EFFECTS OF ALTERED WATER LEVELS AND FLOWS ON FISH IN THE GREAT LAKES CONNECTING CHANNELS

Prepared by

T. Edsall

and

J. Cleland

U.S. Fish and Wildlife Service

National Fisheries Research Center-Great Lakes

1451 Green Road

Ann Arbor, Michigan 48105

February 1989

INTRODUCTION

This report, which addresses International Joint Commission (IJC) Water Levels Reference Study, Task Group 2, Task 202-4, examines the potential effects of hypothetical alterations in the water levels and attendant flows on fish habitat and young fish in each of the Great Lakes connecting channels. The report describes the fish community and primary fish habitats of each connecting channel; the fish use of these habitats; and the approximate areas in each channel that would be dewatered or inundated if the monthly mean lake level at the downstream end of the channel or channel segment of interest was permanently elevated or lowered 1 m from the long term monthly mean for that location. The report also evaluates the effect of the ±1 m scenario on the food web that supports fish reproduction and growth, and on the exacerbation or amelioration of existing use-conflicts that affect fish or fish habitat in the channels.

Scenarios in which the hypothetical alteration represented a 0.3 m compression or expansion of the long term mean monthly level were not evaluated because they required consideration of topographic and bathymetric data on a finer scale of resolution than was available to us.

We have drawn freely on several documents in the preparation of this report: Goodyear et al. (1982); Patch and Busch (1984); Duffy et al. (1987); Edsall et al. (1988a,b); Manny et al. (1988); and UGLCCS (1988). Collectively,
these documents represent recent attempts to describe the Great Lakes connecting channel ecosystems, evaluate the consequences of existing use-conflicts and proposed new developments, and provide a basis for remediation.

Literature searches were conducted of the following commercial data bases: BIOSIS, 1969-88; Aquatic Sciences and Fisheries Abstracts, 1978-88; Life Sciences, 1978-88; Conference Papers Index, 1973-88; and the computerized version of Fisheries Review (formerly Sport Fishery Abstracts), 1955-1988. We also performed a thorough search of the book, periodical, and reprint collection of the Van Oosten Library at the National Fisheries Research Center-Great Lakes, and consulted the following bibliographies: Hoyt 1988; Patch and Busch 1984; and USEPA 1985.

THE ST. MARYS RIVER

Background

The St. Marys River is the 112-km long waterway which drains Lake Superior into Lake Huron (Fig. 1). The river falls 0.1 m in 23 km from Lake Superior to the St. Marys Rapids, 6.0 m in the rapids, and 0.7 m in the remaining 87 km from the rapids to Lake Huron. The river above the rapids is essentially an extended embayment of Lake Superior. Below the rapids the river channel divides, irregularly widens, and contains several large islands. Portions of the river bed have been permanently modified by the dredging of navigation channels and construction of locks to permit the passage of large commercial vessels between lakes Superior and Huron. River discharge has been controlled by compensating gates at the rapids since 1921 to facilitate vessel passage. These gates also direct about 95 percent of the flow of the river through three hydro-electric power stations located in the rapids area.

The St. Marys River is an industrial and municipal water supply for the cities of Sault Ste. Marie, Michigan and Ontario. Water entering the river from Lake Superior is of exceptionally high quality and water and sediment quality are good throughout the river except along the Ontario shoreline from Sault Ste. Marie downstream into Lake George, where discharges from steel and paper mills pollute the river. River sediments are also contaminated along the Michigan shoreline immediately above the rapids near a site once occupied by a tannery.

Prior to European settlement of the area the river and the rapids in particular supported a productive fishery by native peoples. Lake whitefish

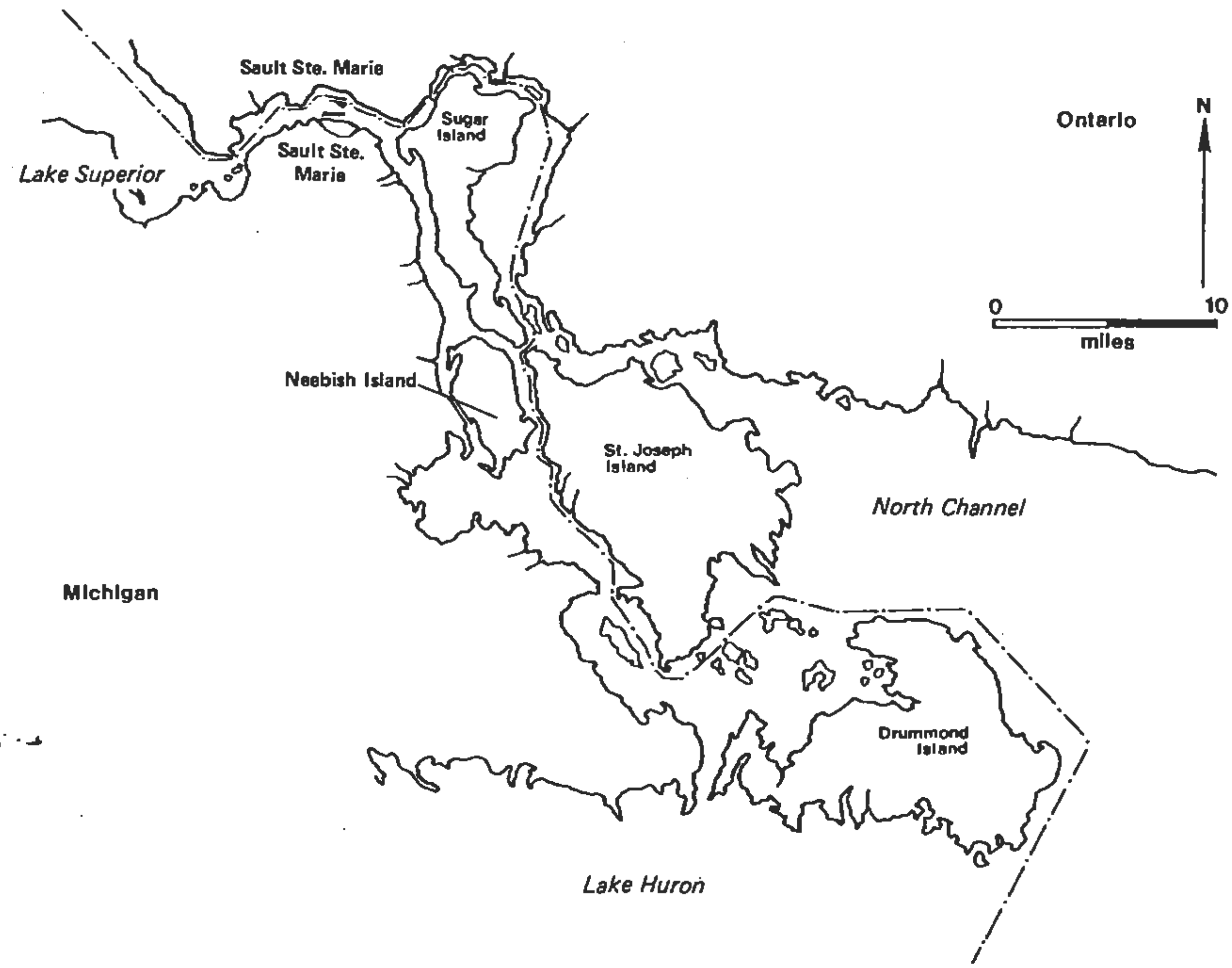


Figure 1. The St. Marys River.

and lake sturgeon were the principal catch. Angler harvest in the U.S. waters of the river in 1986 was: pink salmon, 5,699; coho salmon, 136; chinook salmon, 4,662; rainbow trout, 1,990; brown trout, 538; lake herring, 141,386; lake trout, 203; whitefish, 25,187; northern pike, 20,965; yellow perch, 316,436; and walleye, 25,602 (Anon. 1987). Presently the river supports a recreational fishery valued at more than 1.25 million dollars annually (Koshinsky and Edwards 1983), as well as a limited, Treaty-right, subsistence fishery conducted by the Sault Band of the Chippewa Tribe.

The St. Marys River ecosystem was studied little until the late 1970's, when concern over a proposed extension of the navigation season throughout the winter months focused attention on the river. This resulted in a significant research effort which extended into the mid-1980's and produced baseline environmental data and information on the effects of vessel passage during the winter when normally there is heavy ice cover. A limited literature related to water quality in the river extends back to the 1940's.

The Fish Community

Species Composition

The river supports a relatively diverse fish fauna composed of 75 species in 22 families (Table 1). This fauna compares favorably with those of Lake Superior (73 species and 18 families) and Lake Huron (99 species and 21 families), with which it is contiguous (Duffy et al. 1987; Christie 1974; Lawrie 1978).

Table 1. Fishes identified from the St. Marys River (compiled from various sources by Duffy et al. 1987).

Scientific name	Common name
PETROMYZONTIDAE	
Petromyzon marinus	Sea lamprey
Lampetra lamottei	American brook lamprey
ACIPENSERIDAE	
Acipenser fulvescens	Lake sturgeon
LEPISOSTEIDAE	
Lepisosteus osseus	Longnose gar
AMIIDAE	
Amia calva	Bowfin
CLUPEIDAE	
Alosa pseudoharengus	Alewife
Dorosoma cepedianum	Gizzard shad
SALMONIDAE	
Coregonus artedii	Lake herring
Coregonus clupeaformis	Lake whitefish
Prosopium cylindraceum	Round whitefish
Salmo gairdneri	Rainbow trout
Salmo trutta	Brown trout
Salmo salar	Atlantic salmon
Salvelinus fontinalis	Brook trout
Salvelinus namaycush	Lake trout
Salvelinus fontinalis x *namaycush*	Splake
Oncorhynchus gorbuscha	Pink salmon
Oncorhynchus kisutch	Coho salmon
Oncorhynchus tshawytscha	Chinook salmon
OSMERIDAE	
Osmerus mordax	Rainbow smelt
UMBRIDAE	
Umbra limi	Central mudminnow
ESOCIDAE	
Esox lucius	Northern pike
Esox masquinongy	Muskellunge
CYPRINIDAE	
Carassius auratus	Goldfish
Couesius plumbeus	Lake chub
Cyprinus carpio	Carp
Hybopsis storeriana	Silver chub
Nocomis micropogon	River chub
Notemigonus crysoleucas	Golden shiner
Notropis atherinoides	Emerald shiner
Notropis cornutus	Common shiner

Continued

Table 1. (Continued).

Scientific name	Common name
Notropis heterodon	Blackchin shiner
Notropis heterolepis	Blacknose shiner
Notropis hudsonius	Spottail shiner
Notropis stramineus	Sand shiner
Notropis volucellus	Mimic shiner
Phoxinus eos	Northern redbelly dace
Pimephales notatus	Bluntnose minnow
Pimephales promelas	Fathead minnow
Rhinichthys atratulus	Blacknose dace
Rhinichthys cataractae	Longnose dace
Semotilus atromaculatus	Creek chub
CATOSTOMIDAE	
Catostomus catostomus	Longnose sucker
Catostomus commersoni	White sucker
Moxostoma anisuram	Silver redhorse
Moxostoma erythrurum	Golden redhorse
Moxostoma macrolepidotum	Shorthead redhorse
ICTALURIDAE	
Ictalurus nebulosus	Brown bullhead
Ictalurus punctatus	Channel catfish
ANGUILLIDAE	
Anguilla rostrata	American eel
CYPRINODONTIDAE	
Fundulus diaphanus	Banded killifish
Gadidae	
Lota lota	Burbot
GASTEROSTEIDAE	
Culea inconstans	Brook stickleback
Gasterosteus aculeatus	Threespine stickleback
Pungitius pungitius	Ninespine stickleback
PERCOPSIDAE	
Percopsis omiscomaycus	Trout-perch
PERCICHTHYIDAE	
Morone chrysops	White bass
CENTRARCHIDAE	
Ambloplites rupestris	Rock bass
Lepomis gibbosus	Pumpkinseed
Lepomis macrochirus	Bluegill
Micropterus dolomieui	Smallmouth bass
Micropterus salmoides	Largemouth bass
Pomoxis nigromaculatus	Black crappie

Continued

Table 1. (Continued).

Scientific name	Common name
PERCIDAE	
Etheostoma exile	Iowa darter
Etheostoma nigrum	Johnny darter
Perca flavescens	Yellow perch
Perca caprodes	Logperch
Stizostedion canadense	Sauger
Stizostedion vitreum vitreum	Walleye
SCIAENIDAE	
Aplodinotus grunniens	Freshwater drum
COTTIDAE	
Cottus bairdi	Mottled sculpin
Cottus cognatus	Slimy sculpin
Cottus ricei	Spoonhead sculpin
Myoxocephalus quadricornis	Fourhorn sculpin

Fish Distribution and Habitat Use

Fish are distributed widely throughout the river in four habitats that can be readily defined in physical terms. These primary fish habitats are (1) open-water areas, including the navigation channel, other deep waters; (2) littoral waters, some of which are colonized by emergent plants; (3) emergent wetlands that typically occur in the more sheltered embayments and along other protected shorelines; (4) the St. Marys Rapids; and (5) tributaries to the river (Duffy et al. 1987). Each of these habitats supports an assemblage of fishes which distinguishes it from the other habitats, even though the composition of these assemblages changes seasonally as the various species move about in an attempt to meet their life history requirements.

Open-water - The fish community of this habitat is dominated by demersal species, but two pelagic species, lake herring and rainbow smelt, are numerically abundant in this habitat. Trout-perch, johnny darter, and spottail shiner are the most abundant smaller fish throughout the river. Yellow perch are the most common juvenile fish in open-water habitats. The larger fishes that are abundant throughout the open waters of the river include rainbow smelt, yellow perch, white sucker, and northern pike. Lake whitefish is one of the more abundant large fish in the upper river and lake herring, smallmouth bass, and walleye are abundant large species in the lower river open-water habitat. Lake sturgeon use the deeper portions of the open-water habitat.

Littoral - Juvenile walleye and minnows are common in the shallow areas along the shoreline.

The St. Marys Rapids - The fish community of this habitat is composed of more than 38 species (Koshinsky and Edwards 1983). Longnose dace and slimy sculpin are the most abundant forage species. Anglers catch lake whitefish, rainbow trout, brown trout, lake trout, brook trout, walleye, and chinook salmon in the rapids. The sea lamprey and white and longnose suckers are also seasonally abundant.

Emergent wetland - This habitat supports mainly minnows, juvenile life stages of other species, centrarchids, and periodic use by larger fish (Liston et al. 1983, 1986).

Tributary - The tributaries provide spawning habitat for rainbow smelt, walleye, burbot, trout, and salmon species of fish that are important components of the fish community of the river.

Many of the fishes inhabiting the river undertake seasonal movements from one area to another. For some species these movements only amount to a dispersal into adjoining areas, or from one primary habitat to another, while other species make more extensive movements that take them out the river and into tributaries or lakes Superior or Huron. These movements, which usually also include a return component, are associated with feeding, spawning, or a search for a more favorable thermal regime. Sedentary, year-round resident species including white sucker, yellow perch, rock bass, smallmouth bass, and brown bullhead show only limited movement associated with feeding. Northern pike are also sedentary during most of the year, moving greater distances during the spring spawning period, but also occasionally undertaking extensive, apparently random movements.

Walleye that spawn in Munuscong Lake undertake an extensive seasonal migration within the river, including a pre-spawning movement to Lake Munuscong, followed by a post-spawning dispersal (Liston et al. 1986). Adult walleye sometimes also move in large numbers into emergent wetlands at night to feed.

Lake herring inhabit the river during most of the year and exhibit two types of movement, one associated with feeding and another in response to water temperature (Duffy and Liston 1981). In October and November when water temperature nears 4-5°C lake herring move from Lake Huron and probably the North Channel into the river to spawn. Following spawning, fish remain in the river until late June or early July. At this time, water temperatures usually approached the upper limit tolerated by lake herring, and the fish move from the river to deeper, cooler areas. In years when dispersal from these shallower habitats precedes the mass emergence of burrowing mayflies, lake herring return for several weeks to feed on the mayflies, and then again disperse. Lake whitefish have temperature requirements similar to those of lake herring and may also undertake a summer migration into thermal refugia, although this has not been well documented.

Other fish undertaking seasonal movements or migration in the St. Marys River are chinook salmon and pink salmon which enter the river from Lake Huron in late summer and fall. Pink salmon spawn in most of the tributaries to the St. Marys River, and chinook salmon spawn in the St. Marys Rapids.

Rainbow smelt move into the river from Lake Huron in spring to spawn when water temperatures are 4-5°C and food habit studies of piscivorous fish suggest that low numbers of rainbow smelt remain in the river through summer.

Spawning and Nursery Areas

The St. Marys River is used extensively as spawning and nursery habitat by native and introduced species of fish. Virtually all of the fishes reported from the river probably spawn in the river proper or its tributaries or both and also use the river as a nursery area. Goodyear et al. (1982) compiled information on spawning and nursery areas for the St. Marys River (Fig. 2), and although much of the information presented in the report was anecdotal, the findings are generally supported by field studies that have been conducted in recent years (Liston et al. 1980, 1981, 1983, 1986; Gleason et al. 1981; Duffy 1985; Jude et al. 1986).

Many St. Marys River fishes, including rainbow smelt, trout, salmon, lake herring, whitefish, white sucker, longnose sucker, silver redhorse, shorthead redhorse, walleye, trout-perch, and several species of cyprinids spawn over or on exposed rock, gravel, or rubble in well-oxygenated water in open-water habitats, in the St. Marys Rapids, or in tributaries.

Emergent wetlands are also used extensively as spawning habitat by some of the more important fish species of the St. Marys River, such as northern pike, yellow perch, and smallmouth bass. Northern pike and central mudminnows, which spawn in wetlands very near the water's edge, have adhesive eggs that attach to live or dead vegetation; their larvae are also adapted to low-oxygen conditions, which may occur where decomposing aquatic macrophytes cover the river bottom. Yellow perch drape their egg masses over vegetation, thus avoiding anoxic conditions that may occur on the bottom. Other species that spawn in wetlands including brown bullhead, sculpins, and centrarchids, spawn in nests or cavities which are swept clean of organic debris and oxygenated by the movements of the parent fish.

Most of the St. Marys River is a nursery area for fishes. Duffy et al. (1987) documented the presence of fish larvae of 39 species, including those

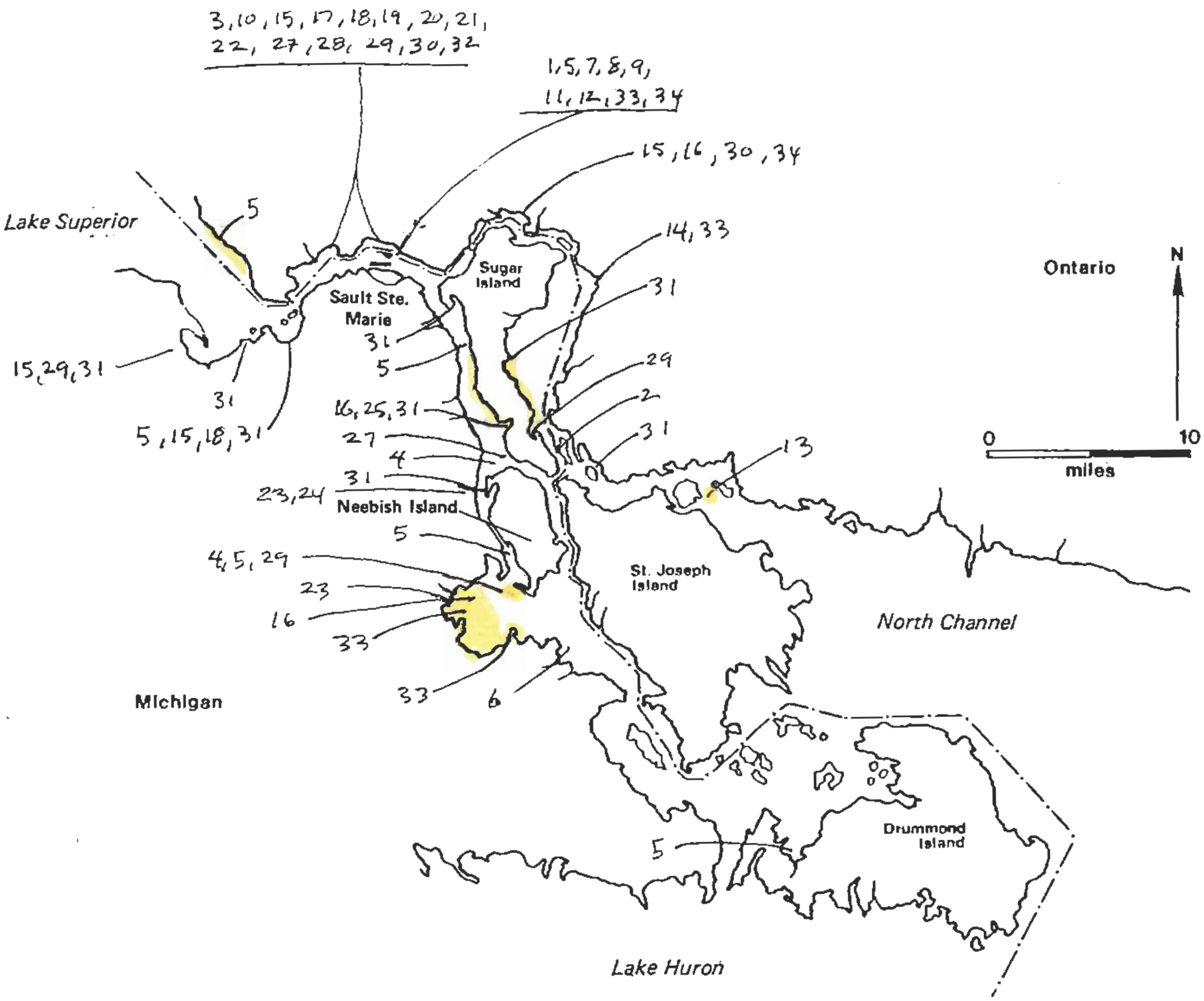


Figure 2. Fish spawning areas in the St. Marys River (Source: Goodyear et al. 1982).

1. Sea lamprey
2. Lake sturgeon
3. Alewife
4. Lake herring
5. Lake whitefish
6. Coregonus spp.
7. Pink salmon
8. Coho salmon
9. Chinook salmon
10. Round whitefish
11. Rainbow trout
12. Brook trout
13. Lake trout[a/]
14. Rainbow smelt
15. Northern pike
16. Common carp
17. Emerald shiner
18. Spottail shiner
19. Mimic shiner
20. Northern red belly dace
21. Longnose sucker
22. White sucker
23. Silver redhorse
24. Shorthead redhorse
25. Brown bullhead
26. Trout perch
27. Burbot
28. Rock bass
29. Smallmouth bass
30. Johnny darter
31. Yellow perch
32. Log perch
33. Walleye
34. Slimy sculpin

a/ Rocky shores of river.

that were permanent residents of the river, those that migrated into the river to spawn in the river proper or its tributaries, and others that drifted into the river from Whitefish Bay, Lake Superior (Table 2). Species that spawn in tributaries and drift downstream to the St. Marys River, such as rainbow smelt, white sucker, and burbot, are usually more abundant in offshore habitats than along the shore. Larvae of fishes that spawn in emergent wetlands, including cyprinids, bluegill, yellow perch, northern pike, bowfin, longnose gar, and brown bullhead generally are much more abundant near this habitat than elsewhere in the river.

A marked seasonal succession of fish larvae is apparent and can be related to the thermal requirements of the various species for reproduction (Table 3). In early spring immediately after ice cover disappears, only the larvae of lake herring, lake whitefish, burbot, and fourhorn sculpin, which spawn in fall-winter, are present. In May and early June, larvae of spring-spawning species, such as rainbow smelt, yellow perch, and white sucker, become abundant and from late June through early September larvae of cyprinids, centrarchids, clupeids and other warmwater species dominate.

Effects of Altered Water Levels

Effects on Fish Habitat

The effects of water level changes in Lake Superior on the portion of the St. Marys River above the water level control structures (the locks) at Sault Ste. Marie are estimated from NOAA-NOS chart No. 14884 (33 Ed. February 26, 1983) for Whitefish Bay and the St. Marys River.

Table 2. Fish larvae collected in the St. Marys River (Source: Liston et al. 1980, 1981, 1986; Ashton, unpubl. data).

Brook lamprey	Brown bullhead
Sea lamprey	Banded killifish
Bowfin	Burbot
Alewife	Ninespine stickleback
Lake herring	Trout-perch
Lake whitefish	Rockbass
Pink salmon	Bluegill
Rainbow smelt	Pumpkinseed
Central mudminnow	Unidentified sunfish
Northern pike	Smallmouth bass
Carp	Freshwater drum
Golden shiner	Johnny darter
Common shiner	Unidentified darter
Emerald shiner	Yellow perch
Mimic shiner	Logperch
Spottail shiner	Unidentified darter
Unidentified shiner	Walleye
Unidentified minnow	Unidentified sculpin
White sucker	Fourhorn sculpin
Unidentified redhorse	

Table 3. Seasonal occurrence of larval fish in the St. Marys River. (Source: Duffy et al. 1987).

	April	May	June	July	August	September
Lake whitefish	---	---				
Lake herring	---	---	---	---		
Burbot	---	---	---	---		
Northern pike	---	---				
Fourhorn sculpin	---	---				
Central mudminnow		---	---			
Rainbow smelt		---	---	---	---	
Yellow perch			---	---	---	
Trout-perch		---	---	---	---	---
Walleye		---	---	---	---	
Cottus sp.			---	---	---	
Cyprinidae			---	---	---	---
Johnny darter			---	---	---	
Logperch			---	---	---	
Percidae			---	---	---	
Etheostoma sp.			---	---		
Ninespine stickleback			---	---	---	
White sucker			---	---		
Moxostoma sp.			---	---		
Rock bass			---	---	---	
Catostomidae				---		
Lepomis sp.				---	---	
Carp				---	---	
Alewife					---	

The water level scenario being considered is one in which the level of Lake Superior is raised or lowered 1 m from the 1900-1986 monthly mean level reported by the U.S. Army Corps of Engineers (USACE 1989). The effect of raising or lowering the lake level 1 m would be superimposed on the existing seasonal range, which is at the minimum in March and at the maximum in September.

The upper river falls about 0.1 m in the reach between Lake Superior and the locks (USDC-NOAA 1982) and an increase in lake level of 1 m at the locks would cause roughly a 1 m elevation of water levels throughout the entire upper river.

Waiska Bay and Chene Island - The most obvious inundation of shoreline would occur at the head of Waiska Bay (Fig. 3). A lowering of the lake level of 1 m at the locks would dewater a portion of Waiska Bay and a substantial portion of the shoal between Gros Cap and Pointe Aux Chenes (Fig. 3).

Waiska Bay is a spawning area for northern pike, smallmouth bass, and yellow perch (Fig. 3). An elevated lake level would benefit northern pike and yellow perch, which spawn in emergent wetlands on submersed vegetation, by providing more extensive spawning and nursery areas; smallmouth bass which spawn on rocky shallows would also probably benefit from an elevated lake level. A lowered lake level would dewater northern pike, yellow perch, and smallmouth bass spawning habitat. Lake whitefish spawning on the shoal between Gros Cap and Pointe Aux Chenes would probably not be greatly affected by an elevated lake level, but a lowered level would dewater an extensive portion of the shoal. Shoal areas such as this also are often important nursery habitat for whitefish larvae.

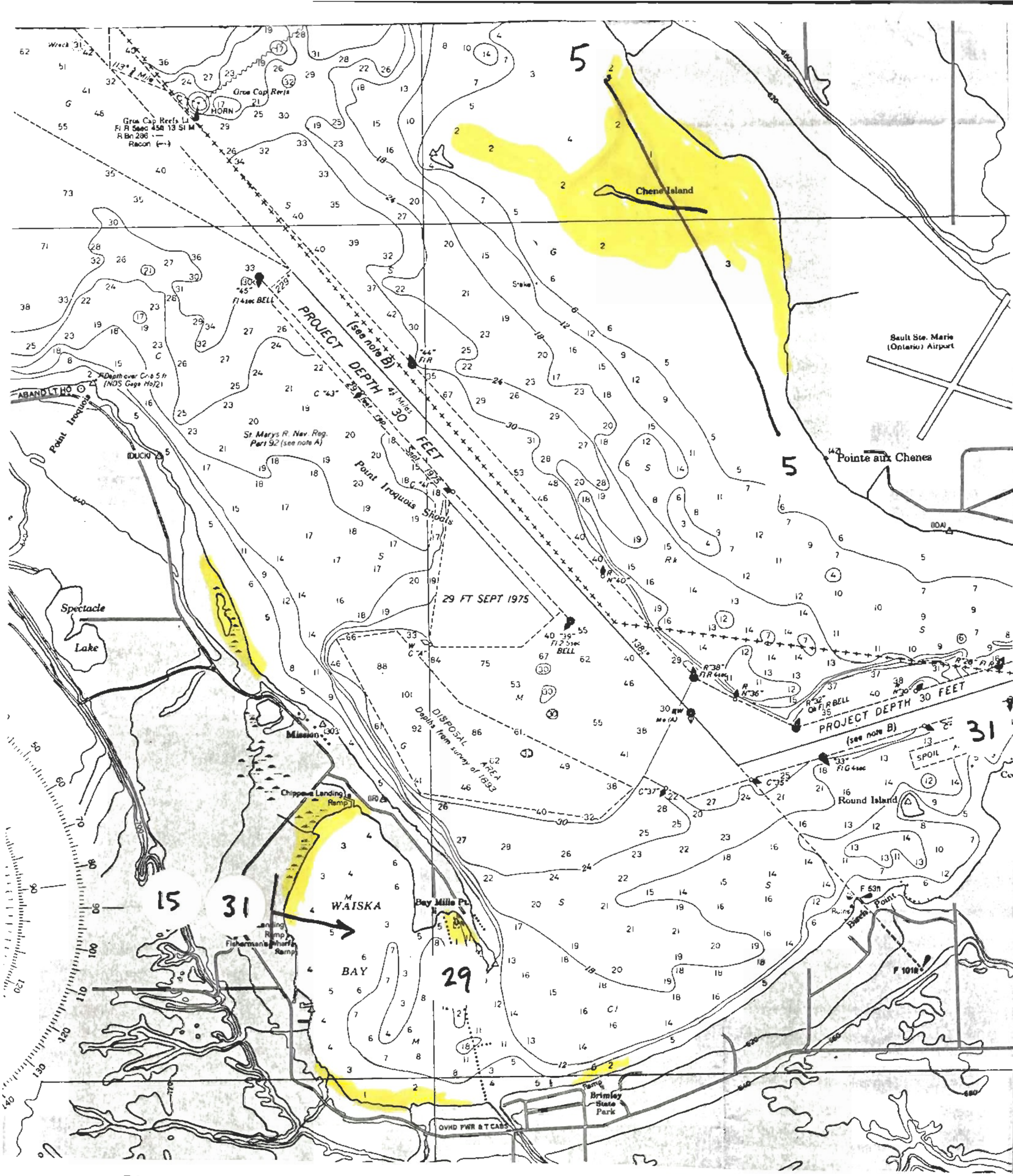


Figure 3. Fish habitat (blackened areas) potentially affected by water level alterations in the St. Marys River--upper river. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 2.

The effects of water level changes in Lake Huron on the portion of the St. Marys River below the water level control structures at Sault Ste. Marie are estimated from NOAA-NOS chart 14883 (35th Ed., December 13, 1980) for the St. Marys River.

The water level scenario being considered is one in which the level of Lake Huron is raised or lowered 1 m from the 1900-1986 monthly mean level reported by the U.S. Army Corps of Engineers (USACE 1989). The effect would be superimposed on the seasonal range of levels which averages about 0.3 m, with a minimum in February and a maximum in July.

The lower river falls 6.1 m in the rapids and 0.6 m in the reach between the foot of the rapids and Lake Huron (USDC-NOAA 1982). Because of the low fall (0.7 m) in the river below the rapids, the effects of raising or lowering the level of Lake Huron by 1 m should extend to the foot of the rapids.

St. Marys Rapids - A 1 m change in the elevation of Lake Huron might be registered by a slight change in river level and flow at the foot of the rapids, but no significant affect on fish habitat in the rapids is anticipated.

Lake George Channel and Little Lake George - Limited flooding or dewatering of littoral areas along the north shore of Sugar Island, in the wetlands in Little Lake George and adjacent to Squirrel Island would occur under the ±1 m scenario (Fig. 4).

Northern pike and common carp spawning and nursery habitat would be improved by elevated water levels and dewatered by lowered levels; johnny darter and slimy sculpin spawning and nursery habitat would also be dewatered by lowered levels.

Lake George - The lake has substantial, shallow, littoral areas and emergent wetlands that could be inundated or dewatered by changes of ±1 m in

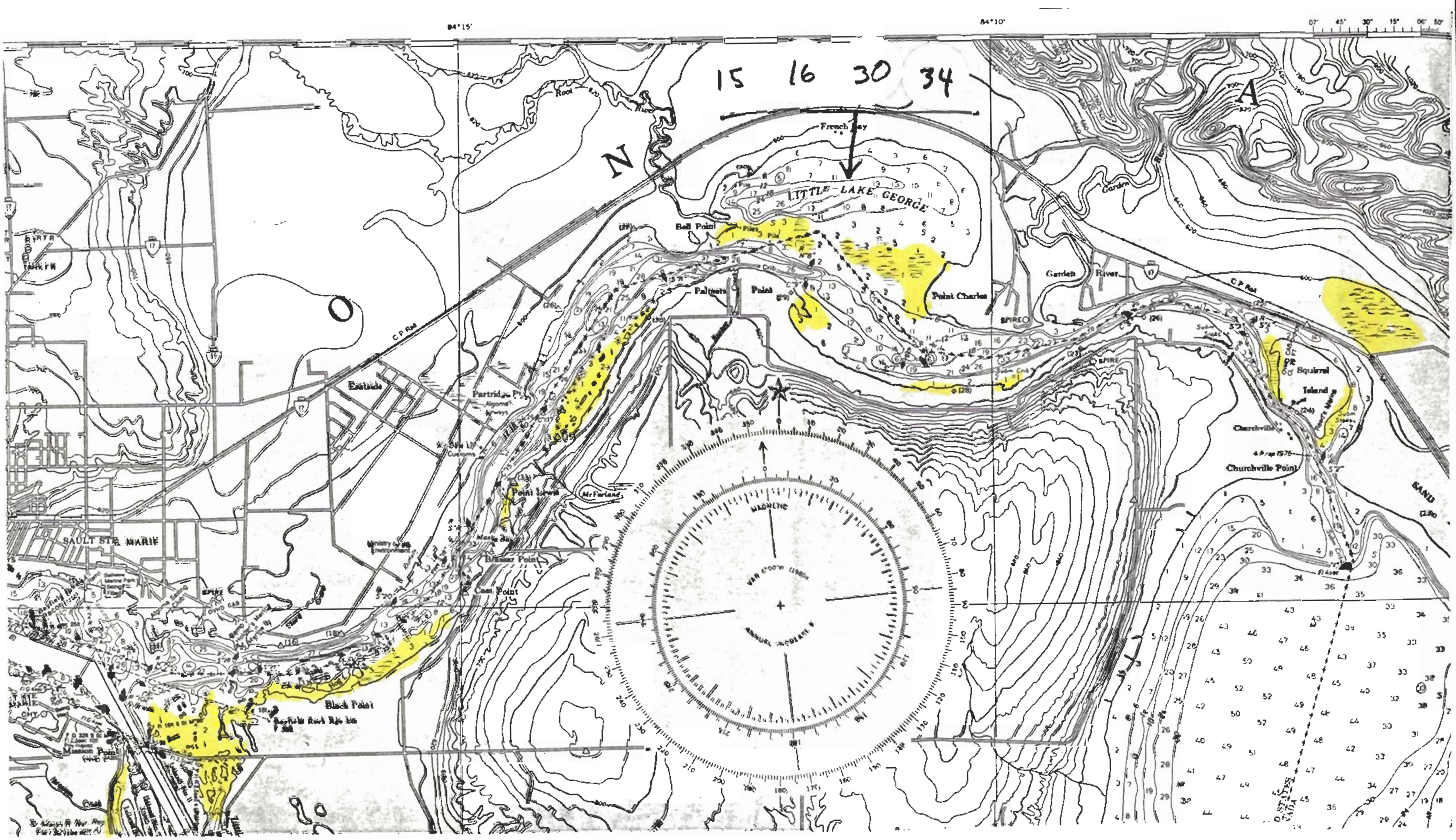


Figure 4. Fish habitat (blackened areas) potentially affected by water level alterations in the St. Marys River--Lake George Channel and Little Lake George. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 2.

the level of Lake Huron (Fig. 5). The broad shoals at the south end of the lake might become emergent wetlands if the lake level fell sufficiently.

Echo Bay, Echo River or both are an important walleye spawning and nursery areas. Elevated water levels would probably not benefit spawning or nursery habitat, but lowered levels would dewater spawning areas in and near the mouth of the river. Yellow perch spawn from Whipple Point to Advance Island. Elevated water levels would improve spawning success and lowered levels would have the opposite effect.

Smallmouth bass spawning in Duck Lake would be improved by elevated water levels; at lowered water levels the entire embayment (lake) would be dewatered and spawning would be prevented.

