumor studies in historical studies of Lake Erie fish is presented in Table 6.1. A total of 10 sites (4 reference sites) have been investigated for external bullhead tumors in the Lake Erie region. Tumors were most abundant historically in Presque Isle Bay (56%), followed by the Black (25%) and Buffalo Rivers (23%). That fish from these three sites had an unusually high rate of tumor prevalence is unquestioned. All locations that had bullhead external tumor prevalence of 19% or more were sites known to be contaminated with PAHs at the time of the study (Baumann et al. 1996). Tumor incidence rates last determined for the Black, Cuyahoga and Buffalo Rivers clearly exceed the assessment criteria bench marks established for determining impairment, although all of these locations are being re-sampled. External tumor incidence in bullhead at Presque Isle Bay declined below the assessment criteria bench mark in the most recent surveys.

External tumor prevalence at the other sites studied are not as easily translated into impairment conclusions. Tumor incidences in the Ashtabula, Detroit, and Buffalo Rivers were 16, 10, and 8.9% respectively. These incidence rates are all either just above or right at the threshold values for impairment. Tumor incidence rates at the reference sites were 2% at Old Woman Creek and 15% at Long Point Bay.

The Long Point Bay area is a provincial and national park setting, dominated by wetlands. However, there are major nearby industrial inputs as well as agricultural inputs from local rivers such as Big Creek. Because of the high prevalence of papillomas on bullheads from Long Point Bay, a least impacted location, drawing an impairment conclusion is problematic. The high prevalence of papillomas on bullheads from Long Point Bay could be caused by a mobile population exposed to PAH in the Nanticoke area to the east or could be construed as evidence of viral involvement in the etiology of these tumors. Since the Long Point Bay data is now almost 15 years old, there is a need for a new tumor survey of that location and other Canadian tributaries for brown bullhead and white sucker.

Taken as a whole, these studies suggest that bullheads in a variety of polluted locations have historically or currently exhibit abnormally high skin tumor rates. No exact cause has been determined, but the general correlation with liver cancers and with sediment contamination suggest a role for chemical carcinogens in the sediment, perhaps in combination with a viral agent.

White Suckers (*Catostomus commersoni*)

White suckers are the most commonly used species to assess tumor prevalence in Great Lakes tributaries and harbors in Canada. An extensive data-base exists which has been recently summarized and reviewed (Baumann et al. 1996). Although no extensive surveys of white suckers have been conducted in the Lake Erie watershed, the potential to use this species certainly exists. Some external tumors on white sucker have been proven to have viral etiology, however external tumor prevalence in this species is usually higher in contaminated areas. Thus a multifactorial etiology for these tumors is suspected, and tumor prevalence is useful for monitoring impairment in tributaries. Liver tumors are considered to be chemically induced, and thus are also useful as an indicator. White sucker populations with an external tumor prevalence above 15% or a liver tumor prevalence of 6% or more have been found in contaminated areas with only a couple of exceptions (Baumann et al. 1996). Therefore, the threshold values for impairment using brown bullhead tumors would apply equally well for white sucker.

6.6 Status Of Lake Erie Fish Tumor or Deformity Prevalence - Ohio DELTS Anomaly Index

Deformities

Besides external tumors, a variety of other grossly visible abnormalities or deformities can occur in fish. These deformities may be caused by environmental degradation, such as contaminant exposure, and include vertebral deformities, skull deformities, fin ray erosion, open lesions, and eye abnormalities. Deformities of the spinal cord and other “teratogenic” effects can be induced by rapid temperature changes during the early development of the larval fish. Deformities can also be caused by viruses, bacteria, or parasites. Fish spawning or migrations can cause fin erosion or result in infected scrapes and cuts which may mimic lesions.

As a result, deformities must be evaluated carefully when trying to assess whether impairment is occurring. For the purposes of this assessment, the above-mentioned abnormalities/deformities will be assessed as a group. Comprehensive fish deformity data exists only for Ohio nearshore waters of Lake Erie and the lake effect zone of Ohio tributaries using the DELT anomaly index.

Background

The DELTs anomaly index has been used by Ohio EPA as one of several quantitative biological indicators of stream water quality in Ohio since 1979. Specifically, the DELTs index evaluates the prevalence of *external* deformities, fin erosion, lesions and/or tumors (DELTs). It applies to all species of fish, regardless of size, and is a broad indicator of environmental degradation rather than a link to any particular cause, such as toxics. Histopathological analysis of tumors is only rarely done in association with use of the DELTs index.

Ohio EPA uses electrofishing methods to sample a 500 meter zone along the shore. All fish collected are examined for DELT anomalies and results are recorded using the definitions and criteria outlined in Appendix 6A to judge the severity of DELTs index data. Anomaly data is collected on individual fish and analyzed at a community scale. There is no reporting of year class or individual species incidences.

All species do not respond identically to environmental disturbances in terms of DELT incidence (Sanders et. al. 1999). Some species, such as redhorse suckers, are highly sensitive and develop lesions and eroded fins at low disturbance levels and disappear (presumably die) before tumors develop, while other species, such as the brown bullhead, continue to exist long after developing extreme levels of external tumor incidence.

Consequently, to calibrate the DELTs indicator Ohio EPA has selected and sampled as wide a range of environmental conditions as possible to obtain an understanding of how DELT anomalies respond to a gradient of environmental conditions. Statewide stream data have shown that the highest percentages of DELT anomalies in Ohio occur in the most biologically and chemically impaired streams, while the lowest percentages have been found in Ohio's least disturbed streams. A similar phenomenon is observed in the waters of Lake Erie.

Calibration of the Lake Erie DELTs Indicator

In 1993, the Ohio EPA began a project designed to develop numerical biological criteria for shoreline waters of Lake Erie, including lake effect zones of Lake Erie tributaries (lacustuaries). The DELTs anomaly index is one of 14 indicators, or metrics, selected as best suited for use in determining Lake Erie nearshore water quality. As of 1999, the DELTs index is used in Great Lakes waters only by Ohio. Most sites along the Lake Erie shoreline have only been sampled once during the period 1993-1996 while lacustuaries have been sampled multiple times.

The analysis of a separate data base for Lake Erie conditions avoids confusing phenomenon occurring in the free flowing waters data base with those occurring in lentic Lake Erie areas. Healthy Lake Erie nearshore and lacustuary fish communities normally have fewer benthic oriented species and individuals than healthy stream communities and may experience less exposure to contaminated substrates.

A sub-selection of samples from the Lake Erie data-base, determined to be least impacted, were used to establish expectations for background DELT levels. Using the framework of the Index of Biotic Integrity, the range of DELT variation was divided into three categories: slightly deviates from pristine conditions (frequently observed levels), moderately deviates from pristine conditions (occasionally observed levels) and strongly deviates from pristine conditions (infrequently observed levels). A fourth category of highly deviant from pristine conditions (a level of DELTs not observed in least impacted sites) has been added for Lake Erie waters. Figure 6.3 in section 6.7 gives the distribution of DELT percentages observed in the Lake Erie data base.

Lake Erie Nearshore Results

From 1993 to 1996, Ohio EPA sampled a total of 90 sites (324 individual collections) in the Lake Erie nearshore (the area within 1-5 meters of the shore). Sites were selected to reflect the fundamental habitat types found in the lake's nearshore areas and to provide a thorough coverage (one site for every 5 miles) of the area investigated. In the lake proper, sites were located along harbor breakwalls, sand/gravel beaches, the shores of the Lake Erie Islands, bedrock cliffs, and modified shorelines with numerous types of structures designed primarily to prevent shoreline erosion. Wetland/bay-like habitats were sampled in Sandusky Bay, East Harbor State Park, and Presque Isle Bay (11 sites).

Reference sites for the Lake Erie nearshore include Middle Harbor, East Harbor and Presque Isle Bay. It should be noted that the Presque Isle Bay reference sites were located on the south shores of Presque Isle Bay State Park opposite the shoreline where sediment contamination has been found. All of the above-mentioned reference sites were selected based on the absence of: a) large tributaries carrying agriculture associated pesticides and sediment, and b) industrial or municipal dischargers in the vicinity of the sampling sites.

Though some bullheads with tumors were taken during Ohio EPA fall sampling at Presque Isle Bay, the incidence of tumor occurrence (and overall DELT percentages) remained below Ohio EPA criteria at these sites. Out of 6,982 fish captured during eight sampling efforts, four fish with tumors were recorded. Of 19 brown bullheads, two individuals were observed with external tumors.

DELT anomalies percentages for the Ohio nearshore sites in Lake Erie proper are summarized in Figure 6.1. More detailed results for each individual site sampled and shown in Figure 6.1 are provided in Figures 6.1.1 through 6.1.10 in Appendix 6C.

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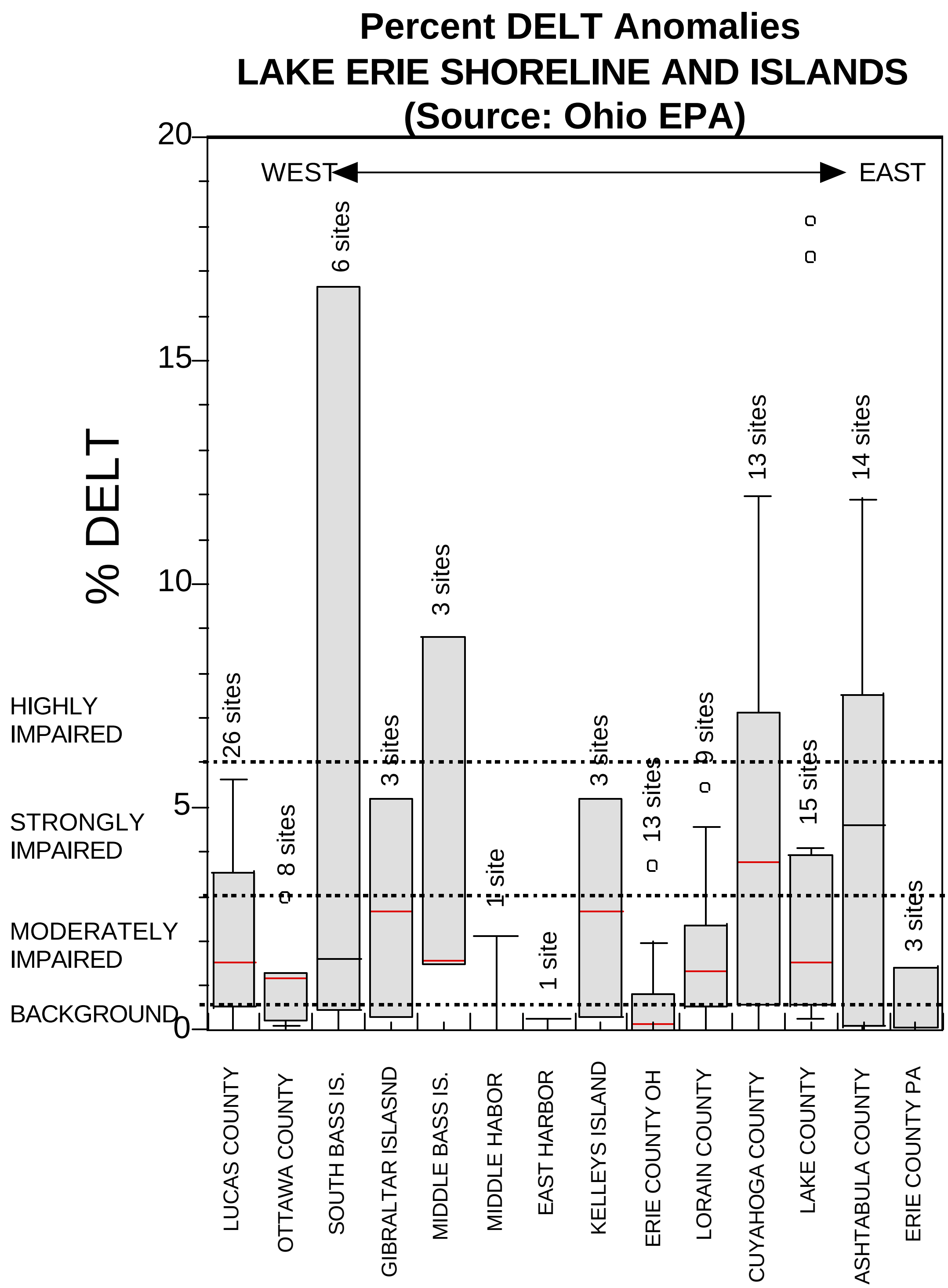

Figure 6.1. Box and whisker plot of Lake Erie shore line fish community DELT occurrence. Box edges mark the 25 and 75 percentiles, bars mark the maximum and minimum range and circles are outlier values. Median values are represented by a line in the box.

acustuary Results

A lacustuary is a transition zone in a river that flows into a freshwater lake. It is the portion of the river affected by the water level of the lake. Lacustuaries begin where lotic conditions end in a river and end where the lake proper begins. The extent of the lacustuary for each Ohio tributary to Lake Erie is provided in Appendix 6B.

Lake affected tributary streams (or lacustuaries) were sampled at 125 sites (593 individual collections) from 1982 through 1996. Sites were located at the mouth, head, and midsections of each lacustuary.

DELT anomalies percentages for Ohio lacustuaries are summarized in Figure 6.2. More detailed results for each individual site sampled are provided in Figures 6.2.1 through 6.2.16 in Appendix 6C. It should be noted that data for fish with *lymphocystis* is **not** included in these figures.

When examining DELT results in combination with species sensitivity to environmental conditions. For example, in areas such as Old Woman Creek fin erosions and lesions dominate the percent DELTs observed and deformity and tumor incidence is very low. These DELTs results are due to low dissolved oxygen conditions.

In contrast, the presence of all types of DELTs during multiple sampling years is considered indicative of chemically induced DELT anomalies. For example, in industrialized areas such as the Cuyahoga and Black Rivers there are also high levels of deformities and tumors from exposure to chemical contaminants along with high levels of eroded fins and body lesions from low dissolved oxygen levels.

In addition, fin erosion and lesion incidence can vary from year to year as a result of temporal pollution events resulting from sewage or nutrient induced oxygen depletion while chemical pollution (especially in sediments) will persist for decades.

Examination of the Black River lacustuary (Figure 6.2.10) illustrates how the removal of contaminated sediments has resulted in a decrease in the incidence of DELTs in the 1997 samples. Samples taken from 1992 show elevated DELTs in response to increased exposure to contaminated sediments immediately after sediment dredging (1990). As clean sediment has covered the freshly exposed sediments DELT incidence has declined.

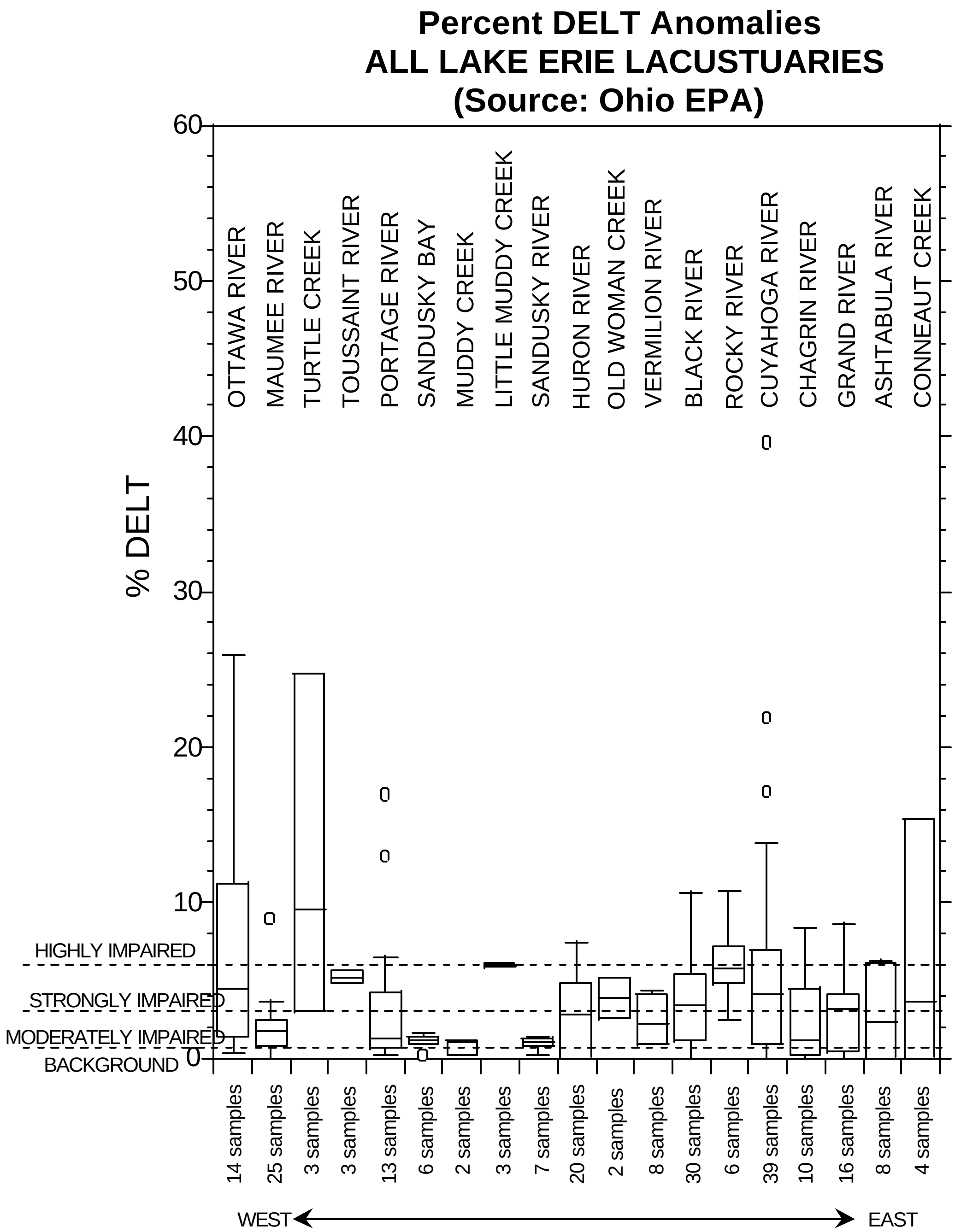

Figure 6.2. Box and whisker plot of Lake Erie lacustuary fish community DELT occurrence. Box edges mark the 25th and 75th percentiles, bars mark the maximum and minimum range and circles are outlier values. Median values are represented by a line in the box.