St. Joseph Channel - Little change would occur in the size of the watered area because the bathymetry and topography are steeply sloping.

Lake Nicolet - At water level changes of ±1 m flooding and dewatering would occur in Baie de Wasai at the north end of the lake and in the south half of the lake along the west shoreline and in Shingle Bay on the east shoreline (Fig. 6).

Yellow perch spawn in Baie de Wasai and Shingle Bay; common carp and brown bullhead also spawn in Shingle Bay; and lake whitefish spawn along the east shoreline from Baie de Wasai to Shingle Bay. Lake herring spawn on shoals at the head of Neebish Island and burbot spawn on the southwest corner of Sugar Island. Elevated water levels would improve spawning conditions for yellow perch, common carp, and brown bullhead which spawn in emergent wetlands, whereas lowered lake levels would reduce the amount of spawning habitat available to three species. Lowered levels would also reduce the amount of spawning and nursery habitat available to lake whitefish and lake herring.

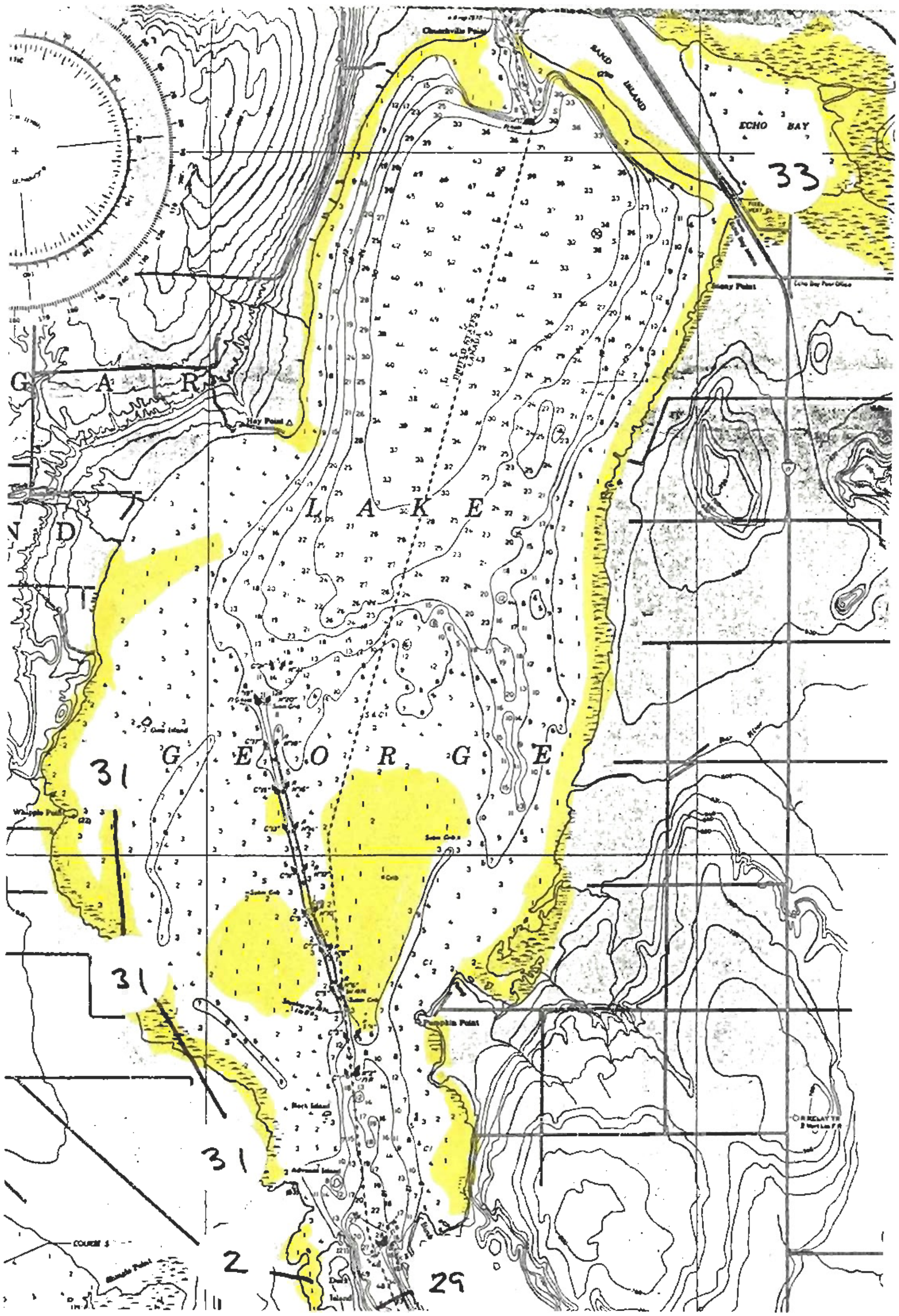


Figure 5. Fish habitat (blackened areas) potentially affected by water level alterations in the St. Marys River--Lake George. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 2.

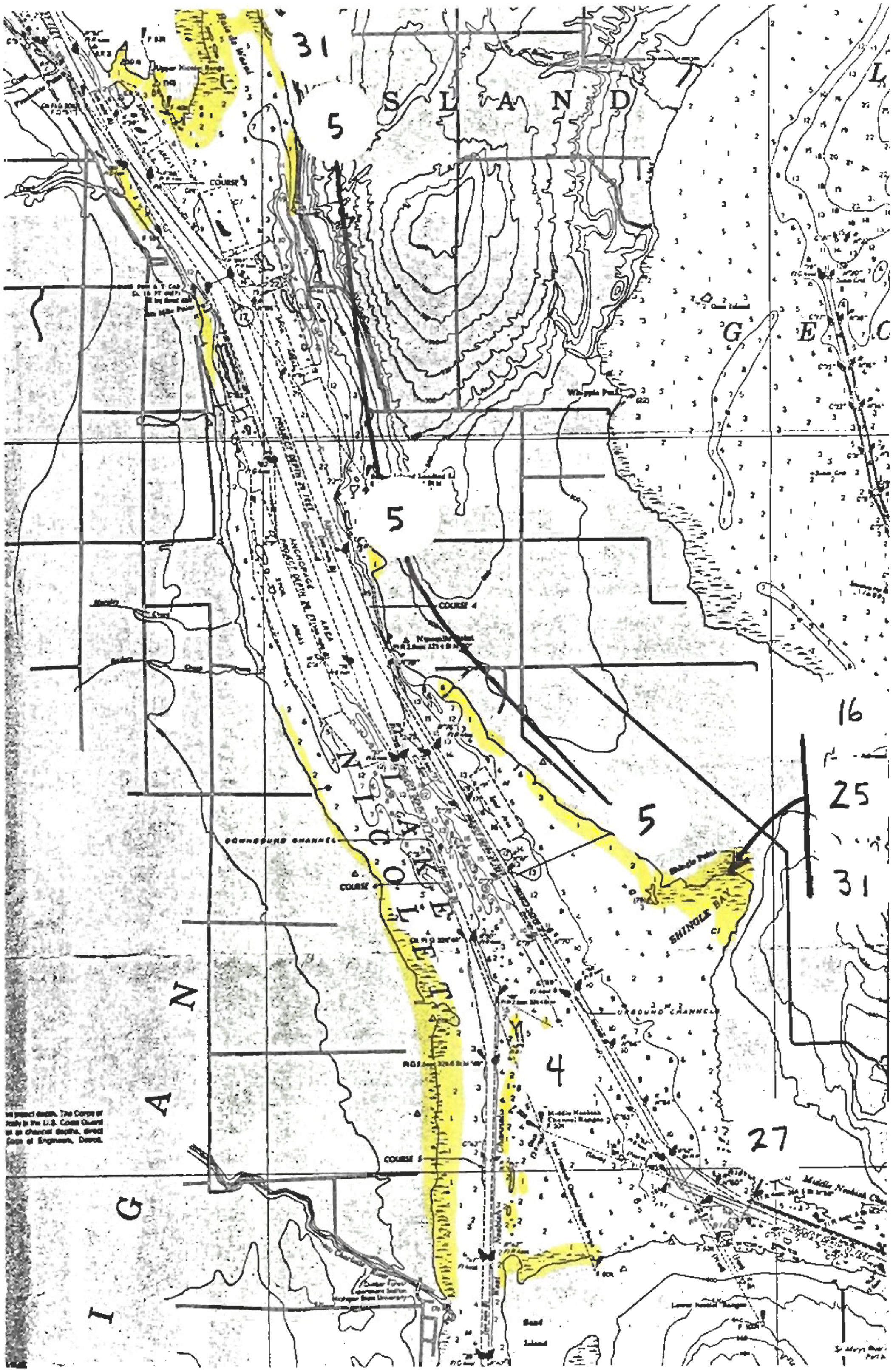


Figure 6. Fish habitat (blackened areas) potentially affected by water level alterations in the St. Marys River--Lake Nicolet. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 2.

Neebish Island Channels - Steep topography and bathymetry in this portion of the river would limit effects mainly to Sand Bay, which would be dewatered at the lower lake level (Fig. 7).

Sand Bay is a spawning area for brown bullhead and yellow perch. Elevated lake levels would benefit both species and lowered lake levels would eliminate almost all of the spawning habitat in the bay.

Munuscong Lake - Substantial flooding or dewatering would occur along the north, west, and south shorelines where topography and bathymetry are gently sloping (Fig. 8). As much as 10-20 percent of the lakebed could be dewatered at lowered levels and offshore emergent plant beds would be eliminated at elevated lake levels.

Munuscong Lake is perhaps the principal spawning and nursery area for walleye in the St. Marys River. Lake herring, lake whitefish, carp, and smallmouth bass also spawn in the lake. Higher water levels would probably benefit nursery habitat for all species, whereas lower levels would dewater portions of this habitat.

Effects on the Food Web

Although the preceding section focuses primarily on fish spawning and nursery areas that would be affected by alterations in water level, it should be recognized that water level effects on the food web can also substantially affect the fish production in the Great Lakes connecting channels. Most of the littoral and emergent wetland habitat in the river including those areas not known to be spawning or nursery areas may be important feeding and resting

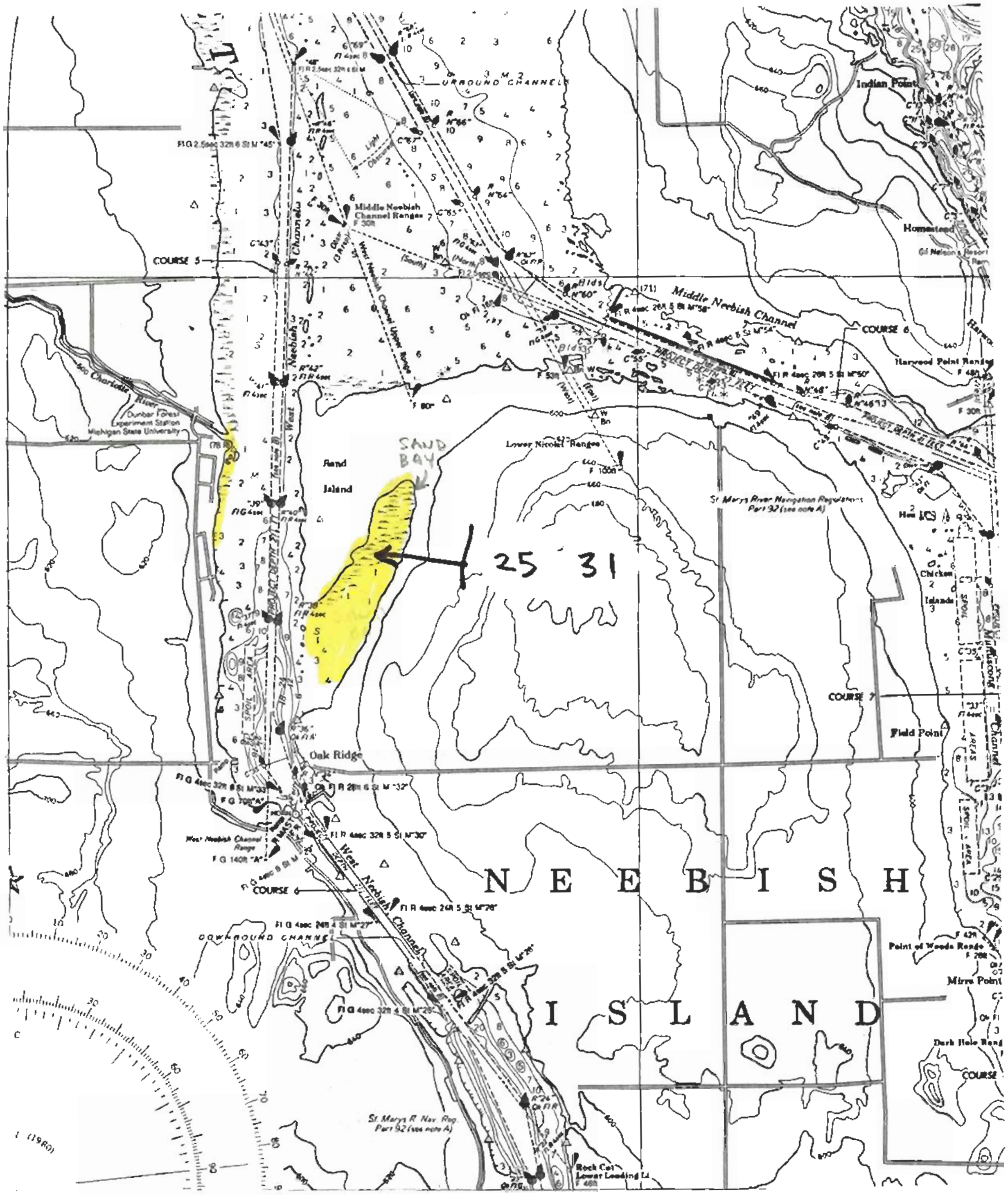


Figure 7. Fish habitat (blackened areas) potentially affected by water level alterations in the St. Marys River--Neebish Island Channels. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 2.

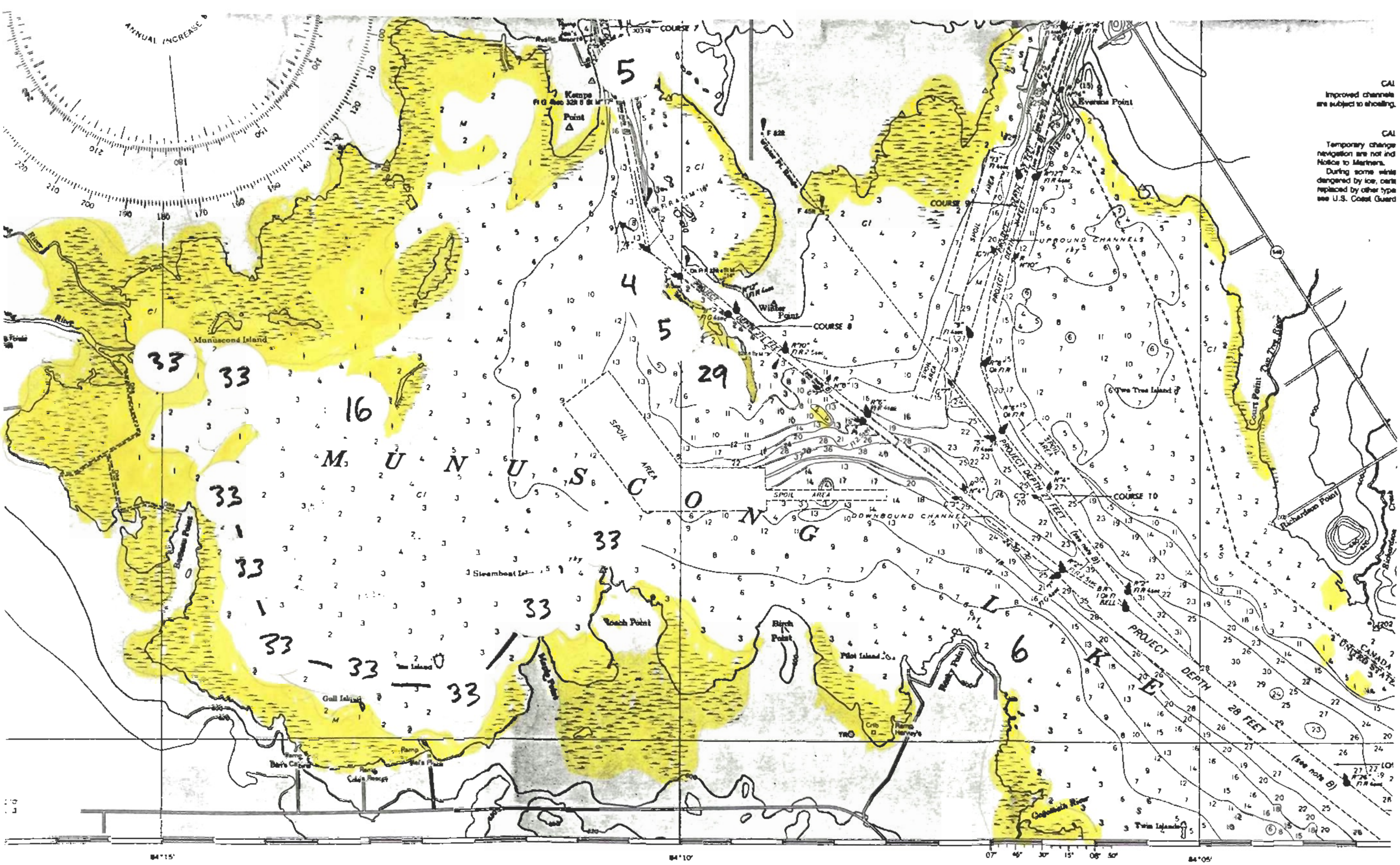


Figure 8. Fish habitat (blackened areas) potentially affected by water level alterations in the St. Marys River--Munuscong Lake. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 2.

areas for many fishes and perhaps also the sites of primary production that provide most of the material and energy that drive the ecosystem. Estimates of the relative contribution of phytoplankton and submersed and emergent plant communities to production in the St. Marys River (Table 4) indicates aquatic macrophytes are probably the most important components in the river. Submersed and emergent macrophytes enter the food web in a minor way as living or fresh plant material that is grazed by aquatic invertebrates, but their major contribution as food for higher organisms is through the detrital food web. The river is pulsed with this detritus annually in May and June providing peak food availability for benthic invertebrates and zooplankton (Table 5) that support fish production (Duffy et al. 1987). Initially this detritus is concentrated in emergent wetlands and in submersed plant beds along the bottom in deeper water. Most of it is mineralized *in situ* and contributes to production locally, but eventually a portion is dispersed to downstream areas by current and wave action.

Elevated water levels would inundate many of the emergent wetlands of the river and probably force them to become reestablished inshore in shallower water and in areas that were formerly terrestrial habitat. This translocation away from the navigation channel and other deep areas with swift current would probably increase nutrient spiralling (Webster 1975) and fish production. Lowered water levels would generally exert the opposite effect.

Effects on Existing Use - Conflicts

Navigation -- Commercial navigation exerts a major influence on the St. Marys River (Duffy et al. 1987). Extensive modifications of the river,

Table 4. Annual net primary productivity in the Lake Nicolet reach of the St. Marys River (Source: Duffy et al. 1987)[a].

Community type	Hectares occupied	g AFDW/m²/yr.	Metric tons AFDW/yr.
Phytoplankton	3,958	5	198
Submersed macrophytes[b]	2,100	35	735
Emergent wetlands	298		
Shoots		650	1,940
Periphyton		12	36
Rootstocks		930	2,770

a/ Ash-free dry weight (AFDW).
b/ Periphyton of submersed macrophytes not included: hence, submersed wetland productivity under estimated by an amount due to periphyton. Submersed plants have little periphyton except during decomposition in summer.

Table 5. Annual secondary production in Lake Nicolet (Source: Duffy et al. 1987).

Organism group	Habitat type	Hectares occupied	Organic weight g dry wt /m²/yr.	Metric tons organic wt/yr
Benthos	Open-water (soft bottom)	2,647	14.46	382.39
Benthos	Emergent wetland	298	24.68	73.55
Zooplankton	Emergent wetland	298	0.56	1.67

including construction of lock and flow-control structures and dredging of navigation channels have physically and hydrologically altered the river; the hydrologic regime is also temporarily, but significantly altered by the passage of each large commercial vessel.

Collectively, these navigation-related developments and activities have impeded fish movement between the upper and lower river, altered fish habitat, and changed the food web by altering materials and energy transport and biological production in the river.

In the upper river, an elevation of Lake Superior of 1 m would probably not greatly exacerbate navigation-related effects on fish or fish habitat, except perhaps by increasing shoreline erosion and turbidity. Elevated turbidity might adversely effect reproductive success of fish by reducing egg survival. Increased turbidity could also reduce the growth of submersed aquatic plants and limit their distribution to shallow water, as it does in Munuscong Lake in the lower river; this would reduce primary production and ultimately fish production.

Lowering the level of Lake Superior by 1 m would probably increase the degree and frequency of dewatering of emergent wetlands and also the broad littoral shelf between Gros Cap and Pointe Aux Chenes that is adjacent to lake whitefish spawning grounds in this river reach and that probably serves as a nursery area for lake whitefish.

Laboratory studies (Holland 1987) have shown that larvae of northern pike and walleye which frequent wetlands were killed by temporary dewaterings that simulated the draw-down effects of vessel passage (Wuebben 1979) on wetland habitat; similar mortality could be expected for lake whitefish larvae exposed to vessel-induced dewatering of nursery habitat.

In the river below the rapids, lowered water levels would perhaps require additional navigation-related channel dredging, thus increasing the portion of the total flow of the river that passed through the channel and further reducing the portion that remained in the emergent wetlands and other habitats outside the navigation channel proper.

A reduction in the depth of water in areas adjacent to the navigation channel would increase the probability that sediment-lift (explosive liquifaction) would occur there when vessels traverse the channel during the period of solid ice cover. Sediment lift (Alger 1979) causes resuspension of lakebed sediments and increased turbidity, which can contribute to the smothering of eggs of fall- and winter-spawning fish in downstream areas. Sediment-lift can also force fish eggs into the water column, where the sudden, strong surge-and-drawdown currents associated with vessel passage during the period of solid ice cover, can sweep them into the navigation channel where they will be rapidly transported to locations unlike those selected for egg deposition by the parent fish. Sediment-lift and surge-and-drawdown currents can also alter food webs by translocating benthic invertebrates, rooted macrophytes, and plant detritus more quickly out of the river, thus effectively reducing nutrient spiralling and biological production (Poe et al. 1980; Poe and Edsall 1982; Jude et al. 1986). Significantly increased mortality of the damsel fly (<u>Lestes disjunctus disjunctus</u>) has also been reported as a result of vessel-induced flushing of overwintering emergent plant stems from the wetland habitat (McNabb et al. 1986).

The effects of vessel-induced ice movement on overwintering fish eggs and the biota that contribute to the food web supporting fish production would also be exacerbated at lowered lake levels that reduced the portion of the flow of the river in non-channel habitats.

Changes in water level that reduced macrophyte and invertebrate production by accelerating the movement of detritus out of the emergent wetlands and the open-water, soft bottom habitats that are productive for benthic invertebrates and zooplankton would reduce fish production. The losses in fish production could be manifested through the adult life stage in species like the lake herring that obtains more than 90% of its annual caloric intake from the burrowing mayfly (Hexagenia limbata), an obligate detritivore. This intake occurs in a pulse that is probably used in gonad development (Duffy et al. 1987) and the subsequent production of viable larvae required to sustain a healthy, stable population of lake herring in the river. Fish production losses could also result from a reduced invertebrate food supply that would reduce the potential for growth and survival of larval and juvenile stages of many fishes that occupy nursery habitat in the emergent wetlands and shallower portions of the open-water habitat during the warmer months of the year.

As described in an earlier section of this report, elevated water levels would tend to displace emergent wetlands and submersed plant beds shoreward and away from the areas of higher current velocity where the detritus they produce would be less rapidly entrained and flushed downstream; lowered water levels would probably have the opposite effect, favoring a more rapid loss of materials and energy from the sites of primary production.

Waste Disposal -- Concerns over degraded water quality in the St. Marys River are generally focused on the combined toxic effect of ammonia, cyanide, and heavy metals; oil and grease; phenol levels, which are high downstream from industrial discharges; and PAHs, because of their carcinogenic nature (UGLCCS 1988). Water quality in the river is most severely impacted in a narrow band approximately 500 m wide, extending 3 km along the Canadian shore downstream from industrial discharges. Partial recovery is apparent 5 km downstream from the Algoma Steel and St. Marys Paper discharges, and more complete recovery is evident in the lower section of Lake George, 24 km downstream from these discharges. Clean-water fauna characterizes the relatively non-industrialized U.S. shore, all portions of the river upstream of pollution sources, and in Lake Nicolet.

Contaminant levels in sediments of the St. Marys River exceeded both the Ontario Ministry of the Environment (MOE) and U.S. Environmental Protection Agency (EPA) dredging guidelines (IJC 1982). Parameters of concern are arsenic, cadmium, chromium, cyanide, copper, iron, lead, mercury, nickel, zinc, nutrients, oils and greases, together with chlorinated organics, and PAHs. In general the contaminated sediments are largely confined to the Ontario shore. Levels of trace metals and solvent extractables along the Michigan side of the lower river are well within the MOE and EPA dredging guidelines. The sediments in the river upstream of the industrial complexes are also contaminated. These sediments may not be the final sink for persistent contaminants and major fractions of toxic compounds that are deposited in the sediments may transfer to water, biota, and the atmosphere.

Industrial discharges to the river are the source of most of the toxic contaminants found in the river, but spills and contaminated ground water reaching the river from industry located near the river can also be important. Spills can be a significant source of contamination to the system and constitute a major concern, not only because they increase the total annual loading, but also because they can subject the biota of the river to a suddenly increased or "shock" contaminant loading that may be several orders of magnitude greater than the annual loading (UGLCCS 1988). For example, a shock loading of phenol of about 2,400 tonnes, which is about 7,000 times greater than the normal annual loading of phenol to the river, occurred over a 3-day period in 1983.

Contaminated ground water entering the river is much less conspicuous than a contaminated effluent or spill, but the effects on water and sediment quality may be similar. A study of ground water movement along the river from Whitefish Bay to Neebish Island revealed that potentially serious local impacts of contaminated ground water on the water quality of the St. Marys River are posed by only the Cannelton Industries Tannery site in Michigan and the Algoma Steel Slag Dump in Ontario (UGLCCS 1988). Both sites are located in the upper river. Loadings of contaminants to the river from these sources have not been computed, but studies are underway to better define their impact on the river and remedial action is underway at the Michigan site.

The impacts of waste discharges, spills, and ground water inflow to the St. Marys River have not been analyzed separately, but process modelling has been undertaken to describe the transport and fate of contaminants entering the river from all sources (UGLCCS 1988). Model output describing the effects of elevated or lowered water levels in the upper and lower sections of the river was not available to us at the time this report was prepared. In the absence of model output we speculate that lowered water levels would accelerate downstream dispersal of contaminants, perhaps extending the length of the polluted reach of the river. Lower water levels could result in resuspension of contaminated sediments in deposition areas, thus increasing the loadings to which much of the biota would be exposed. The effect of the resuspension of contaminated sediments on the river's biota is difficult to predict, but the role of contaminated sediments in the loss of burrowing mayfly populations from the rapids downstream into Lake George has been extensively documented (UGLCCS 1988). The available evidence indicates this mayfly has a central role in trophic relations in the river, converting detritus into a food resource that is utilized extensively by lake herring, walleye and other important fishes of the river (Duffy et al. 1987), and that the loss of this benthic detritivore must have adversely affected fish production of key species in the river.

Research is needed to determine how contaminant transport and fate would be affected by an elevation or lowering of the water level in lakes Superior and Huron, and to better demonstrate the effects of existing and altered contaminant regimes on the fish and the food web in the St. Marys River ecosystem.

THE ST. CLAIR RIVER

Background

The St. Clair River is the 64-km long channel that connects Lake Huron to Lake St. Clair (Fig. 9). The upper reach of the river, from Port Huron to Algonac, is a straight channel with narrow, steep shoulders. Two islands are present in this portion of the river. South of Algonac the river forms a broad delta with three main channels, several smaller channels, and several islands.

The average flow of the St. Clair River is 5,095.8 m^3/s (USACE 1984). A navigation channel dredged to a depth of 8.2 m has increased flow and has resulted in a permanent reduction of the Lake Michigan-Huron level by 0.27 m (Derecki 1985). The total fall of the river is 1.5 m, most of which occurs gradually in the upper river. The main tributaries to the river are the Black, Belle, and Pine rivers. These rivers contribute little to the flow of the St. Clair River and most of the water entering the St. Clair River is from relatively oligotrophic Lake Huron.

Although the water entering the river is of high quality, water and sediments in the river are contaminated by effluents from 31 industrial and 13 municipal outfalls (Edsall et al. 1988). Industrial activity is concentrated at the head of the river near the cities of Sarnia and Port Huron in a stretch called "Chemical Valley". Attention to the water quality problems in the river has led to improvements in recent years. Other uses of the river are hydro-electric power generation, navigation, and recreation. The St. Clair River presently supports a valuable recreational fishery.

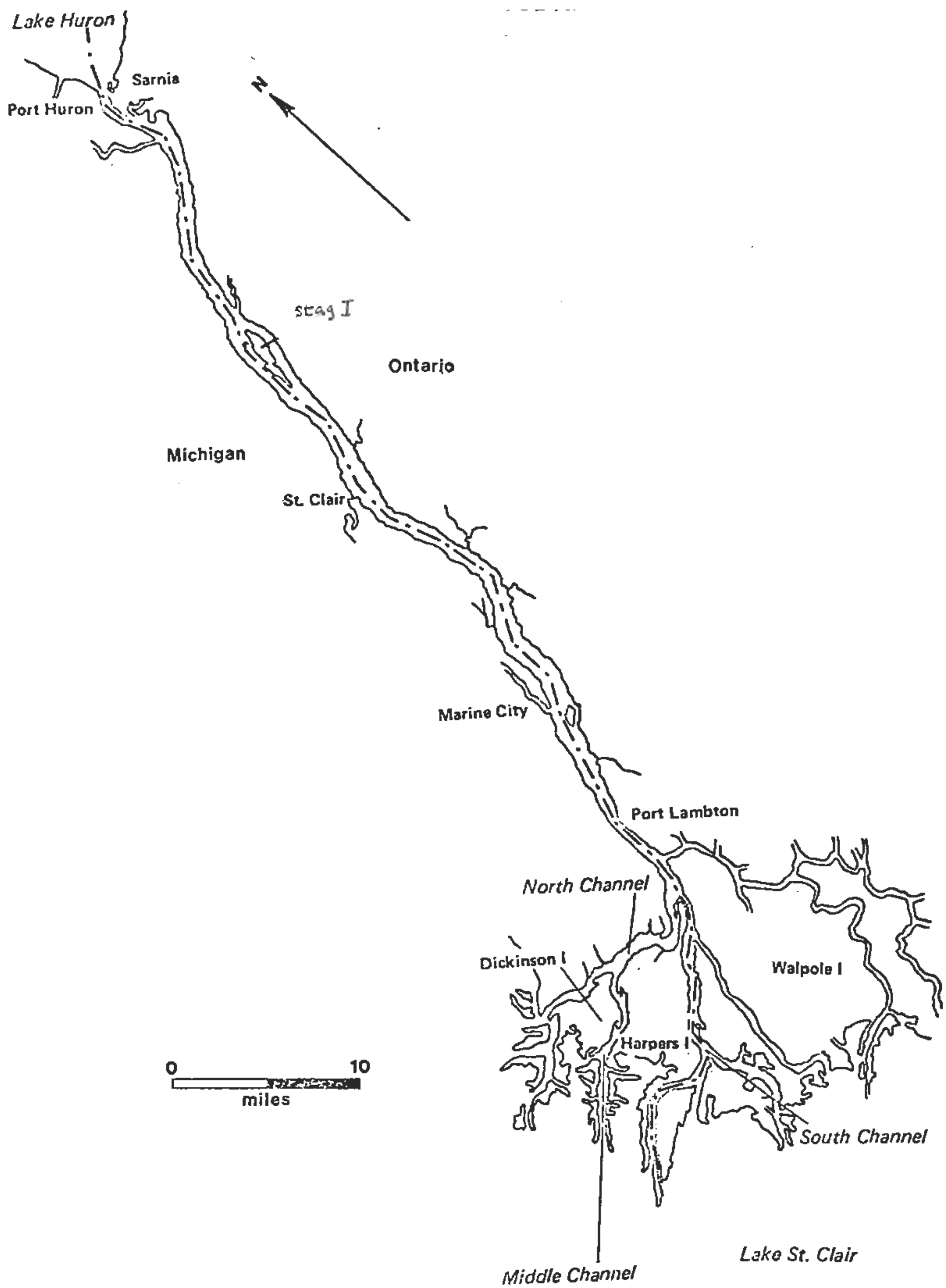


Figure 9. The St. Clair River.

The Fish Community

Species Composition

Ninety fish species have been reported in the St. Clair River (Edsall et al. 1988a) and the more common species are listed in Table 6. Some fish are year-round residents, others enter or leave the river to spawn, and a third group uses the river as a migratory route between lakes Huron and Erie. Both warmwater and coolwater species are found in the river year-round. Cold water species including lake trout, lake herring, and lake whitefish once used the river during the colder months, but are now encountered only rarely.

Fish Distribution and Habitat Use

The major fish habitats in the river are (1) open-water, (2) littoral, (3) emergent wetland, and (4) tributary.

Open-water -- This habitat occupies areas deeper than 3 m that are sparsely vegetated or without vegetation. Open-water habitat type is abundant in the St. Clair River, and includes the 8.2 m-deep navigation channel. Currents are swift and the water is well-mixed in open-water habitat. The most characteristic open-water inhabitants of the river are lake sturgeon, walleye, and channel catfish (Edsall et al. 1988b). Fish usually associated with shallow waters, like smallmouth bass, may move into open-water habitat during summer (Edsall et al. 1988b).

Littoral -- Littoral habitat of the St. Clair River extends from the

Table 6. Common and scientific names of fishes collected from the St. Clair River, May 1974-April 1975 (Source: Texas Instruments 1975).

Scientific name	Common name
PETROMYZONTIDAE	
Ichthyomyzon unicuspis	Silver lamprey
Lampetra lamottei	American brook lamprey
ACIPENSERIDAE	
Acipenser fulvescens	Lake sturgeon
LEPISOSTEIDAE	
Lepisosteus osseus	Longnose gar
CLUPEIDAE	
Alosa pseudoharengus	Alewife
Dorosoma cepedianum	Gizzard shad
SALMONIDAE	
Salmo trutta	Brown trout
S. gairdneri	Steelhead
Salvelinus fontinalis x *namaycush*	Splake
Oncorhynchus tshawytscha	Chinook salmon
O. kisutch	Coho salmon
OSMERIDAE	
Osmerus mordax	Rainbow smelt
UMBRIDAE	
Umbra limi	Central mudminnow
ESOCIDAE	
Esox lucius	Northern pike
Esox masquinongy	Muskellunge
CYPRINIDAE	
Cyprinus carpio	Carp
Carassius auratus	Goldfish
Hybopsis storeriana	Silver chub
Nocomis biguttatus	Hornyhead chub
Nocomis micropogon	River chub
Notropis analostanus	Satinfin shiner
Notropis atherinoides	Emerald shiner
Notropis cornutus	Common shiner
N. boops	Bigeye shiner
Notropis hudsonius	Spottail shiner

Continued

Table 6. (Continued).

Scientific name	Common name
Notropis volucellus	Mimic shiner
Notropis heterolepis	Blacknose shiner
N. bifrenatus	Bridle shiner
N. blennius	River shiner
Opsopoedus emiliae	Pugnose minnow
Pimephales promelas	Fathead minnow
P. vigilax	Bullhead minnow
Pimephales notatus	Bluntnose minnow
Rhinichthys atratulus	Blacknose dace
Rhinichthys cataractae	Longnose dace
CATOSTOMIDAE	
Erimyzon oblongus	Creek chubsucker
Catostomus commersoni	White sucker
Hypentelium nigricans	Northern hogsucker
Moxostoma anisuram	Silver redhorse
Moxostoma macrolepidotum	Shorthead redhorse
Minytrema melanops	Spotted sucker
ICTALURIDAE	
Ictalurus punctatus	Channel catfish
I. melas	Black bullhead
Ictalurus nebulosus	Brown bullhead
I. natalis	Yellow bullhead
Noturus flavus	Stonecat
N. furiosus	Carolina madtom
PERCOPSIDAE	
Percopsis omiscomaycus	Trout-perch
ATHERINIDAE THERINIDAE	
Lebidesthes sicculus	Brook silverside
GASTEROSTEIDAE	
Pungitius pungitius	Ninespine stickleback
Culea inconstans	Brook stickleback
PERCICHTHYIDAE	
Morone chrysops	White bass
CENTRARCHIDAE	
Ambloplites rupestris	Rock bass
Lepomis cyanellus	Green sunfish
Lepomis gibbosus	Pumpkinseed
Lepomis macrochirus	Bluegill
Micropterus dolomieui	Smallmouth bass
Micropterus salmoides	Largemouth bass
Pomoxis nigromaculatus	Black crappie

Continued

Table 6. (Continued).

Scientific name	Common name
PERCIDAE	
Etheostoma nigrum	Johnny darter
E. caeruleum	Rainbow darter
E. flabellare	Fantail darter
Perca caprodes	Logperch
P. copelandi	Channel darter
Perca flavescens	Yellow perch
Stizostedion vitreum vitreum	Walleye
SCIAENIDAE	
Aplodinotus grunniens	Freshwater drum
COTTIDAE	
Cottus bairdi	Mottled sculpin
Cottus cognatus	Slimy sculpin

shoreline to a depth of 3 m. Current velocity is moderate in littoral habitat in the river and submersed macrophytes may be present. In the St. Clair River, littoral habitat with submersed plants is found only in scattered locations along river shoulders, around Stag and Fawn islands, and in shallow mid-river areas. This habitat in the St. Clair River is used as a feeding and resting area by many of the river's coolwater and warmwater fishes and as a nursery and spawning ground for both resident and migrant species including alewife, rainbow smelt, carp, white sucker, rockbass, yellow perch, and walleye (Goodyear et al. 1982).

Emergent wetland -- This habitat is usually contiguous with littoral habitat that supports stands of submersed plants, and the fish communities in the two habitats are also often contiguous. Emergent wetland habitats are not abundant in the St. Clair River. They are located along the North Channel at Russell Island, Point Aux Chenes, and Point Aux Tremble (Herdendorf et al. 1981). Small beds of emergent macrophytes may be found up river at Stag Island and Sarnia Bay. The fish community of emergent wetlands is composed of warmwater and coolwater species including centrarchids, cyprinids, and bullheads. Emergent wetlands are also used as spawning and nursery habitat by non-wetland residents.

Tributary -- Tributaries to the St. Clair River include the Black, Pine, and Belle rivers and a number of creeks (Fig. 9). Water in tributaries is warmer than the St. Clair River, current velocities are low, and a variety of substrates is present. A fairly discrete segment of the fish community including alewife, rainbow trout, Pacific salmon, suckers, redhorse, smallmouth bass, and walleye migrates into these tributaries for spawning (Goodyear et al. 1982).

Habitat use by fish in the St. Clair River may change seasonally or with life history stage as dictated by changing temperature, cover, and food availability. Lake sturgeon using the St. Clair River, for example, live as adults in lakes Huron and Erie, spawn in the river channel, and their larvae migrate to nursery areas in emergent wetlands in the delta (Goodyear et al. 1982). Other species, like yellow perch, are habitat generalists and may be found in virtually all of the habitats in the river (Edsall et al. 1988b).

The movements of adult fish were investigated in a tagging study (Haas et al. 1985). Most of the species found in the St. Clair River were relatively sedentary year-round residents of the river. Among those that undertake short migrations or movements within the river and its tributaries are smallmouth bass, brown bullhead, white sucker, and redhorse. White bass migrate into the river from Lake St. Clair during the spring spawning season, and rock bass move into the river from Lake St. Clair during the summer.

Until early in this century, lake trout, lake herring, and lake whitefish entered the St. Clair River from Lake Huron and Lake Erie in the autumn and winter. These migrations no longer occur, but some introduced, coldwater species including brown and rainbow trout and coho and chinook salmon migrate into the river during the colder months (Edsall et al. 1988b).

Spawning and Nursery Areas

Records of fish spawning in the St. Clair River have been summarized by Goodyear et al. (1982) and spawning sites have been identified (Table 7; Fig. 10). Spawning occurs primarily in the littoral and tributary habitats.

Table 7. Fishes which spawn in the St. Clair River (Source: Goodyear et al. 1982).

Sea lamprey	Northern hog sucker
Lake sturgeon	Channel catfish
Alewife	Trout-perch
Gizzard shad	Burbot
Lake herring	White bass
Lake whitefish	Rock bass
Rainbow trout	Smallmouth bass
Lake trout	Yellow perch
Rainbow smelt	Logperch
Muskellunge	Walleye
Carp	Freshwater drum
Silver chub	Mottled sculpin
Emerald shiner	Slimy sculpin
White sucker	Fourhorn sculpin

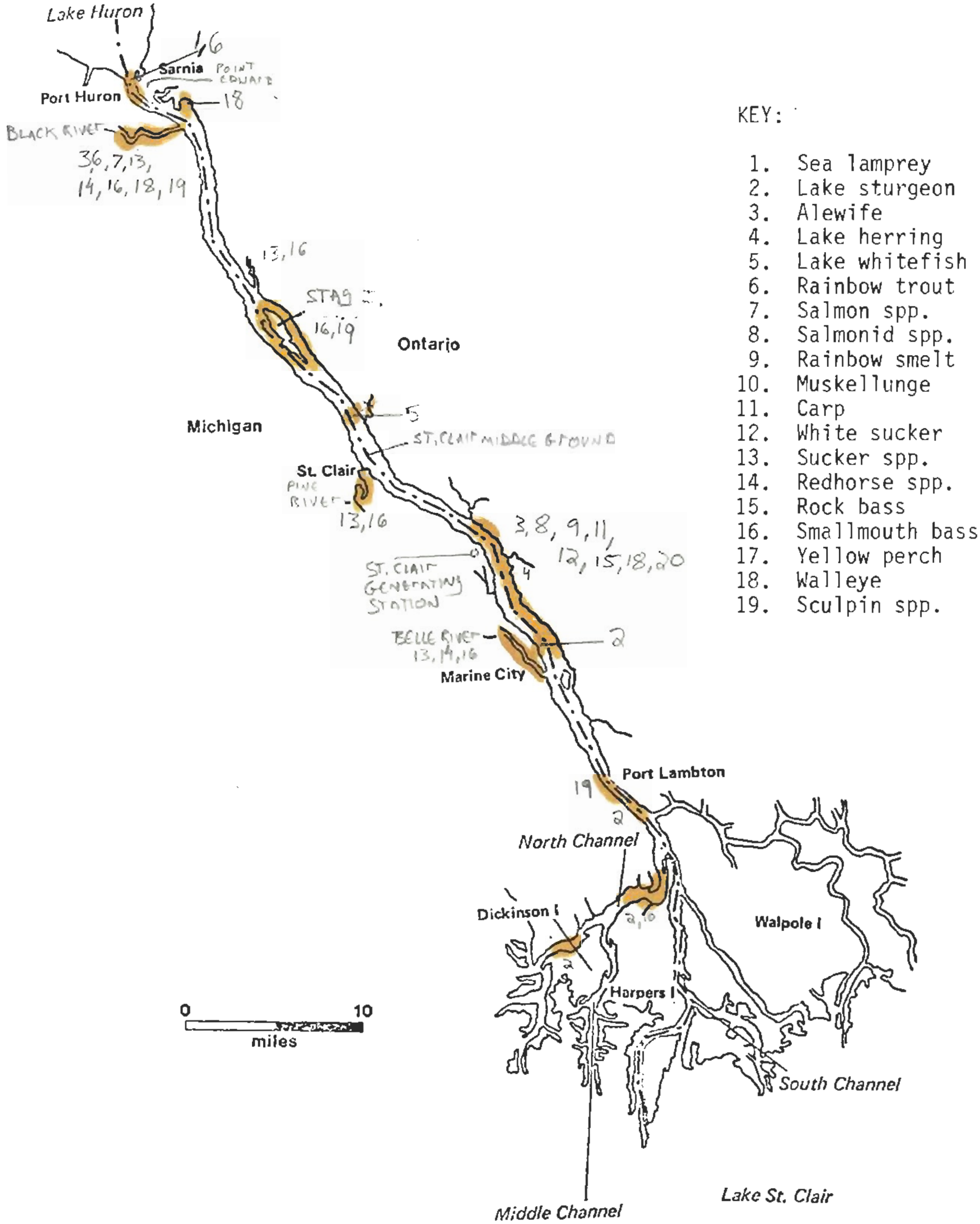


Figure 10. Fish spawning areas in the St. Clair River and channels of the St. Clair Delta (Source: Goodyear et al. 1982).

Navigation channel habitat is used for spawning by lake sturgeon. Most other species spawn in shallower, more protected habitats. Major littoral spawning areas occur along the Canadian shoreline from the St. Clair Generating Station to Marine City, around Stag Island, and near the head of the river at Point Edward and Port Huron. Species spawning in the littoral zone include sculpin, yellow perch, smallmouth bass, rock bass, white sucker, carp, and alewife. Tributary habitats include the Black, Belle, and Pine rivers and smaller tributaries.

Nursery habitat is more broadly distributed in the river than spawning habitat. Although few species spawn in the open-water habitat, larvae of nearly every St. Clair River species can be found in the open-water drift (Muth et al. 1986). The most abundant larvae in the drift are those of forage species, including rainbow smelt, alewife, and gizzard shad. These species spawn in the river and its tributaries, but many of the larvae probably also originate from spawnings in Lake Huron. Larvae of species that are less abundant in the drift may have been displaced from preferred nursery habitats. Species using littoral habitats for nursery areas are primarily the same species spawning in these habitats.

Effects of Altered Water Levels

Effects on Fish Habitat

To evaluate the impacts of water level changes on the fish habitats of the St. Clair River, water level changes of ±1 m on Lake St. Clair from the

1900-1989 mean level are assumed. Areas potentially dewatered or flooded on the St. Clair River by ±1 m water level changes in the level of Lake St. Clair are shown in Figs. 11-18, which are produced on USACE chart 14853 for the Detroit River, Lake St. Clair, St. Clair River (8th Ed., Apr. 14,1979) and USACE chart 14851 for Lake St. Clair (7th Ed., July 6, 1985). Although the 1.5 m fall in the river from Lake Huron to Lake St. Clair suggests that the effect of raising or lowering the level of Lake St. Clair by 1 m would not extend upstream to the head of the river, we have assumed that the area of effect could actually extend, at times, to the Point Edward section of the river. The effect would be graduated and would be greatest in the lower reaches of the river.

The effects of these water level changes would differ among each of the habitats. Littoral and emergent wetland habitats are most vulnerable to a 1 m water level drop because they are shallow, and because the areal extent of those habitats in the river is not great. A 1-m drop in level would dewater a sizable portion of the existing littoral habitat including patches along the river shoulders, particularly along the Canadian shore that contain submersed vegetation. Most of the littoral habitat from the St. Clair Generating Station to Marine City would be dewatered. Littoral areas around Stag and Fawn Islands would be partially dewatered. The St. Clair Middle Ground and the Sarnia embayment would also be partially dewatered.

A 1-m rise in St. Clair River water level would flood low shoreline areas, perhaps adding new littoral habitat. Innundated areas supporting submersed vegetation would probably occur in patches along both shorelines and on the islands, but specific areas cannot be identified without better topographic information.

Figure 11. Fish habitat (blackened areas) potentially affected by water level alterations in the St. Clair River--Port Huron and Sarnia. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 10.

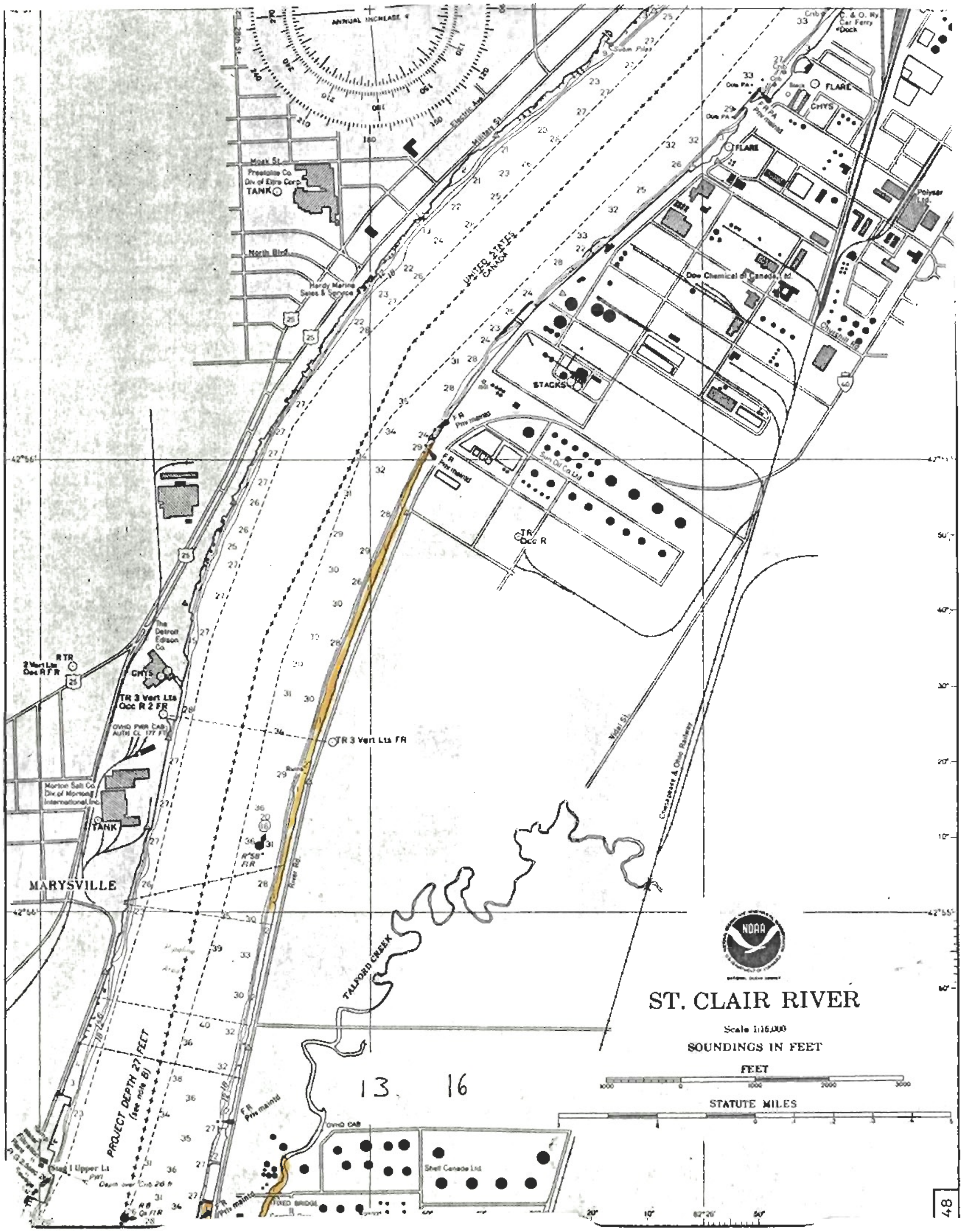


Figure 12. Fish habitat (blackened areas) potentially affected by water level alterations in the St. Clair River--Marysville. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 10.

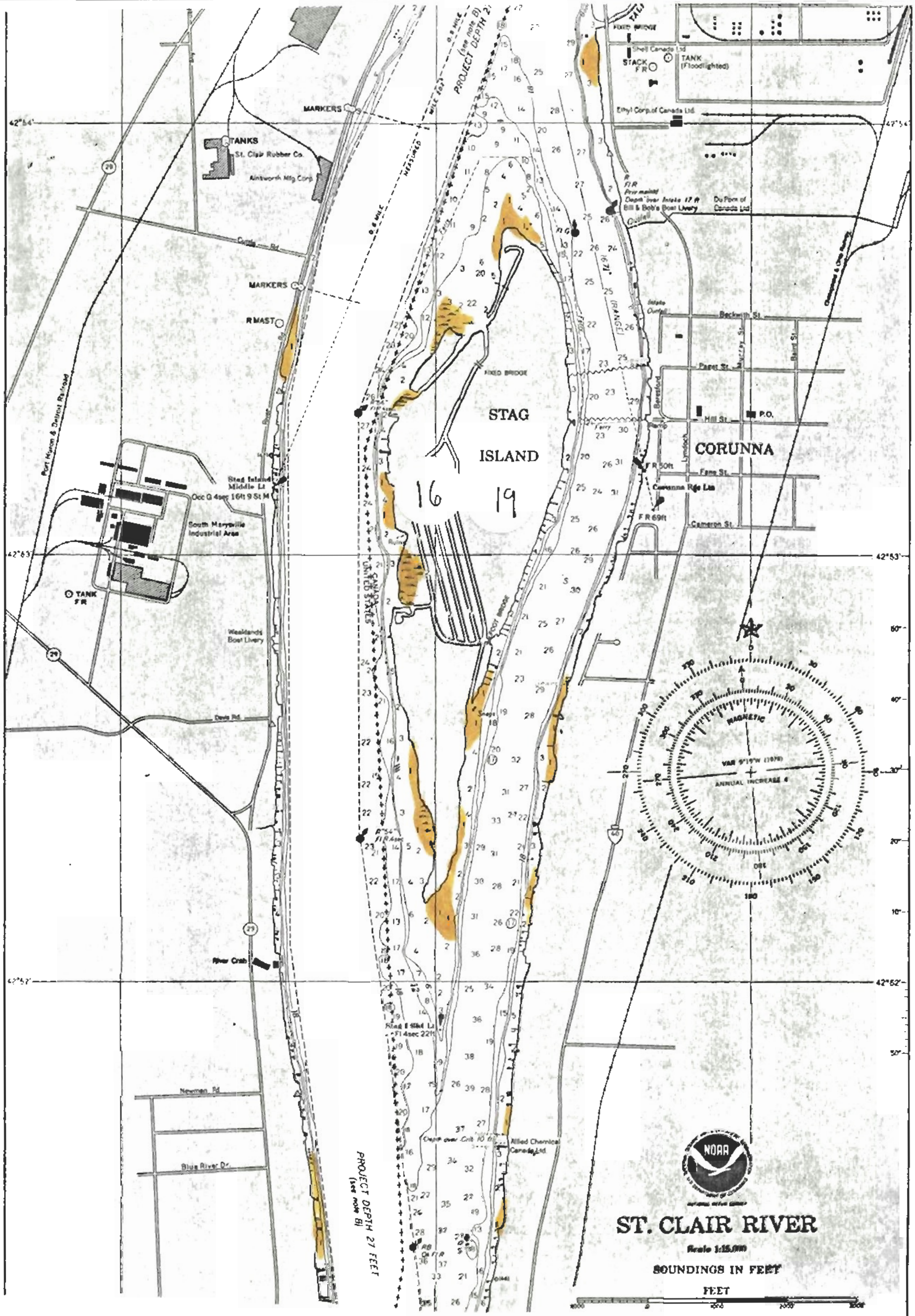


Figure 13. Fish habitat (blackened areas) potentially affected by water level alterations in the St. Clair River--Stag Island. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 10.

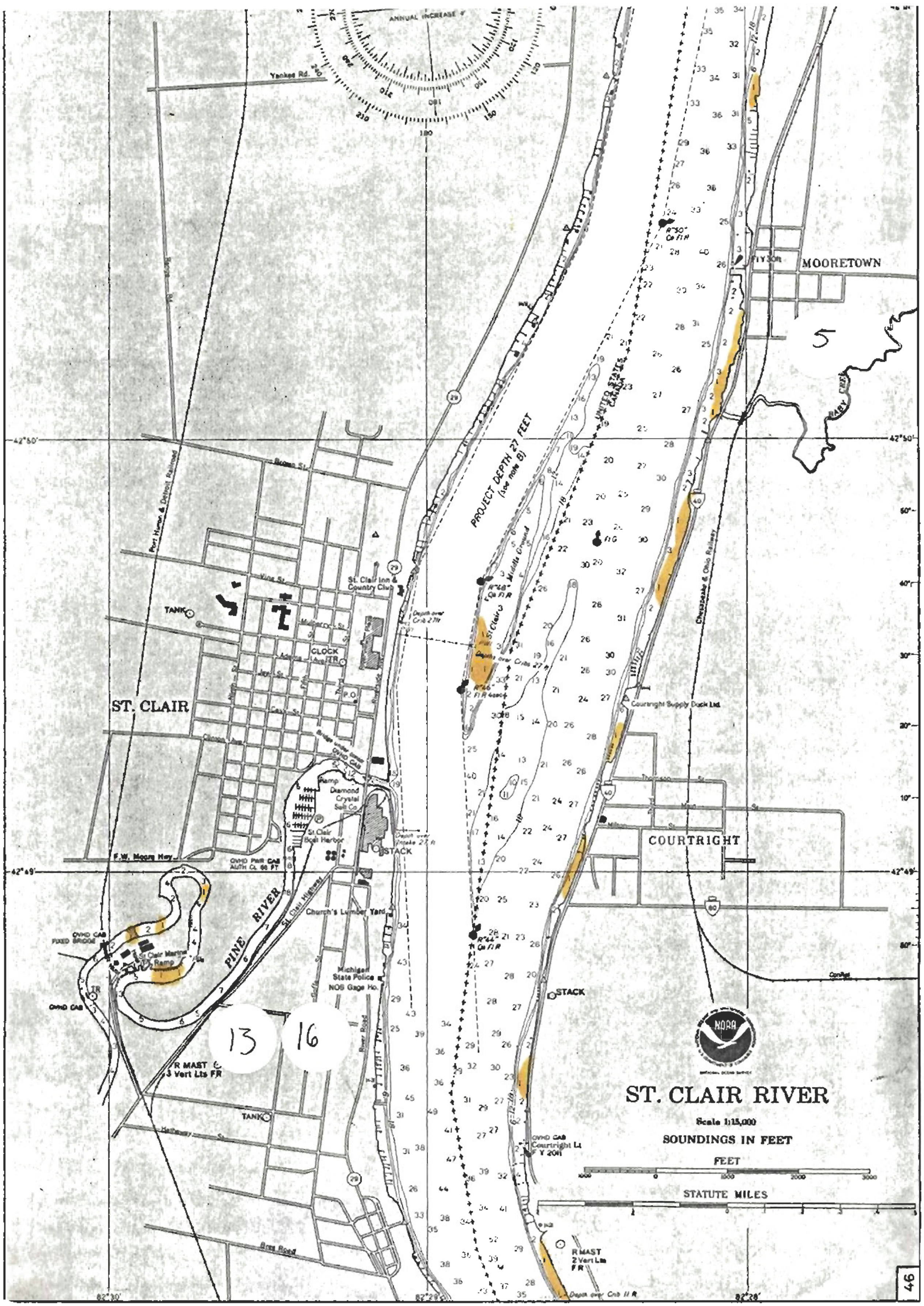


Figure 14. Fish habitat (blackened areas) potentially affected by water level alterations in the St. Clair River--St. Clair. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 10.

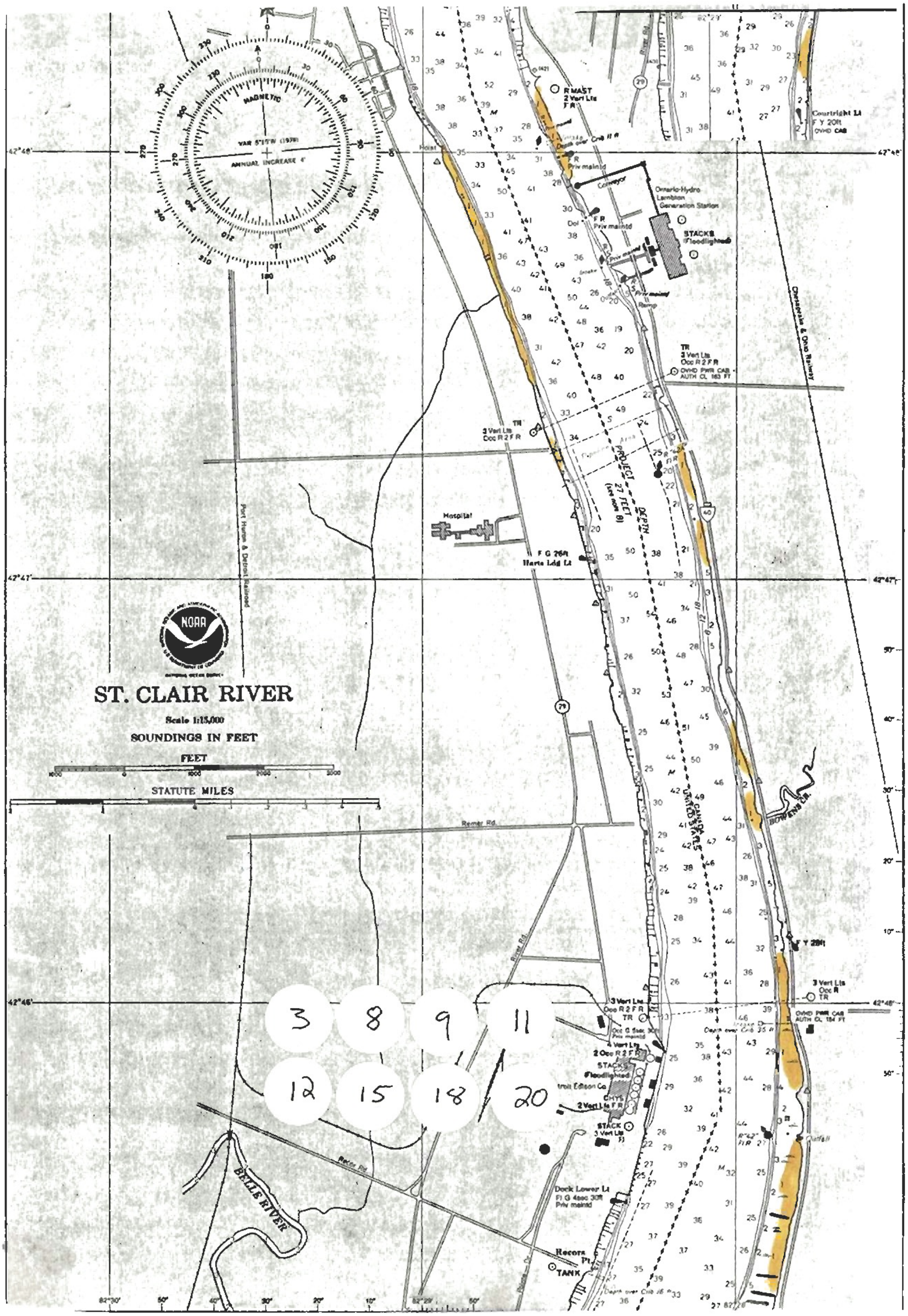


Figure 15. Fish habitat (blackened areas) potentially affected by water level alterations in the St. Clair River--Lambton. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 10.

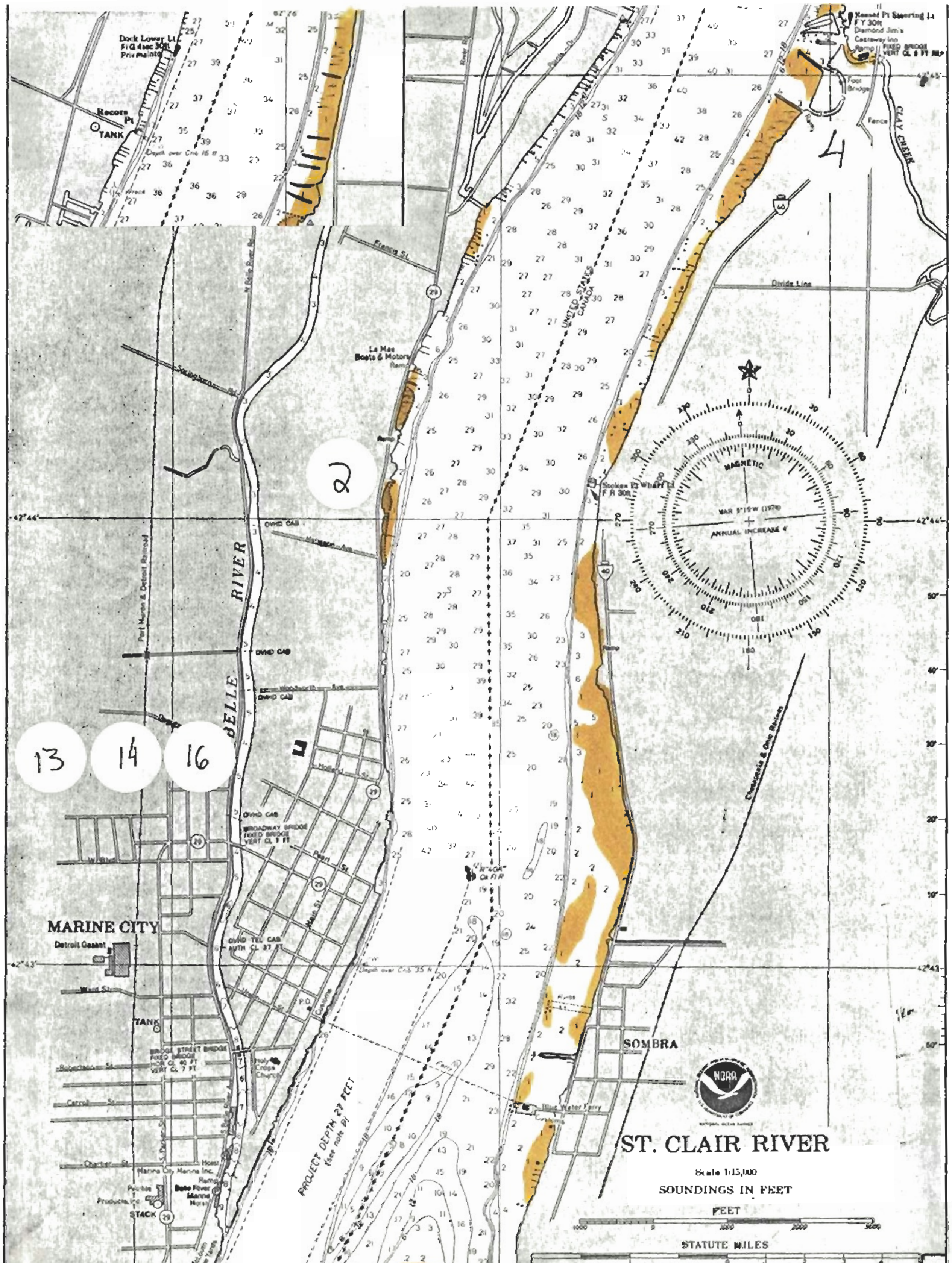


Figure 16. Fish habitat (blackened areas) potentially affected by water level alterations in the St. Clair River--Marine City. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 10.

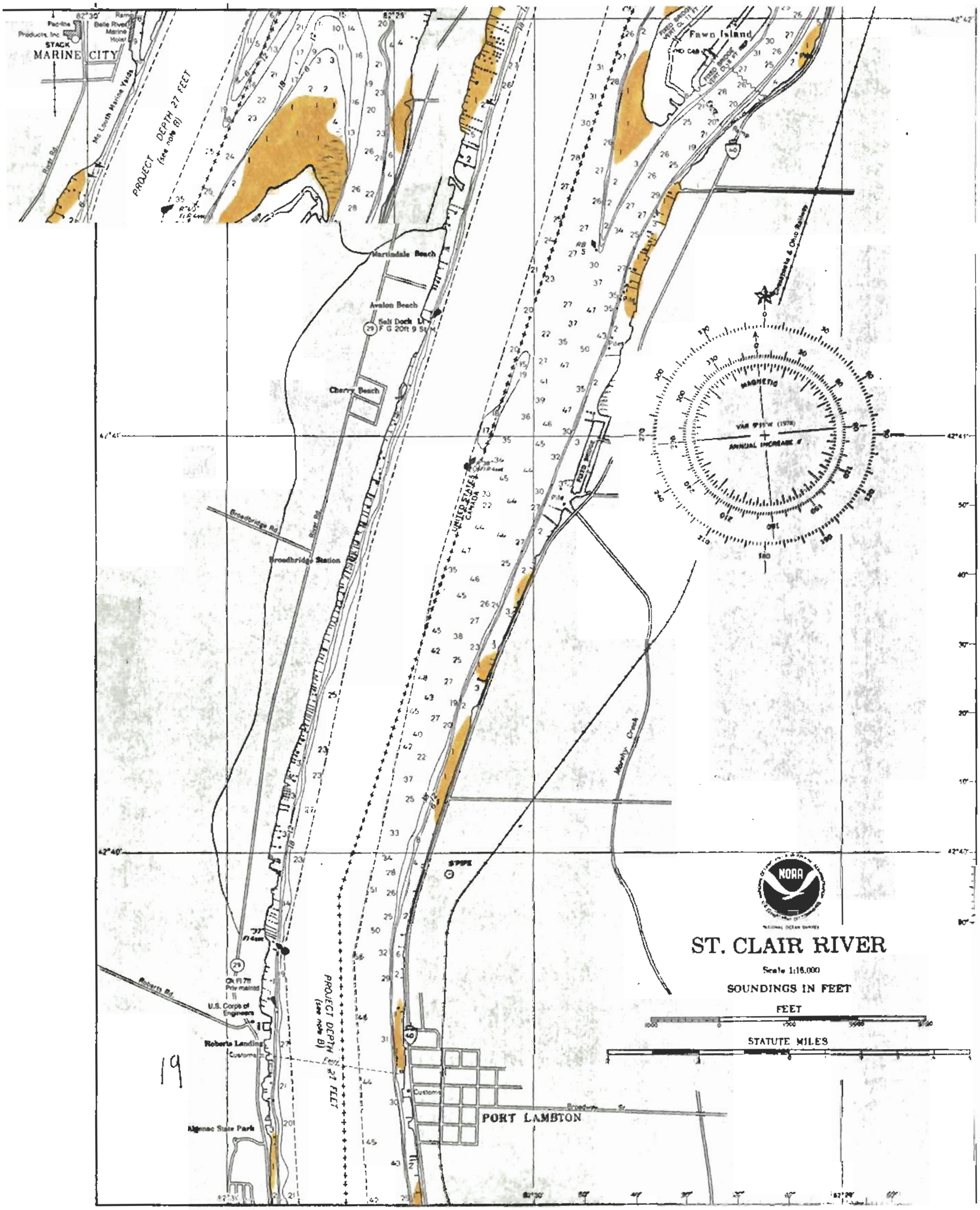


Figure 17. Fish habitat (blackened areas) potentially affected by water level alterations in the St. Clair River--Fawn Island. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 10.

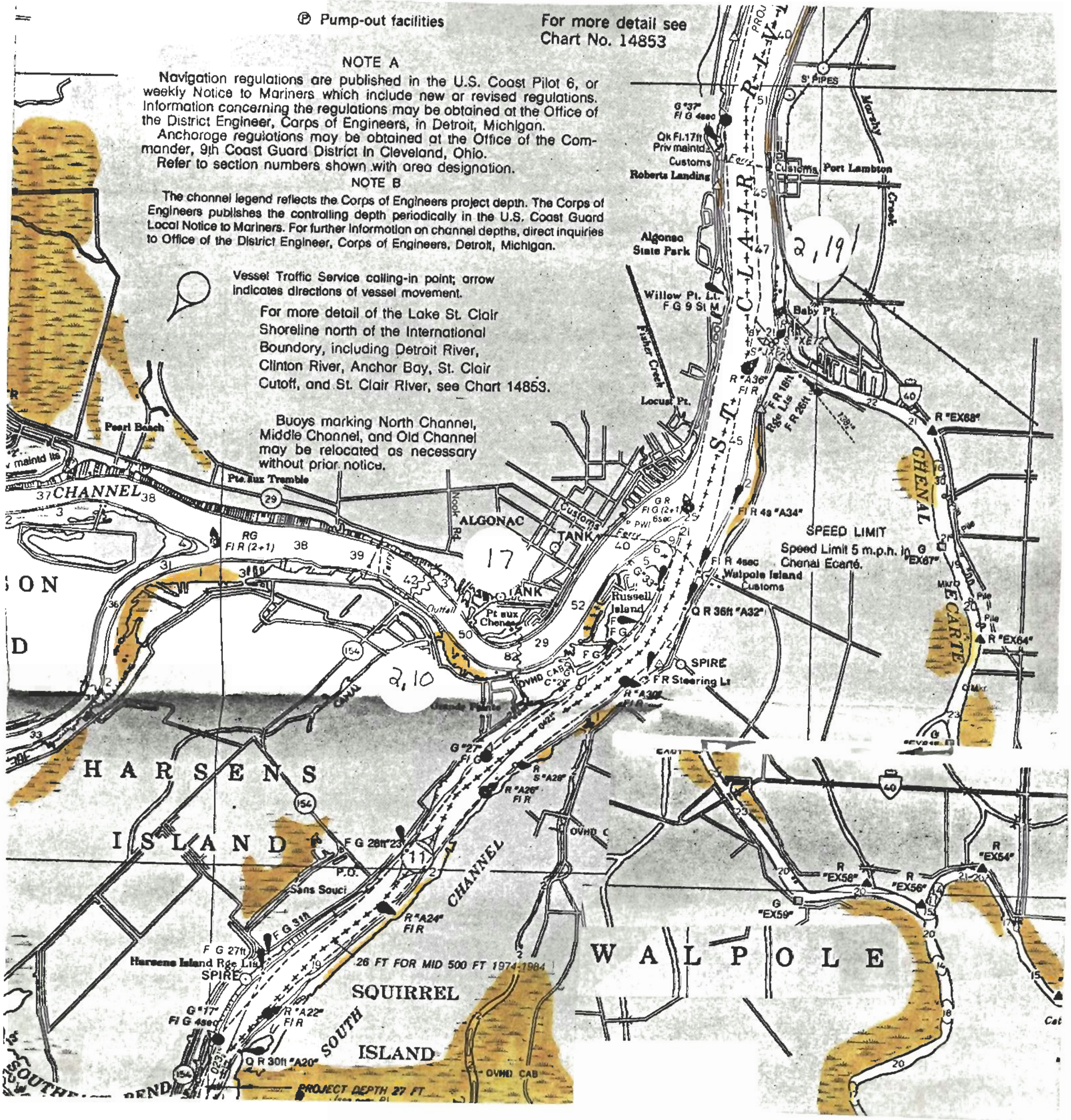


Figure 18. Fish habitat (blackened areas) potentially affected by water level alterations in the St. Clair River--Algonac. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 10.