6.7 Summary of Fish Tumor or Deformity Impairment Conclusions

Individual Species Studies

Per the IJC listing criteria, a fish tumor or fish deformity impairment occurs when the incidence rates of fish tumors or other deformities exceed rates at unimpacted control sites. Finding a truly unimpacted control site in Lake Erie has been nearly impossible to date. However, using expected rates of tumor/deformity incidence at relatively unimpacted sites, the BUIASC arrived at the tumors/deformity incidence rate threshold ranges outlined in section 6.2. When these threshold values are exceeded, impairment is occurring. A summary of impairment conclusions by basin is presented in Table 6.2. Details of impairment are outlined in the text below.

Liver and external tumor incidence rates in brown bullhead are exceeding the threshold criteria established for determining fish tumor impairment in Lake Erie benthic species (Item 1, Section 6.2). Specifically, external tumor incidence rates that signify impairment occurred in 5 out of 6 non-reference sites monitored. Liver tumor incidence rates that signify impairment occurred in 3 out of 6 non-reference sites monitored.

Ohio DELTs Index

Again, per the IJC listing criteria a fish tumor or fish deformity impairment occurs when the incidence rates of fish tumors or other deformities exceed rates at unimpacted control sites.

The Ohio EPA has sampled fish communities throughout Ohio for 2 decades in all types of habitats and stream sizes. Evaluation of the resulting data base of nearly 6,000 sites indicates that in areas of zero or minimal environmental impact, DELT anomalies occur at rates less than 0.5%. Therefore, DELTs index values of 0.5% or below are representative of background or unimpacted conditions. In the case of the Lake Erie lacustuaries and shoreline, background conditions are found at sites in and near Presque Isle Bay, Pennsylvania and Middle Harbor and East Harbor, Ohio.

DELTs index values > 0.5% are considered indicative of impairment. The degrees of impairment are classified as outlined below using the mean value for the overall area. A total of 80% of all sites sampled in Lake Erie waters display some level of impairment (Water quality data using other metrics for fish communities in Lake Erie nearshore waters show the same trend (Thoma 1999)). A summary of DELTs index results is provided in Figure 6.3.

NONE IMPAIRED - DELTs index values of > 0.0% to 0.5%. An examination of all Lake Erie sites shown in Figure 6.3 reveals that approximately 20% of all collections made had DELT incidences less than the 0.5% level (approximately 12% had a zero occurrence of DELTs) and are classified not impaired. Based on DELTs anomaly data, “none impaired” conditions are found in East Harbor Ohio, Erie County Ohio and Erie County PA.

MODERATELY IMPAIRED - DELTs index values of > 0.5% to 3.0%. Approximately 35% of all sites sampled were moderately impaired. Based on DELTs anomaly data, moderate impairment is occurring along the shoreline in Lucas, Ottawa, Lorain and Lake counties, South Bass, Middle Bass, Kelleys and Gibraltar Islands and Middle Harbor in Ohio. Moderate impairment is also occurring in the lacustuaries of the Maumee, Portage, Sandusky, Huron, Vermilion, Chagrin and Ashtabula Rivers, Muddy Creek, and Sandusky Bay.

STRONGLY IMPAIRED - DELTS index values of > 3.0% to 6.0%. Approximately 25% of all sites sampled were strongly impaired. Based on DELTs anomaly data, strong impairment is occurring along the shoreline in Cuyahoga and Ashtabula Counties. Strong impairment is also occurring in the lacustuaries of the Toussaint, Black, Rocky, Cuyahoga and Grand Rivers, and Little Muddy and Conneaut Creeks.

HIGHLY IMPAIRED - DELTs index values of > 6.0%. Approximately 20% of all sites sampled had DELT occurrences greater than 6.0% and are classified highly impaired. Based on DELTs anomaly data, high levels of impairment are occurring in the lacustuaries of the Ottawa River as well as Turtle and Old Woman Creeks.

In summary, these data indicate that it is not unusual for a sample to have no DELT anomalies and that the presence of an elevated incidence of external anomalies is not a normal background condition to be expected.

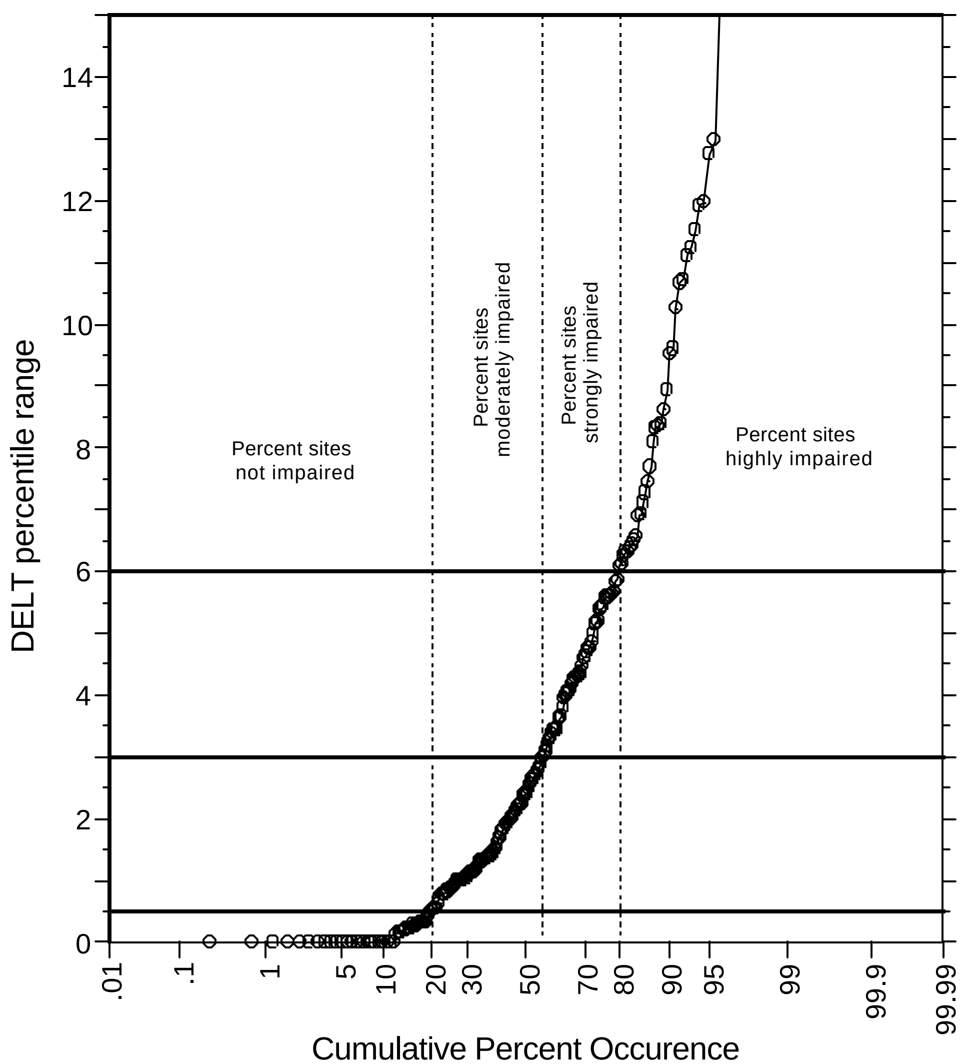

Figure 6.3. Cumulative percentages of average DELT anomalies observed in the Lake Erie data base (218 data points) with non, moderately, strongly and highly impaired classifications delimited.

A summary of impairment conclusions by basin, combining the data from single species studies and DELTs index values is provided in Table 6.3.

Table 6.3. Summary of Lake Erie Fish Tumor or Deformity Impairment Conclusions By Basin

Western Basin Nearshore	Western Basin Offshore	Central Basin Nearshore	Central Basin Offshore	Eastern Basin Nearshore	Eastern Basin Offshore
Impaired- in 6 tributaries, the Lake Erie islands, and along the Lake Erie shoreline in 2 Ohio counties	No conclusive documentation of impairment.	**Impaired** - in 13 tributaries, 1 bay, and along the Lake Erie shoreline in 4 Ohio counties	No data to indicate impairment.	**Impaired** - in 1 tributary and 1 bay	No conclusive documentation of impairment.

6.8 Current Research

USGS is currently coordinating a research and monitoring effort, in partnership with a number of principle investigators around Lake Erie, to re-evaluate conditions in all of the Areas of Concern (AOCs). One aspect of this project is monitoring the current rate of tumor incidence in all of the AOCs. Data results are expected to be available in phases over the next 2 to 3 years. The USGS project, once completed, will provide an update to the information presented in this assessment report and is also expected to provide some new reference site data. At a minimum, reference site data will be available from the Huron River.

6.9 Potential Future Research Issues

There is a general lack of knowledge about the extent of the occurrence of tumors in fish from Lake Erie as well as the rest of the Great Lakes, in species other than drum and bullhead. Specific causes of the various types of fish tumors or deformities are also unknown for many of the species evaluated in this assessment. Most of the existing information about tumor occurrence deals with the fish of the harbor, bay, and tributary areas. Tumors or deformities in fish of the open lake have been studied much less.

Potential research opportunities might include some of the following items:

1. Studies of the prevalence of internal and external tumors in various fish species should be initiated using a standardized sampling method so that studies in various states and lakes would be comparable. For instance, a statistically valid sample of the most abundant length classes of adult fish of a given species would be used instead of including all length classes.

2. Associated with prevalence studies, should be studies of the histology of the tumors, particularly for fish species that have not been studied much previously. One of the objectives of tumor histology studies would be determining viral, bacterial, and parasitic causes. For those species that can be kept in captivity, live specimens could be kept for an extended period of time to monitor tumor growth for signs of remission (indicative of a viral, bacterial, or parasitic origin).

3. Investigations of the causes of tumors by using long-term experiments challenging fish with tumerogens and tumor promoters. For example, these types of studies could use native species that are known to be tumor-prone and subject the fish to a suite of chemical concentrations, including at least one concentration that is currently known to be present in the Lake Erie aquatic environment.

4. Studies that characterize other components of the ecosystem inhabited by tumor bearing fish might indicate the value of tumor prevalence as a predictor of ecosystem health.

5. Studies of the effects of tumors on fish survival and reproduction. For example, tumor impacts on swimming energetics (e.g. - increased drag from external tumors).

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6.10 References

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Appendix 6A

Ohio EPA's Guide for Determining the Severity of Deformities, Erosion, Lesions, and Tumor "DELT" External Anomalies (Ohio EPA, 1996).

C DEFORMITIES - are defined as twisted, missing, forked, or bulging body parts including deformed fins, barbels, abdomen, or skeleton (e.g.-head, vertebrae).

Deformities are classified as light (DL) when they are limited to 1 deformed fin or 1 deformed barbel (e.g.-forked). Deformities are classified as heavy (DL) when there are $\geq$ 2 deformed fins or barbels, or any deformity of the skeleton of other body part exclusive of fins or barbels occurs.

C EROSION - is defined as loss of tissue on the fins, gill covers, and/or barbels.

Erosion is classified as light (EL) when :

a) 1 fin is not eroded past a ray fork, or
b) $\leq$ 2 barbels eroded less than half the barbel length, or
c) gill cover eroded, but no exposed gill tissue.

Erosion is classified as heavy (EH) when:

a) $\geq$ 2 eroded fins, or
b) 1 fin eroded past a single ray fork, or
c) gill cover eroded with exposed gill tissue, or
d) $\geq$ 3 eroded barbels, or
e) a barbel eroded more than half its total length.

Figures 1 and 2 illustrate the application of the erosion criteria.

LESIONS - are defined as open sores, exposed tissue, and/or prominent bloody areas.

Lesions are classified as light (LL) when there are $\leq$ 2 lesions smaller than or equal to the size of the largest scale (or eye on catfish). Lesions are classified as heavy (LH) when there are > 2 small lesions , when there is a lesion larger than the size of the largest scales (or eye on catfish), or when there is raw tissue.

TUMORS - are defined as tumor like masses that cannot be easily broken when squeezed.

Tumors are defined as light (TL) when $\leq$ 2 tumors $\leq$ the diameter of the eye. *Lymphocystis* patches are counted as one tumor. Tumors are defined as heavy (TH) when there are $\geq$ 3 tumors or there is 1 tumor larger than the diameter of the eye.

MULTIPLE DELTS - occur when fish have two or more DELT anomalies (M).

Appendix 6B

Extent of Ohio Lacustuaries

The following is the distance, in miles, of the lake effect zone for each Ohio tributary to Lake Erie as determined by Ohio EPA field investigations during the summers of 1993 to 1996.

The distance the lake effects extends upstream varies with lake levels and will increase as lake levels rise. Each year a lacustuary is sampled, the distance the lake effect extends upstream must be reassessed. Distances for the lacustuaries asterisked (*) below differ from Brant & Herdendorf 1972 because lake levels were higher during the sampling period than they were in 1972.

Ottawa River 6.8;	Maumee River 14.8;
Crane Creek 2.9;	Turtle Creek 5.6;
Toussaint River 10.0;	Portage River 16.7;*
Muddy Creek 5.2;	Sandusky River 15.7;*
Huron River 9.8;*	Old Woman Creek 1.3;
Vermilion River 2.4;*	Black River 5.8;*
Rocky River 1.5;*	Cuyahoga River 7.0;*
Chagrin River 1.4;*	Grand River 4.6;*
Ashtabula River 1.8;	Conneaut Creek 2.1*

Appendix 6C

DELTs Anomalies Percentages
Ohio Lake Erie Nearshore Waters
Figures 6.1.1 to 6.1.10

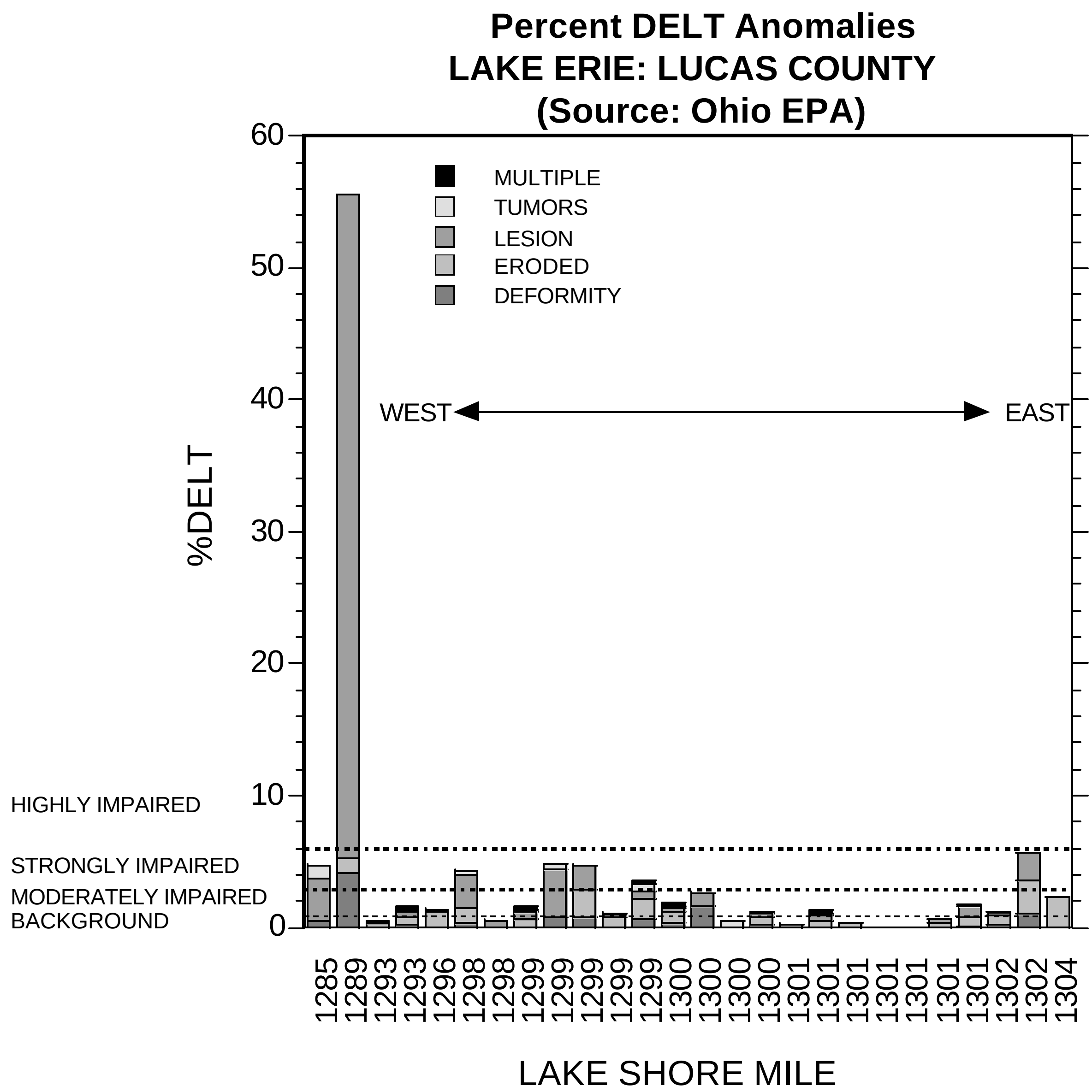

Figure 6.1.1. Lucas County DELT plot.

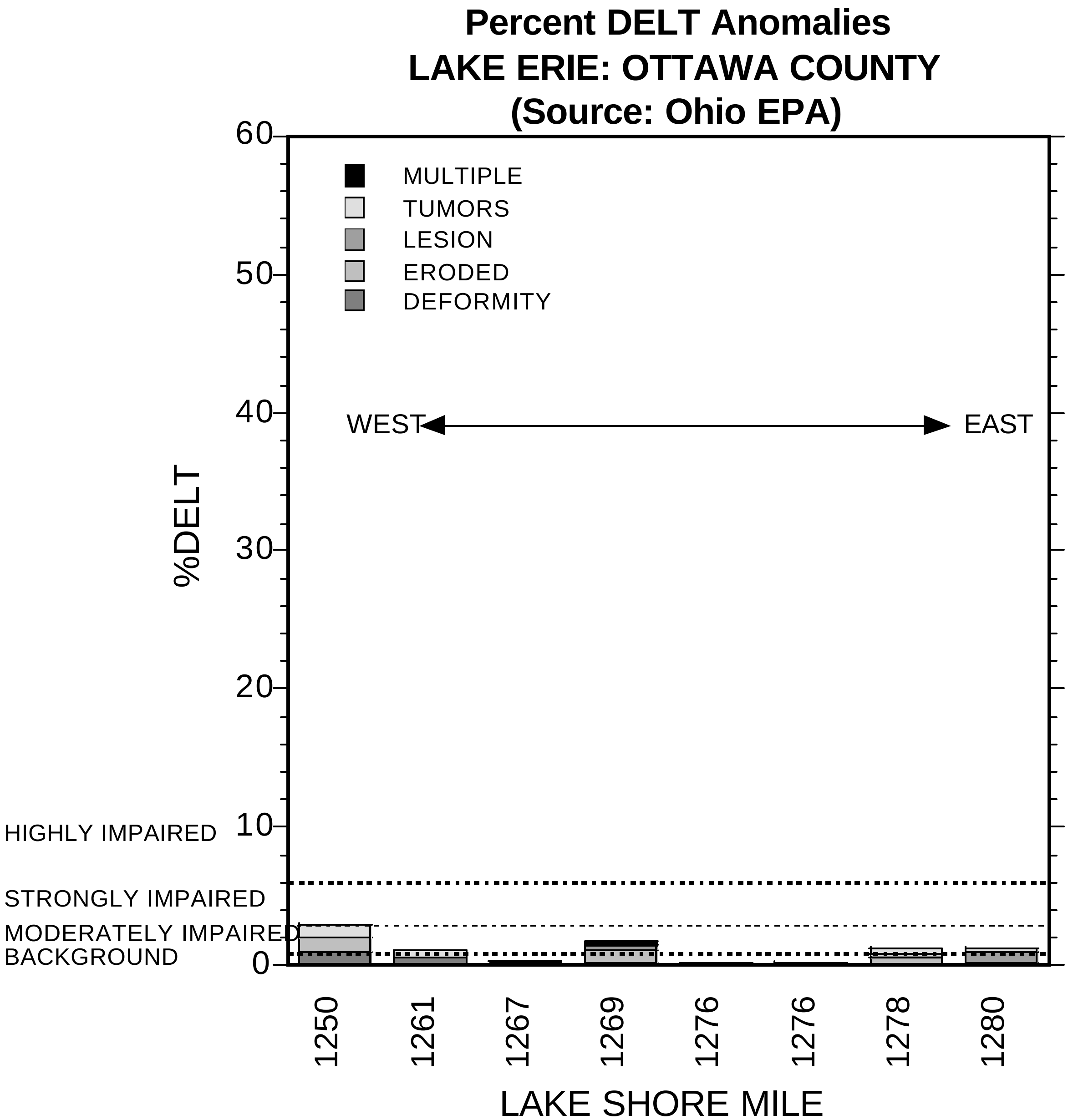

Figure 6.1.2. Ottawa County DELT plot.

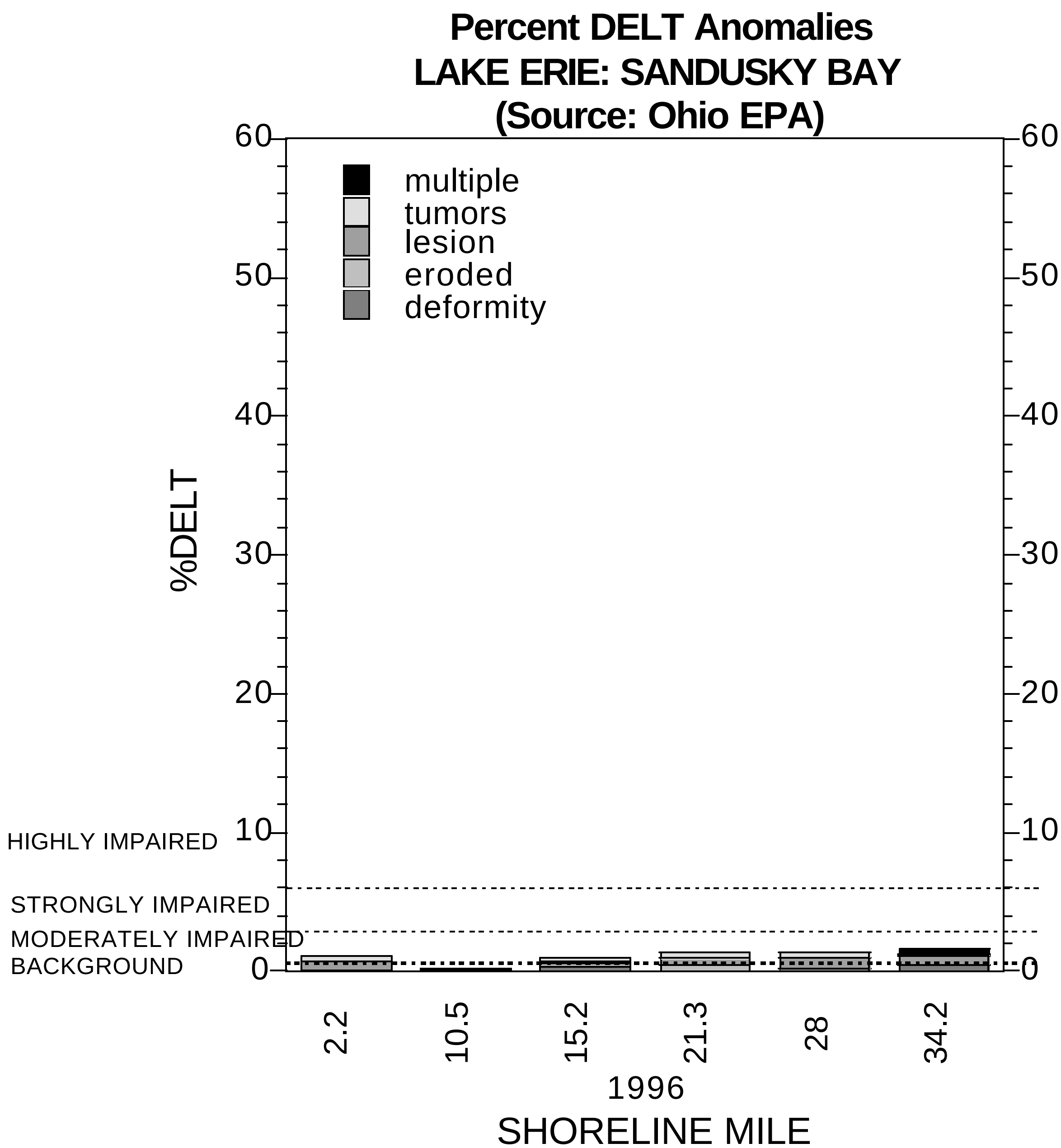

Figure 6.1.3. Sandusky Bay DELT plot.

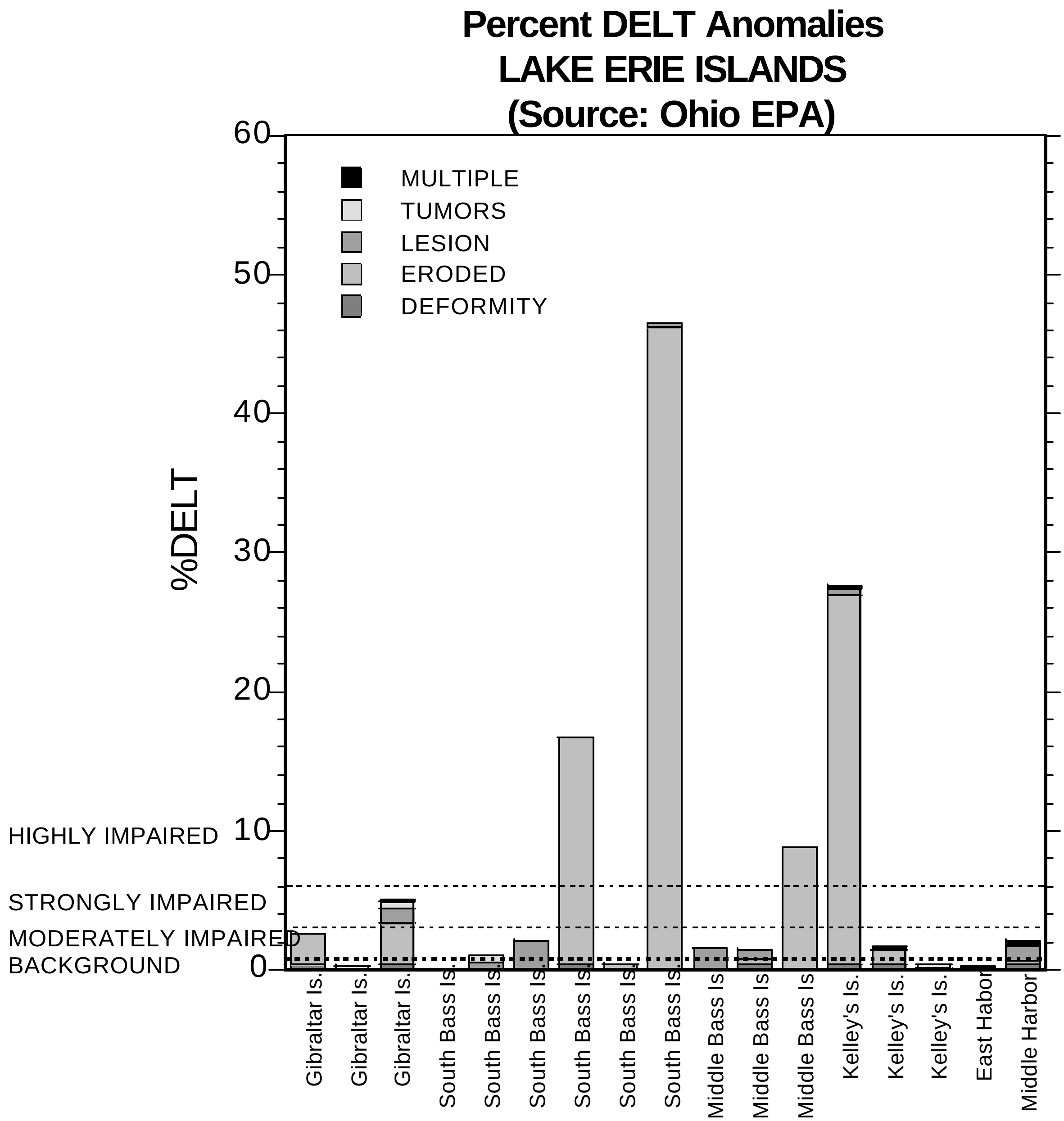

Figure 6.1.4. Lake Erie Islands DELT plot.

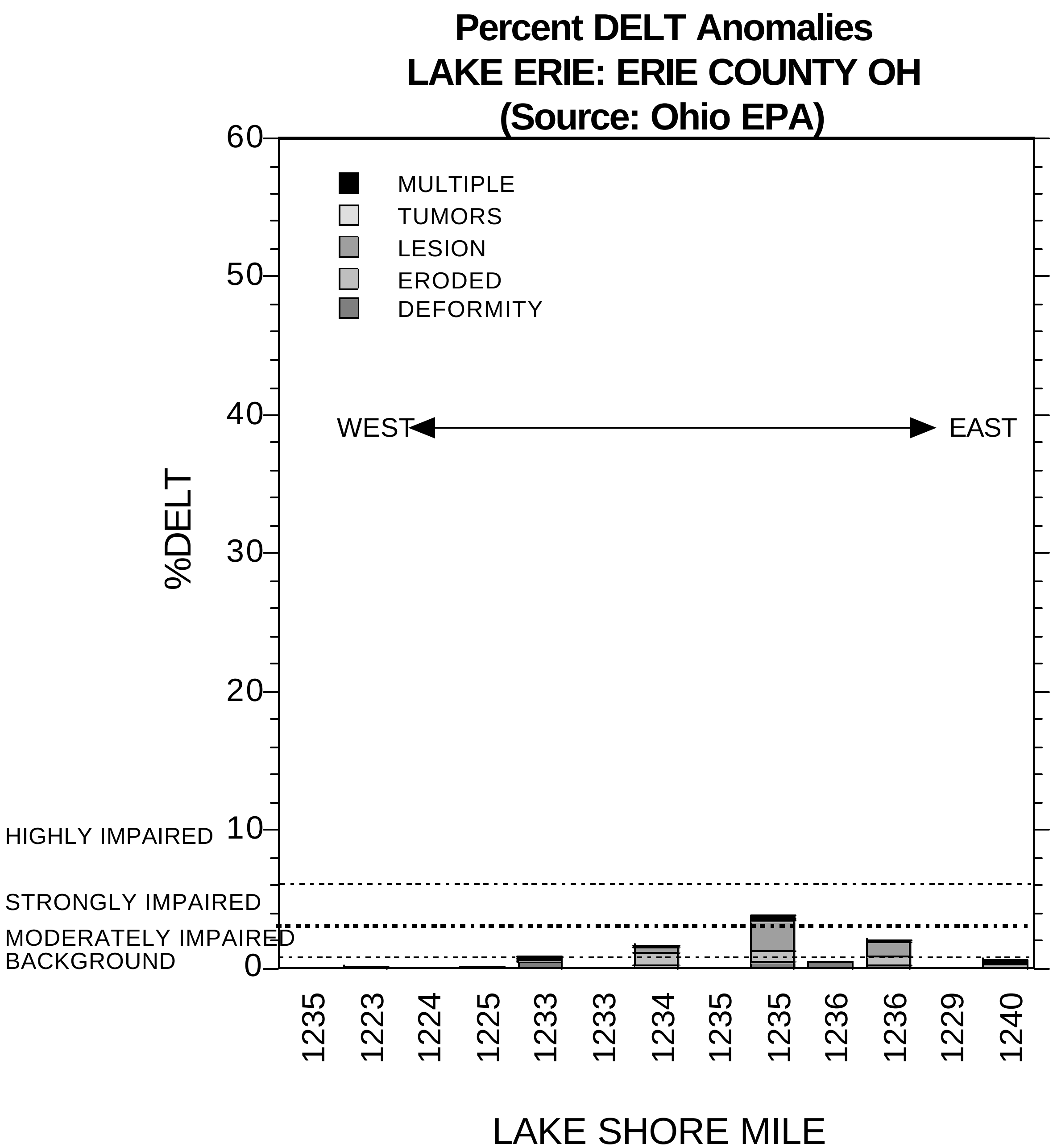

Figure 6.1.5. Erie County DELT plot.