Although emergent wetland habitat is subject to flooding and dewatering by a ±1 m change in water level in Lake St. Clair we found it difficult to delineate areas of effect without better bathymetric topographic data and a more complete description of the distribution of this habitat within the river system.

A change of ±1 m on the water level in Lake St. Clair would not greatly change the amount of open-water habitat in the river, but would effect the water velocity and flushing time.

The information available to us did not allow us to predict the effects of changed levels in the St. Clair River on levels and flows in its tributaries.

The littoral areas dewatered by a 1-m water level reduction in the St. Clair River are, in some cases, important spawning and nursery habitats. At the embayment at Sarnia, the shallowest areas of yellow perch spawning habitat would be dewatered (Fig. 11). Smallmouth bass and walleye spawning areas in littoral habitat around Stag Island (Fig. 13) diminishes sharply. About half of the littoral habitat on the river shoulder from the St. Clair Generating Station south to Sombra, Ontario (Figs. 15 and 16) would be lost if water levels are reduced by 1-m. Rock bass, lake herring, and other species that spawn here have few other suitable habitats in the St. Clair River. Water velocity increases caused by a 1-m level decrease would facilitate the displacement of larvae from these nurseries into the open-water drift. Water level increases of 1-m at any of these littoral sites could be expected to increase the area of habitat available to these species.

A 1-m change of water level in Lake St. Clair would not interfere with the spawning of lake sturgeon or other open-water spawners using the river, nor would these changes directly impact the value of the open-water habitat as a nursery for important forage species. Increased water velocity would flush drifting larvae from the river more quickly.

Emergent wetlands in the upper St. Clair River were not identified by Goodyear et al. (1982) as important spawning and nursery areas. A 1-m level increase could create new emergent wetlands, while a drawdown of 1 m could dewater some existing areas particularly at Russell Island, Point Aux Chenes, and Point Aux Tremble.

Under a ±1-m water level change, tributaries will remain valuable as spawning and nursery habitats for such species as alewife, rainbow trout, salmon, suckers, redhorse, smallmouth bass, yellow perch, and walleye.

Effects on the Food Web

The trophic structure and nutrient dynamics of the St. Clair River have not been well studied. Because the Lake Huron water entering the river is relatively oligotrophic, nutrient input to the system is dominated by sewage treatment effluents and run-off. Sediment phosphorous measurements range from 10 mg/kg at Port Huron-Sarnia to 600 mg/kg at the St. Clair Delta (Edsall et al. 1988b). Primary production in the St. Clair River is dominated by macrophytes (Table 8). Phytoplankton of the river, which resemble the Lake Huron community, move through the system quickly and may be little-used by the consumers of the river. Periphyton in the river is unstudied, but probably contributes little to the productivity of the river (Table 8). Macrophytes, which are concentrated in the littoral habitats, are food for primary consumers

Table 8. Mean standing crop, net production, and system production of primary producers and consumers in St. Clair River (Source: Edwards et al. 1987)[a/].

	St. Clair River		
	Standing crop	Net production	System production
Primary producers			
Phytoplankton	0.45	67	3,900
Periphyton	2.0	26	1,160
Submersed macrophytes	131[b]	164	2,290
Emergent macrophytes	532[b]	665	22,620
Total			29,970
Primary consumers			
Zooplankton	.56	10	590
Macrozoobenthos	1.0	7	440

a/ Tabular values are reported as follows: standing crop and net production as grams ash-free dry weight/m²; system production as metric tons ash-free dry weight/yr. Surface areas of the river was estimated to be 5,813 ha.

b/ Seasonal maximum standing crop.

by grazing and as detritus. As detritus, macrophytes are probably the largest component of the suspended organic matter in the river. Most of the macrophyte biomass becomes detritus each year and is either consumed or moved downriver. The macrophytes are also important as cover and as substrate for periphyton and phytomacrofauna (Edsall et al. 1988a). The invertebrates that feed on macrophytes and phytoplankton in the river are vital to fish recruitment as a food source for larvae and reproductive adults.

Water level changes may easily alter the trophic structure of the St. Clair River by determining the distribution and abundance of macrophytes and controlling the retention of nutrients in the river ecosystem. A 1-m reduction of the water level in Lake St. Clair would reduce levels, increase current velocities, and reduce the width of the St. Clair River. Loss of littoral habitats from dewatering of the river shoulders would decrease production of emergent and submersed macrophytes and consequently decrease production throughout the ecosystem. Lowered levels on Lake St. Clair would constrict down-river flow and increase the velocity. Increased flushing of nutrients and suspended organic load from the system would decrease productivity in important down-river littoral habitats near the St. Clair Generating Station, Marine City, and Russell Island. Up-river habitats closer to the influence of Lake Huron would experience less impact.

Increased water level would increase littoral habitat area and move these areas farther from the navigation channel. These effects would increase macrophyte production, reduce susceptibility to wave- and current-induced damage, and increase nutrient spiraling. Decreased current velocity from backwatering would increase deposition and retention of suspended nutrients and organic load. Fish, especially those in the lower river, would benefit from a 1-m rise in Lake St. Clair water level as a result of the enriched forage base.

Effects on Existing Use-Conflicts

Navigation -- The effect on levels and current velocities in the St. Clair River of raising or lowering the level of Lake St. Clair by 1 m would be a most obvious in the portion of the river downstream from the St. Clair Generating Station and exacerbation of navigation-related impacts on the biota and their habitats also would be greatest in this reach of the river. A lowering of the Lake St. Clair water level by 1 m would dewater the shallower littoral and emergent wetland habitat and reduce the width of the St. Clair River. The portions of the littoral and emergent wetland habitat that remained would be those closer to the navigation channel where effects of ship passage would be greatest.

Short duration drawdown produced by ship passage can cause larval fish mortality (Holland 1983; Wuebben 1979). Vessel-induced wave action can uproot macrophytes and make it difficult for colonies to persist in exposed areas (Schnick et al. 1982). Closer proximity of littoral habitats to the navigation channel also decreases nutrient spiraling when macrophytes, other biota, and detritus are drawn into the navigation channel, as a result of vessel passage, and swept downstream and out of the system by the more rapid currents in the navigation channel (Poe et al. 1980; Poe and Edsall 1982; Jude et al. 1986).

Lowered water levels may increase sediment resuspension and turbidity during vessel passage; increased turbidity may also result, if lowered water levels require dredging to maintain the water depth needed for navigation. Macrophytes can be restricted to shallower areas as light penetration is reduced by turbidity resulting from ship movement and navigation-related dredging. Resuspended sediments that are contaminated with toxic or conventional pollutants can also interfere with larval fish feeding (Poe 1983; Kreis 1988) and can smother fish eggs. Dredging would, in turn, tend to further dewater littoral and emergent wetland habitat.

Navigation channels are generally considered to be marginal habitat for young fishes partly because of vessel-induced turbulence and bottom scour that occurs there. When water levels are reduced, vessel movement will cause increased bottom scour and turbulence in the more restricted channel. Mortality of fish larvae due to vessel-induced turbulence has been hypothesized but not yet adequately documented.

Scouring by ship-induced ice movement is more extensive than direct vessel scouring. Lowered water levels will increase the portion of the littoral habitat that is vulnerable to ice scour resulting from the movement of vessels in the connecting channels during winter. Macroinvertebrate, fish eggs, and macrophytes are vulnerable to ice scour in the littoral zone.

The navigation-related effects on the St. Clair River and its biota would be lessened by a 1-m rise in water level of Lake St. Clair. Littoral areas from the St. Clair Generating Station to the mouth of the river (Figs. 15-18) would increase the width, and damage to fish larvae, macrophytes, and phytomacrofauna from the surge and drawdown effects of vessel passage would be reduced. Turbidity and resuspension of contaminants would be reduced, and nutrient spiraling and production would be increased. Lower current velocity would encourage nutrient deposition in littoral areas, particularly in the St. Clair Delta.

Water Withdrawal -- The St. Clair River contains 25 operating industrial and municipal water intakes, most of which are located in the upper river near Sarnia and Port Huron (Edsall et al. 1988b). Two steam-electric power plants, the Lambton Generating Station and the St. Clair Generating Station, are located mid-way down the river, south of the town of St. Clair (Fig. 15). These two generating stations entrained 6,257,000 larvae, and 452,000 older fish per year in the mid-1970's (MDNR 1976).

Entrainment of small fish at water intakes in the river can be estimated as the product of their density in the river water and the volume of water withdrawn (Kelso and Milburn 1979). A 1-m reduction of the Lake St. Clair water level would cause dewatering of the river shoulders in the lower St. Clair River, thus forcing more of the larvae into the deep waters where the intakes are located and increasing the potential for their entrainment at water intakes in the lower river.

Fish species most vulnerable to entrainment at water intakes are gizzard shad, rainbow smelt, and alewife (Muth et al. 1986) which are the most abundant larvae in the river and are the most common in the open-water drift. A 1-m increase would cause back-watering and reduced current velocity, which could concentrate larvae in the lower river and increase their potential for entrainment.

Waste Disposal -- Thirty-one private and 13 municipal outfalls release 2 x 10^6 m^3 of effluent into the St. Clair River and its tributaries daily (Edsall et al. 1988a). Among the contaminants present in these effluents are

PCB's, halogenated aromatic hydrocarbons and polymers, heavy metals, fuels, and solvents. The sources of most of these contaminants are chemical factories near Sarnia and Port Huron (UGLCCS 1988). Because there is little cross-channel mixing in the St. Clair River, pollutants from industrial outfalls remain concentrated along the shoreline downstream from the outfalls. It is along the shoreline on the river shoulders that these contaminants can exert their most serious effect on the river's biota.

In the past, poor regulation of effluent discharges resulted in impacts throughout the entire length of the river. Surveys indicate the benthic community in 1968 was abnormal or impaired along the entire Canadian shoreline south of Sarnia, while the U.S. shoreline had a normal community (Fig. 19). Attention to the problem led to major improvements by 1977 (Fig. 20) and recovery of the benthic community in most of the river continues (Fig. 21), although impaired or degraded conditions still persist along the Canadian shoreline from Sarnia to Stag Island and a toxic zone is present south of Sarnia near Dow Chemical Canada Ltd. Degraded zones also persist adjacent to smallmouth bass and walleye habitats around Stag Island.

Changes of ±1 m of the water level in Lake St. Clair would probably not affect sediment and water quality in the upper river, but in the lower river, a reduction of the Lake St. Clair level by 1 m would narrow the river and increase current velocity. Contaminants would be flushed from the river more quickly. With a 1-m rise in Lake St. Clair water level, the lower river would widen, the current velocity would be reduced, and settling of contaminants might increase.

We cannot predict how water level changes in Lake St. Clair and the lower St. Clair River would affect fish habitat in tributaries to the river. Levels

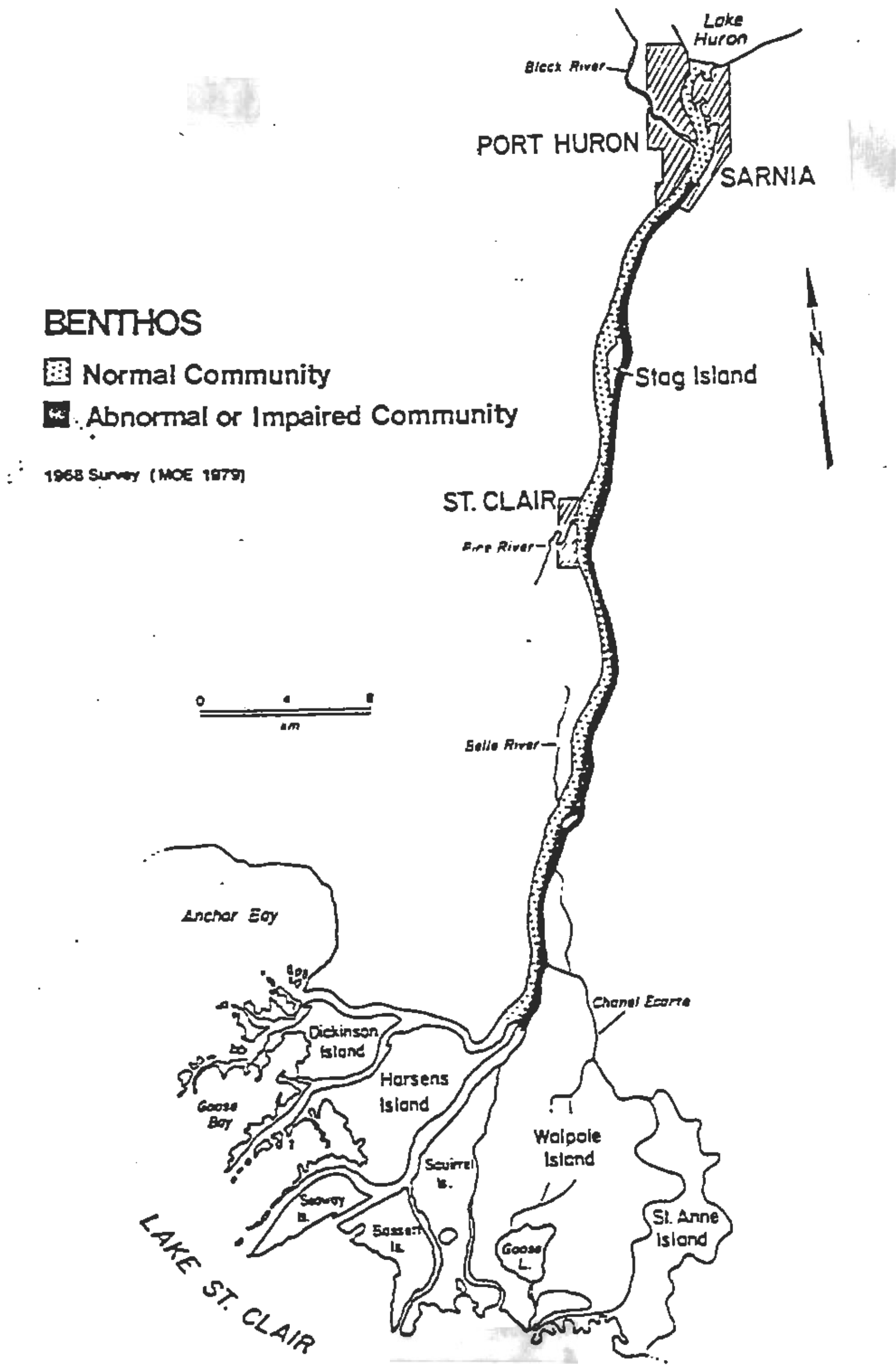


Figure 19. Benthos distribution in the St. Clair River, 1976-1977 (Source: Limno-tech, Inc. 1985).

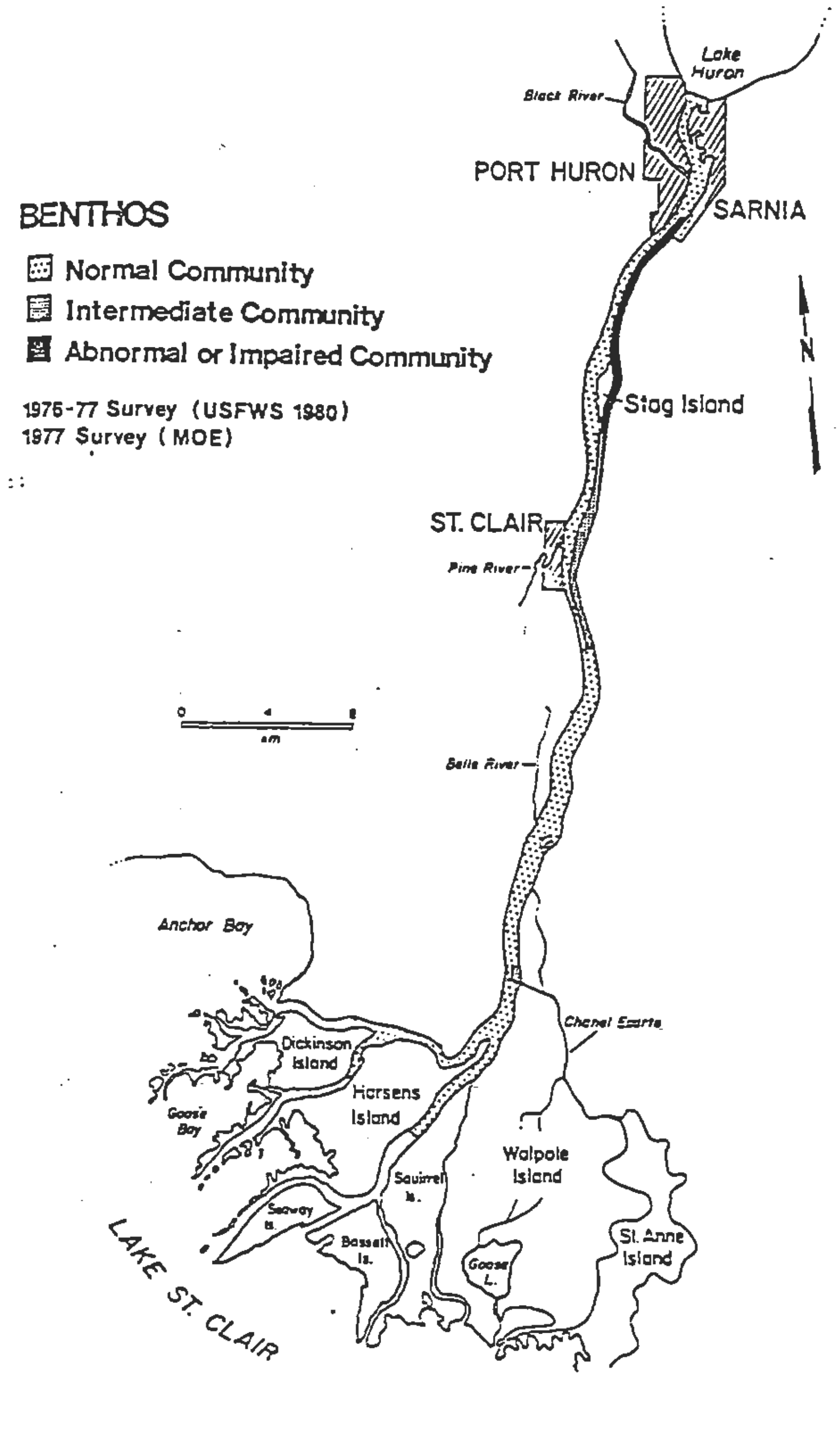


Figure 20. Benthos distribution in the St. Clair River, 1968 (Source: Limno-tech, Inc. 1985).

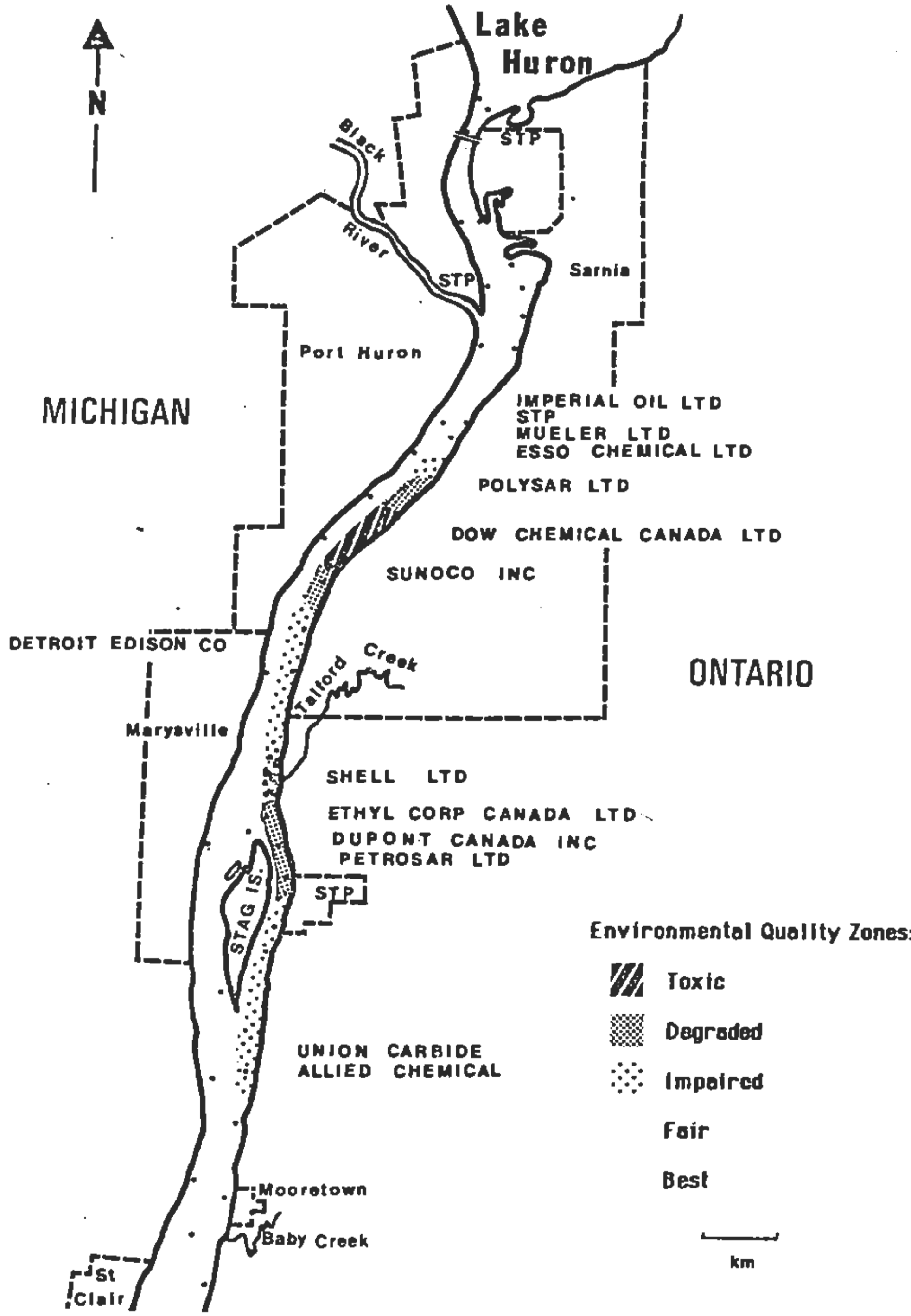


Figure 21. Distribution of environmental quality zones in the St. Clair River, May 1985 (Source: Griffiths 1987).

and flows in tributaries entering the upper St. Clair River would probably be affected little, whereas in the lower river, back-watering or accelerated flushing of the lower reaches of the tributaries would probably result. As a consequence, the movement of contaminated water and sediments out of tributaries, such as the Belle River, would either be slowed or accelerated.

Despite control efforts, spills of toxic materials still occur. The U.S. Coast Guard (USCG 1980) estimated nearly 19,000 L of hazardous substances were spilled into the Michigan waters of the river in 1973-79 and more than 23,344 tons of oil and other hazardous substances were reported spilled into Canadian waters of the river in 1974-85 (DOE/MOE 1986). Under criteria established by the U.S. Fish and Wildlife Service (Adams et al. 1984) spills of petroleum products and other hazardous substances were judged to represent a threat to fish spawning and nursery areas and wetlands in the Detroit River (Manny and Inman 1986) and similar reasoning can be applied to spills in the St. Clair River. The impact of spills depends not only on the substance and quantity spilled but also on the hydrologic regime where the spill occurred. The hydrologic regime will affect the movement of the spilled material and in the lower St. Clair River lowered water levels will accelerate its movement downstream and elevated levels will retard downstream movement and cause increased exposure of the biota.

LAKE ST. CLAIR

Background

Lake St. Clair is the shallow, heart-shaped lake which receives its inflow primarily from the St. Clair River and is drained by the Detroit River (Fig. 22). The lake has a total surface area of 1,113 km and an average depth of 3 m. The St. Clair Delta covers much of the northern end of the lake where the distributary channels of the St. Clair River enter the lake, creating a large number of embayments and extensive wetlands. Other major tributaries to the lake are the Thames River, the Sydenham River and the Clinton River.

A navigation channel has been dredged to a depth of 8.3 m between the St. Clair cutoff channel and the Detroit River. Record high and low water levels are +1.05 m and -1.02 m from the 1900-1986 average level. Water quality in Lake St. Clair remains high because the lake flushes rapidly (2-30 days) and because most of the water reaching the lake is from Lake Huron which has high water quality. Wind and currents maintain 2 discrete water masses in the lake. The northwest mass is primarily fed by Lake Huron water via the St. Clair River while the more stable, southeast mass is fed by the nutrient-rich Ontario tributaries.

The U.S. shoreline is highly urbanized and there is little industrial use of the lake's water. In Ontario much of the land near the lake is devoted to agriculture.

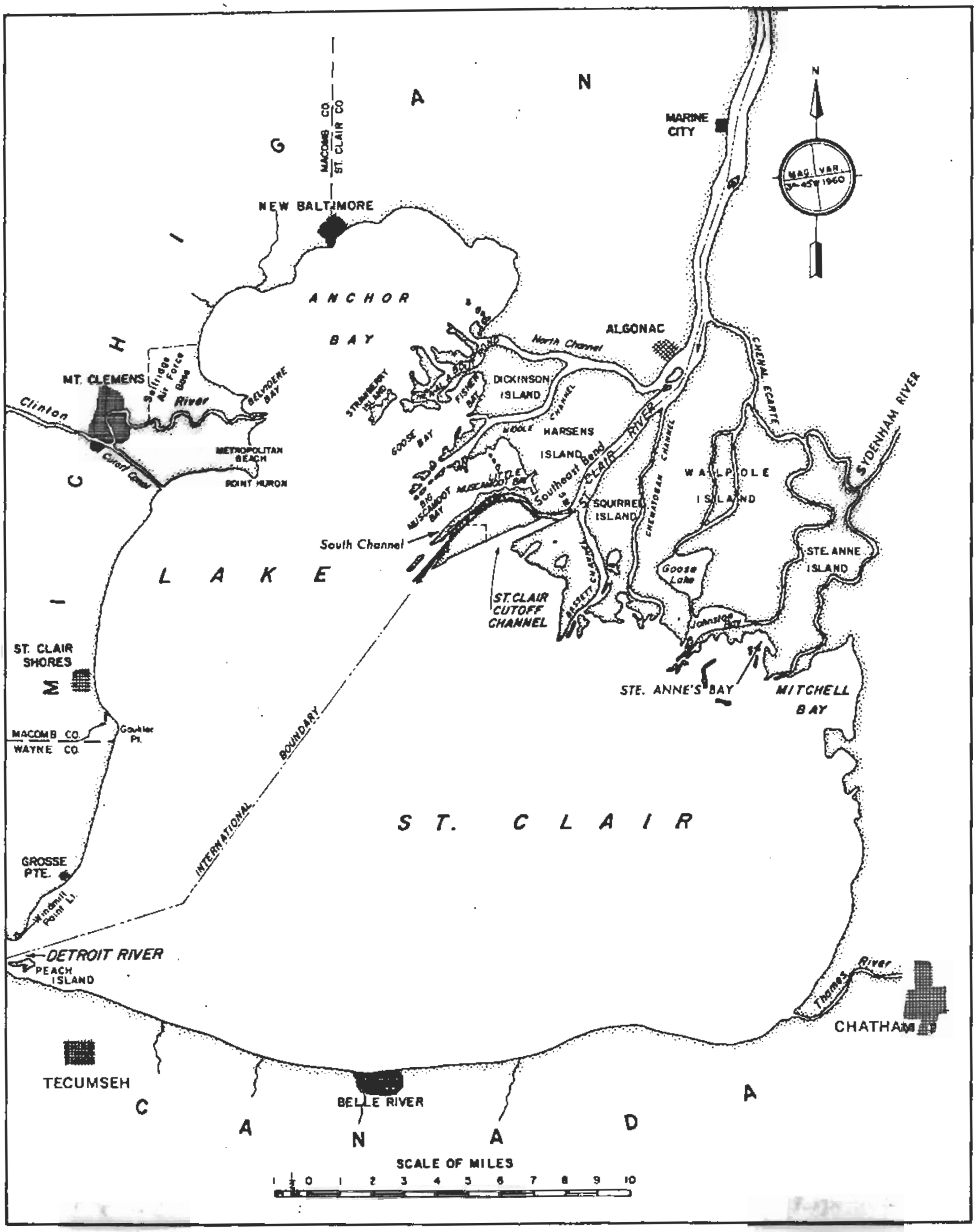


Figure 22. Lake St. Clair.

The Fish Community

Species Composition

At least 70 fish species have been reported from Lake St. Clair. Some species are year-round residents; others move between the lake and the St. Clair and Detroit Rivers, or lakes Huron and Erie, to spawn or feed; and a third group uses the lake as a migratory route between lakes Huron and Erie. Diversity of both warm and cool water species in the lake is high. Introduced and native Great Lakes species that prefer cold water are encountered in the lake only during the cooler months of the year. Lake St. Clair supports an important recreational fishery for yellow perch, walleye, smallmouth bass, muskellunge and white bass.

Fish Distribution and Habitat Use

Important fish habitats in Lake St. Clair are (1) open-water, (2) littoral, (3) emergent wetland, and (4) tributary.

Open-water -- This habitat occurs in the portions of the lake that are deeper than 3 m and includes most of the 1,113 km^2 covered by the lake. This habitat is sparsely vegetated with charophytes, the substrate is predominantly muddy sand, and it is an important feeding and resting area for many fish species (UGLCCS 1988).

Littoral -- This habitat is also abundant in Lake St. Clair, occurs in water less than 3 m deep, and usually supports dense beds of submersed macrophytes. In Lake St. Clair littoral habitat occurs in wide bands along the lake shores, in the embayments of the St. Clair Delta, and nearly all of Anchor Bay. Nearly all species of fish in the lake can be found in the littoral habitat. Littoral and emergent wetland habitats and their fish communities are often contiguous.

Emergent wetland -- This habitat occurs in water less than 2 m deep and supports dense beds of emergent macrophytes, usually with an understory of submersed macrophytes. A variety of emergent wetland types defined by their plant communities have been identified in Lake St. Clair (Jaworski and Raphael 1979; Raphael and Jaworski 1982; Herdendorf 1981). Emergent wetlands on Lake St. Clair are nearly continuous from the mouth of the Thames River, north through the islands and embayments of the St. Clair Delta and occur in patches around Anchor Bay to the mouth of the Clinton River. These areas provide spawning and nursery habitat and feeding and resting areas for fish and they are used by nearly all of the fish found in the lake.

Tributary -- Tributaries to Lake St. Clair (excluding the St. Clair River) are the Thames River, the Clinton River, Sydenham River, and several smaller rivers and creeks. These habitats have warmer waters with generally higher nutrient loads than the lake. A number of species migrate into the tributaries in spring and summer to spawn.

Most of the fish of Lake St. Clair may occupy different habitats seasonally, as dictated by changing temperature, cover and food requirements, and the need to fulfil reproductive requirements. Most of the resident warm and coolwater species are not strongly migratory (Haas et al. 1985). Muskellunge migrate in a clockwise direction around the lake after spawning in the littoral areas of the north and western lake shores. White bass, channel catfish and rock bass migrate up into the St. Clair River in the spring and summer. A number of non-resident species, including sea lamprey, alewife, gizzard shad, and rainbow smelt spawn in the lake and its tributaries. Historically, spawning runs of lake trout, lake herring, and lake whitefish entered the lake and currently brown trout, rainbow trout, coho salmon, and chinook salmon may be present in the lake during the colder months, as they feed and migrate between lakes Huron and Erie (Edsall et al. 1988b).

Spawning and Nursery Areas

Goodyear et al. (1982) compiled records of fish spawning in Lake St. Clair (Table 9). Spawning in Lake St. Clair occurs in littoral and emergent wetland habitats and in the tributaries (Fig. 23). The submergent and emergent wetland habitat are used as spawning grounds by many fish species. The marshes and embayments of the St. Clair Delta from Bouvier Bay to Mitchell Bay are used by almost every species found in Lake St. Clair. Littoral habitats from Mitchell Bay to the Thames River on the eastern shore of the lake are used for spawning by at least 15 species. The littoral habitat areas of the southern shore from the Thames River to the Detroit River are used for spawning only by walleye. Spawning along the western shoreline from the Detroit River through Anchor Bay is continuous but the species compliment varies along this stretch with pockets of higher diversity in Lanse Creuse Bay and Belvidere Bay.

Tributaries are also important spawning habitats. The Thames River is used by sea lamprey, channel catfish, white bass, and walleye. The Clinton

Table 9. Fishes which spawn in Lake St. Clair (Goodyear et al. 1982).

Sea lamprey	Muskellunge	Channel catfish
Lake sturgeon	Goldfish	White bass
Longnose gar	Carp	Rock bass
Bowfin	Golden shiner	Pumpkinseed
Alewife	Emerald shiner	Bluegill
Gizzard shad	Common shiner	Smallmouth bass
Mooneye	Spottail shiner	Largemouth bass
Lake herring	Spotfin shiner	White crappie
Lake whitefish	Bluntnose minnow	Black crappie
Rainbow trout	Fathead minnow	Greenside darter
Northern pike	Brown bullhead	Yellow perch
		Walleye

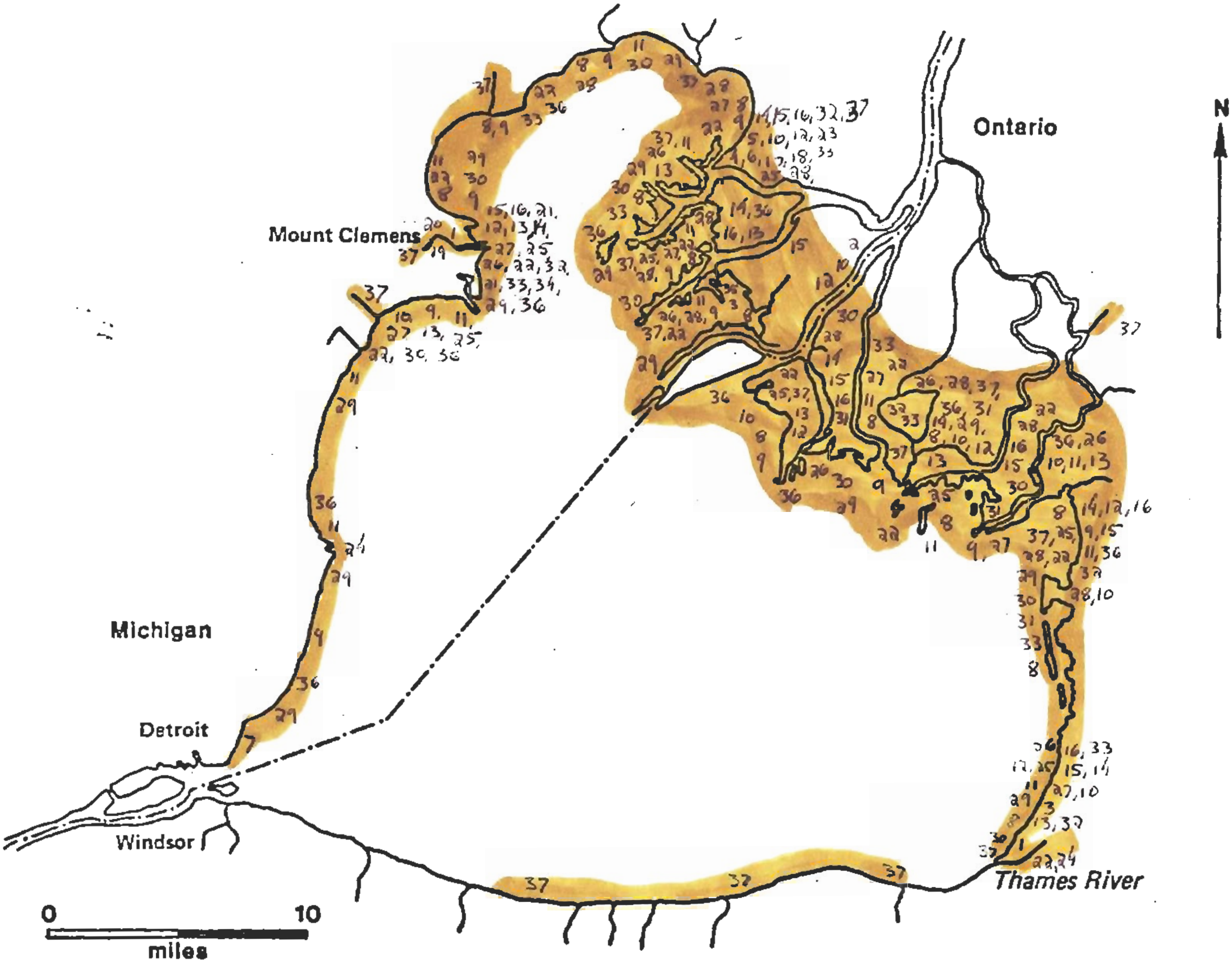


Figure 23. Fish spawning areas in Lake St. Clair (Source: Goodyear et al. 1982).

KEY

1.	Sea lamprey	13.	Emerald shiner	25.	Rock bass
2.	Lake sturgeon	14.	Common shiner	26.	Pumpkinseed
3.	Longnose gar	15.	Spottail shiner	27.	Bluegill
4.	Bowfin	16.	Spotfin shiner	28.	Sunfish spp.
5.	Alewife	17.	Bluntnose minnow	29.	Smallmouth bass
6.	Gizzard shad	18.	Fathead minnow	30.	Largemouth bass
7.	Lake whitefish	19.	Sucker spp.	31.	Bass spp.
8.	Northern pike	20.	Redhorse spp.	32.	White crappie
9.	Muskellunge	21.	Brown bullhead	33.	Black crappie
10.	Goldfish	22.	Channel catfish	34.	Crappie spp.
11.	Carp	23.	Bullhead spp.	35.	Greenside darter
12.	Golden shiner	24.	White bass	36.	Yellow perch
				37.	Walleye

River at the opposite end of the lake is used by sea lamprey, sucker, redhorse, channel catfish and walleye. Open-water habitat is not known to be used for spawning in Lake St. Clair.

Nursery areas in Lake St. Clair are generally also spawning areas. Most of the species spawning in emergent wetlands and littoral habitats use them as nursery habitats. Lake sturgeon larva originating from spawnings in the St. Clair River and its distributary channels use the St. John's Marsh area as a nursery. Although open-water habitat is not an important spawning area, it is a nursery area.

Effects of Water Level Changes

To evaluate the effects of water level changes on the fish habitats of Lake St. Clair, water level changes of ±1 m from the 1900-1989 mean monthly level were assumed. Areas flooded or dewatered by ±1 m water level changes (Figs. 24 and 25) were marked on USACE Chart 14853 (Detroit River, Lake St. Clair, St. Clair River 8th Ed. APR. 14 1979). For this scenario, it is assumed that water levels of the lake are controlled at the head of the Detroit River.

Jaworski and Raphael (1981) investigated the effects of water level changes of ±0.5 m on the macrophyte communities of the St. Clair Delta by comparing areal photographs of Dickinson Island during years of high (1975) and low (1964) water levels. They found that during the low water period most of the islands littoral habitat was emergent wetland. As the water levels rose to the 1975 level, submergent littoral greatly increased in area displacing by inundation much of the low water emergent wetland area.

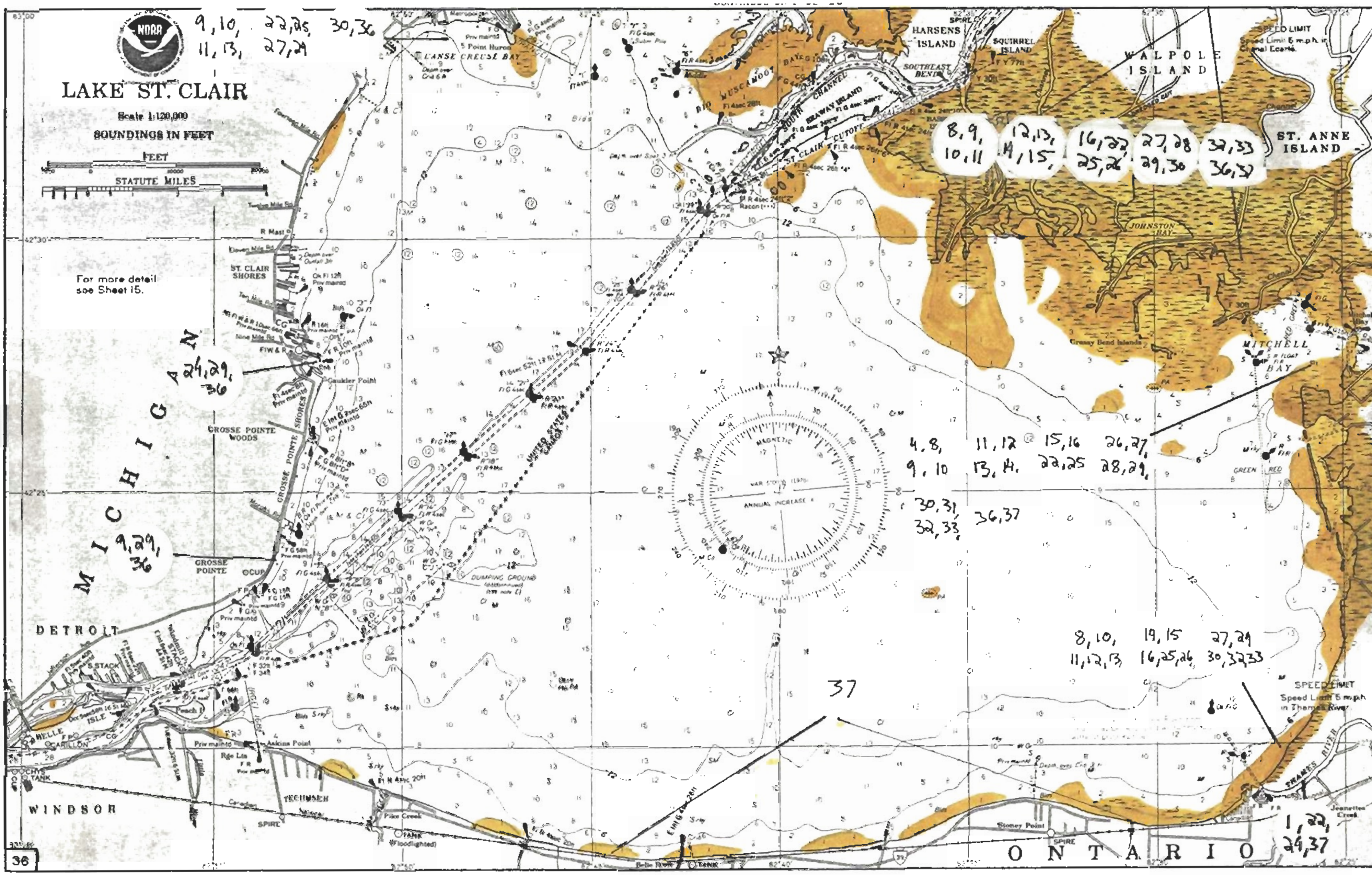


Figure 24. Fish habitat (blackened areas) potentially affected by water level alterations in Anchor Bay, Lake St. Clair. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 23.

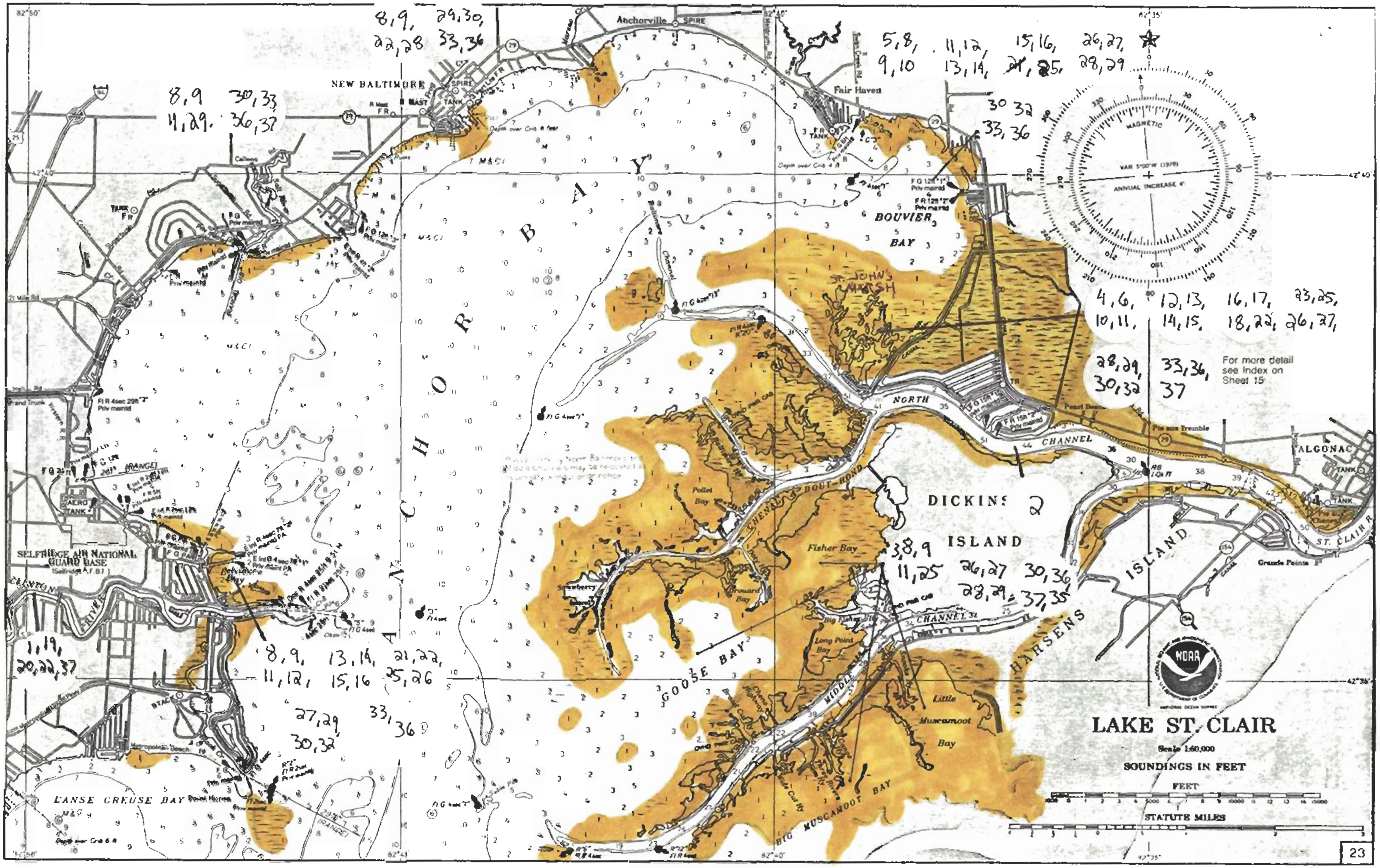


Figure 25. Fish habitat (blackened areas) potentially affected by water level alterations in Lake St. Clair, exclusive to Anchor Bay. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 23.

A 1-m increase on Lake St. Clair would have a similar effect. Most of the emergent wetlands in the St. Clair Delta eastern shore of the lake and along the shore of Anchor Bay probably would be inundated and converted to littoral habitat. Patches of emergent wetland would remain and some new areas would be created by flooding of low shoreline areas. Although a 1-m water level increase would reduce emergent wetlands, the amount of littoral habitat containing submersed vegetation would increase, especially in the St. Clair Delta, while some of the existing, deeper littoral habitats would cease to support dense beds of submersed macrophyte. The deepest areas in Anchor Bay would exceed 3 m if the lake level rose by 1 m and these areas would become open-water habitat. Open-water habitat would also increase considerably in wide bands at Lanse Creuse Bay, and south of the Delta near Mitchell Bay. Tributaries would experience some backwatering if the Lake St. Clair water level rose 1 m, but we are uncertain how the tributary habitats would respond.

Because Lake St. Clair is shallow, a 1-m drop in water level could cause a large decrease in the area of the lake by the dewatering existing littoral habitats. Extensive dewatering would occur in the St. Clair Delta. Dewatering of emergent wetlands would encourage terrestrial vegetation on the islands of the St. Clair Delta. Contiguous littoral habitats in Anchor Bay and the lake proper would become emergent wetland habitat. Lakeward migration of littoral habitat would occur around the perimeter of the lake. Encroachment of littoral habitats on open-water habitat of the central lake would cause a reduction in the amount of open-water habitat.

Effects on Spawning and Nursery Habitats

A 1-m water level reduction would dewater important existing spawning and nursery habitat in Lake St. Clair. The diverse spawning areas of the inter-distributary islands of the St. Clair Delta and the adjacent mainland marshes would be extensively dewatered. Based on the observations of Jaworski and Raphael (1979), much of the present submergent littoral habitat would become emergent wetland habitat. It is likely that the plant communities of these habitats would be displaced lakeward. The diverse assemblage of fishes that spawns in Bouvier Bay, St. Johns Marsh, Goose Bay and Fisher Bay would be forced to choose other sites to the east in Anchor Bay. Fishes spawning in Big Muscamoot Bay and the marshes of the Canadian islands of the Delta would shift southward toward the main body of the lake. There would be some net loss of littoral habitat in the St. Clair Delta, but substantial amounts of both emergent wetland and littoral habitat would remain.

Many species spawn in the littoral habitats from Mitchell Bay to the Thames River. These habitats would probably be translocated westward. Littoral spawning habitats for walleye along the southern shore would dewater in patches with a 1-m water level reduction, but some suitable habitat would remain. The lake bottom drops off more rapidly on the western shore from the head of the Detroit River to L'anse Creuse Bay and relatively small losses of littoral habitat would occur in this important spawning area for yellow perch, smallmouth bass, and various other species. Important spawning habitats in Anchor Bay are at Belvidere Bay and New Baltimore. These areas would be partially dewatered, but abundant littoral habitat would remain in Anchor Bay.

The effect of water level reduction on the tributary habitats is unclear, but spawning would undoubtedly continue there.

A 1-m elevation of Lake St. Clair water level would increase the amount of littoral habitat by inundating emergent wetlands in the St. Clair Delta. Most species that spawn in the littoral habitats of the St. Clair Delta utilize both emergent wetlands and littoral habitats. Valuable littoral habitat for muskellunge would increase. Fish depending more on emergent wetland habitats, like sturgeon larva and spawning bluegills, would experience a reduction in available habitat as some emergent macrophyte beds were inundated. A 1-m water level rise would benefit species spawning along the western shore where flooding would create new littoral habitats. Along the urbanized eastern shore from the mouth of the Detroit River through Anchor Bay, there would be little change in spawning habitat area. Little new littoral area would be added by flooding, and present littoral areas would probably remain.

Food Web Effects

Production in Lake St. Clair is moderated by the relatively low nutrient content of the Lake Huron water entering the lake. The main nutrient inputs to the lake are senescent plant material, sewage, and agricultural runoff from tributaries. Primary production is probably dominated by emergent macrophytes (Table 10), because rapid flushing limits the utilization of phytoplankton. Macrophytes, which are concentrated in the St. Clair Delta, provide food and cover for consumers. Although most of the macrophytes die back in the fall

Table 10. Mean standing crop, net production, and system production of primary producers and consumers in Lake St. Clair (Source: Edwards et al. 1987)[a/].

	Standing crop	Net production	System production
Primary producers			
Phytoplankton	0.64	54	60,160
Periphyton	2.5	32	16,720
Submersed macrophytes	46[b]	58	13,780
Emergent macrophytes	532[b]	665	60,990
Total			151,650
Primary consumers			
Zooplankton	0.44	7.9	8,800
Macrozoobenthos	1.1	6.8	7,600

a/ Tabular values are reported as follows: standing crop and net production as grams ash-free dry weight/m²; system production as metric tons ash-free dry weight/yr. Surface areas of the lake was estimated to be 111,400 ha.

b/ Seasonal maximum standing crop.

(Schloesser et al. 1985), only a small fraction of the annual macrophyte and epiphyton biomass produced in the St. Clair system enters the Detroit River in May-October (National Fisheries Research Center-Great Lakes, unpubl. data). This senescent plant material that lingers in the system during the winter provides an abundant food source for macrozoobenthos, which in turn are, in turn a vital food for fish.

A 1-m decrease in the Lake St. Clair water level would reduce production of macrophytes, and, in turn, production at higher trophic levels. The contribution of emergent macrophytes in primary production would perhaps become even greater as emergent wetlands invade large, shallow littoral areas in Anchor Bay and the lake proper. The decreased lake volume would shorten flushing time, thus decreasing the utilization of phytoplankton, detritus, and nutrients. Overall, the loss of littoral habitats would cause a decrease in spawning and nursery habitat and in food availability.

A 1-m water level rise in Lake St. Clair would increase the size of littoral habitats and the abundance of food for fish. The composition of the fish community could shift toward greater representation of species favoring littoral habitat. A longer flushing time would increase the utilization of phytoplankton, detritus, and nutrients. Forage fish larvae drifting in from the St. Clair River would also remain in the lake longer, perhaps improving their survival and growth and the significance of their contribution to the food web.

Effects on Existing Use-Conflicts

Water Withdrawal -- In 1982 there were nine operational water intakes on Lake St. Clair (IJRT 1982), most of which were on the U.S. shoreline from

Gross Point through Anchor Bay. These intakes pose a threat to species using the spawning habitats near Gross Pointe, St. Clair Shores, L'anse Crues Bay, Belvidere Bay, New Baltimore and Bouvier Bay (Figs. 24 and 25). Along the south shore water intakes are located in the littoral area in walleye spawning habitat. A water level increase of 1 m on the lake would alleviate some of this threat by increasing the depth over intakes and by increasing the amount of littoral habitat shoreward of the intakes in which young fish could be sheltered. Conversely, a 1-m water level drop would shift remaining littoral habitats closer to the intakes and increase the entrainment vulnerability of species that use littoral habitat for nursery areas.

Navigation -- The navigation channel in the lake passes through open-water habitat. The effects of water level changes on the navigation-related impacts in the open lake have not been adequately assessed. Substrate scouring of the channel and near-channel area during vessel passage would increase under the lower water level scenario.

Waste Discharge -- Only four wastewater treatment plants and one industry release wastes directly into the lake (UGLCCS 1988). Most of the contaminants in the lake originate with sources on the St. Clair River and the other tributaries to the lake. Water quality in Lake St. Clair is maintained by flushing with clean Lake Huron water, but contaminants from the St. Clair River have accumulated in sediments where they may affect benthic invertebrates and the food web. Contaminated sediments are deposited most heavily in open-water areas, but small depositional areas are also located at tributary mouths (UGLCCS 1988).

Changes of ±1 m in the water level of the lake could alter the current patterns and the locations of open-water depositional areas. Modeling would be required to predict these alterations. A 1-m water level increase would lengthen the flushing time, thus prolonging the opportunity for contaminants to settle and enter the food web. A 1-m water level reduction would increase the rate of flushing, but would perhaps concentrate contaminants by reducing the area and volume of the lake.

THE DETROIT RIVER

Background

The Detroit River is the 51-km long channel that connects Lake St. Clair and Lake Erie (Fig. 26). The shorelines of the river are heavily developed and the cities of Detroit (Michigan) and Windsor (Ontario) border the river near its source in Lake St. Clair. The upper 21 km of the river differs from the lower river, both biologically and morphologically. The upper river is narrow and contains two islands, Belle Isle and Peach Island. Water quality in this stretch of the river is like that of Lake St. Clair. The lower river is wide and contains many islands, including Grosse Ile and Fighting Island, and many dredged channels and harbors. The water of the lower river is heavily polluted, particularly on the U.S. shore. The river has several tributaries including the Rouge, Ecorse, and Canard rivers.

The average monthly flow of the Detroit River is 5,200 m^3/s and the flushing time is 20 hrs (Manny et al. 1988). The river has a total fall of only 0.9 m and flow reversals in the lower river have been documented (Quinn 1988). The Detroit River provides water for homes and industries of Windsor and the Detroit metropolitan area and also receives their effluents directly and from tributaries.

The Fish Community

About 65 fish species are recorded for the Detroit River (Table 11). Of these, 32 are permanent residents and 28 use the river seasonally for spawning,

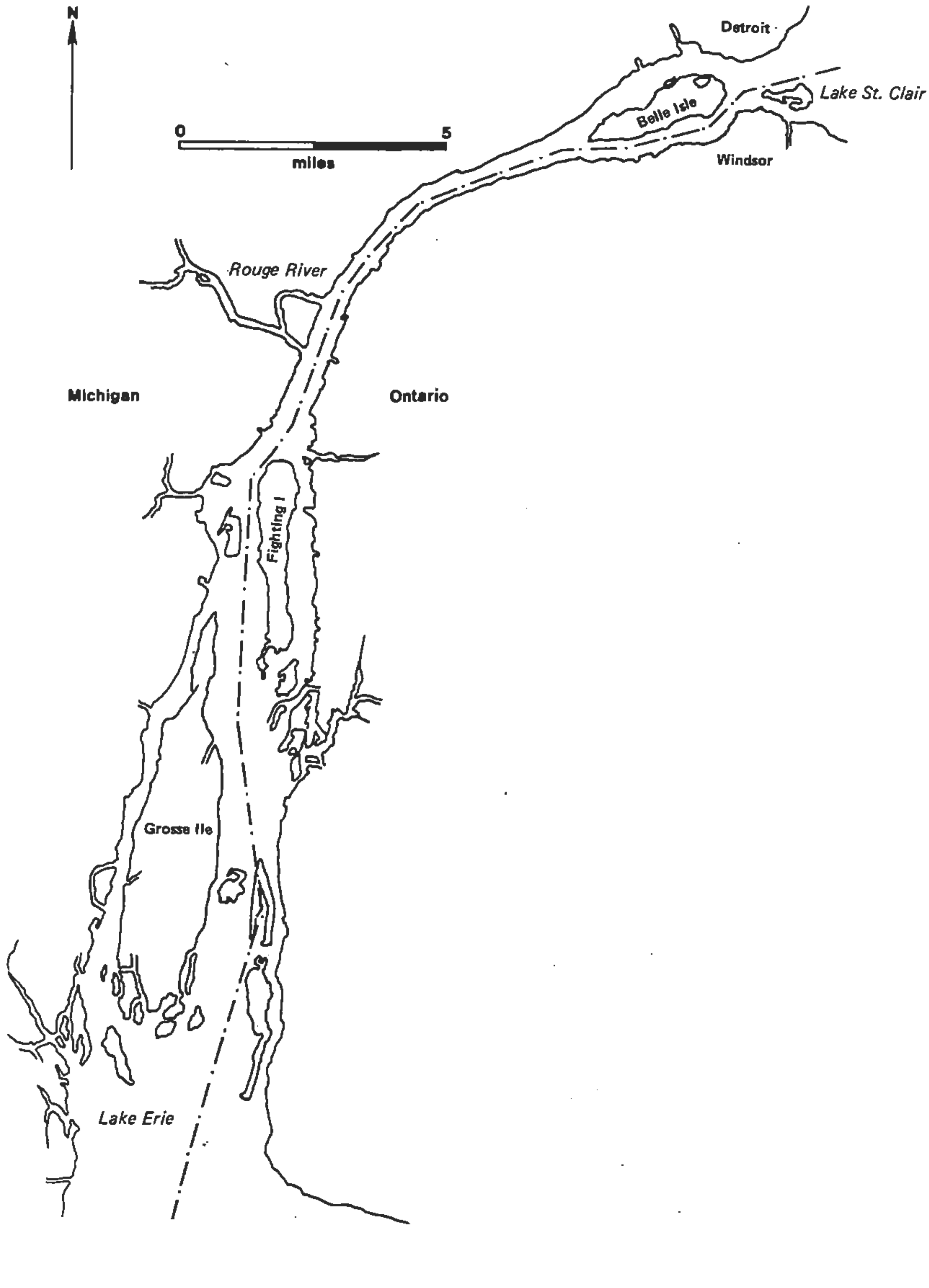


Figure 26. The Detroit River.

Table 11. List of 65 fishes commonly found in the Detroit River (Lee et al. 1980; Goodyear et al. 1982; and Haas et al. 1985).

Common name	Scientific name
Sea lamprey	*Petromyzon marinus*
Lake sturgeon	*Acipenser fulvescens*
Spotted gar	*Lepisosteus oculatus*
Longnose gar	*Lepisosteus osseus*
Bowfin	*Amia calva*
American eel	*Anguilla rostrata*
Mooneye	*Hiodon tergisus*
Alewife	*Alosa pseudoharengus*
Gizzard shad	*Dorosoma cepedianum*
Chinook salmon	*Oncorhynchus tshawytscha*
Coho salmon	*Oncorhynchus kisutch*
Pink salmon	*Oncorhynchus gorbuscha*
Rainbow trout	*Salmo gairdneri*
Brown trout	*Salmo trutta*
Lake trout	*Salvelinus namaycush*
Lake whitefish	*Coregonus clupeaformis*
Rainbow smelt	*Osmerus mordax*
Northern pike	*Esox lucius*
Muskellunge	*Esox masquinongy*
Goldfish	*Carassius auratus*
Common carp	*Cyprinus carpio*
Silver chub	*Hybopsis storeriana*
Golden shiner	*Notemigonus crysoleucas*
Emerald shiner	*Notropis atherinoides*
Pugnose minnow	*Notropis emiliae*
Blacknose shiner	*Notropis heterodon*
Spottail shiner	*Notropis hudsonius*
Sand shiner	*Notropis stramineus*
Mimic shiner	*Notropis volucellus*
Quillback	*Carpiodes cyprinus*
Longnose sucker	*Catostomus catostomus*
White sucker	*Catostomus commersoni*
Northern hogsucker	*Hypentelium nigricans*
Bigmouth buffalo	*Ictiobus cyprinellus*
Smallmouth buffalo	*Ictiobus bubalus*
Spotted sucker	*Minytrema melanops*
Redhorse, unidentified	*Moxostoma* spp.
Silver redhorse	*Moxostoma anisurum*
Golden redhorse	*Moxostoma erythrurum*
Shorthead redhorse	*Moxostoma macrolepidotum*
River redhorse	*Moxostoma carinatum*

(Continued)

Table 11. Continued.

Common name	Scientific name
Black bullhead	*Ictalurus melas*
Yellow bullhead	*Ictalurus natalis*
Brown bullhead	*Ictalurus nebulosus*
Channel catfish	*Ictalurus punctatus*
Stonecat	*Noturus flavus*
Trout-perch	*Percopsis omiscomaycus*
Burbot	*Lota lota*
Brook silversides	*Labidesthes sicculus*
White perch	*Morone americana*
White bass	*Morone chrysops*
Rock bass	*Ambloplites rupestris*
Green sunfish	*Lepomis cyanellus*
Pumpkinseed	*Lepomis gibbosus*
Bluegill	*Lepomis macrochirus*
Smallmouth bass	*Micropterus dolomieui*
Largemouth bass	*Micropterus salmoides*
White crappie	*Pomoxis annularis*
Black crappie	*Pomoxis nigromaculatus*
Logperch	*Percina caprodes*
Yellow perch	*Perca flavescens*
Sauger	*Stizostedion canadense*
Walleye	*Stizostedion vitreum vitreum*
Freshwater drum	*Aplodinotus grunniens*
Four horn sculpin	*Myoxocephalus quadricornis*

feeding, or a migratory pathway (Manny et al. 1988). Year round residents in the river are warm and coolwater species. Coldwater species are not found in the river during the warmer months of the year.

Fish Distribution and Habitat Use

The major fish habitats of the Detroit River are (1) open-water areas including the navigation channels and other deep areas, (2) littoral areas, (3) emergent wetlands, and (4) tributaries. Use of these habitats by fish of the Detroit River may change seasonally or with life history stage as dictated by changing requirements of temperature, cover, and food availability.

Open-water -- Open water habitats are greater than 3 m in depth, non-vegetated or sparsely vegetated, and may have high current velocities. This habitat is abundant throughout the Detroit River. The upper river from Lake St. Clair to Fighting Island, is almost entirely open-water habitat, whereas the lower river is shallower and open-water habitat is found mostly in the navigation channels. Few fishes spawn in the open-water habitat, which partly explains the relative lack of spawning in the upper river.

Littoral -- Littoral habitats are shallower than 3 m. Current velocities are moderate, and beds of submersed macrophytes or rocky shoals may be present. These habitats occur in the upper river around Belle Isle, Peach Island, the Scott Middle Ground, and in patches along steep shorelines. In the lower river, littoral habitat is abundant around the many islands, in shallow mid-river areas, and along irregular shorelines of the river. The macrophytes in these areas provide cover and food for the fish. Almost all fish species in the river utilize the littoral habitat.

Emergent Wetland -- Emergent wetlands occur in shallow areas with low current velocities. They contain thick beds of emergent macrophytes and an understory of submersed macrophytes also may be present. In the upper river, emergent wetlands are found on Belle and Peach islands. In the lower river, emergent wetlands are more abundant, occurring around most islands and in patches along the river bank. Large emergent wetlands are located at Fighting Island, Grosse Ile, Celeron Island, Turkey Island, and Hickory (Meso) Island. Emergent wetlands are usually contiguous with littoral habitats that contain beds of submersed macrophytes, and both habitats support similar fish communities, which include most of the species found in the river.

Tributary -- Tributaries to the Detroit River include the Rouge River, Ecorse River, Canard River and several smaller creeks. The Ecorse and Rouge rivers are heavily polluted (Manny et al. 1988).

Recorded movements of fish in the river mainly involve non-resident species that spawn in or migrate through the river. Non-residents that spawn in the river or its tributaries include lake sturgeon, alewife, gizzard shad, rainbow smelt and burbot. Lake herring, lake whitefish, and lake trout also once entered the river to spawn. In the spring and summer, large numbers of fish larvae drift out of the river into Lake Erie. Many of these larvae originate from spawnings in Lake Huron and the St. Clair system (Muth et al. 1986). The most abundant larvae in the drift are rainbow smelt, gizzard shad, yellow perch, and alewife (Hatcher and Nester 1983).

Spawning and Nursery Areas

Goodyear et al. (1982) summarized records of fish spawning in the Detroit River (Fig. 27, Table 12). Open-water habitats of the lower river channels are used for spawning by freshwater drum. Most other species spawn in the emergent wetland and littoral habitats near islands and shorelines of the lower river. Particularly diverse spawning areas are located at Stony Island, Elba Island, Hickory (Meso) Island, Sturgeon Bay, and Milleville Beach. Little information exists on spawning in the tributaries.

The littoral, emergent wetland, and tributary habitats of the Detroit River serve as nursery areas for species spawning in these areas. Open-water habitats may also be considered nursery habitat because in the spring and summer they contain large numbers of fish larvae from spawnings in the river, its tributaries, and the St. Clair system.

Effects of Altered Water Levels

Effects on Fish Habitat

The effects of water level changes on the upper river are estimated using NOAA-NOS Chart 14853 (8th Ed. April 14, 1979) for the Detroit River, Lake St. Clair, and the St. Clair River. The scenario being considered is one in which water levels in the river respond to changes of ±1 m in the level of Lake Erie. Because the river has a fall of only 0.9 m, changes of ±1 m would affect water levels throughout the river.

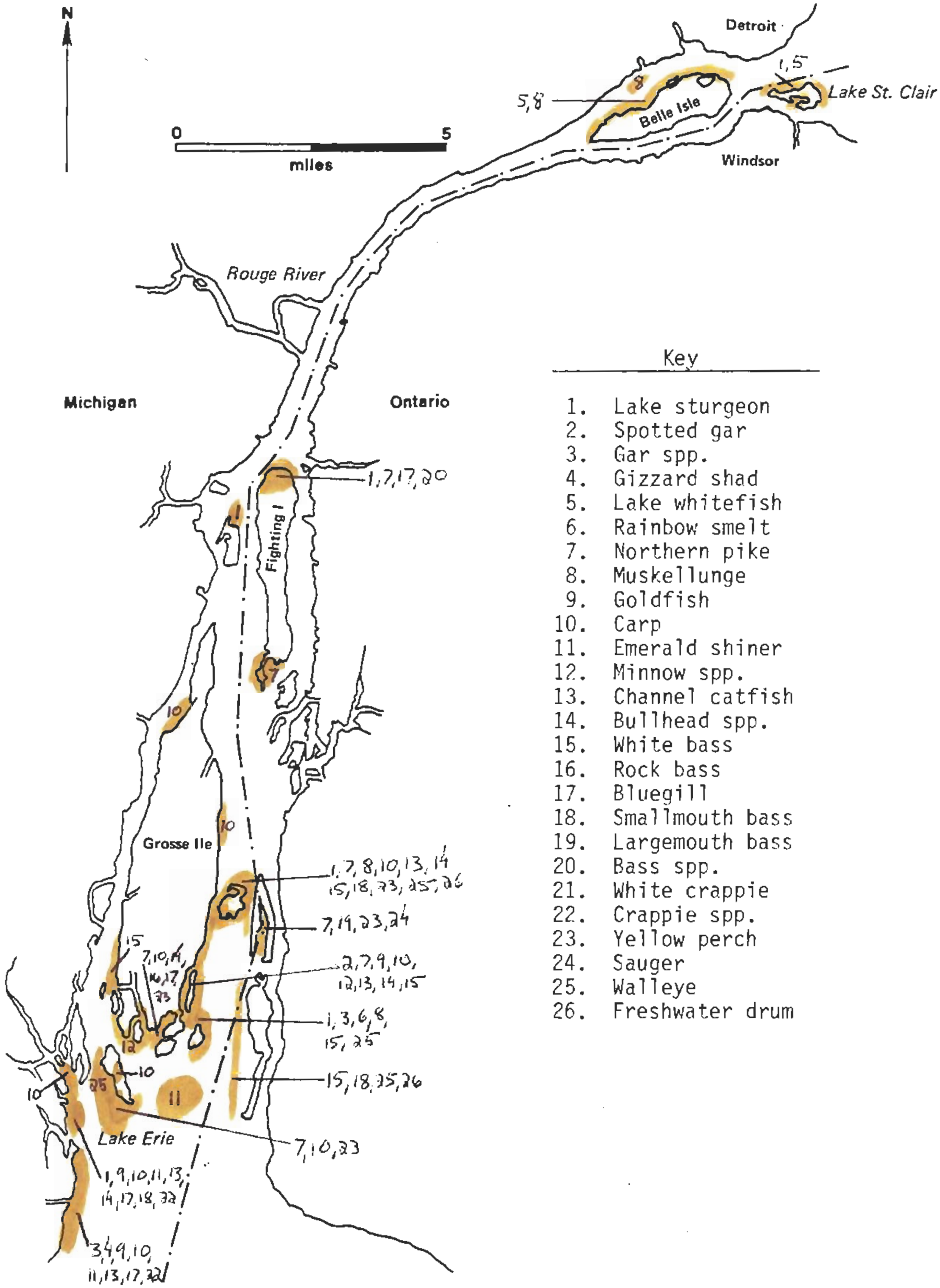


Figure 27. Fish spawning areas in the Detroit River (Goodyear et al. 1982).

Table 12. Fishes that spawn in the Detroit River (Goodyear et al. 1982; R. Haas, Mich. Dep. Nat. Resour., pers. comm.).

Lake sturgeon	Trout-perch
Spotted gar	Burbot
Longnose gar	Brooksilverside
Bowfin	White bass
Alewife	Rock bass
Gizzard shad	Green sunfish
Lake herring	Pumpkinseed
Lake whitefish	Bluegill
Lake trout	Smallmouth bass
Rainbow smelt	Largemouth bass
Northern pike	Black crappie
Muskellunge	White crappie
Goldfish	Johnny darter
Carp	Yellow perch
Emerald shiner	Logperch
Spottail shiner	Sauger
White sucker	Walleye
Northern hog sucker	Freshwater drum
Channel catfish	Fourhorn sculpin
Stonecat	

Peach Island -- A 1-m water level reduction in this area (Fig. 28) would dewater a broad littoral shelf along the extreme southwestern shore of Lake St. Clair at the head of the Detroit River. Also dewatered would be littoral areas around Peach Island, and an emergent wetland on Peach Island. A 1-m water level increase could inundate this wetland and perhaps flood low areas of the island. Open-water habitat in this area would not be dewatered but shallow littoral areas would come close to the surface with a 1 m water level reduction.

Belle Isle -- Small patches of littoral habitat around Belle Island and along the river banks would be dewatered by a 1-m water level reduction (Fig. 29). A larger littoral area in the Scott Middle Ground, where muskellunge spawn, would also be dewatered. Most of the littoral area around Belle Isle where muskellunge and lake whitefish have been known to spawn would not be dewatered. A 1-m water level increase could flood some areas on Belle Isle. Better topographic information is needed to identify specific areas that would be flooded.

Detroit - Windsor -- The Detroit River at the cities of Detroit and Windsor has bulkheaded or very steep banks (Fig. 30). The river in this area is almost entirely deep, open water habitat and no fish spawning has been recorded here. Water level changes (±1 m) would have little effect on the habitat in this area.

Zug Island -- (Fig. 31). The Detroit River near the mouth of the River Rouge is almost entirely deep, open-water habitat. Small patches mostly around Zug Island may be dewatered. No fish are known to spawn here. Water level changes would have little effect on the habitat in this area.