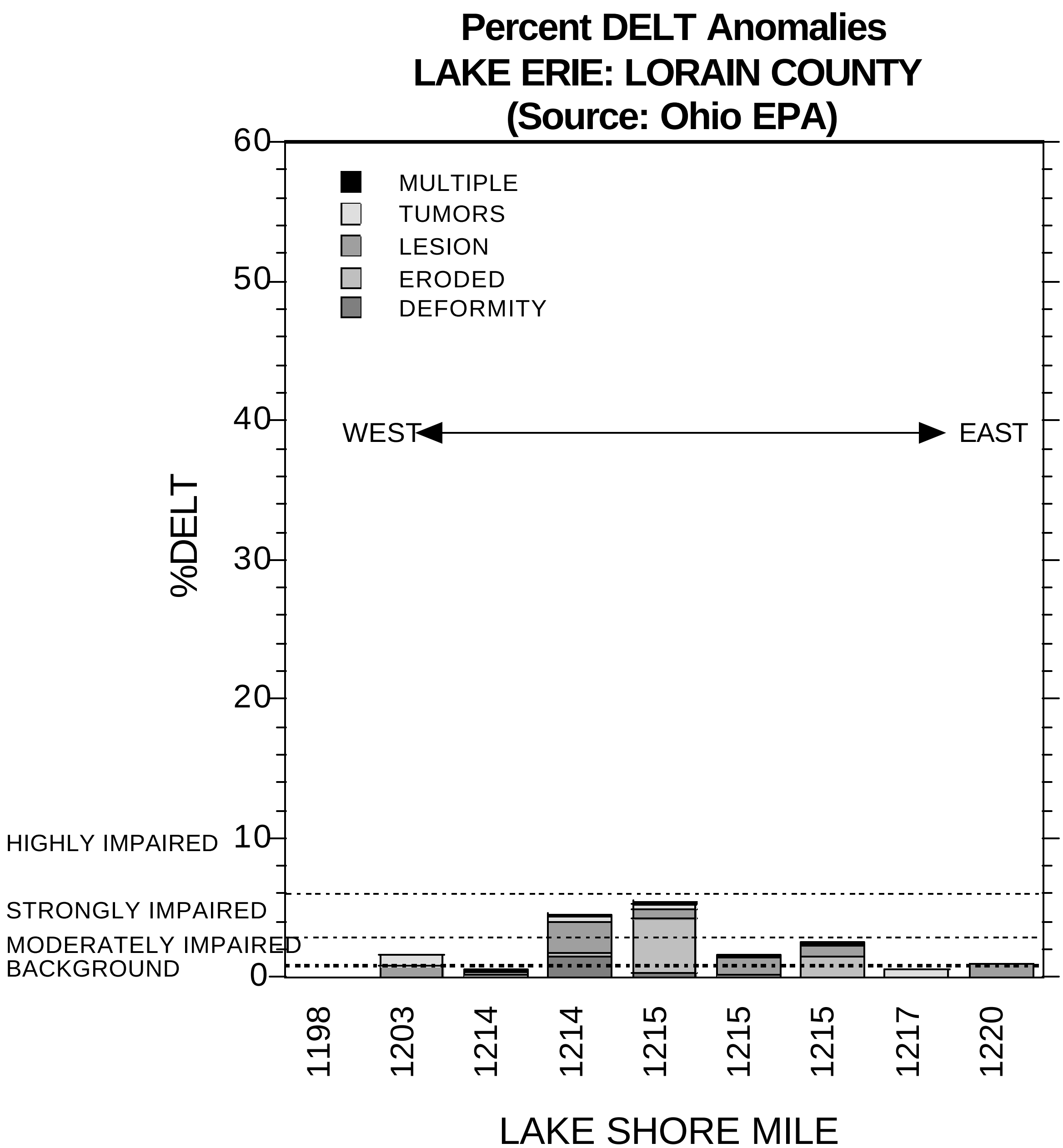

Figure 6.1.6 Lorain County DELT plot.

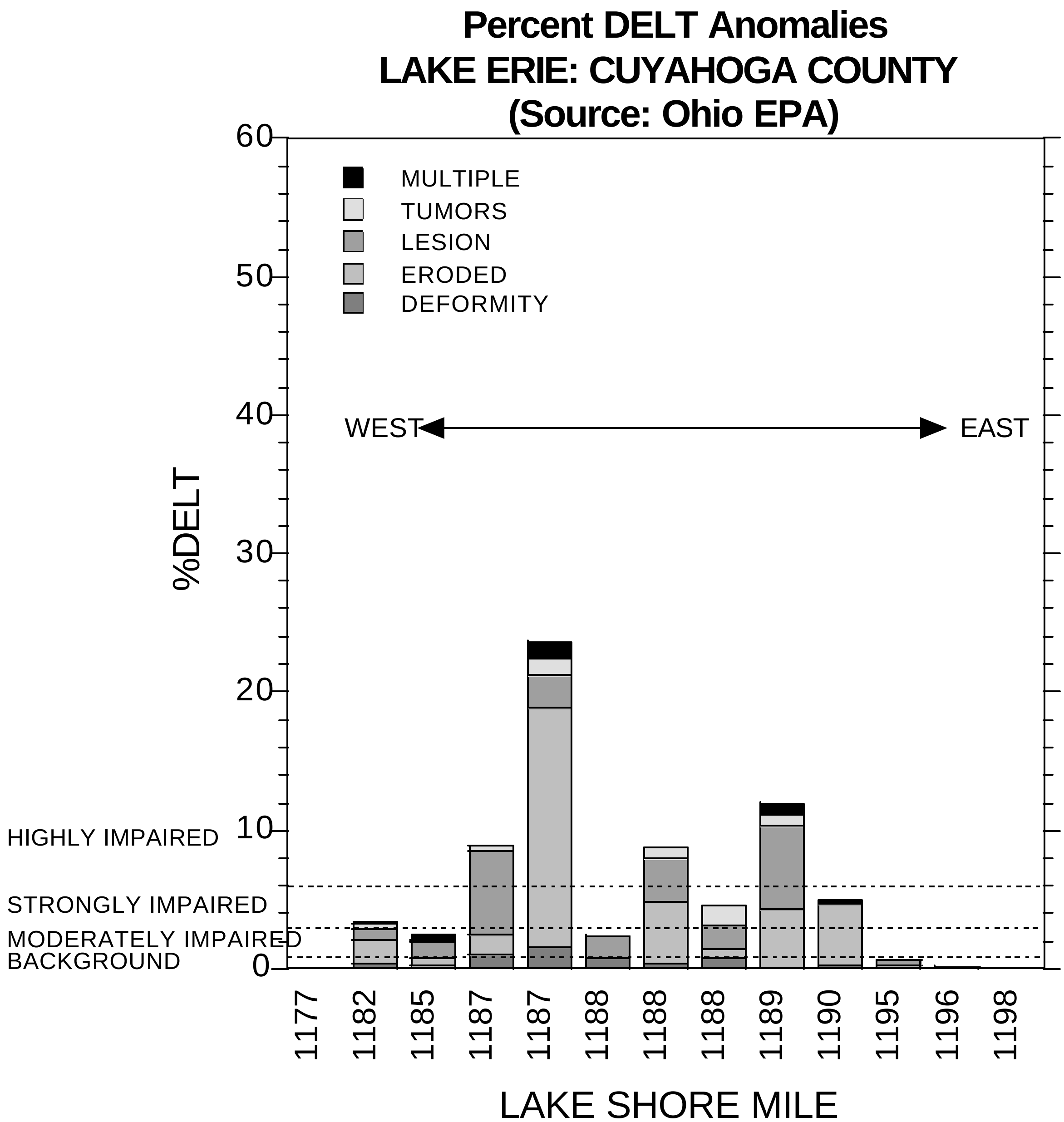

Figure 6.1.7. Cuyahoga County DELT plot.

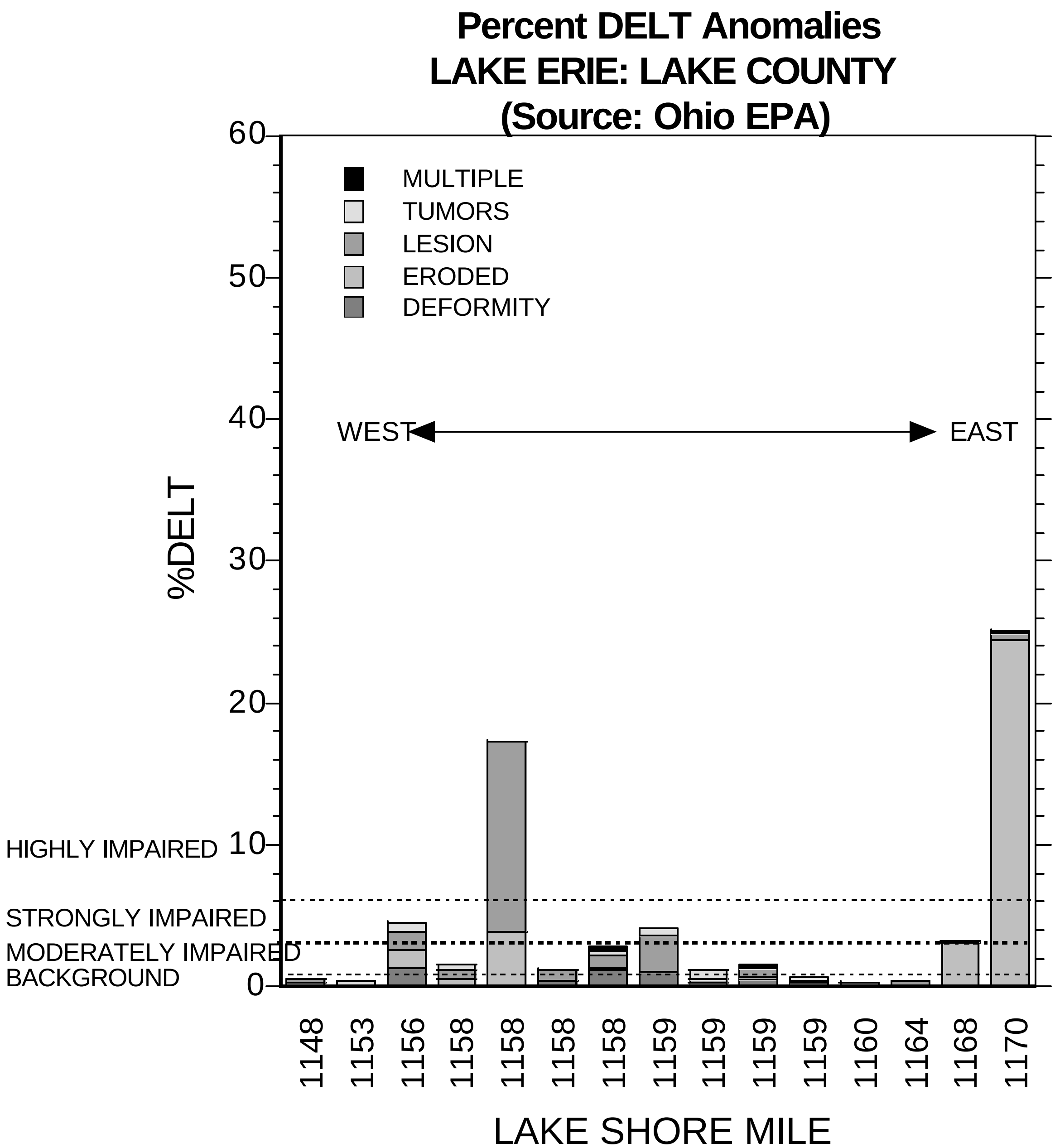

Figure 6.1.8. Lake County DELT plot.

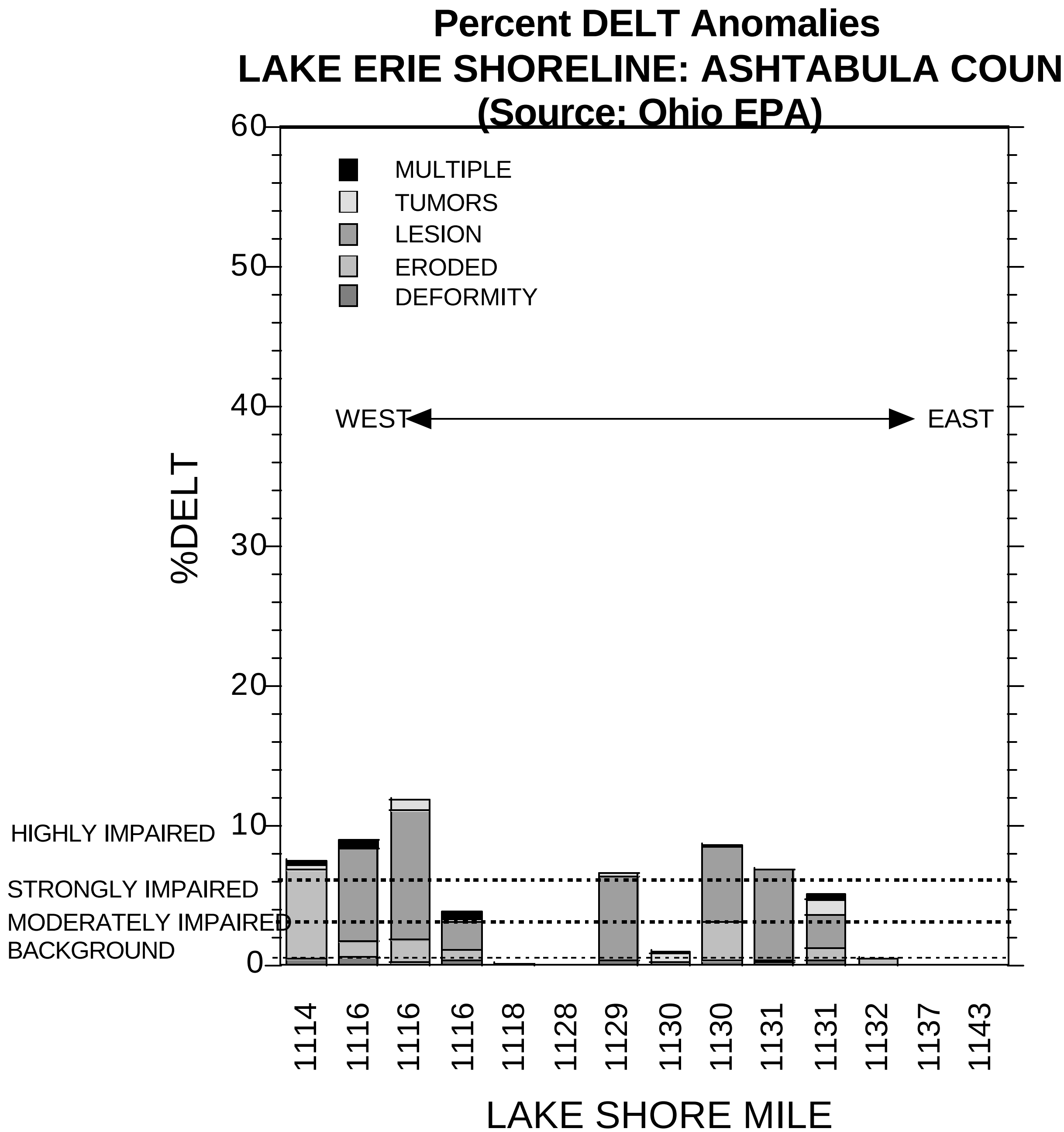

Figure 6.1.9. Ashtabula County DELT plot.