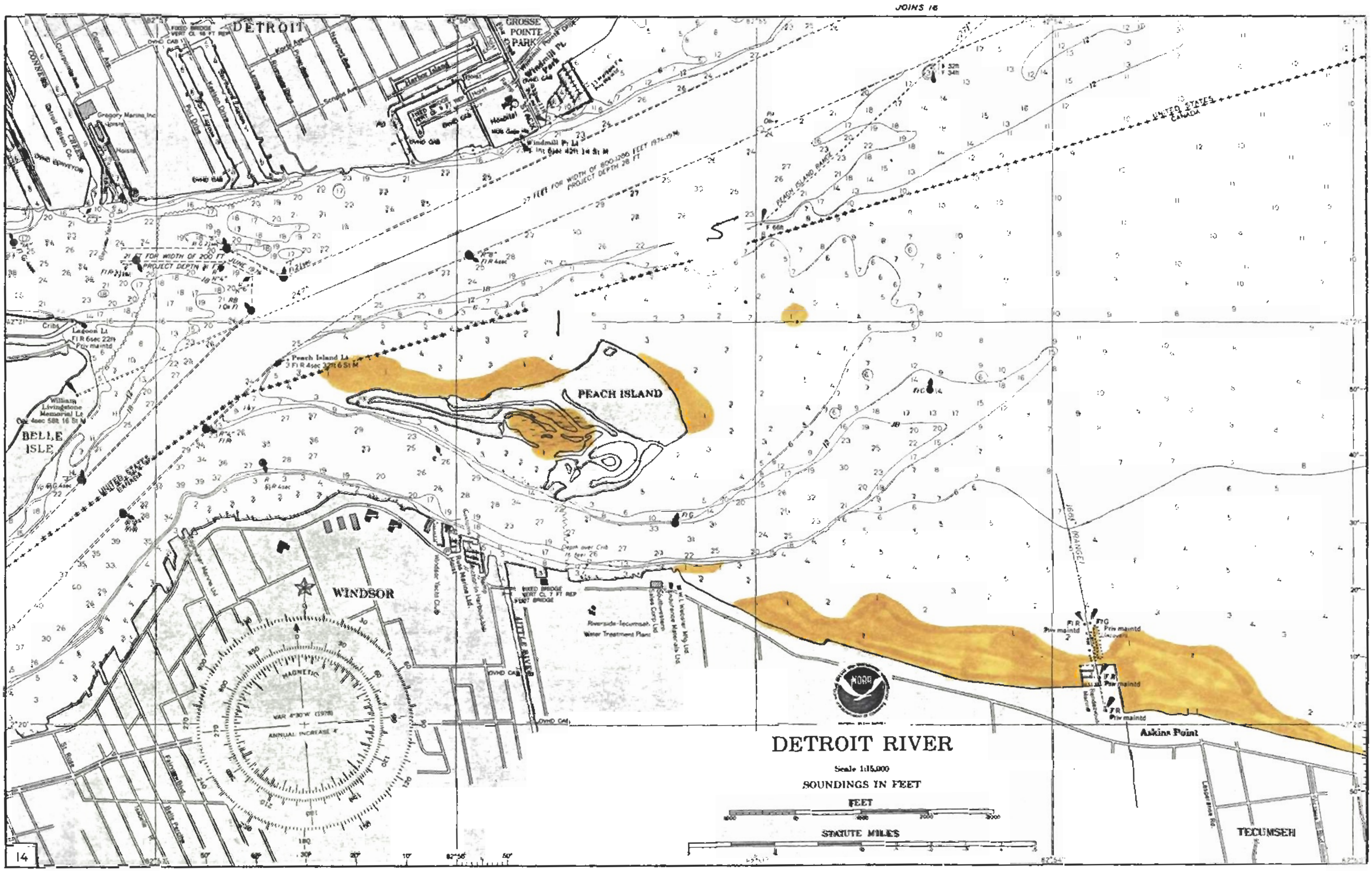


Figure 28. Fish habitat (blackened areas) near Peach Island potentially affected by water level alterations in Lake Erie. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 27.

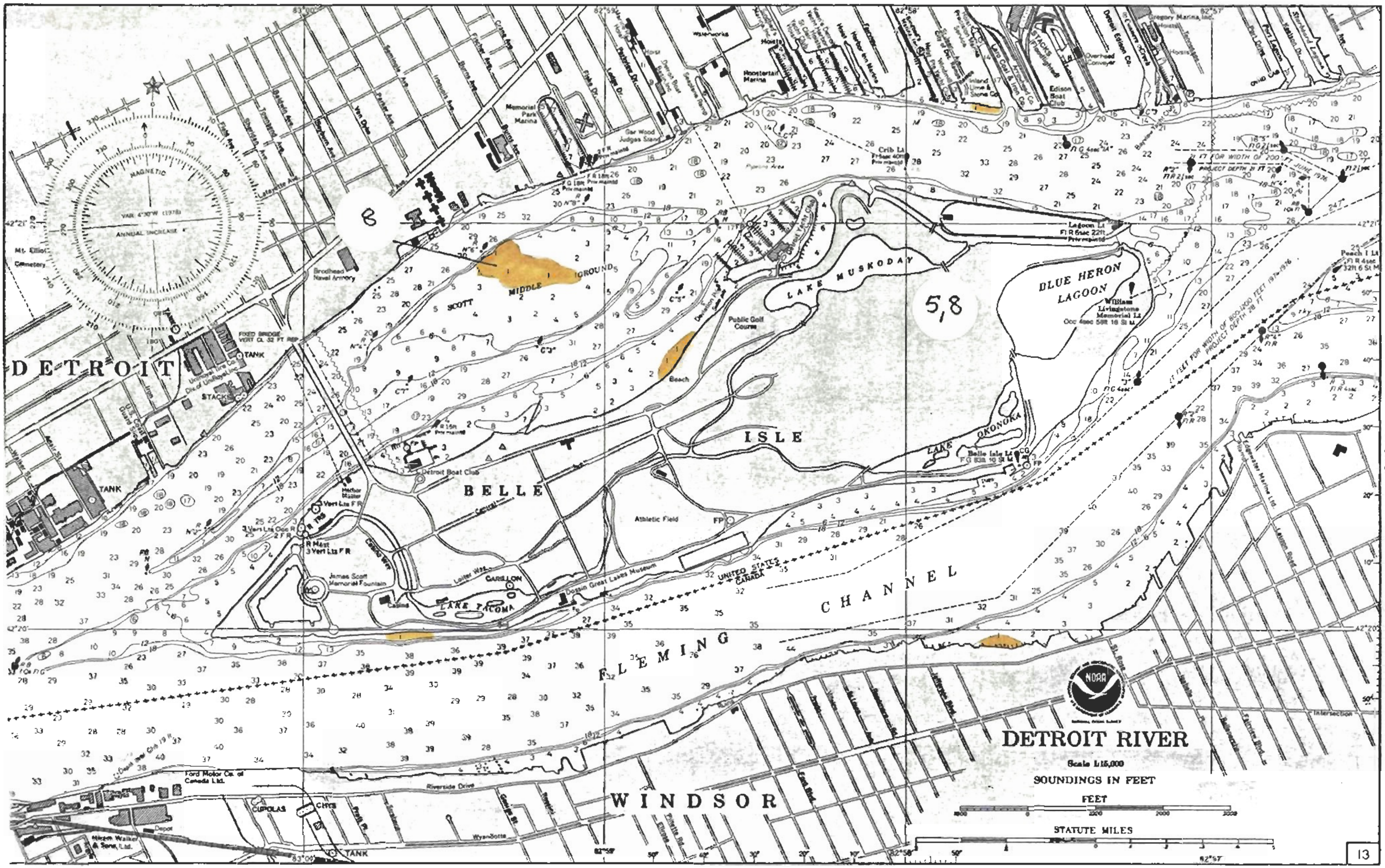


Figure 29. Fish habitat (blackened areas) near Belle Isle potentially affected by water level alterations in Lake Erie. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 27.

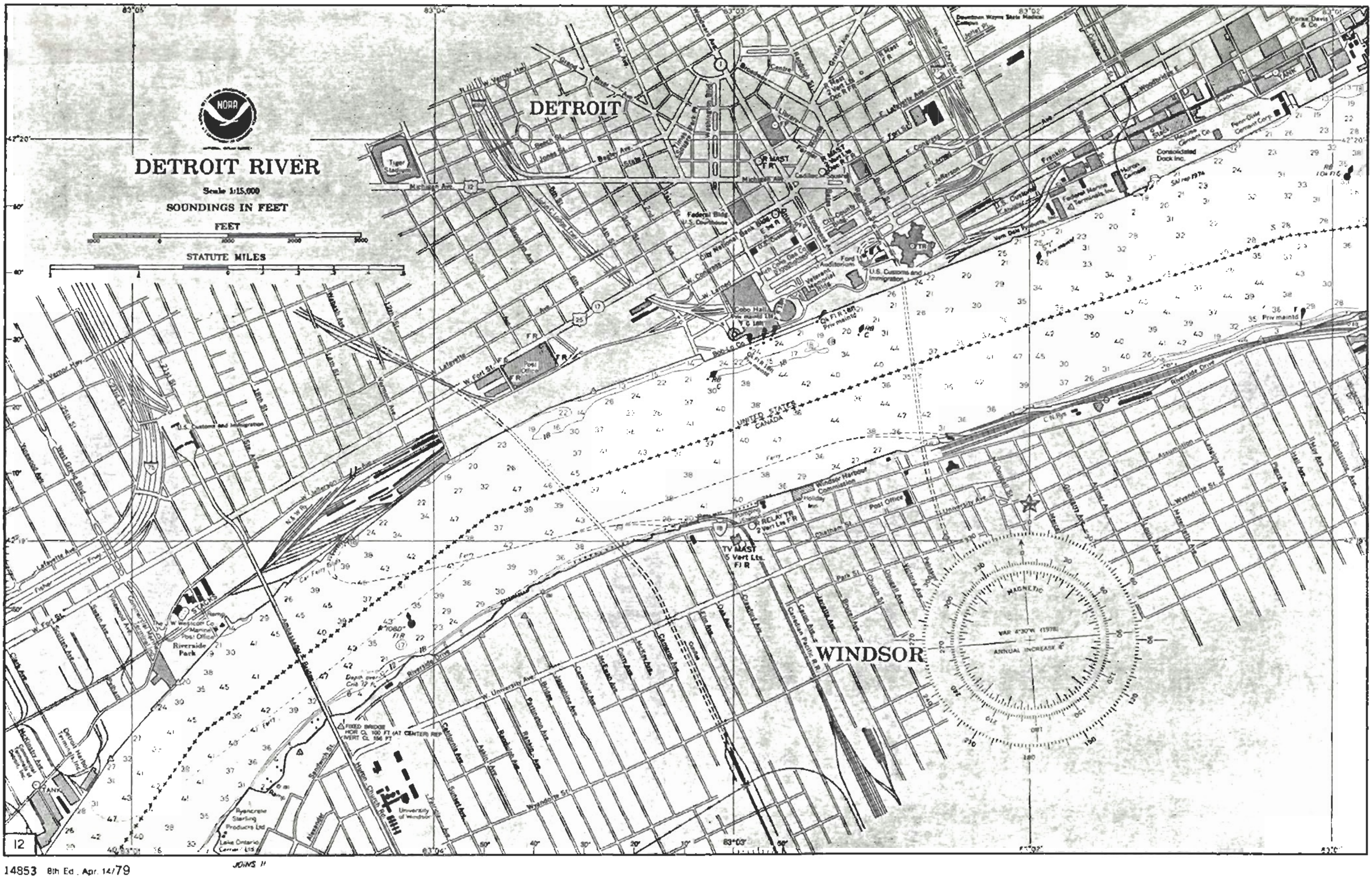
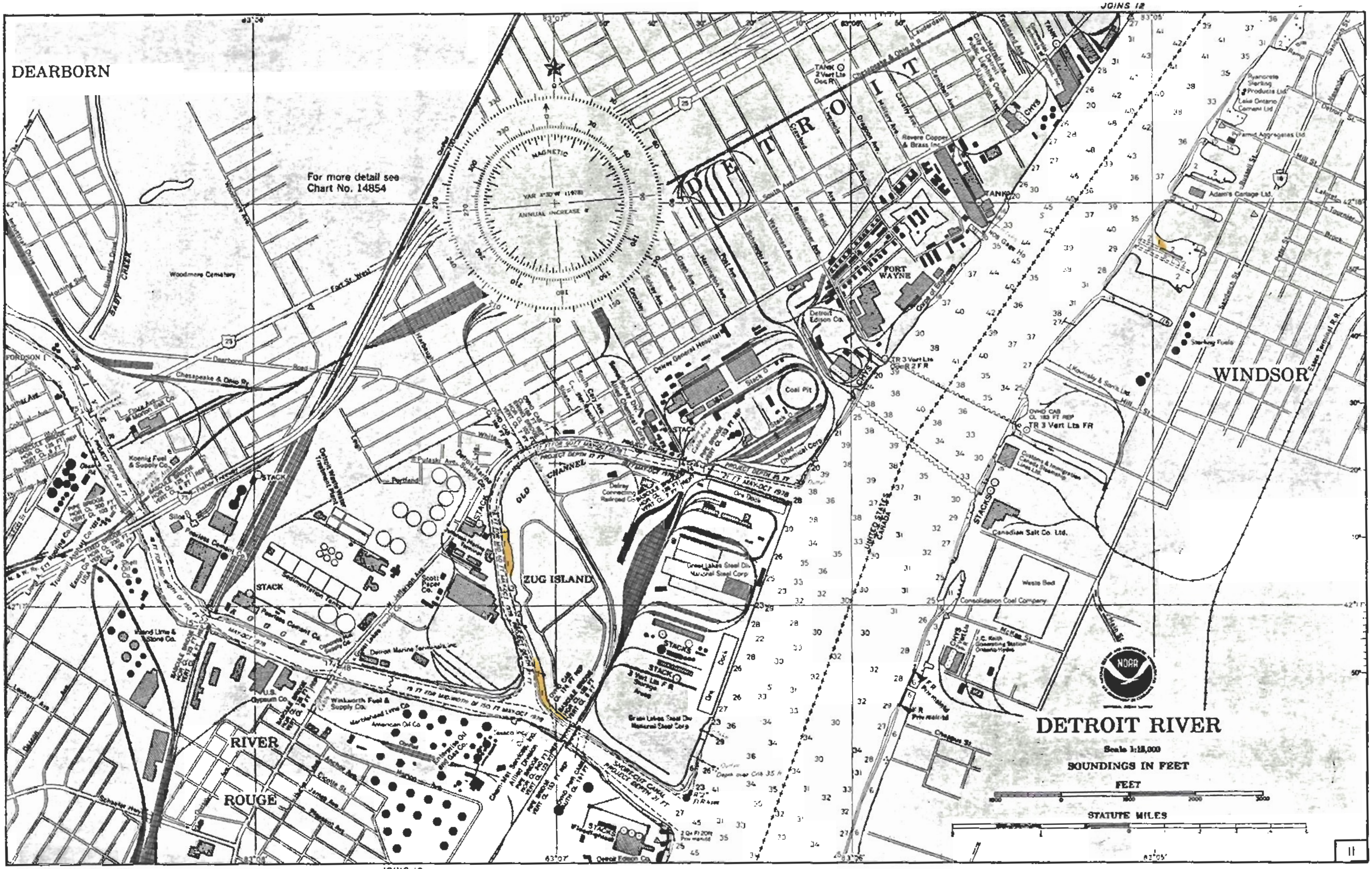


Figure 30. Fish habitat (blackened areas) near Detroit - Windsor potentially affected by water level alterations in Lake Erie. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 27.



14853 8th Ed., Apr. 14/79

Figure 31. Fish habitat (blackened areas) near Zug Island potentially affected by water level alterations in Lake Erie. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 27.

River Rouge -- A 1-m water level reduction in the area of River Rouge (Fig. 32), Michigan would cause dewatering of patches of littoral habitat on both shorelines and at the northern tip of Fighting Island (Fig. 33). Emergent wetlands at the mouth of Turkey Creek and north Fighting Island are succeptible to flooding and dewatering. Most of the river in this area is open-water habitat and would not be affected by water level changes of ±1 m.

Fighting Island -- In the vicinity of northern Fighting Island, littoral, emergent wetland, and open-water habitats are all abundant (Fig. 33). A 1-m water level reduction in this area would dewater most of the emergent wetland habitat on Fighting Island, Grass Island, and patches of emergent wetland along the Canadian shore. Large areas of littoral habitat in the shallow areas surrounding Fighting, Grass, and Grassy islands would be dewatered, as would large patches along the Canadian shoreline. A 1-m water level increase in this area would increase littoral areas by flooding lowlands and inundating emergent wetlands. Emergent wetland habitat in this area would be greatly decreased by a 1-m water level rise.

Emergent wetlands of northern Fighting Island, which are used for spawning by northern pike, bluegill, and black bass would be affected by either an increase or decrease of water level by 1 m. Lake sturgeon spawn in open-water habitat at a depth of about 9 m just north of Fighting Island. Water level changes of ±1 m would not interfere with this sturgeon spawning habitat, except perhaps by increasing or decreasing the current velocity.

Grosse Ile -- A 1-m water level reduction in this area would dewater emergent wetlands at Stony Island, northwest Grosse Ile, Turkey Island, south Fighting Island, and much of a large bed along the Canadian shore north of the

Figure 32. Fish habitat (blackened areas) near River Rouge potentially affected by water level alterations in Lake Erie. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 27.

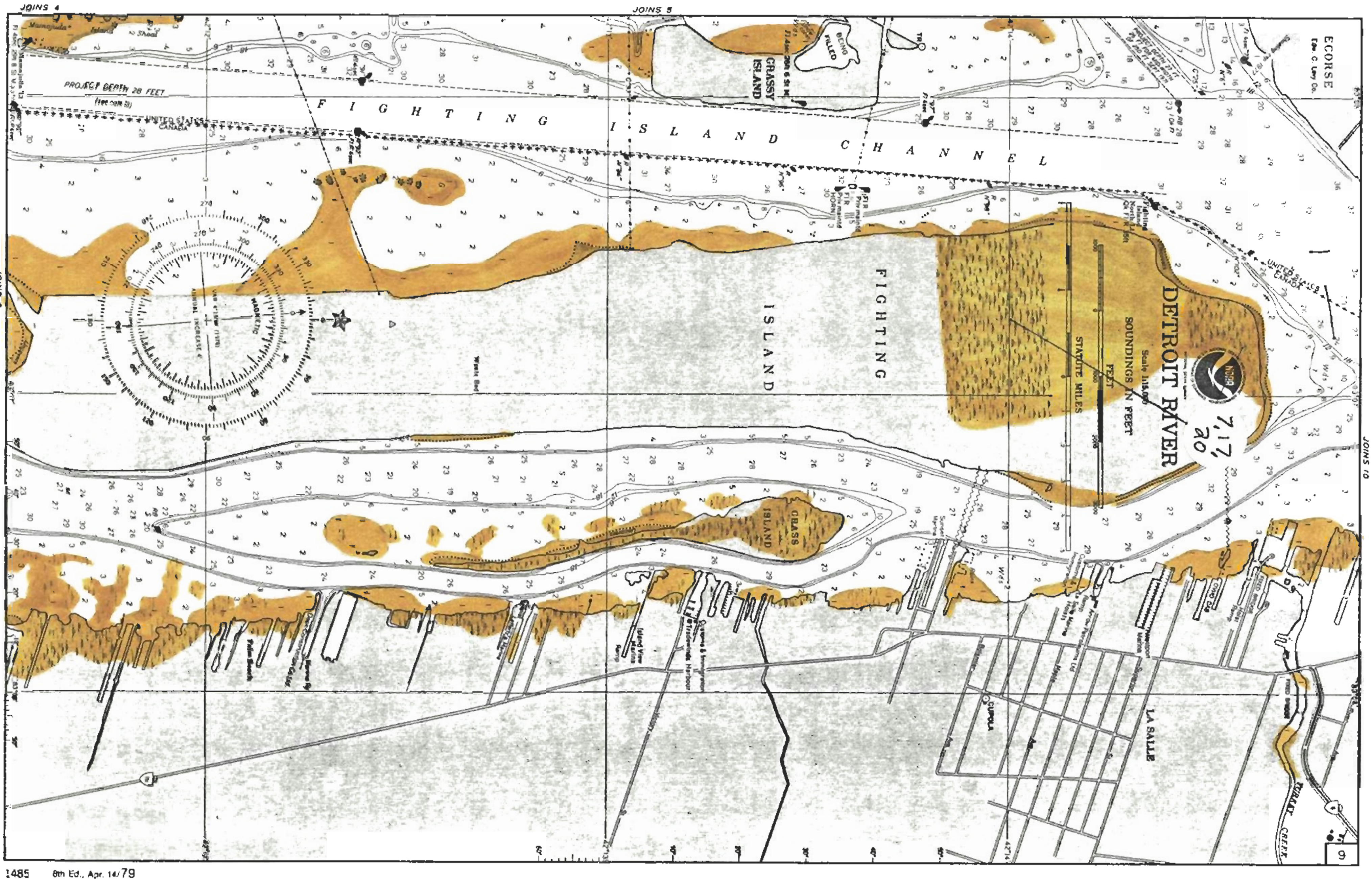


Figure 33. Fish habitat (blackened areas) near Fighting Island potentially affected by water level alterations in Lake Erie. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 27.

Canard River (Fig. 34). Littoral habitats in these areas and at isolated shoals would also be dewatered. A 1-m water level increase would flood emergent wetlands converting many of them to littoral habitat. Low areas on the islands and near the Canadian shore would also be converted to littoral habitat.

Carp spawning areas around Grosse Ile and northern pike spawning grounds in the marshes of southern Fighting Island would be partially dewatered. Eleven species spawning around Stony Island would benefit from a level increase but, a 1-m drawdown would dewater some emergent wetland habitat.

Southern Grosse Ile -- A reduction of the water level around southern Grosse Ile by 1 m would expose littoral areas around islands and rocky shoals (Fig. 35). Large littoral and emergent wetland areas in Gibraltar Bay and Elba Bay would be dewatered. A 1-m water level increase would flood emergent wetlands in these areas. Better topographic information is needed to determine the extent of flooding on the islands resulting from a 1-m water level increase. Crystal Bay is a spawning area for northern pike, goldfish, and yellow perch. Crystal Bay is also the only known sauger spawning habitat in the Detroit River. A 1-m water level reduction would not dewater any of Crystal Bay, but most of it would become very shallow and vulnerable to short term, wind-driven fluctuations. Seventeen species spawn in the littoral and emergent wetland habitats around and between Sauger, Elba, and Hickory (Meso) Islands. Some spawning habitat around Sauger Island and large areas around Elba and Hickory (Meso) Islands would be dewatered. Flooding in this area would benefit the species using littoral habitats, but species using emergent wetlands including northern pike, carp, and goldfish would suffer habitat loss

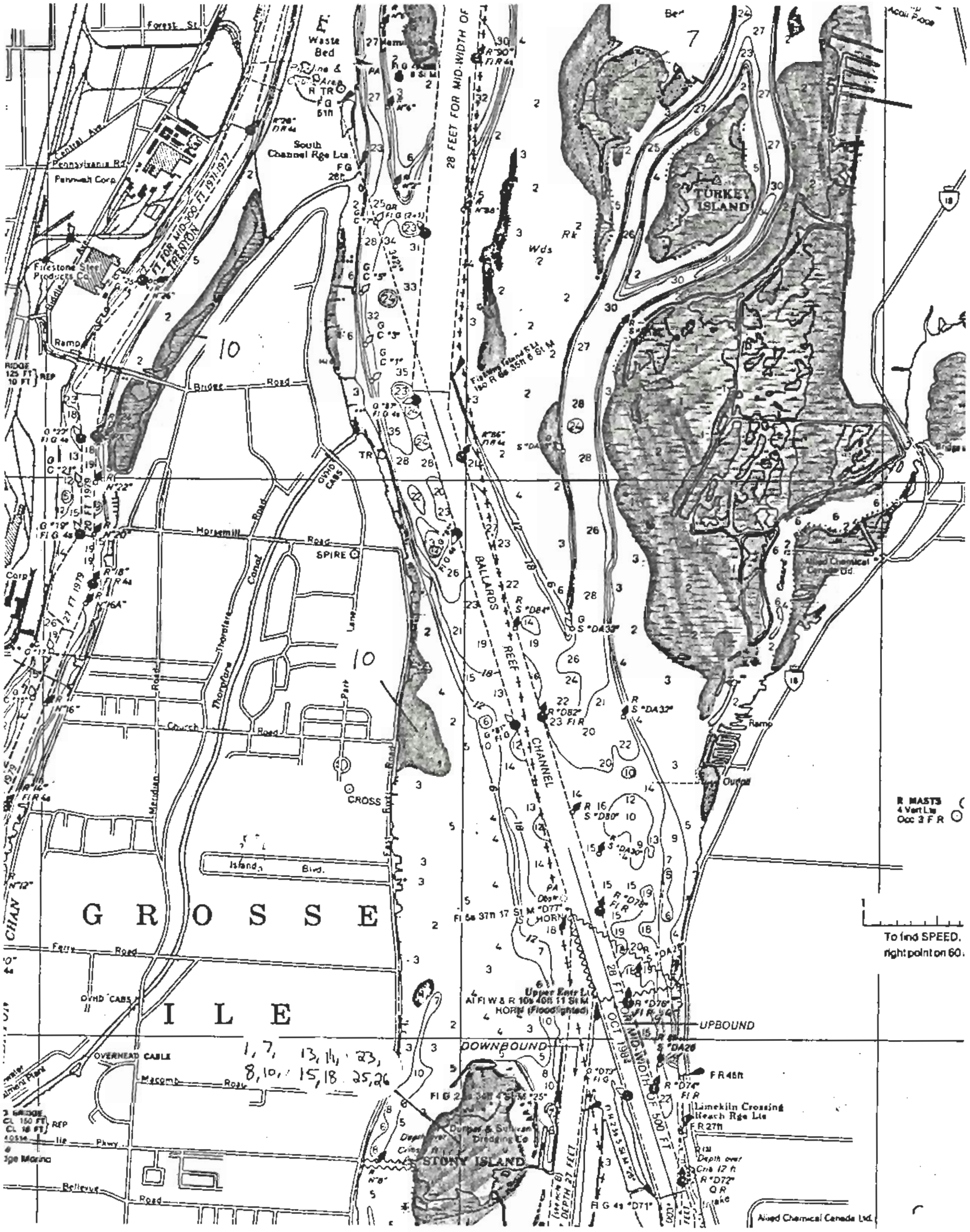


Figure 34. Fish habitat (blackened areas) near Grosse Ile potentially affected by water level alterations in Lake Erie. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 27.

Figure 35. Fish habitat (blackened areas) near Southern Grosse Ile potentially affected by water level alterations in Lake Erie. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 27.

from emergent wetland inundation. Emerald shiners spawn in deeper littoral areas south of Hickory (Meso) Island. Like the littoral habitat of Crystal Bay, this habitat would not be dewatered by a 1-m water level reduction, but it would become more vulnerable to wind-driven drawdowns. Unspecified species of minnows spawn at the south west tip of Grosse Ile in waters less than 1.2 m deep. A 1-m water level reduction would seriously impact this spawning area, but a 1-m increase would augment the habitat. White bass spawn in littoral habitat on the west side of Grosse Ile. A 1-m water level decrease would partially dewater this spawning habitat.

Celeron Island -- Most of the river in this area is littoral habitat (Fig. 36). Emergent macrophyte beds are found on Celeron Island and in backwater areas along the U.S. shore. Carp, northern pike, and yellow perch spawn in the littoral habitat immediately surrounding the southern tip of Celeron Island. This littoral area and a contiguous emergent wetland on the island would be partially dewatered by a 1-m water level reduction. A 1-m increase here would expand this spawning habitat onto the island. Carp spawn in a pond on Celeron Island. Better bathymetric and topographic information is needed to determine the fate of this pond if river water levels change. Carp also spawn in the backwater area at the mouth of Brownstone Creek. More than 50% of this littoral area would be dewatered by a 1-m drawdown. Flooding would result from 1-m increase in lake level and would increase the spawning area. Walleye spawn in a strip of open-water and deep littoral habitat that extends from Celeron Island north to the Trenton Channel power plant. Water level changes of ±1 m would not affect the habitat in this area. A broad littoral shelf extends along the U.S. shore south of Celeron Island. A

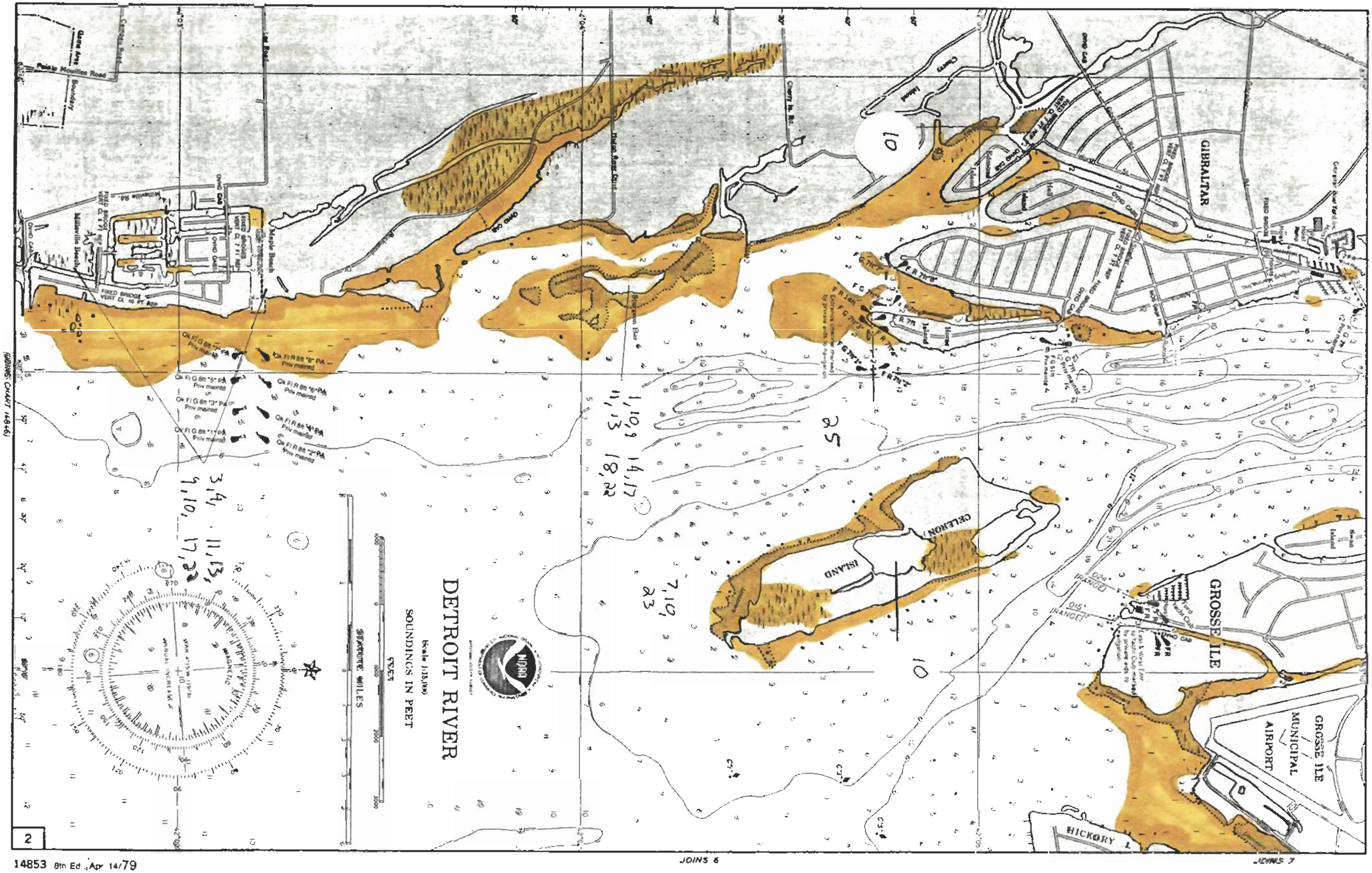


Figure 36. Fish habitat (blackened areas) near Celeron Island potentially affected by water level alterations in Lake Erie. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 27.

variety of species spawn in this area at Sturgeon Bar, Maple Beach, and Milleville Beach. Dewatering caused by a 1-m level reduction would be extensive, and a rocky shoal and an emergent wetland at Milleville Beach would be entirely exposed. Flooding in this area caused by a 1-m water level rise could add to these spawning areas.

Grassy Island -- A 1-m water level reduction in this area would dewater large habitat areas on and around Fighting Island (Fig. 33), Mud Island, and Grassy Island (Fig. 37). A rocky shoal to the south near Grosse Ile would also be dewatered. Lake sturgeon spawn north of Grassy Island at a depth of 9 m. Water level changes (±1 m) would have no adverse effects on this open-water spawning habitat, except perhaps to alter the current velocity.

Livingstone Channel -- The channel is a spawning area for white bass, smallmouth bass, walleye, and freshwater drum (Fig. 38). Because this open-water habitat is about 8 m deep, water level changes of ±1 m would not affect the spawning habitat, except by altering the current regime. A 1-m reduction could introduce a need for dredging in the channel. Dredging could remove essential substrate along channel shoulders, killing macrozoobenthos, and resuspending contaminated sediments.

Effects on the Food Web

Primary production in the Detroit River is probably dominated by submersed macrophytes, because phytoplankton is flushed from the river before it can contribute significantly to fish production (UGLCCS 1988). Sewage treatment plants have added more organic matter to the Detroit River than

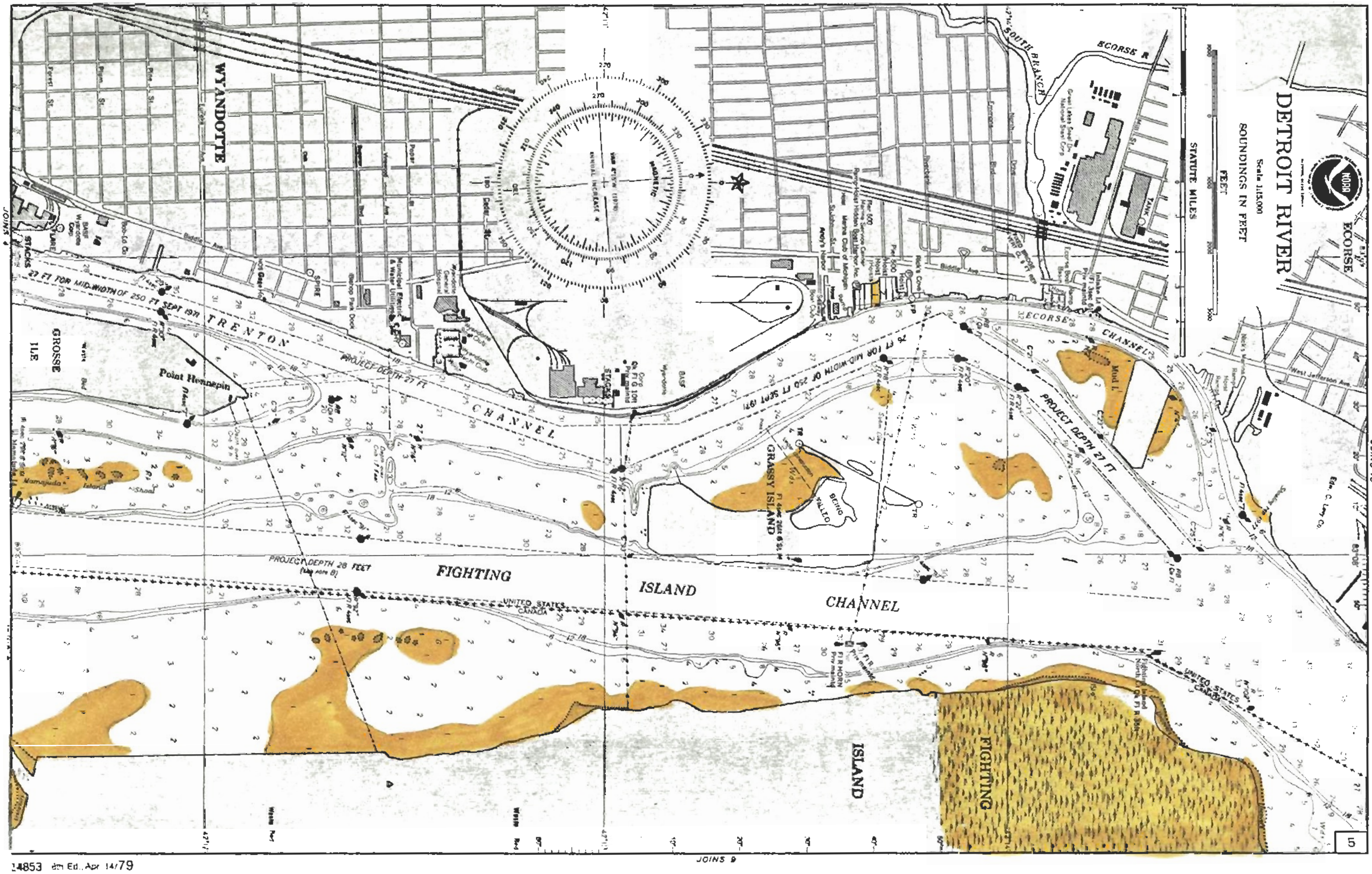


Figure 37. Fish habitat (blackened areas) near Grassy Island potentially affected by water level alterations in Lake Erie. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 27.