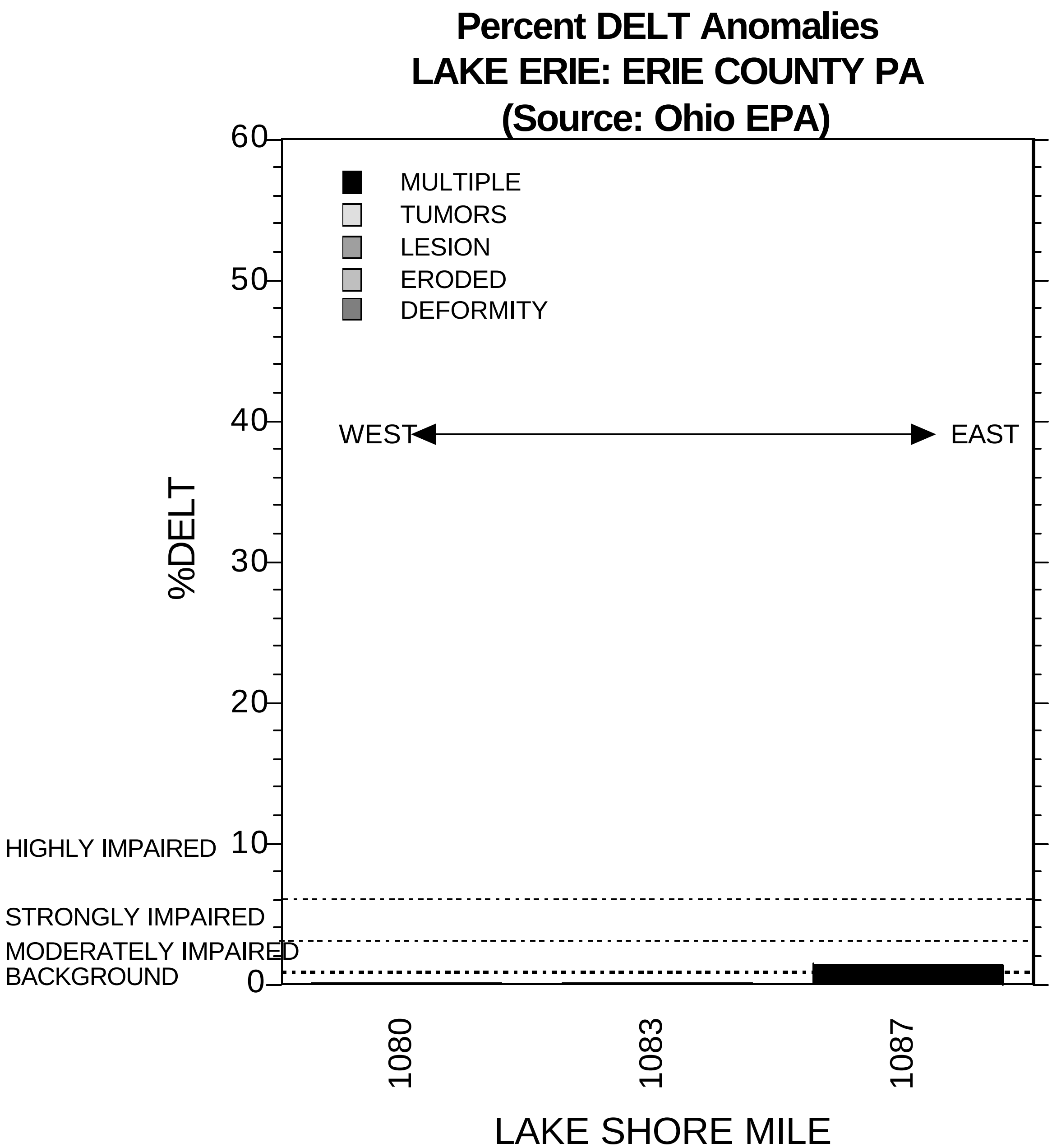

Figure 6.1.10. Erie County PA DELT plot.

Appendix 6D

DELTs Anomalies Percentages
Ohio Lacustuaries
Figures 6.2.1 to 6.2.15

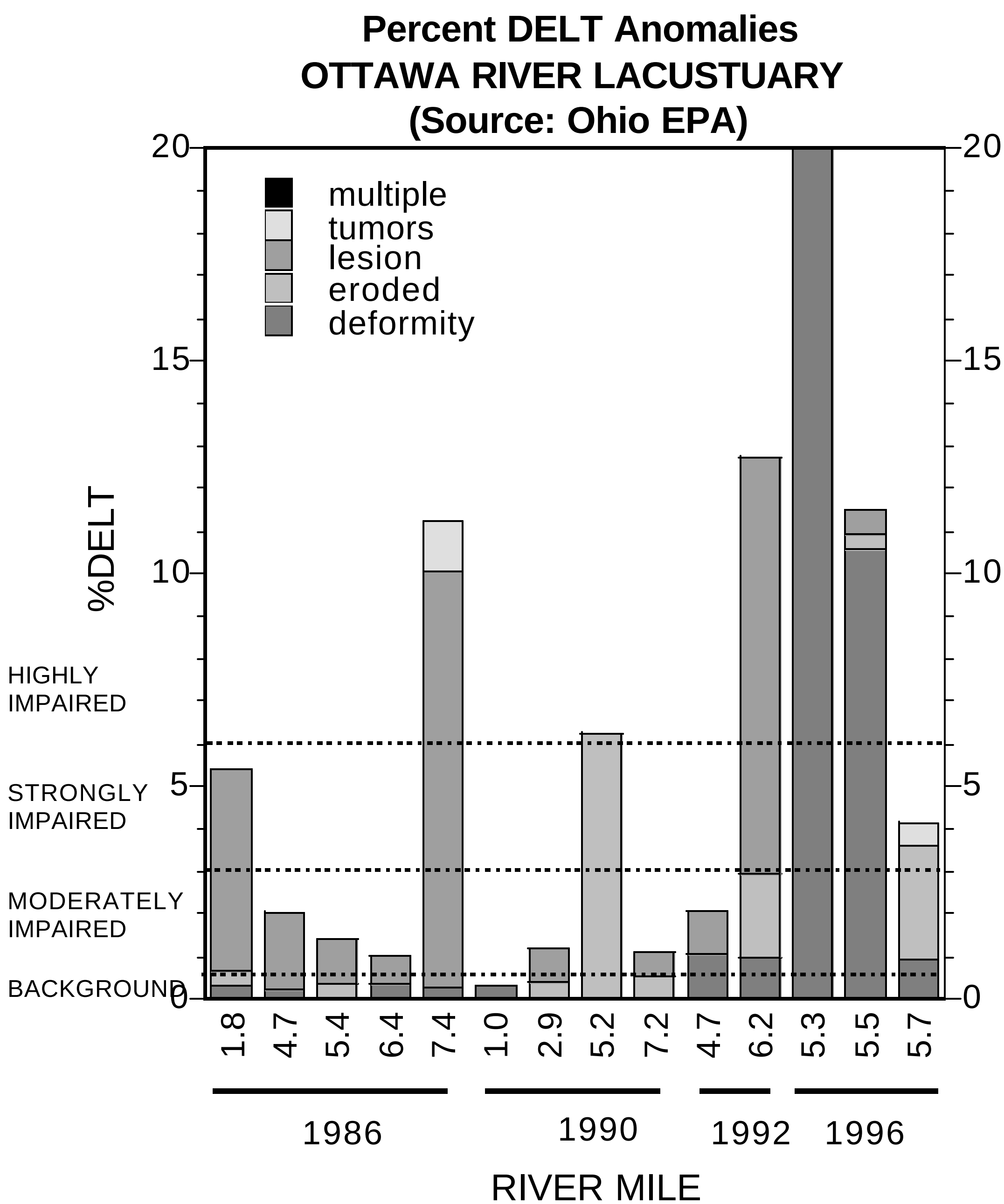

Figure 6.2.1. Ottawa River lacustuary DELT plot.

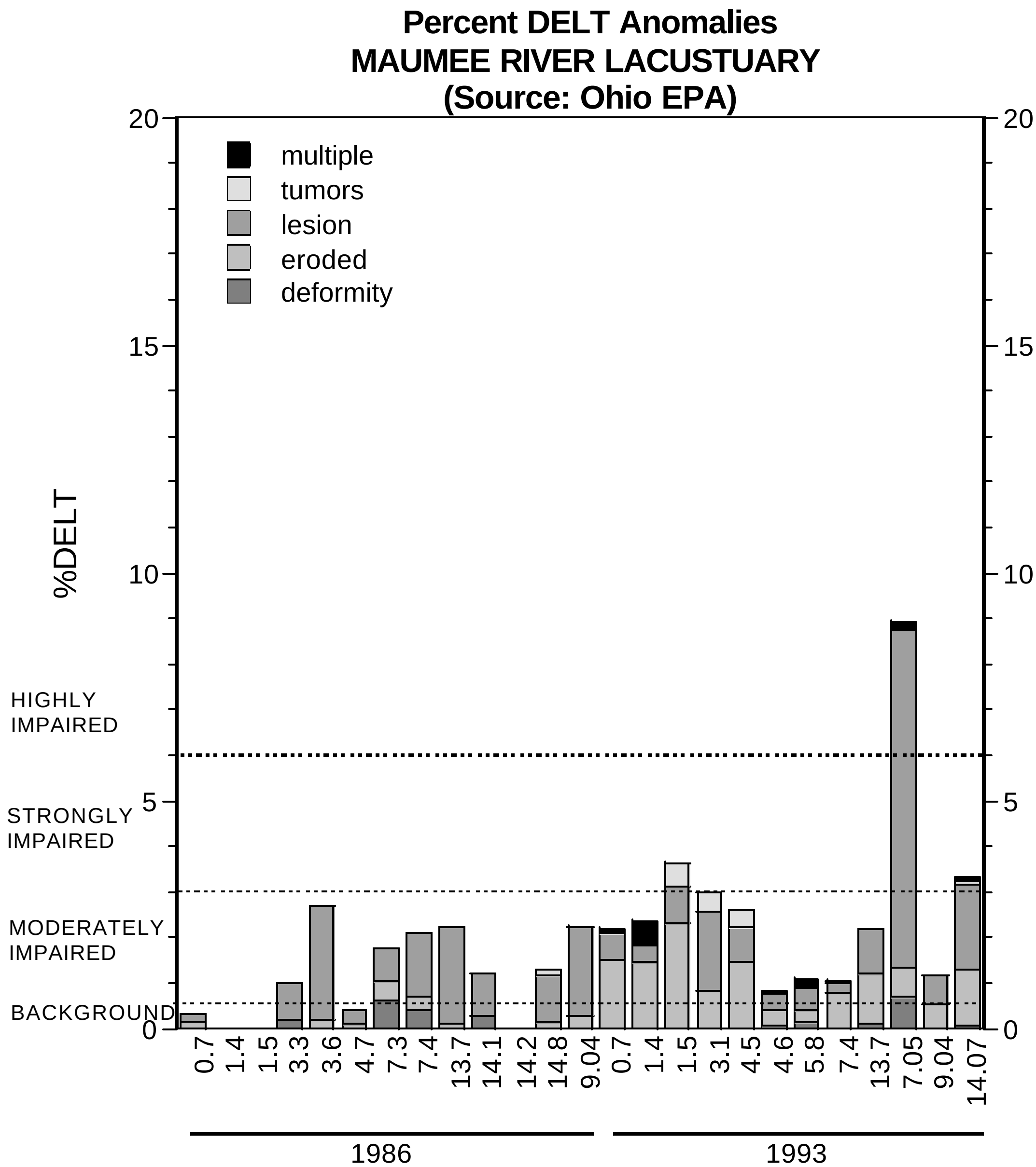

Figure 6.2.2. Maumee River lacustuary DELT plot.

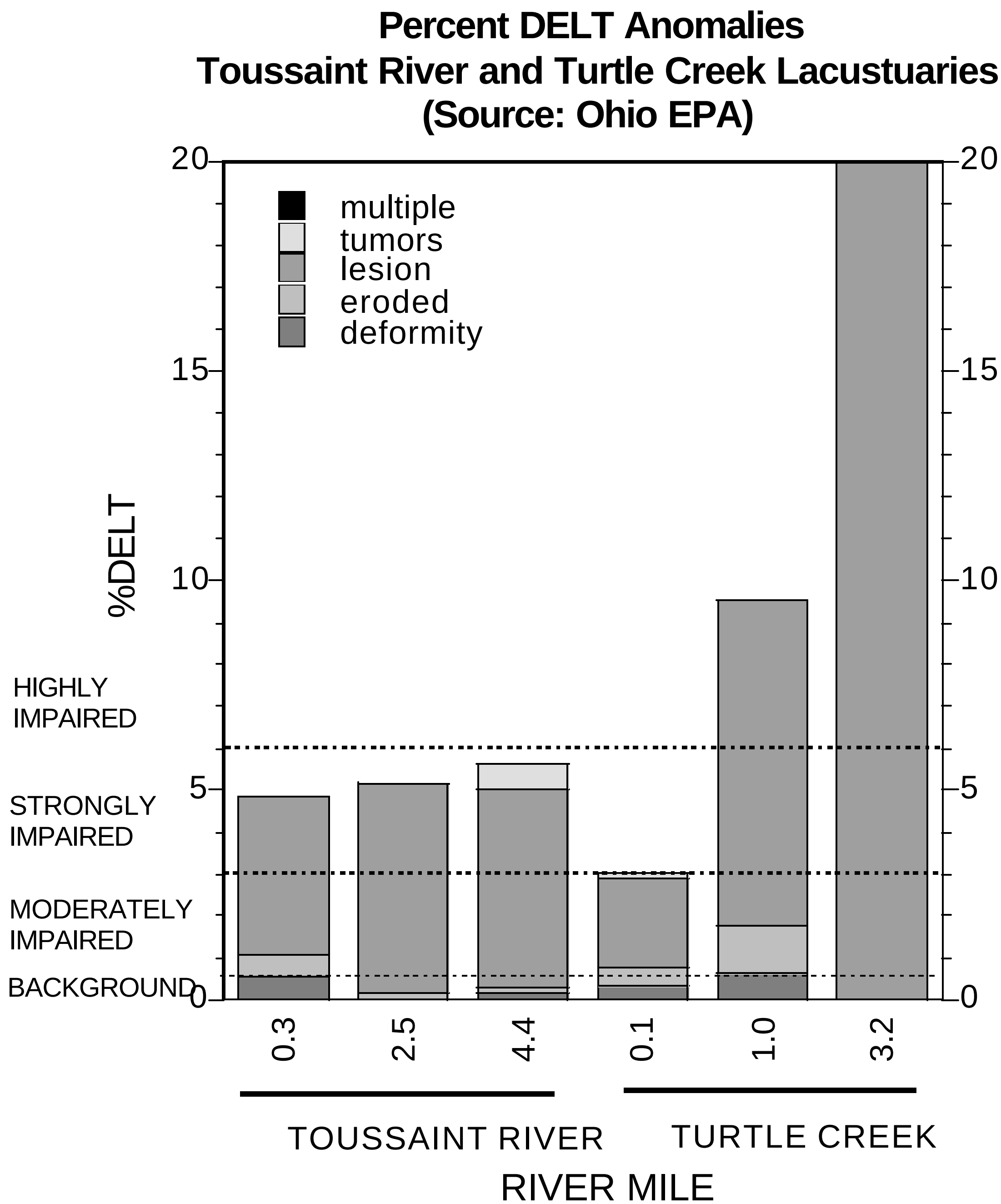

Figure 6.2.3. Toussaint River and Turtle Creek lacustuary DELT plot.

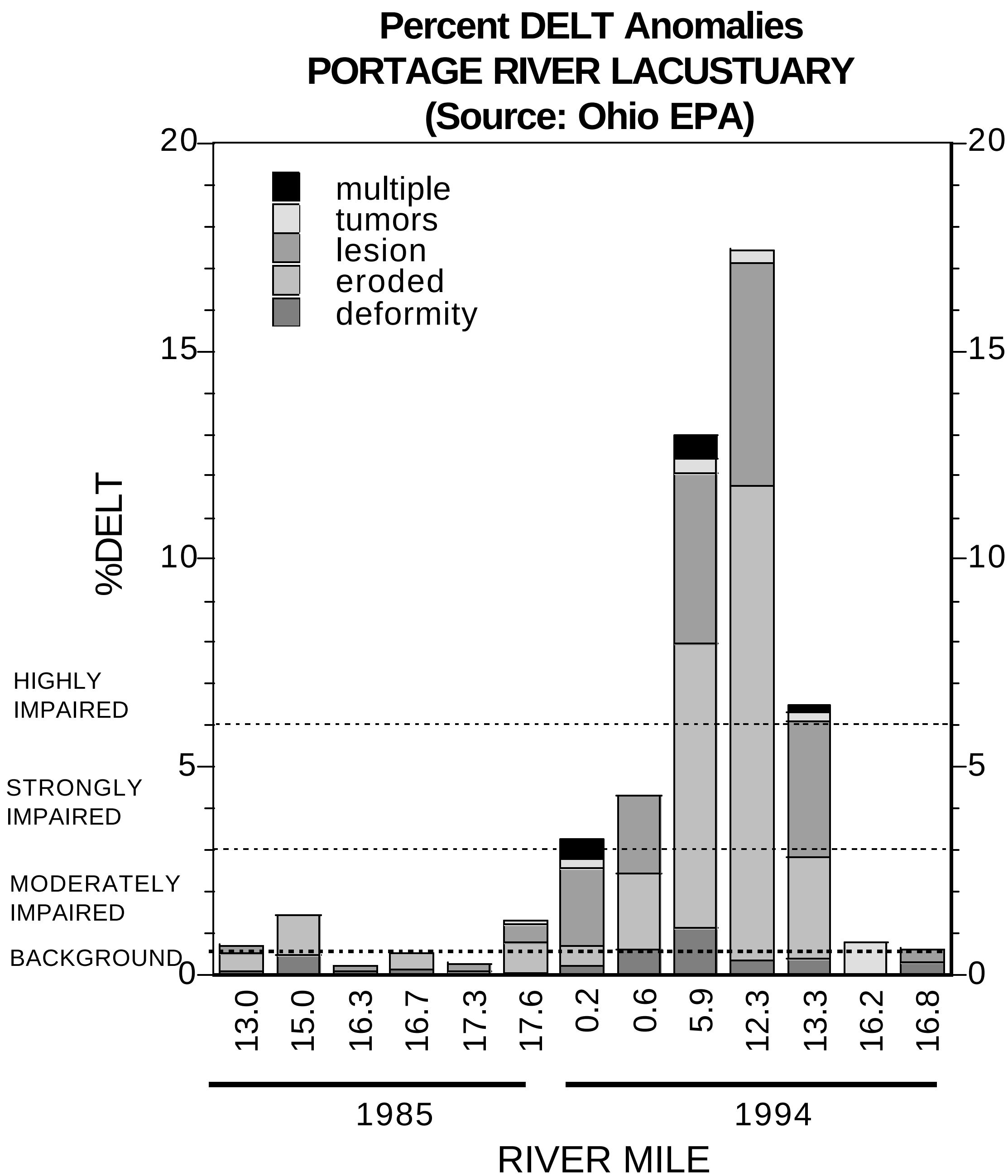

Figure 6.2.4. Portage River lacustuary DELT plot.

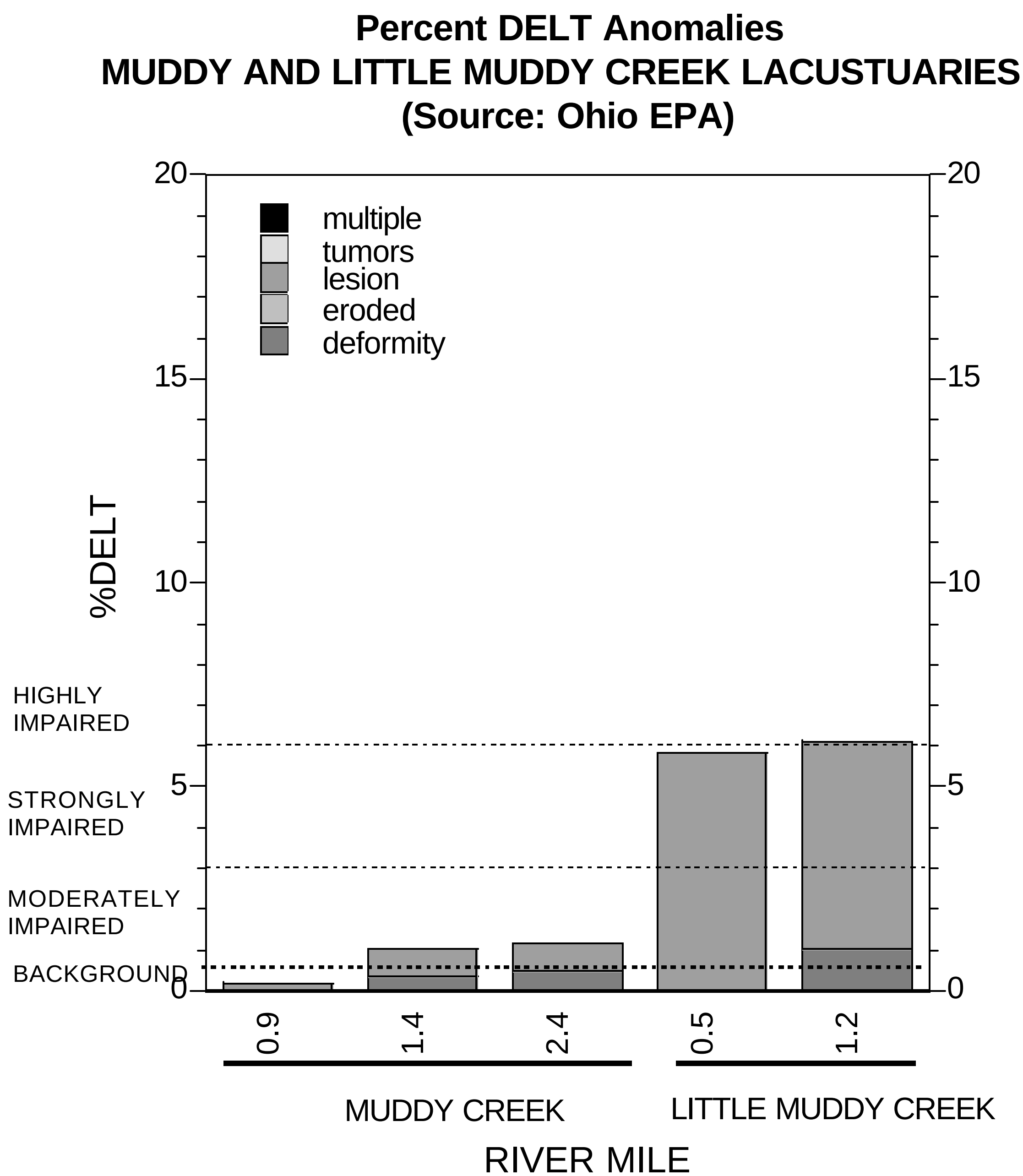

Figure 6.2.5. Muddy and Little Muddy Creek lacustuary DELT plot.

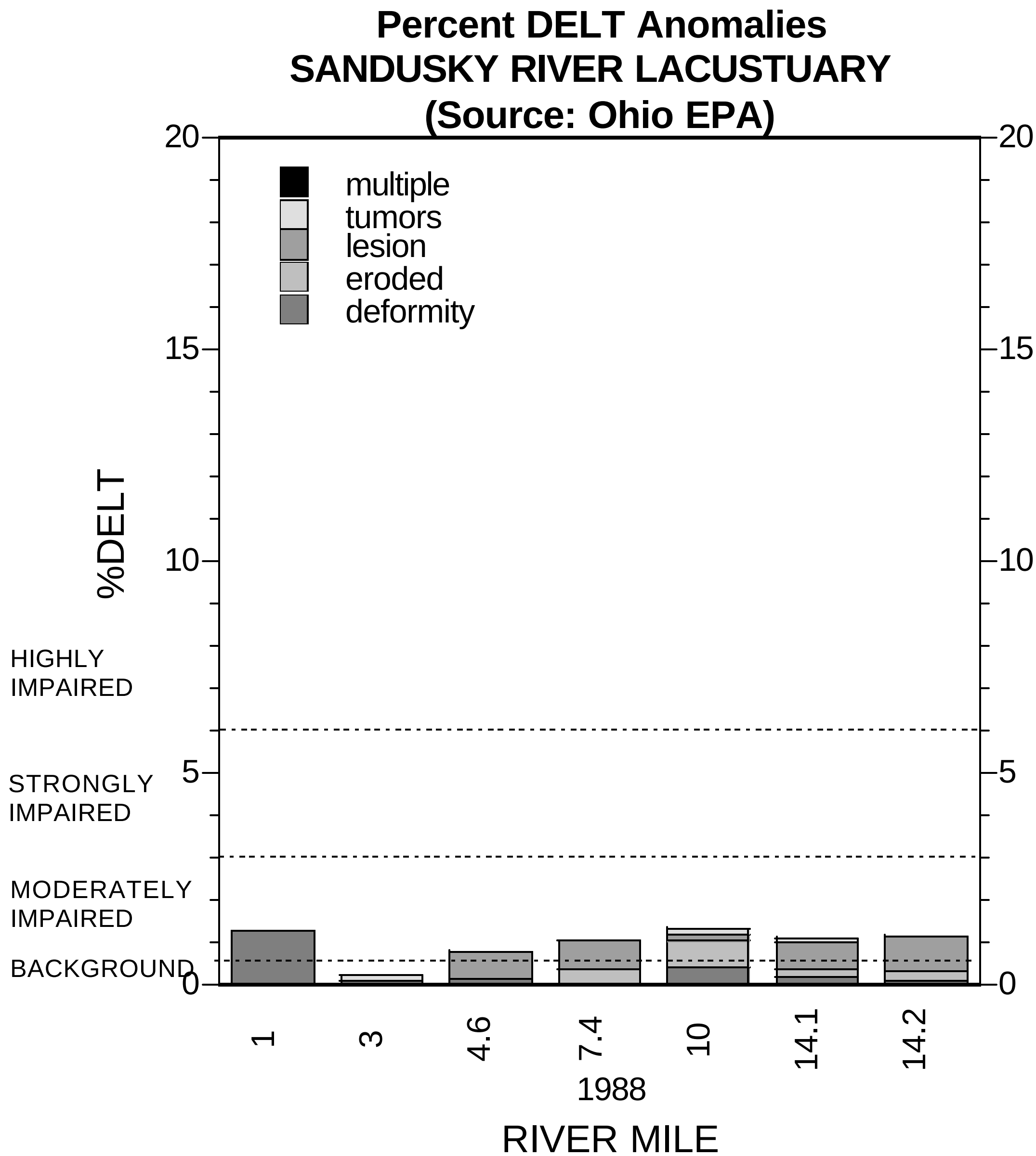

Figure 6.2.6. Sandusky River lacustuary DELT plot.

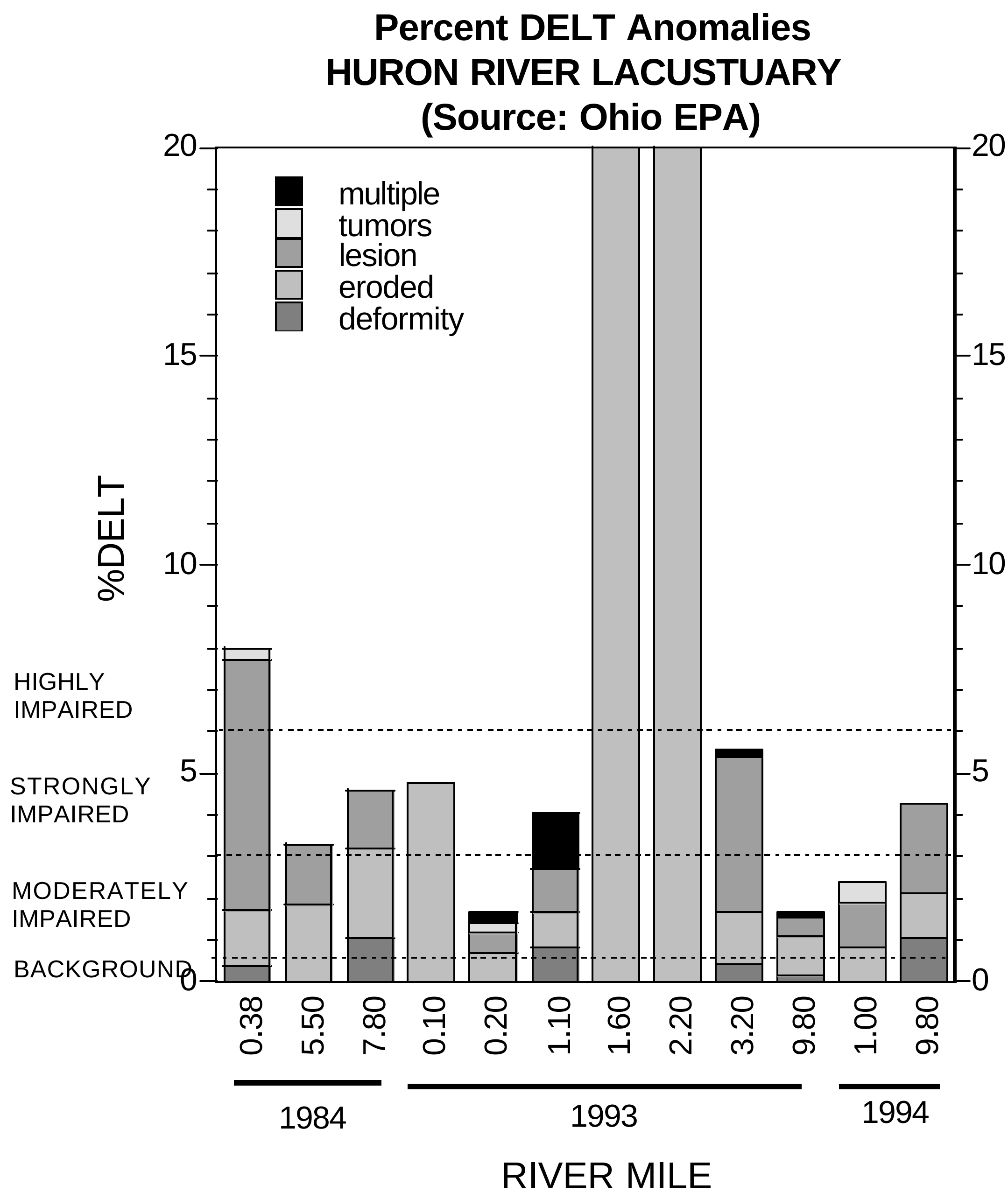

Figure 6.2.7. Huron River lacustuary DELT plot.