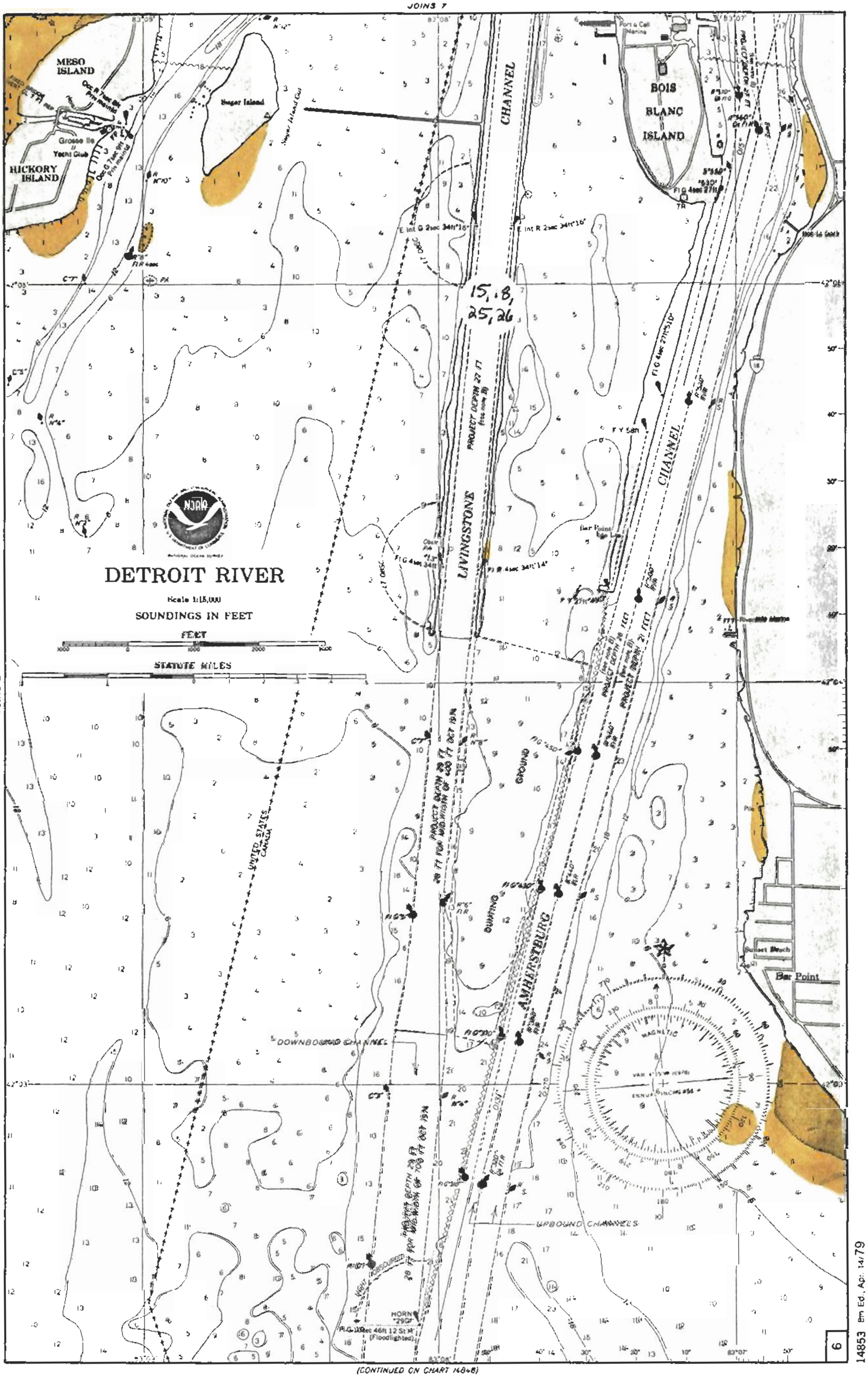


Figure 38. Fish habitat (blackened areas) near Livingstone Channel potentially affected by water level alterations in Lake Erie. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 27.

primary producers for a least 30 years (Manny et al. 1988), but the contribution of this organic matter to fish production in the river has not been investigated. Grazing of submersed macrophytes appears to be minimal in the Detroit River and most of the macrophyte production that ultimately supports fish production in the river is probably utilized, as detritus, by benthic invertebrates.

Submersed macrophyte distribution in the Detroit River is limited by turbidity (Hudson et al. 1986) and a 1-m rise in the level of the river would probably eliminate much of the existing community that could not migrate to new shallow-water areas created by shoreline flooding. Emergent macrophyte habitat would be reduced without replacement, because much of the shoreline of the river is already severely modified and unsuitable for the production of submersed or emergent plants. Thus, a water level elevation of 1 m would threaten much of the remaining plant community. Reduced current velocity resulting from a 1-m water level increase on Lake Erie would stimulate production in the river by increasing consumption of drifting detritus, phytoplankton, and zooplankton. Deposition of suspended organic matter and nutrient sewage would also increase. The increased depth and width of the river would reduce the physical damage and the flushing of biota and nutrients that result from ship passage in a narrow river channel.

A 1-m water level decrease on Lake Erie would dewater both littoral and emergent wetlands and would cut production of submersed and emergent macrophytes and the organisms that rely on them. Littoral and emergent wetland habitat would be smaller and closer to the navigation channel. These habitats would be more easily affected by ship passage. Increased current velocity would increase the flushing or phytoplankton, zooplankton, and detritus from the river. The effects of changed (±1 m) water level on the Detroit River ecosystem would be most severe from Fighting Island to the mouth of the river where most littoral and emergent wetland habitats are found.

Effects on Existing Use-Conflicts

Navigation -- The Detroit River is the busiest waterway in the Great Lakes system (Manny et al. 1988). To accommodate this vessel traffic, a number of channels have been dredged in the shallow, lower half of the river south of Fighting Island. The passage of ships through the river and its channels has a number of effects on the biota of the river and water levels in the river can affect the severity of these effects.

The shallow reaches in the Detroit River are the locations of littoral and emergent wetland habitats. A 1-m water level reduction would result in a narrowing of the river by dewatering its shallow reaches. This, in turn, would move littoral and wetland habitats closer to the navigation channels, where waves generated by passing ships could uproot macrophytes and make it difficult for macrophyte communities to remain established (Schnick et al. 1982). Turbidity caused by passing ships and by navigation-related dredging reduce light penetration, thus limiting macrophytes to shallower locations. Ship passage can increase mortality of fish in littoral and wetland habitats through dewatering (Holland 1987; Wuebben 1979) and smothering of eggs. The resuspension of contaminated sediments by vessels is a potential threat to the biota of the river. A 1-m water level reduction would decrease nutrient spiraling because passing ships would sweep more detritus from these habitats into the main current drift, where it would be more easily flushed out of the system. Nutrient spiraling would also be reduced by the higher current velocities caused by water level reduction.

Navigation-related impacts on the fish and fish habitat generally would be lessened by a 1-m rise in water level.

Water Withdrawal -- In 1982 the Detroit River contained at least 30 operational water intakes (IJRT 1982). Intakes are located throughout the river, but are most concentrated on the U.S. shore near Zug Island and in the Trenton Channel. A 1-m water level increase on Lake Erie would widen and deepen the river and provide new littoral habitat. These changes would help fish larvae avoid intakes, especially in the river below Fighting Island. Near Zug Island the river would deepen, but widening and development of littoral and emergent wetland habitat would be prevented by bulkheading. Lowered water currents would increase the exposure of drifting fish larvae to entrainment.

If water levels decreased by 1 m, the abundance of littoral and emergent wetland resting areas would also decrease. Entrainment would be increased, especially near Zug Island where the river is narrow and no littoral or emergent wetlands occur.

The richest spawning areas of the Detroit River are located downriver, away from the water intakes on the mainland. The fish most vulnerable to entrainment are the abundant forage species that drift downriver from spawnings in the St. Clair River, Lake St. Clair and the upper Detroit River.

Rainbow smelt, gizzard shad, and alewife are the most common larvae drifting in the river (Hatcher and Nester 1983). Less common species that spawn in the Detroit River above Zug Island are lake sturgeon, lake whitefish and muskellunge (Goodyear et al. 1982). Species that spawn between Zug Island and Grosse Ile are lake sturgeon, northern pike, minnows, bluegill, carp, and bass (Goodyear et al. 1982). Because these species are not highly abundant, losses of relatively few individuals would significantly impact their populations.

Waste Discharge -- The waters of the Detroit River are polluted by a variety of organic chemicals, heavy metals, and conventional pollutants. In 1986 there were at least 75 point source discharges in the Detroit River releasing $9{,}233 \times 10^3$ m^3/day (UGLCCS 1988). Water is polluted most heavily along the Detroit City shoreline and at the mouths of the Rouge and Ecorse rivers. The cleanest water is found in the upper river and at mid-channel in the lower river (Manny et al. 1988). Fish spawning areas of the lower river east of Grosse Ile are less threatened by water pollution than those south and west of the island.

Because the water level scenario being considered is one in which levels are controlled from Lake Erie, changes of ± 1 m will not effect the dilution of contaminants. A 1-m water level reduction would decrease the width and depth of the lower river and increase the current velocity. These changes would flush effluents from the river more quickly. Flow modelling would be needed to determine if the greater portion of the effluent would remain in the Trenton Channel or spread to the east of Grosse Ile to impact the littoral and emergent wetland spawning areas in that area.

A 1-m water level increase on Lake Erie would increase contaminant deposition and the exposure of the organisms of the river to these contaminants.

Flow modeling would be needed to verify that the Detroit contaminant plumes would remain concentrated along shore and west of Grosse Ile.

The effects of these water level changes on tributary habitats is uncertain, but presumably the high concentrations of effluent discharged from the Rouge and Ecorse rivers would continue to degrade water quality in the Detroit River.

THE NIAGARA RIVER

Background

The Niagara River is the 60-km connecting channel that flows north draining Lake Erie into Lake Ontario (Fig. 39). The 99.3 m fall of the river is the greatest in any of the Great Lakes connecting channels. Most of this (55.4 m) fall occurs over the Niagara Falls, which divide the river into physically and biologically distinct upper and lower reaches. The upper river contains several islands, the largest of which, Grand Island, separates much of the upper river into 2 channels. The upper river has shallow bays, rocky shoals, and dense macrophyte beds. From the head of the river to Squaw Island, the river is narrow with fast but variable currents and a rocky substrate (GLBC 1975). The lower river is deep and swift and supports narrow patches of aquatic vegetation (Goodyear et al. 1982). Rapids make much of the lower river unnavigable, from the falls to Lewiston, New York. The shores of the Niagara River are heavily developed and the river serves industries, municipalities, hydro-electric generating facilities, and recreation, tourism.

The average flow of the river is 5,605.4 m^3/s (USACE 1984). Modification of the flow through the river has been extensive. A 6.4-m navigation channel and a second shallower channel have been dredged in the upper river providing access to the cities of Buffalo, Tonawanda, North Tonawanda, and Niagara Falls along the U.S. shoreline. These channels also provide access to the New York State Barge Canal System. Diversions, which by-pass water around the falls and operate six hydro-electric plants in the area are the largest in the

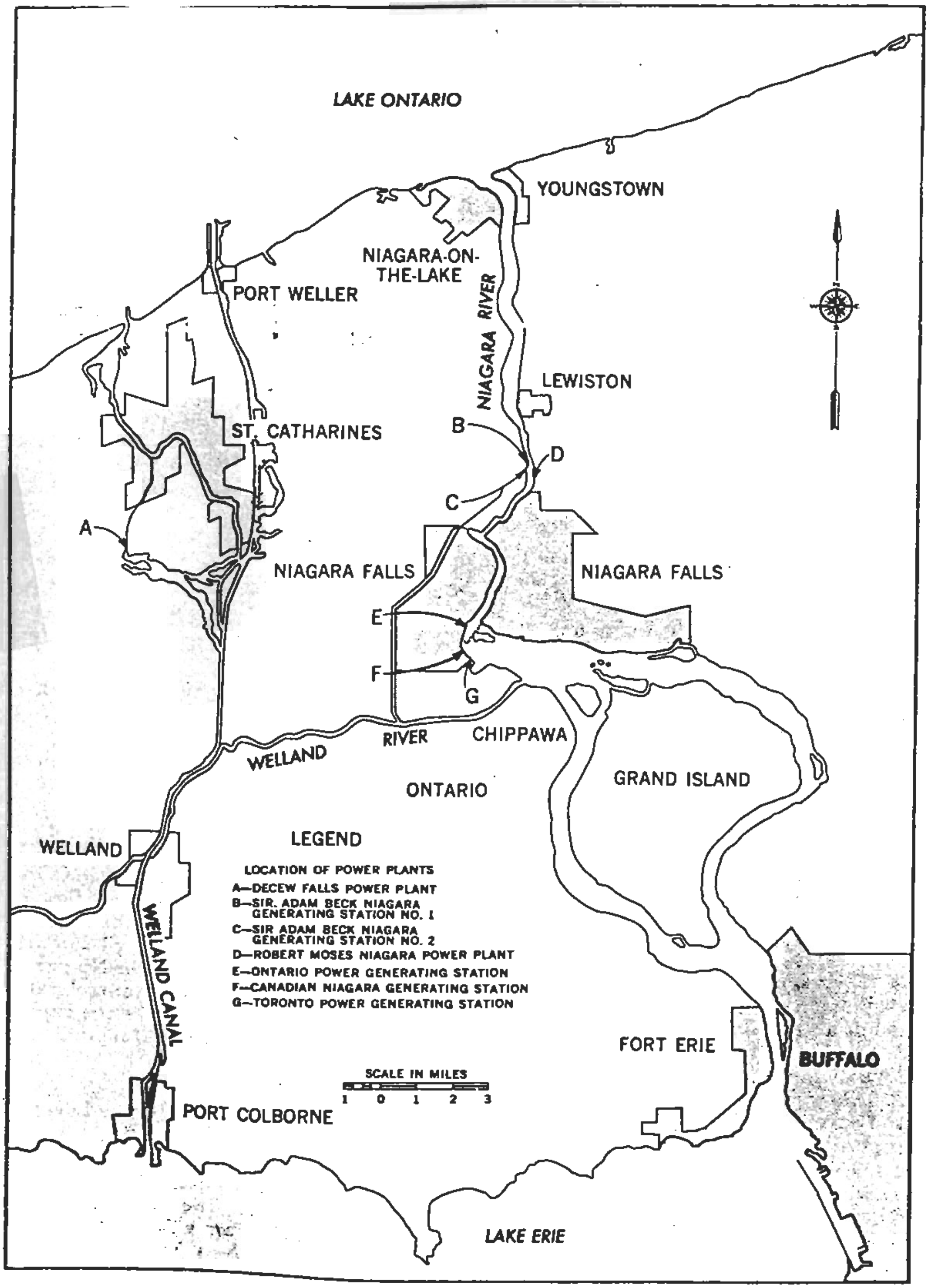


Figure 39. The Niagara River.

Great Lakes. Changes in flow through these diversions can cause large, rapid changes in water levels and flows at the falls and in the lower river (GLBC 1975). Water is also diverted into the New York State Barge Canal System and from Lake Erie to Lake Ontario through the Welland Canal. The flow through these canals totals 240.6 m^3/s (USACE 1984). Diversion through the Welland Canal has permanently lowered Lake Erie by 9.8 cm (GLBC 1975).

The Fish Community

Species Composition

Very little information exists on the fish of the Niagara River. About 80 species have been recorded for the river (Table 13). Both year-round residents and seasonal migrants inhabit the river.

Fish Distribution and Habitat Use

Fish habitats in the Niagara River include (1) open-water (2) emergent wetlands, (3) littoral habitat, (4) rapids and (5) tributaries. Use of these habitats by fish may change seasonally or with life history stage as dictated by changing requirements of temperature, cover, and food availability.

Open-water -- Open-water habitat in the Niagara River occupies water deeper than 3 m with relatively high current velocity. This habitat occurs in pools, mid-river areas, and navigation channels in the upper river. In the lower river, open-water habitat is found mid-river from about Lewiston, New

Table 13. Partial list of the fishes of the Niagara River. (Source: Goodyear et al. 1982).

Scientific name	Common name
ACIPENSERIDAE	
Acipenser fulvescens	Lake sturgeon
LEPISOSTEIDAE	
Lepisosteus osseus	Longnose gar
SALMONIDAE	
Coregonus artedi	Lake herring
Salmo salar	Atlantic salmon
S. gairdneri	Rainbow trout
OSMERIDAE	
Osmerus mordax	Rainbow smelt
ESOCIDAE	
Esox lucius	Northern pike
Esox masquinongy	Muskellunge
CYPRINIDAE	
Cyprinus carpio	Carp
Notropis atherinoides	Emerald shiner
Notropis hudsonius	Spottail shiner
Notropis heterodon	Blackchin shiner
Notropis heterolepis	Blacknose shiner
CATOSTOMIDAE	
Catostomus commersoni	White sucker
Moxostoma valenciennesi	Greater redhorse
PERCOPSIDAE	
Percopsis omiscomaycus	Trout-perch
GASTEROSTEIDAE	
Gasterosteus aculeatus	Threespine stickleback
PERCICHTHYIDAE	
Morone chrysops	White bass
CENTRARCHIDAE	
Ambloplites rupestris	Rock bass
Micropterus dolomieui	Smallmouth bass
Micropterus salmoides	Largemouth bass
PERCIDAE	
Perca flavescens	Yellow perch
Stizostedion vitreum vitreum	Walleye

York to the mouth of the river. In the open-water habitat below the hydro-electric generating stations on the lower river, water depth reaches 48.6 m. Little is known of the use fish make of this open-water habitat.

Littoral -- Littoral habitats are areas shallower than 3 m where current velocity is usually moderate and dense beds of submersed macrophytes may be present. Littoral habitats occur along shorelines and islands of the upper river, in the shallow portion of the river from Navy Island to the Falls, and along the shores of the lower river from Lewiston to Lake Ontario. River shoulders along most of the river are steep and littoral areas are narrow. Most species of the Niagara River use the cover and food resources in littoral habitats and many also spawn there.

Rapids -- Rapids in the upper river occur around Goat Island just above the Falls. Below the Falls, rapids extend roughly from the Falls to Lewiston, New York. These habitats are turbulent, shallow, rocky, and swift. Fish use of rapids habitat of the Niagara River has not been adequately studied.

Tributary -- The upper Niagara River has several small tributaries including Cayuga Creek, Miller Creek, Frenchman Creek, Black Creek, Baker Creek, Ushers Creek, Two Mile Creek, Ellicott Creek, and the Welland River. Grand Island also has small tributaries including Gun Creek, Spicer Creek, Big and Little Six Mile Creeks, Woods Creek and Burnt Ship Creek. Some of these tributaries are used by fish.

Emergent wetlands -- Most of the Grand Island tributaries support emergent wetlands (Herdendorf et al. 1981). The only other Niagara River wetlands are located at Strawberry and Motor islands.

Spawning and Nursery Areas

Records of fish spawning in the Niagara River (Fig. 40) have been summarized by Goodyear et al. (1982). In the river above the falls spawning occurs primarily in the littoral habitats and tributaries. Littoral areas with dense macrophyte beds between Grand Island and the Navy, Beaver, Motor, and Strawberry Islands are especially important spawning areas. The tributaries of Grand Island support emergent wetlands and northern pike spawn in these tributaries. All tributaries on the river are spawning areas for greater redhorse. Lake sturgeon and northern pike spawn in open-water habitat at the head of the river and northern pike also spawn in the Black Rock Canal. Little is known about fish spawning in the rapids. Littoral habitat in the upper river is also a nursery area for many fish species (Goodyear et al. 1982). In the river below the falls northern pike and smallmouth bass spawn in littoral areas and lake herring may have spawned in the rapids.

Effects of Altered Water Levels

The effects of water level changes on the upper river are estimated using NOAA-NOS Chart 14832 (28th Ed. June 13, 1981) for the upper Niagara River. The scenario being considered is one in which water levels in the upper Niagara River change in response to ±1 m changes of the Lake Erie mean level (1900-1989). Water level fluctuations on the upper Niagara River equal changes in the Lake Erie level at the head of the river and gradually diminish downstream to the area just above the falls (USDC-NOAA 1982).

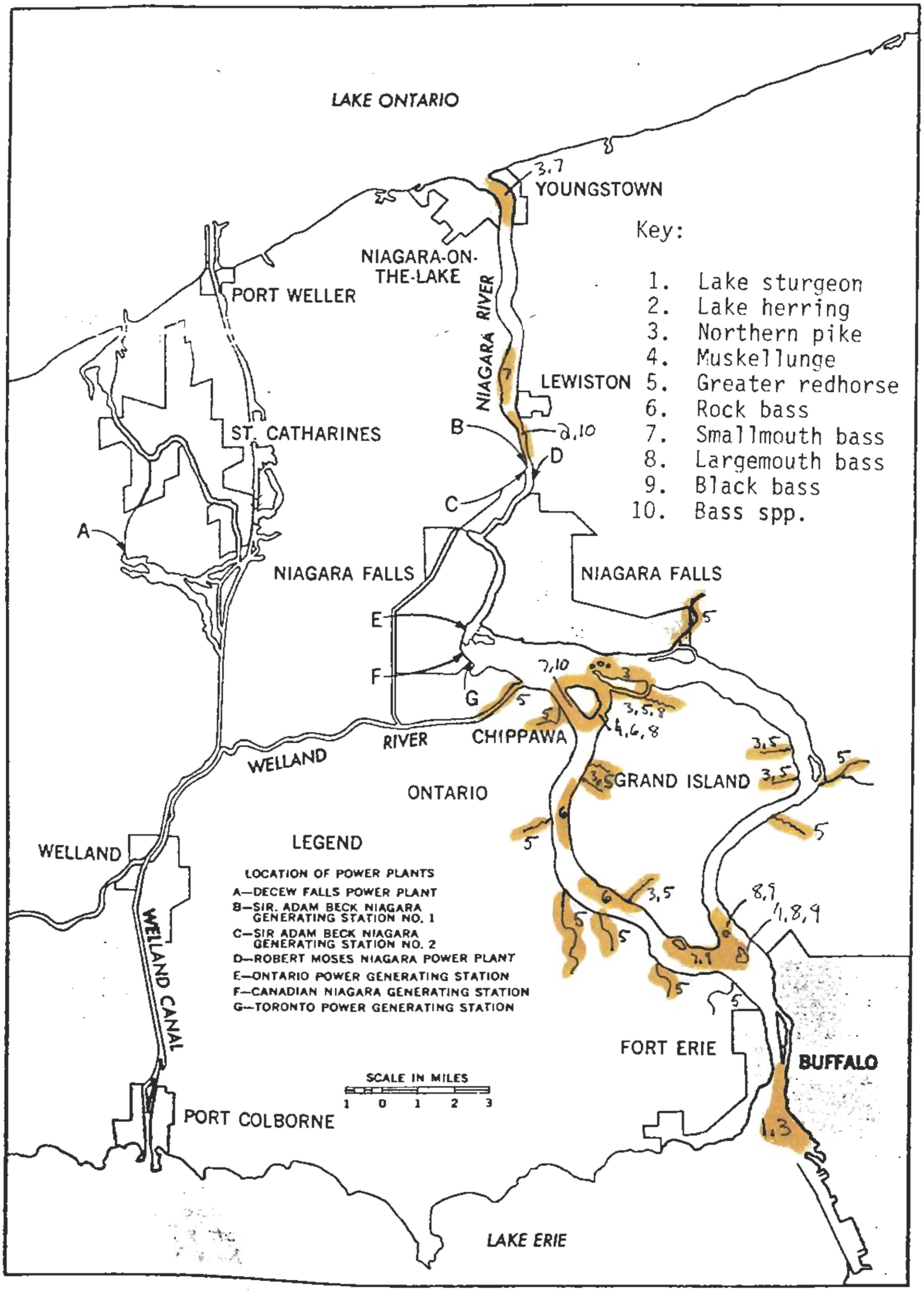


Figure 40. Spawning areas in the Niagara River. (Source: Goodyear et al. 1982).

A 1-m reduction of the Lake Erie level could result from either decreased inflow from the upper Great Lakes, increased division through the Welland Canal, or both. An increase of 1 m on Lake Erie could result from a natural, long-term increase in the flow into Lake Erie.

Lake Erie to Grand Island -- A 1-m water level reduction in this area (Fig. 41) would dewater nearshore littoral habitats at the mouth of the river around the southern tip of Grand Island, and around Beaver, Motor, and Strawberry Islands. Species spawning in this area are muskellunge, smallmouth bass, largemouth bass, and black bass. Flooding along low shorelines in this area could increase the littoral habitat available to these species. Lake sturgeon and northern pike spawning in the open water habitats off Buffalo, New York would not be affected by either an increase or decrease of water level. The effects of these changes on the tributary habitats of Frenchman and Miller creeks are uncertain. More detailed topographic information is needed.

Southwest Grand Island -- Dewatering of littoral habitat along the southwest shore of Grand Island (Fig. 42) could reduce rock bass spawning in the area. Flooding in the same area could create new littoral habitat. Northern pike and greater redhorse spawn in the tributaries feeding this reach. The affects of water level changes on these tributaries is uncertain.

Grand Island to Niagara Falls -- The diverse littoral spawning areas along northern Grand Island and Navy Island would experience limited dewatering of flooding with ±1 m water level changes on Lake Erie (Fig. 43). The marsh area of Burnt Ship Creek could be dewatered by a 1-m reduction. Rock bass spawning off Grand Island would be unaffected by either an increase or a

Figure 41. Fish habitat (blackened areas) from Lake Erie to Grand Island potentially affected by water level alterations in the Niagara River. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 40.

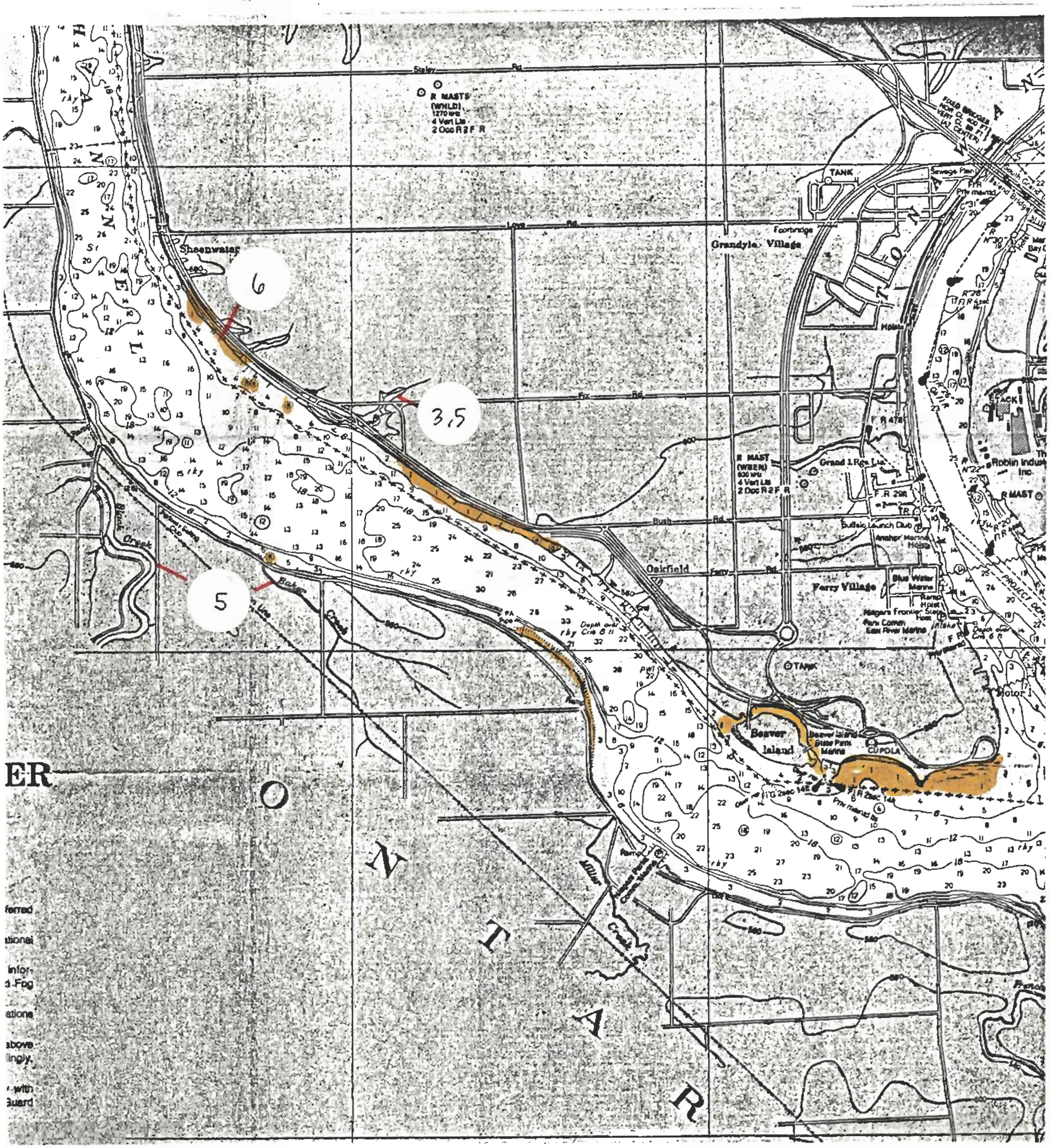


Figure 42. Fish habitat (blackened areas) near Southwest Grand Island potentially affected by water level alterations in the Niagara River. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 40.

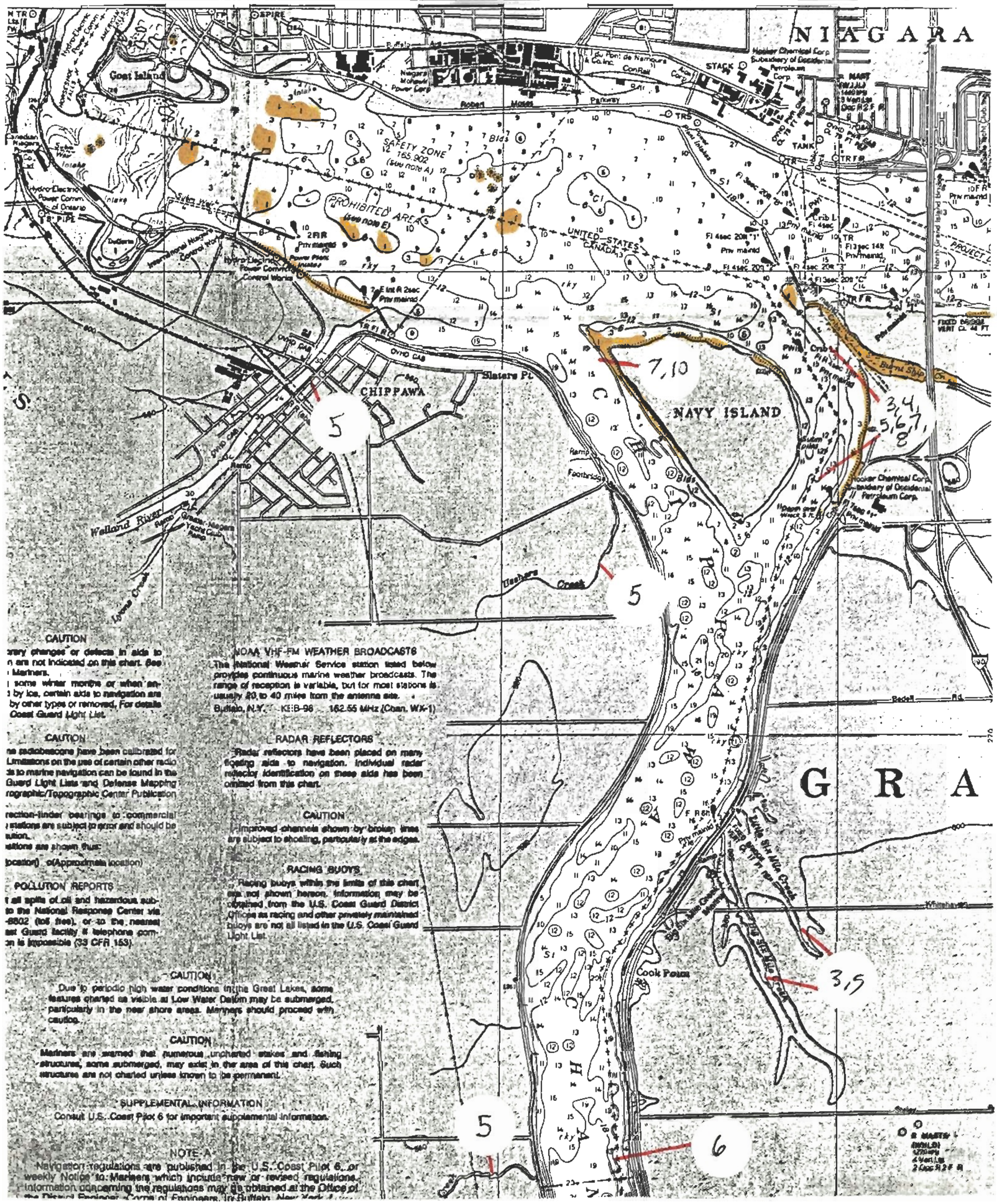


Figure 43. Fish habitat (blackened areas) from Grand Island to Niagara Falls potentially affected by water level alterations in the Niagara River. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 40.

decrease of water level. Impacts of level changes on northern pike and greater redhorse spawning in the area cannot be determined without better topographic information.

Northern Grand Island -- A 1-m water level reduction on Lake Erie would cause a partial dewatering of littoral areas on northern Grand Island and near Cayuga Island (Fig. 44). Northern pike and largemouth bass spawning habitat would be adversely affected. A similar increment of water level in these areas would increase the size of these littoral habitats. The affects of water level changes on northern pike, greater redhorse, and largemouth bass spawning habitats in Woods Creek and Cayuga Creek are uncertain.

North Tonawanda -- The river shoulders of the Niagara River east of Grand Island are steep and no known spawning habitats are found in this reach of the river (Fig. 45). Water level changes would have little effect on the river habitats. Greater redhorse and northern pike spawn in the tributaries in this area. The effects of water level changes on these tributary habitats are uncertain.

The effects of water level changes on the lower Niagara River are estimated using NOAA-NOS Chart 19816 (20th Ed. Sept. 19, 1981) for the lower Niagara River. The levels in the lower river fluctuate from controlled flow over the falls and flow from the hydro-electric facilities near Queenston, Ontario. The fall over through the rapids is 25.3 m and the fall from Lewiston to Lake Ontario is less than 0.2 m. Fluctuations in water level at Lewiston generated by the hydro-electric outflows about 0.1 m or less (GLBC 1975). In the river directly below the falls changes in the flow resulting from hydro-electric use cause sudden fluctuations in level of more than 3 m.

Figure 44. Fish habitat (blackened areas) near northern Grand Island potentially affected by water level alterations in the Niagara River. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 40.

Figure 45. Fish habitat (blackened areas) near North Tonawanda potentially affected by water level alterations in the Niagara River. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 40.

Water level fluctuations on the lower river below Queenston could be caused by the control of Lake Ontario levels at the Iroquois Dam and Moses-Saunders Dam on the St. Lawrence River.

The water level scenario considered for the lower Niagara River is one in which the water level of Lake Ontario is changed ±1 m. These changes would alter levels and current velocities upstream into the rapids.

Niagara Falls to Queenston -- A change of ±1 m in the level of Lake Ontario would affect only the lower end of the rapids habitat (Fig. 46). Littoral and open-water habitats along shore at Queenston, Ontario that are or were used for spawning by lake herring and bass would also remain unaffected by either a 1-m reduction or increase in the water level of Lake Ontario.

Lewiston to Lake Ontario -- A 1-m water level reduction in this reach of the Niagara River would dewater narrow littoral patches along the Ontario river shoulder (Fig. 47). Some loss of smallmouth bass spawning habitat could occur on the Ontario shore near Lewiston. Because the banks are steep in this stretch of the river, a 1-m water level rise in Lake Ontario would create little new littoral habitat by inundation. A spawning habitat for northern pike and smallmouth bass near the mouth of the river would suffer no adverse affects from a 1-m water level reduction. The effects of a 1-m water level rise at this location cannot be determined without more detailed topographic information.