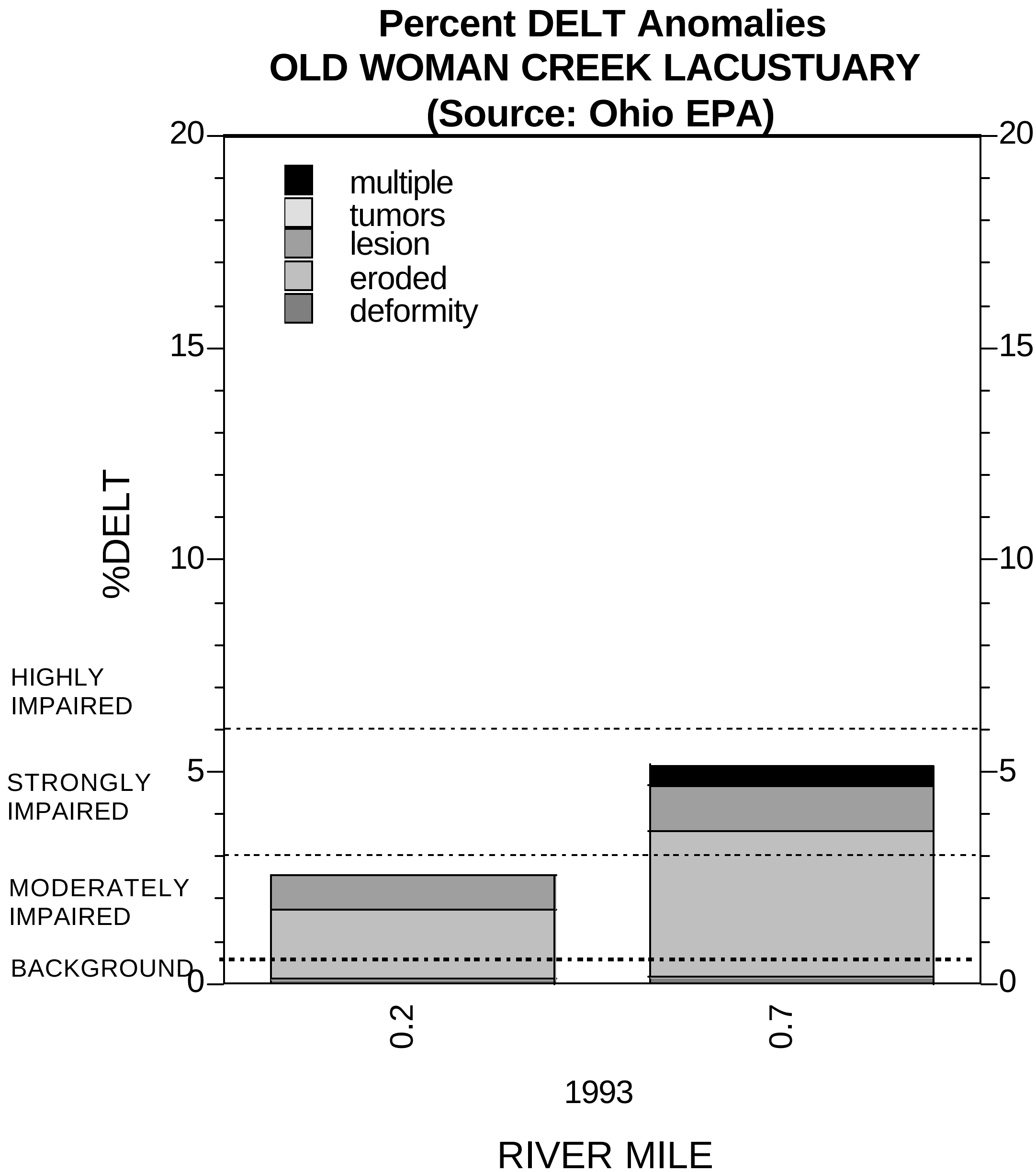

Figure 6.2.8. Old Woman Creek lacustuary DELT plot.

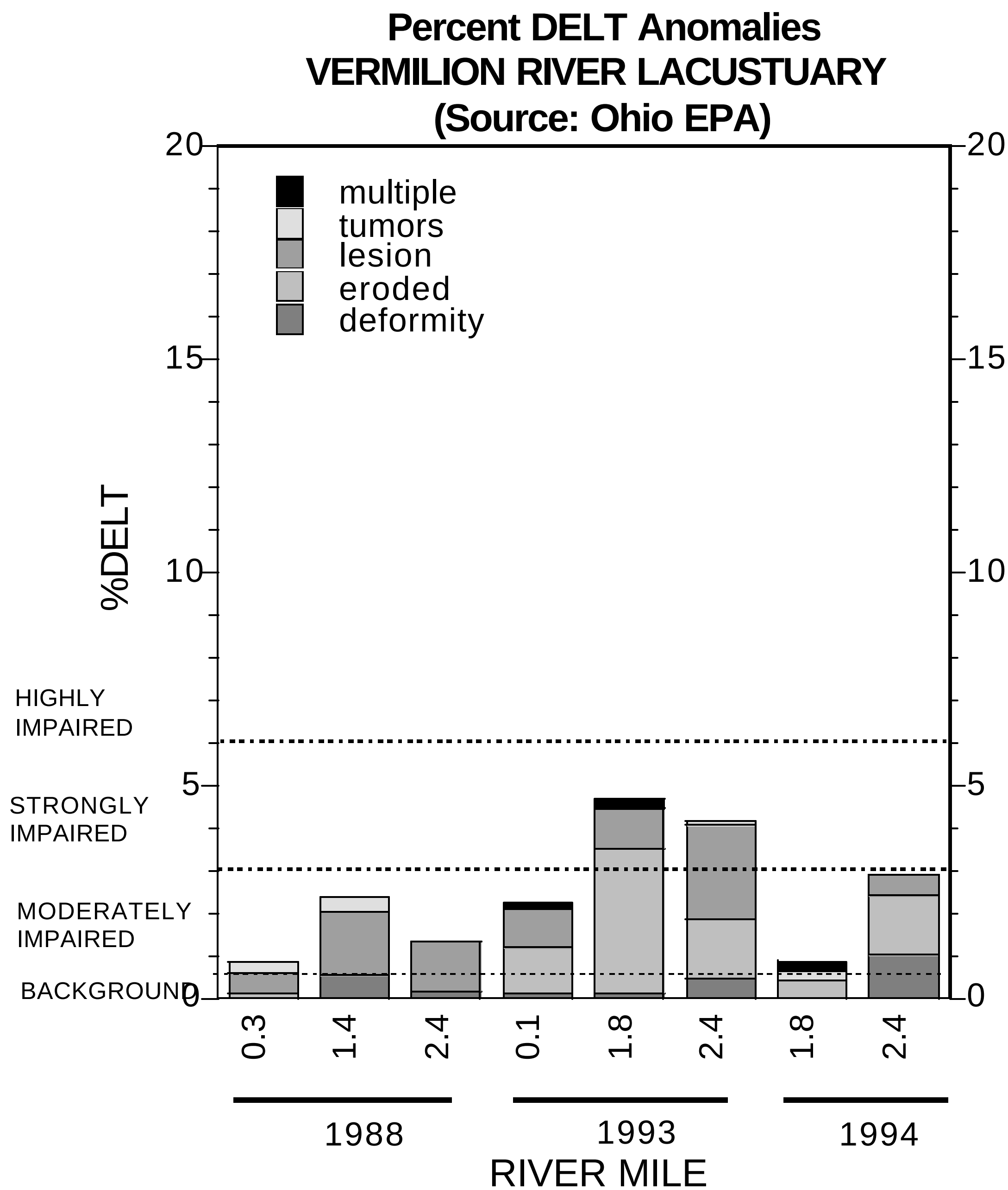

Figure 6.2.9. Vermilion River lacustuary DELT plot.

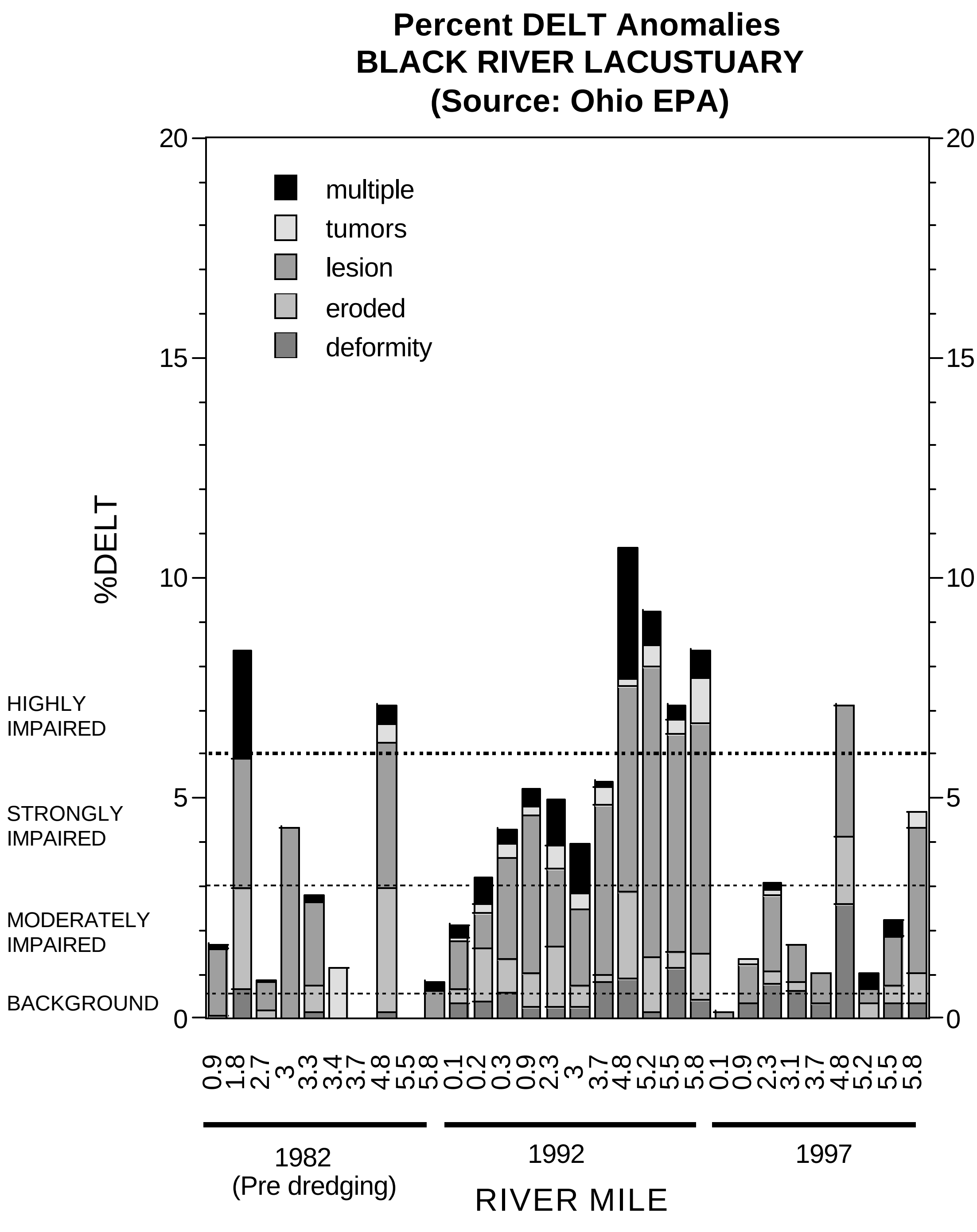

Figure 6.2.10. Black River lacustuary DELT plot.

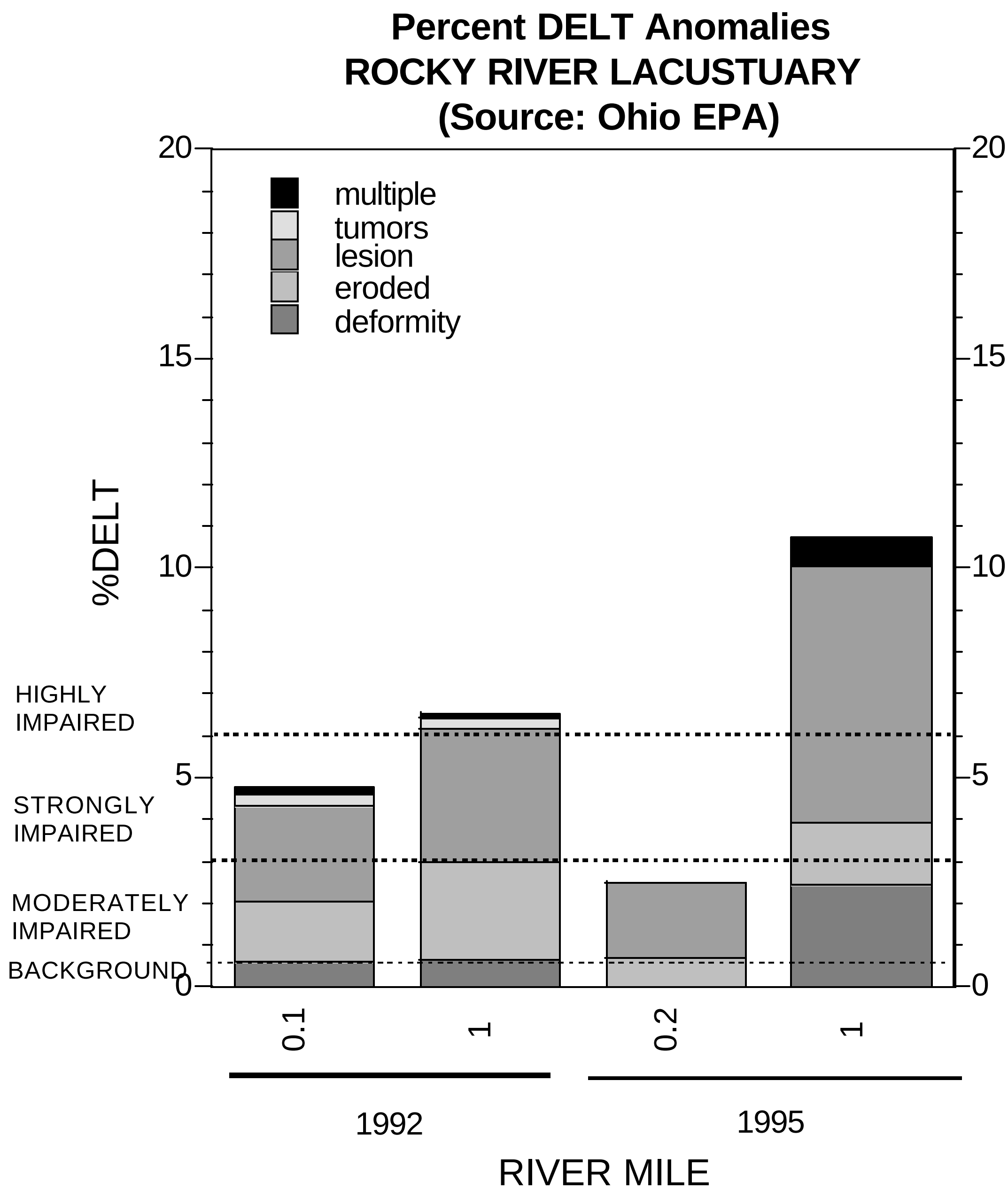

Figure 6.2.11. Rocky River lacustuary DELT plot.

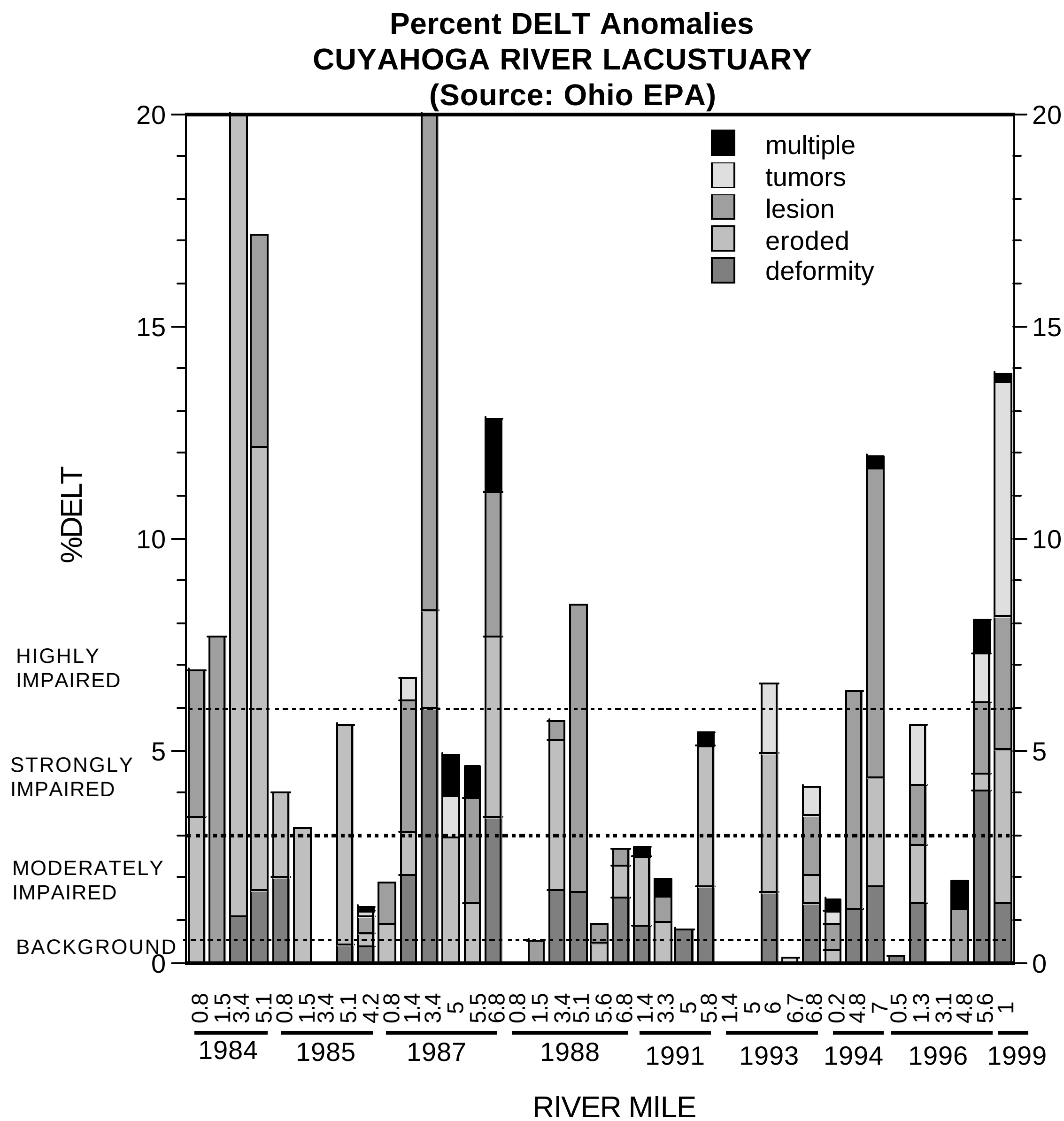

Figure 6.2.12. Cuyahoga River DELT plot.

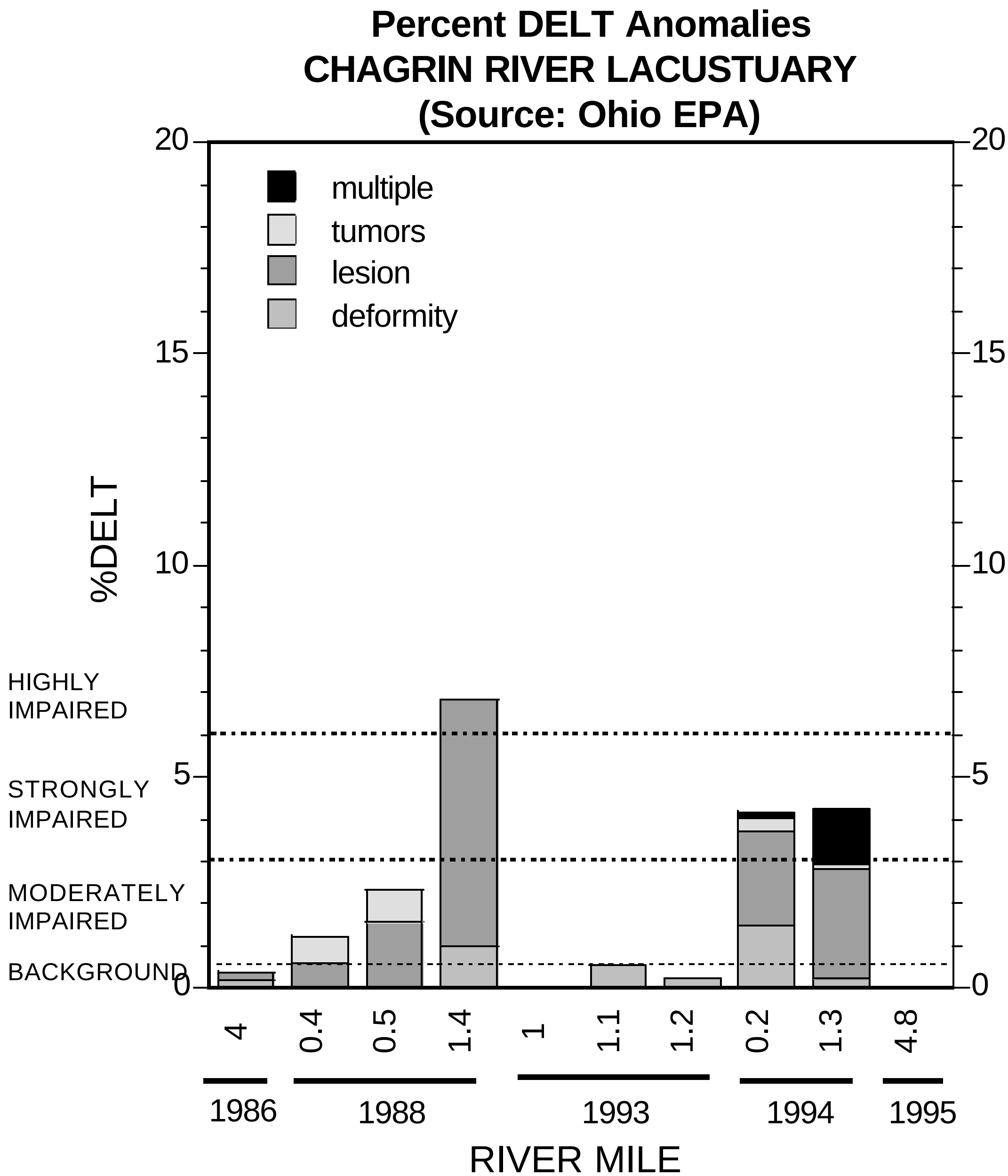

Figure 6.2.13. Chagrin River lacustuary DELT plot.

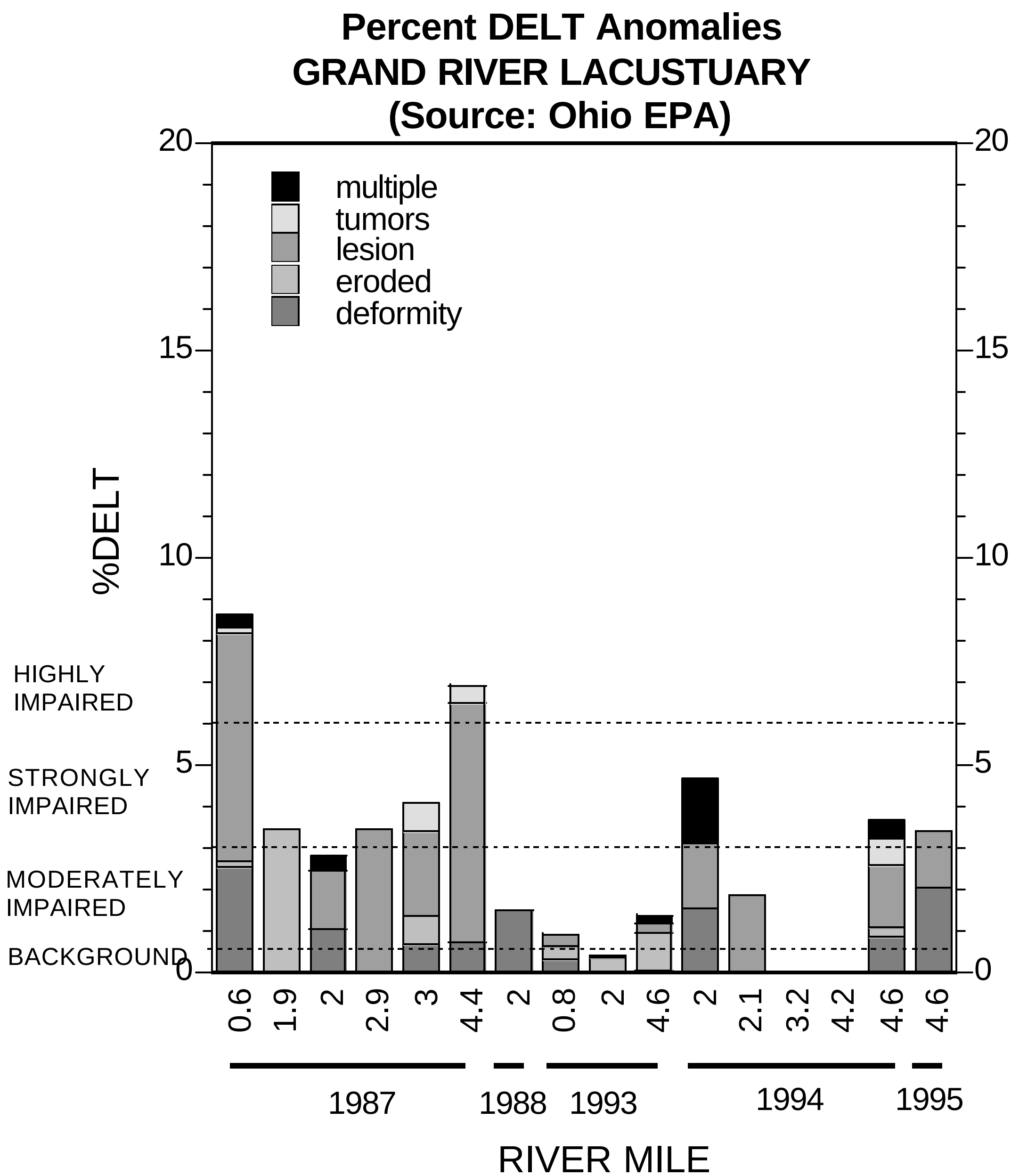

Figure 6.2.14. Grand River lacustuary DELT plot.

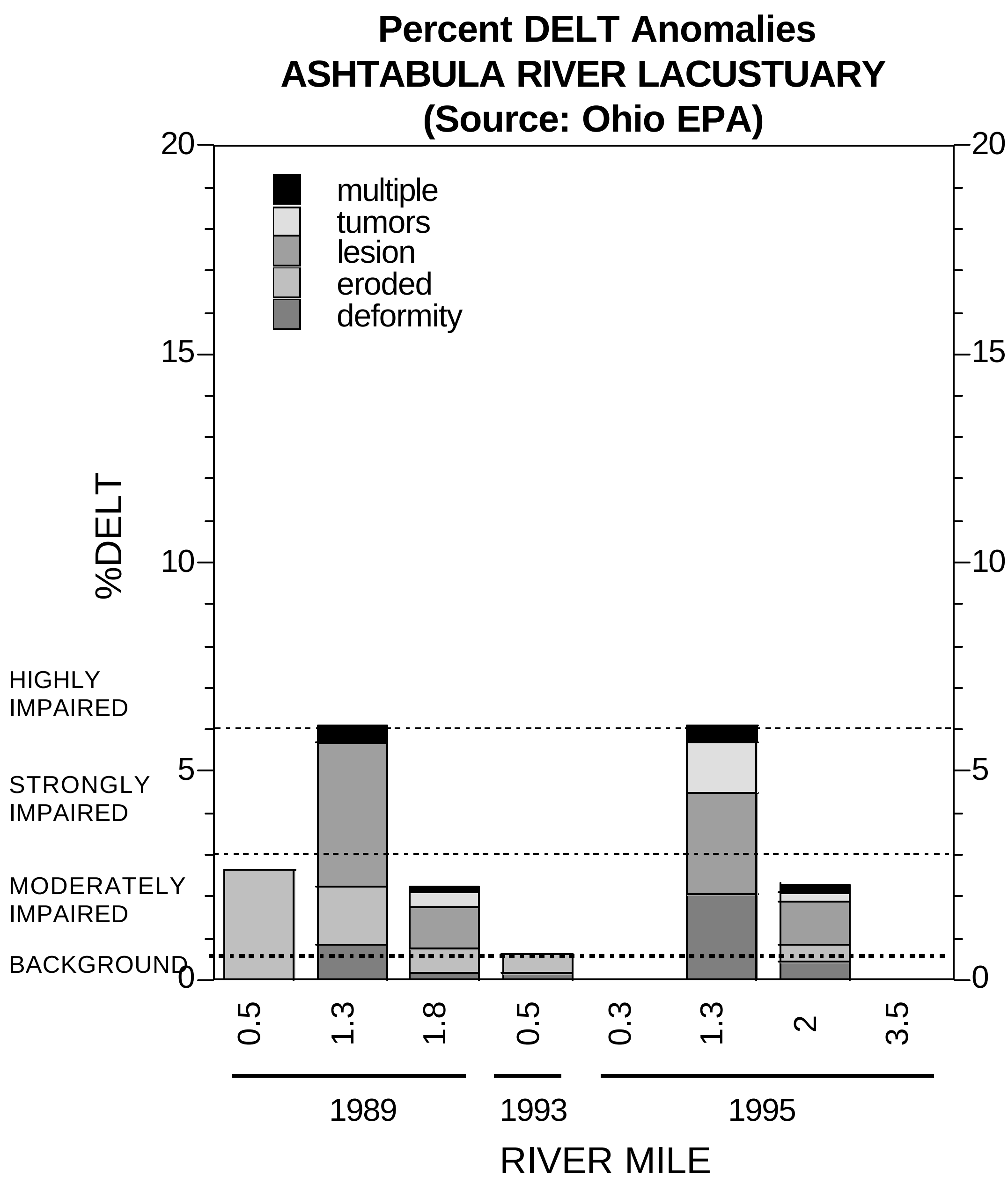

Figure 6.2.15. Ashtabula River lacustuary DELT plot.

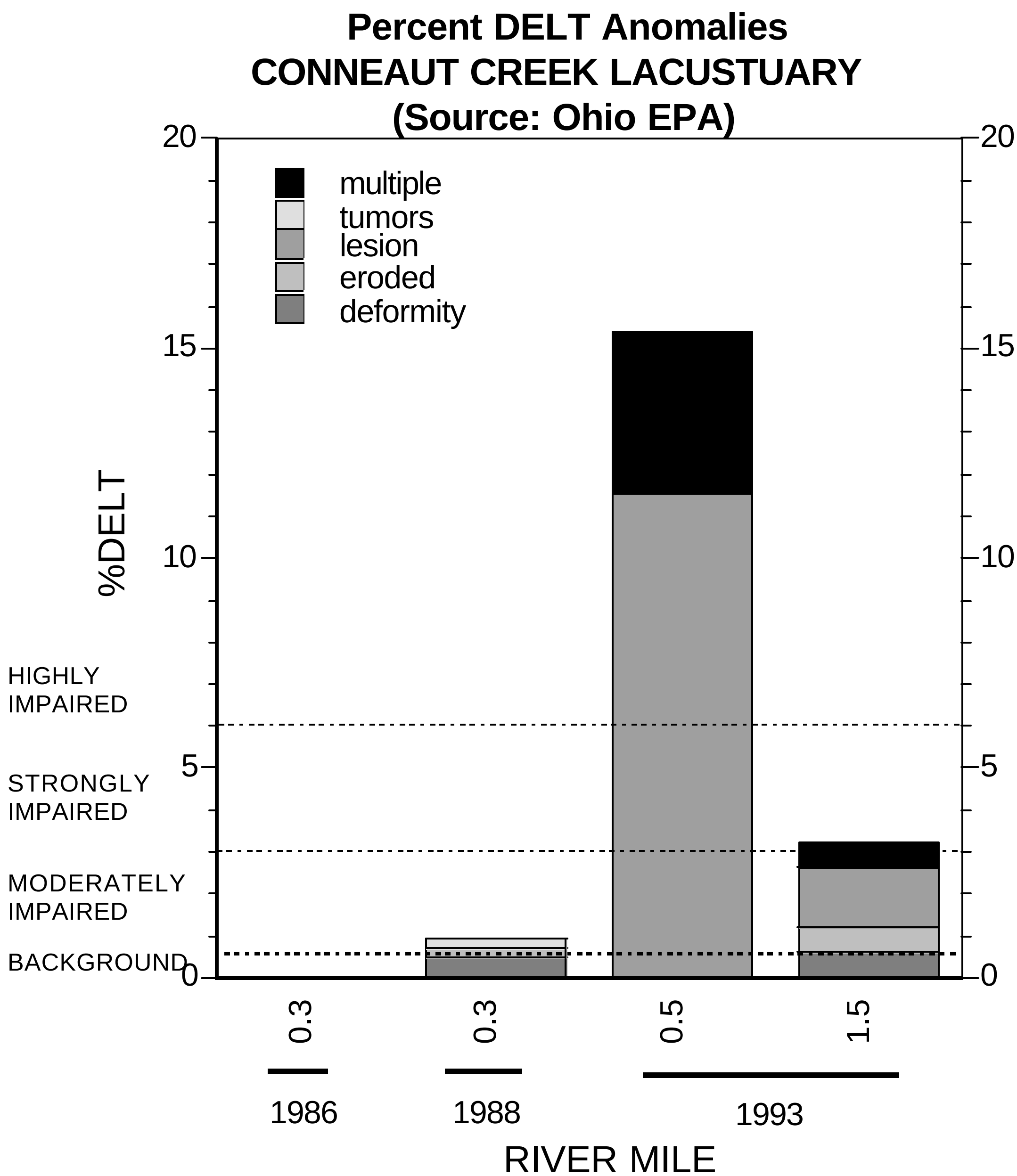

Figure 6.2.16. Conneaut Creek lacustuary DELT plot.