Effects on the Food Web

Existing information does not permit adequate description of the food web or nutrient dynamics of the Niagara River. Dense macrophyte beds in the river

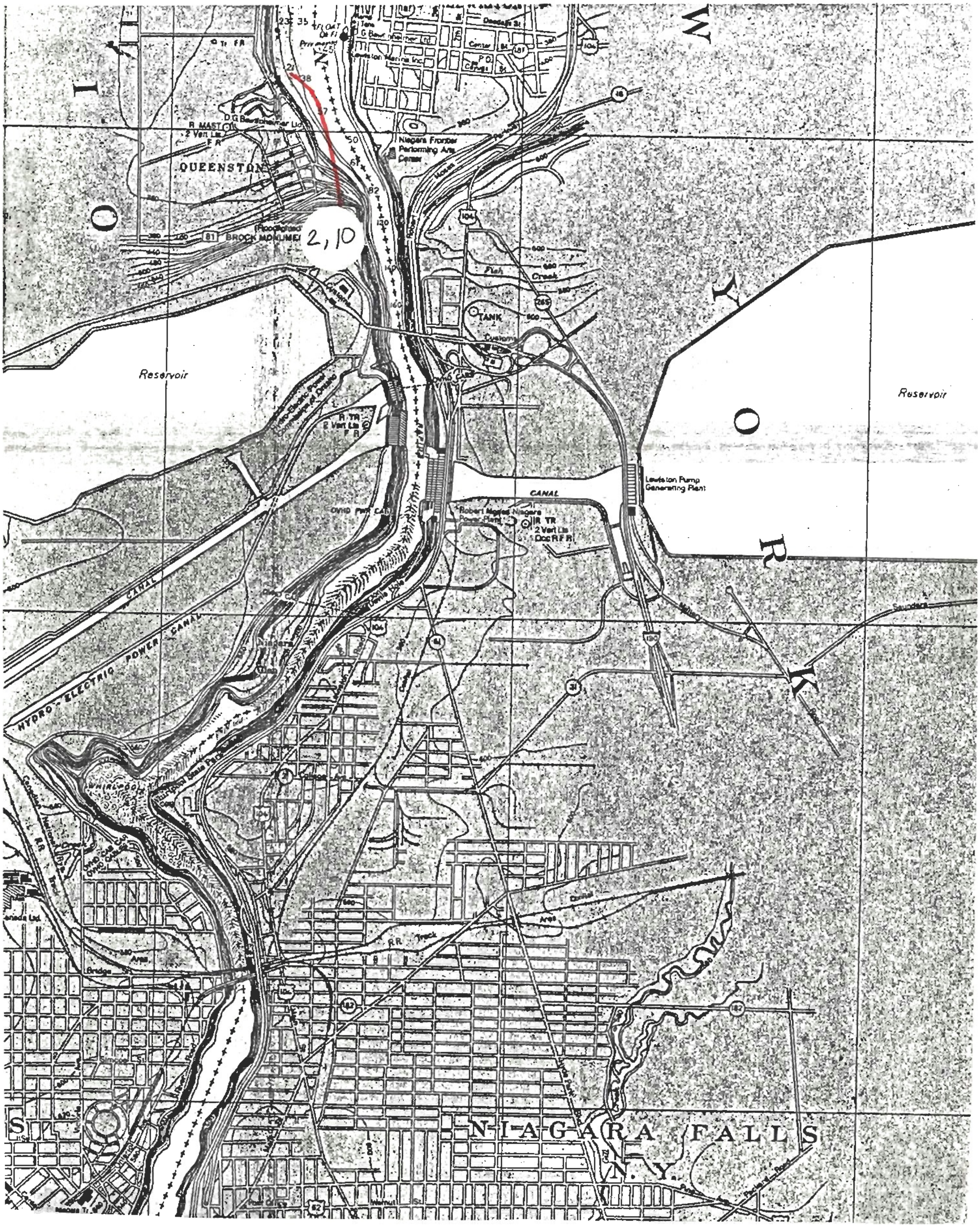


Figure 46. Fish habitat (blackened areas) from Niagara Falls to Queenston potentially affected by water level alterations in the Niagara River. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 40.

Figure 47. Fish habitat (blackened areas) from Lewiston to Lake Ontario potentially affected by water level alterations in the Niagara River. Fish spawning areas identified by Goodyear et al. (1982) are shown by encircled numbers; species key is given in Fig. 40.

(Goodyear et al. 1982) and in the coastal wetlands of the river (Herdendorf et al. 1981) are used by the fish community. These macrophyte beds, in addition to being spawning, feeding, and resting areas for fish, may be the sites of primary production that provide energy to fuel the river ecosystem. A large population of caddisflies in the upper river serves as a major food source for the fish community (IGLLB 1973). Lowered water levels in the upper Niagara River would dewater shallow, littoral areas which are habitat for macrophytes and caddisflies.

Effects on Existing Use-Conflicts

Navigation -- Commercial navigation on the river above the falls is confined to the Black Rock and Niagara River channels. The 6.4-m deep Black Rock Channel ends near Tonawanda Island, where ships have access to the New York State Barge Canal System and the Niagara River Channel. The 3.7-m deep Niagara River Channel provides access to the city of Niagara Falls.

Scouring and navigation-related wave action have been identified as detrimental in riverine systems (Schnick et al. 1982). Scouring of substrates by vessel-induced turbulence and by ship-induced ice movement may cause mortality to caddisflies in the river. Scouring may also uproot macrophytes. Wave action generated by passing ships can adversely affect river ecosystems by temporarily dewatering larval fish (Holland 1987), increasing turbidity (Schnick et al. 1982), and drawing organisms into the drift (Poe and Edsall 1982; Poe et al. 1980; and Jude et al. 1986).

Littoral habitats most vulnerable to the effects of ship passage in the upper river are located at the head of the river near Buffalo, New York, around Strawberry and Motor Islands, around the southern tip of Grand Island, and along the northwestern tip of Grand Island across the river from Niagara Falls, New York. Water level reduction in the upper river would exacerbate the navigation-related effects on these habitats by reducing the width of the river, and bringing the remaining littoral and emergent wetland habitats closer to the navigation channel, where they may be readily exposed by drawdown. Water level reduction may also increase the need for navigation-related dredging, especially in the shallow Niagara River Channel. Dredging can adversely affect the river ecosystem by disturbing contaminated sediments and increasing turbidity. An increase in the water level would generally reduce navigation related impacts by expanding the area of littoral habitats and increasing their depth.

The Niagara River below the falls is only navigable from Lake Ontario to Lewiston, New York. No navigation channels have been dredged in the lower river. Because this reach of the river is deep, vessel scouring is probably not a problem. A 1-m water level reduction in the lower river would increase the impact of ship-induced wave action and turbulance on the littoral and emergent wetland habitats by reducing the average depth of existing littoral habitats. A 1-m rise in water levels in the lower river would lessen navigation-related effects.

Water Withdrawal -- Numerous industrial and municipal water intakes are located in Niagara River above the falls. The greatest concentration of intakes occur in New York State off the cities of Buffalo, Tonawanda, North Tonawanda, and Niagara Falls. A partial list published in 1975 of private and public water users of the United States, not including the hydro-electric power companies, showed the river contains more than 24 intakes with a total withdrawal of about 78 billion gallons per day (Beeton and Strand 1975). Large-volume intakes supplying the hydro-electric generating facilities are concentrated in the portion of the river between Navy Island and the falls. Peak total intake of the U.S. and Canadian hydro-electric power companies reaches almost 4,700 m^3/s.

Important fish habitats located near the highest intake concentrations are the open-water, littoral and emergent wetland habitats at Motor and Strawberry Islands, and southern Grand Island, and the littoral habitats at the northwest corner of Grand Island. Information on fish use of habitats near the hydro-electric intakes is lacking and an evaluation of water withdrawal on the fish populations of the upper river is problematic. Water level reductions on the upper river would increase the risk of entrainment for fish by reducing the area of littoral habitat which provides resting areas with low current velocities and by narrowing the river and bringing the remaining littoral refugia closer to the water intakes. A water level increase would increase river width and depth and perhaps also the amount of littoral habitat. Entrainment does not appear to constitute a threat to the fish community of the river and it appears unlikely that the situation would be changed by a change of ±1 m in the water level of Lake Ontario.

Waste Discharge -- The U.S. shoreline of the upper Niagara River is intensively developed for use by industries that release chemical wastes into the river. Water samples taken from the east and west branches of the river at the southern end of Grand Island, and in the east branch at the city of Niagara Falls (Herdendorf et al. 1981) show slightly lower water quality values in the industrialized east branch, and lowest water quality values down river. Sanitary wastes are released at at least 8 locations on the river and its tributaries (Herdendorf et al. 1981). Despite high inputs of industrial and municipal wastes, the quality of the water is maintained by the large flow from Lake Erie (Herdendorf et al. 1981). Flow over the Falls and rapids may benefit water quality by increasing dissolved oxygen, and by releasing volatile contaminants to the atmosphere. A 1-m water level reduction of Lake Erie by either restricting the flow from the upper Great Lakes, or by increasing the diversion through the Welland Canal would reduce flow to the Niagara River, increase the flushing time concentration of contaminants in the river. Higher water levels resulting from decreased diversion, seiches, or high annual percipitation would benefit the organisms in the river by diluting effluents and flushing them from the river more rapidly. Lower river concentrations of industrial effluents depend on concentrations arriving from the upper river and from water levels influenced by Lake Ontario. Above Lewiston, changes in Lake Ontario water level have little influence on river level. In this rapids area, contaminant concentrations depend on flushing from Lake Erie. Increased diversion around the Falls would not change effluent concentrations flowing from the upper river, but would decrease the level and flushing time in the rapids. In the river below the rapids, water quality would be influenced primarily by Lake Ontario levels. Backwatering from high Lake Ontario levels would increase river depth and width and reduce current velocity in the river below Lewiston. Effects on fish of this scenario would be a compromise between increased habitat area and increased contaminant deposition resulting from lower current velocities. If Lake Ontario was lowered 1 m, current velocity would increase, aiding removal of contaminants, but the narrow patches of nearshore littoral habitat would be dewatered.

THE ST. LAWRENCE RIVER

Background

The St. Lawrence River (Fig. 48) is the 870-km long outlet of the Great Lakes to the Gulf of St. Lawrence and the Atlantic Ocean. This report deals only with the International section of the river, which forms the border between the U.S. and Canada. This International section of the river is about 180 km long and extends from Lake Ontario to the downstream end of Lake St. Lawrence, which is formed by the Moses-Saunders and Long Sault dams near Massena, New York and Cornwall, Ontario.

The present set of dams and associated locks, which were constructed to regulate the outflow of Lake Ontario and benefit power and navigation interests, became fully operational with the closing of the Moses-Saunders Dam and subsequent filling of the power pool above the dam in 1958. Following the closing of the Moses-Saunders Dam in 1958, the relatively fast and free flowing river upstream of the dam was changed into three limnologically distinct sections (NYDEC 1978). The upper or Thousand Islands section, which consisted of large islands, expansive bays, numerous small islands, and shoals, was not changed much. It remains under the influence of Lake Ontario and behaves essentially like an extension of the lake, with large, open expanses of slowly-flowing water. The middle section, which extends from Chippewa Point to Ioquois Lock is narrow with few islands and shoals, except in the Ogdensburg-Cardinal reach. The transition from channel to upland is abrupt in this reach. The Red Mills Rapids which dropped about 5 m in about 19 km in this section of the river now

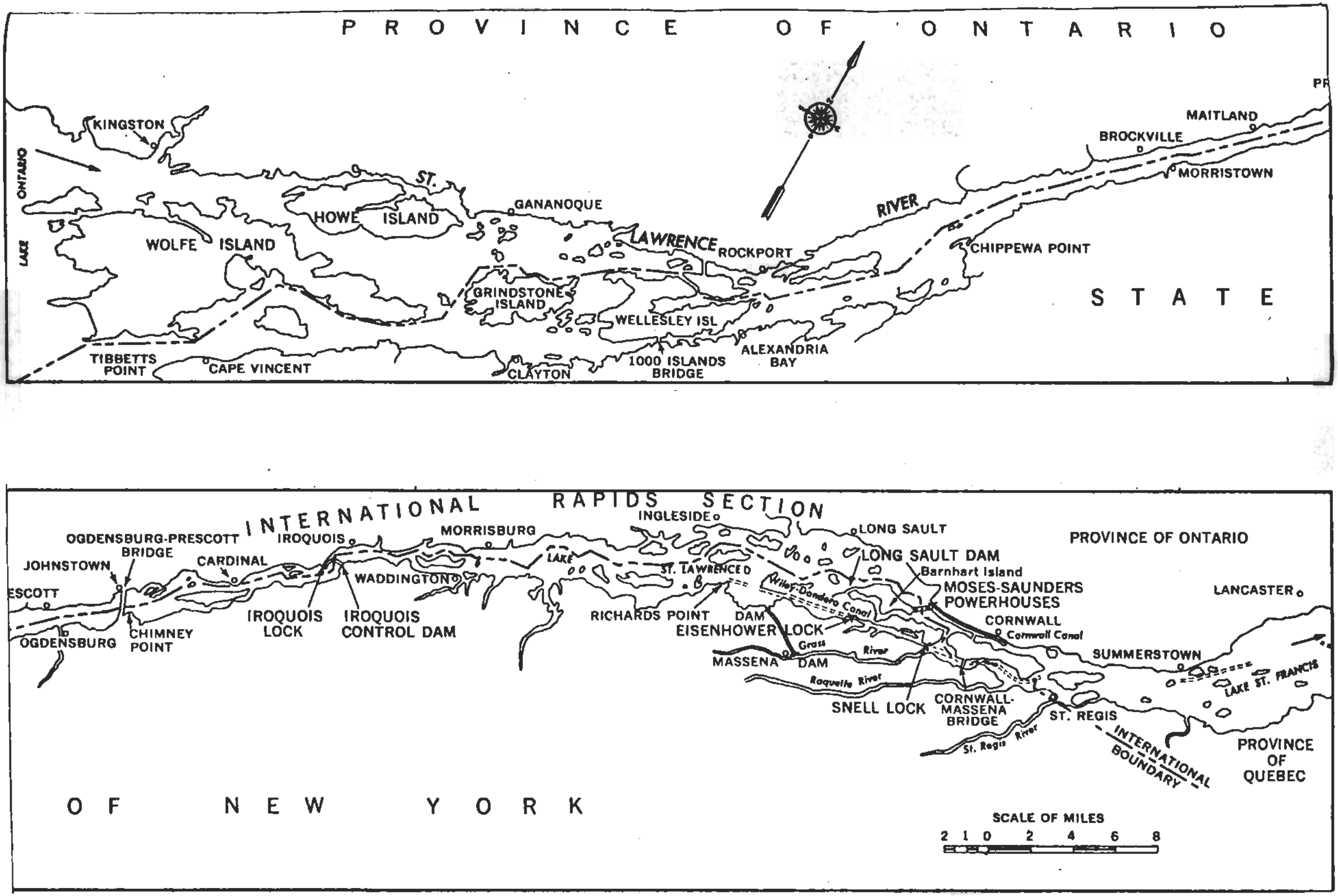


Figure 48. The St. Lawrence River.

have been inundated and the drop has been reduced to only 0.3 m. The lower section of the river, now known as Lake St. Lawrence, is highly modified and contains several large islands and many extensive shoals, that were formerly islands. This section of the river, which was fast-flowing water, is now a reservoir that serves as the power pool for the Moses-Saunders Hydro-electric Project. Presently the river falls about 1.3 m in the 124 km from Lake Ontario to the Iroquois Dam and about 0.3 m more to the end of Lake St. Lawrence. The average flow of the river is 6,880 m^3/sec. In addition to meeting navigation and power generation needs, the river is used for waste disposal, as a water supply, and is a major recreational focus for the region. The river supports an important recreational fishery. In Canada the commercial fishery landings, consisting of mainly yellow perch, sunfish, and bullhead, were about 159,000 kg in 1980.

Biological studies conducted on the International section of the river through about 1983 are summarized by Patch and Busch (1984). Most of these were conducted after the mid-1970's in response to proposals to extend the navigation season into or through the winter months.

The Fish Community

Species Composition

A total of 99 species of fish in 22 families have been identified in the river since the first surveys were conducted in the 1930's (Table 14). The fish fauna of the International section of the river is similar to, and can probably be considered to be contiguous with that of eastern Lake Ontario.

Table 14. Fishes of the St. Lawrence River.

Scientific name	Common name
Ichthyomyzon fossor	Northern brook lamprey
Ichthyomyzon unicuspis	Silver lamprey
Lampretra lamottei	American brook lamprey
Petromyzon marinus	Sea lamprey
Acipenser fulvescens	Lake sturgeon
Lepisosteus osseus	Longnose gar
Amia calva	Bowfin
Anguilla rostrata	American eel
Alosa sapidissima	American shad
Alosa pseudoharengus	Alewife
Dorosoma cepedianum	Gizzard shad
Hiodon tergisus	Mooneye
Coregonus artedii	Cisco
Coregonus clupeaformis	Lake whitefish
Prosopium cylindraceum	Round whitefish
Salmo gairdneri	Rainbow trout
Salmo salar	Atlantic salmon
Salmo trutta	Brown trout
Salvelinus fontinalis	Brook trout
Salvelinus namaycush	Lake trout
Osmerus mordax	Rainbow smelt
Umbra limi	Central mudminnow
Esox americanus	Grass pickerel
Esox lucius	Northern pike
Esox masquinongy	Muskellunge
Esox niger	Chain pickerel
Carassius auratus	Goldfish
Clinostomus elongatus	Redside dace
Couesius plumbeus	Lake chub
Cyprinus carpio	Carp
Exoglossum maxillingua	Cutlips minnow
Hybognathus hankinsoni	Brassy minnow
Hybognathus nuchalis	Silvery minnow
Nocomis micropogon	River chub
Notemigonus crysoleucus	Golden shiner
Notropis anogenus	Pugnose shiner
Notropis atherinoides	Emerald shiner
Notropis bifrenatus	Bridle shiner
Notropis blennius	River shiner
Notropis cornutus	Common shiner
Notropis heterodon	Blackchin shiner

Continued

Table 14. Continued

Scientific name	Common name
Notropis hudsonius	Spottail shiner
Notropis rubellus	Rosyface shiner
Notropis spilopterus	Spotfin shiner
Notropis stramineus	Sand shiner
Notropis volucellus	Mimic shiner
Phoxinus eos	Northern redbelly dace
Phoxinus neogaeus	Finescale dace
Pimephales notatus	Bluntnose minnow
Pimephales promelas	Flathead minnow
Rhinichthys atratulus	Blacknose dace
Rhinichthys cataractae	Longnose dace
Semotilus atromaculatus	Creek chub
Semotilus corporalis	Fallfish
Semotilus margarita	Pearl dace
Carpiodes cyprinus	Quillback
Catostomus catostomus	Longnose sucker
Catostomus commersoni	White sucker
Erimyzon oblongus	Creek chubsucker
Moxostoma anisurum	Silver redhorse
Moxostoma carinatum	River redhorse
Moxostoma duquesnei	Black redhorse
Moxostoma hubbsi	Copper redhorse
Moxostoma macrolepidotum	Shorthead redhorse
Moxostoma valenciennesi	Greater redhorse
Ictalurus melas	Black bullhead
Ictalurus natalis	Yellow bullhead
Ictalurus nebulosus	Brown bullhead
Ictalurus punctatus	Channel catfish
Noturus flavus	Stonecat
Noturus gyrinus	Tadpole madtom
Percopsis omiscomaycus	Trout-perch
Lota lota	Burbot
Fundulus diaphanus	Banded killifish
Labidesthes sicculus	Brook silverside
Culaea inconstans	Brook stickleback
Gasterosteus aculeatus	Threespine stickleback
Pungitius pungitius	Ninespine stickleback
Morone americana	White perch
Morone chrysops	White bass
Ambloplites rupestris	Rock bass
Lepomis gibbosus	Pumpkinseed
Lepomis macrochirus	Bluegill
Lepomis megalotis	Longear sunfish
Micropterus dolomieu	Smallmouth bass
Micropterus salmoides	Largemouth bass
Pomoxis annularis	White crappie

Continued

Table 14. Continued

Scientific name	Common name
Pomoxis nigromoculatus	Black crappie
Ammocrypta pellucida	Eastern sand darter
Etheostoma caeruleum	Rainbow darter
Etheostoma exile	Iowa darter
Etheostoma flabellare	Fantail darter
Etheostoma nigrum	Johnny darter
Etheostoma olmstedi	Tessellated darter
Perca flavescens	Yellow perch
Percina caprodes	Logperch
Percina copelandi	Channel darter
Stizostedion canadense	Sauger
Stizostedion vitreum vitreum	Walleye
Aplodinotus grunniens	Freshwater drum
Cottus bairdi	Mottled sculpin
Cottus cognatus	Slimy sculpin
Myoxocephalus quadricornis	Deepwater sculpin

An evaluation of changes in abundance of the more important recreational and commercial species (Patch and Busch 1984) revealed that brown bullhead, rock bass, pumpkinseed, and yellow perch numbers have increased, lake sturgeon, has become rare, and walleye and muskellunge have decreased over the period of record.

Fish Distribution and Habitat Use

The primary habitats of the river that are available to fish were described by Patch and Busch (1984). Their habitat classification system differs from the one we use in this report, but there is enough correspondence between the two to permit them to be used interchangeably, for the purposes of this report:

Patch and Busch (1984)	Present report
Deep-water (+6 m)	Open-water (+3 m)
Deep littoral (2-6 m)	Littoral (0-3 m)
Shallow littoral (0-2 m)	
Deep shoal (2-8 m)	
Shallow shoal (0-2 m)	
Emergent wetlands	Emergent wetlands
	Tributaries

The principal difference between the two systems is that Patch and Busch (1984) include more of the open-water (deep-water) habitat in the littoral (littoral and shoal) zone than does the system used throughout this report. The significance of the difference between the two habitat classification systems cannot be assessed at this time because the fish community occupying the International section of the river since the closing of the Moses-Saunders Dam has not been studied sufficiently to permit detailed description of species distributions and habitat use. However the habitat preferences of the warmwater species that presently make up the majority of the fish community in the river (Table 15) suggests that they are probably distributed widely throughout the available habitat in the river.

Spawning and Nursery Areas

The important fish spawning and nursery areas in the International section of the St. Lawrence River are in the inshore areas, including the extensive wetlands and marshes, and the tributary streams (Geis and Hyduke 1978; LMS 1977; SLEOC 1978; Werner and Ford 1972). Historically, the tributaries, which warm earlier than the main stem of the river, were very important spawning and nursery grounds for many St. Lawrence fish species. These fishes often ran long distances upstream, but their habitats and migration patterns have been drastically altered by the dam construction. In the early 1930's, dams stopped spawning runs on the Grass and St. Regis Rivers (Hazzard 1931) and presently the spawning movements of fish are impeded by the Moses-Saunders Dam on the main river at Cornwall and by dams on every major tributary to the International section of the river (SLEOC 1978). River mouths, including that of the Oswegatchie River, are still important spawning areas (Geis and Hyduke 1978). Landons Bay, on the Canadian shore opposite Wellesley Island, is a long-recognized spawning site (Environment Canada 1977), as are many other such embayments on the river.

Of the nearly 100 species recorded as residents or migrants in the St. Lawrence River, at least 45 were reported to use the river for spawning and

Table 15. Life history summary of major warmwater sport and commercial fish in eastern Lake Ontario and the St. Lawrence River. (Source: Patch and Busch 1984).

Species	Adult habitat Spring	Adult habitat Summer	Adult habitat Fall/Winter
American eel	Shallow inshore waters	Inshore areas in vegetation and mud	Inshore areas buried in mud
Brown bullhead	Shallow bays, slow moving rivers	Shallow bays and streams	Open bays
Carp	Weedy shallows	Slow moving waters	Slow moving waters
Lake sturgeon	Shoal areas	Shoal areas and deeper water	Moderate depths
Largemouth bass	Shallow bays	Upper waters of slow moving rivers	Bottom areas, somewhat active in winter
Muskellunge	Wetlands, weedy bays	Weedy bays, slow moving rivers	Weedy bays, slow moving rivers
Northern pike	Shallow weedy areas of creeks, wetlands	Weedy bays, slow moving rivers	Weedy bays, slow moving rivers
Pumpkinseed	Shallow inshore waters	Cover of submerged vegetation	Cover of submerged vegetation
Rock bass	Shallow inshore waters	Shallow water, associated with bass	Shallow water, associated with bass
Sea lamprey	Estuaries and streams	Deep water as parasites	Stream or lake
Smallmouth bass	Shallow inshore waters	Seek deeper water	Bottom areas, inactive in winter
Walleye	Spring run to shallow shoals or tributary rivers	Large streams, rivers, lakes. Seek turbid water and other shields from sunlight	Same as summer but avoid strong currents
White perch	Shallow inshore waters	Move inshore at night and to deeper water at dawn	School in lake
Yellow perch	Shallow inshore waters	Open lake in areas of moderate vegetation (under 30 ft. deep)	Under 30 ft. depth, school in lake, active all winter

spawning areas have been identified for 36 of them (Fig. 49). The open-water habitat of the river is apparently not used for spawning by any species. Tributaries are or were used for spawning by mooneye, Atlantic salmon, suckers, redhorse, and walleye. The mouths of tributaries and littoral areas are spawning habitat for alewife, rainbow smelt, minnows, catfishes, and centrarchids. Offshore littoral areas (shoals), tributaries, and littoral areas are used by lake sturgeon and smallmouth bass, and emergent wetlands are spawning habitat for northern pike, muskellunge, carp, centrarchids, and yellow perch.

Effects of Altered Water Levels

Effects on Fish Habitats

The St. Lawrence River presently falls about 1.6 m from Lake Ontario to the lower end of Lake St. Lawrence and an increase or lowering of the level of Lake St. Lawrence by 1 m would cause dewatering or flooding of shallow littoral shorelines and emergent wetlands. This effect would extend upstream from the Iroquois Dam for some undetermined distance, perhaps reaching the upper third of the river above Chippewa Point. The result probably would be a moderate dislocation of the emergent wetlands in the middle third of the river and a more severe dislocation of those in Lake St. Lawrence in the lower third of the river (Fig. 50). The extent to which emergent wetland area might increase or decrease as a result of the dislocation cannot be determined from the available information. An increase in water level that increased the

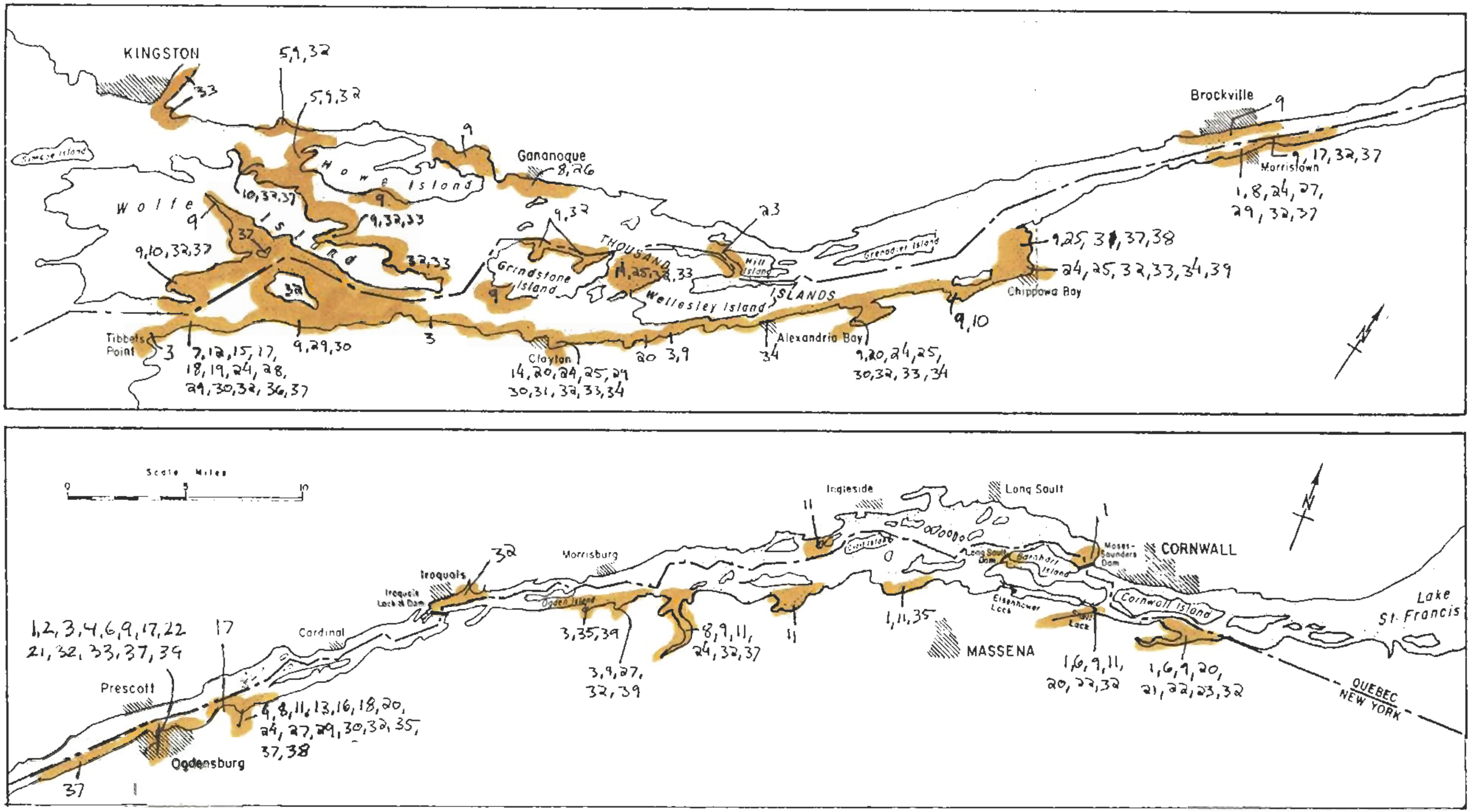


Figure 49. Fish spawning areas in the St. Lawrence River (Source: Goodyear et al. 1982).

Key

1. Lake sturgeon
2. Longnose gar
3. Alewife
4. Mooneye
5. Coho salmon
6. Atlantic salmon
7. Lake trout
8. Rainbow smelt
9. Northern pike
10. Muskellunge
11. Common carp
12. River chub
13. Golden shiner
14. Pugnose shiner
15. Bridle shiner
16. Common shiner
17. Spottail shiner
18. Bluntnose minnow
19. Longnose dace
20. White sucker
21. Silver redhorse
22. Shorthead redhorse
23. Greater redhorse
24. Brown bullhead
25. Channel catfish
26. Stonecat
27. Burbot
28. Banded killifish
29. Rock bass
30. Pumpkinseed
31. Bluegill
32. Smallmouth bass
33. Largemouth bass
34. Black crappie
35. Iowa darter
36. Johnny darter
37. Yellow perch
38. Log perch
39. Walleye

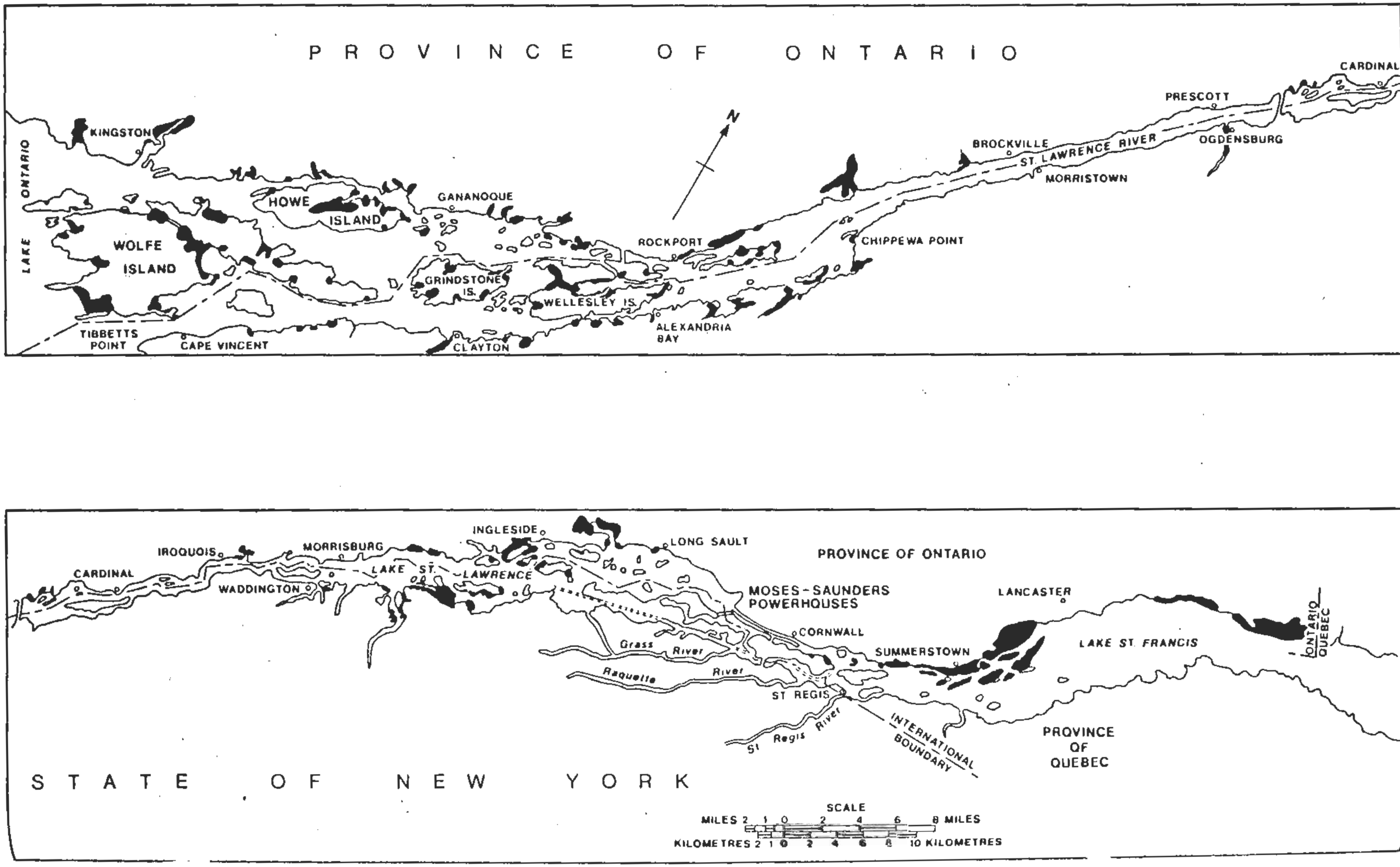


Figure 50. Wetlands of the International section of the St. Lawrence River (Source: ILEB 1981).

amount of shallow littoral, shoal, and emergent wetland habitat would probably benefit most of the species in the river that spawn in such habitats and would not interfere with spawning by the other main group of fishes that spawn in tributaries.

The impoundment of the International section of the St. Lawrence River, which was completed with the closing of the Moses-Saunders Dam in 1958, provides a relatively recent case history and data base from which some of the effects of altered water levels and flows on the other Great Lakes connecting channels can perhaps be evaluated. The U.S. Fish and Wildlife Service performed an intensive mapping project on the river and was able to document and compare the amounts and kinds of habitat present before and after flooding (Patch and Busch 1984). The effects of impoundment were most dramatic in the section of the river between the Iroquois Dam and the Moses-Saunders Dam, where the fall of the river was the greatest and the narrow, rapidly flowing river was transformed into a lake. The largest quantified change in habitat observed in 1962, four years following impoundment, was a nearly 20% increase in open-water (deepwater) habitat; at this time the littoral habitat had increased about 35%, offshore littoral (shoal) habitat about 55% and emergent wetlands by 2%. When viewed again in 1979, 20 years after impoundment, the total amounts of open-water (deepwater) and offshore littoral (shoal) habitat were unchanged from those present in 1962, but the emergent wetlands had decreased about 7%.

The significance of these changes to the fish community of the St. Lawrence River is difficult to assess, because there is a lack of pre- and post-impoundment data on the fish community of the river and on the manner in which materials and energy cycle in the river ecosystem to support that community; this shortcoming also limits the extent to which the St. Lawrence case history can be used in assessing the effects of water level alterations in the other connecting channels. Nevertheless, it is clear that despite major changes in habitats caused by damming and flooding of the St. Lawrence River in 1958 many fish species including northern pike, centrarchids, and brown bullhead apparently still spawn successfully and thrive in the St. Lawrence River; however, muskellunge have declined; and lake sturgeon and walleye, have declined greatly probably due to loss of spawning habitat, blockage of migration routes, or both (Patch and Busch 1984).

Effects on Food Webs

A consideration of food webs and the flow of energy and materials is essential to an understanding of the effect of habitat alterations on the fish community of the St. Lawrence River. Unfortunately the information available to describe the food webs of the river is limited. Prior to impoundment in 1958, studies were conducted of the plankton and other invertebrates (ANSP 1953) and of the food habits of selected fish species (Sibley and Rimsky-Korsakoff 1931). A study performed after 1958 (Cooley 1978) indicates the dominant autochthonus energy source in the river is probably periphyton, or macrophytes, although the complexity of the river ecosystem makes it difficult to demonstrate this is the case throughout the entire river.

Macrophyte productivity enters the food web of the St. Lawrence River primarily through the detrital pathway. Raynal and Geis (1978) reported the presence of an overwintering loose layer of whole or fragmented plants on the bottom in certain 4-5 m deep portions of the St. Lawrence River with irregular bottom topography and Mills et al. (1981) found that the benthic invertebrate community was more diverse and invertebrate abundance was 3.5 times higher in these decaying vegetation mats than in adjacent barren areas.

Edwards et al. (1988) believe phytoplankton is responsible for most of the primary production (Table 16) and that zooplankton provide the major invertebrate biomass in the river. Studies of the diets of juvenile fish (Sibley and Rimsky-Korsakoff 1931; Johnson 1983) showed the usual early dependence on invertebrates, followed by a shift to piscivory in some species following attainment of larger size.

Aditional research is needed to describe the contemporary food webs of the river and to identify the key linkages and components that support fish production.

Table 16. Primary production in the International section of the St. Lawrence River (Source: Duffy et al. 1987)[a].

Community type	Hectares occupied	g AFDW/m²/yr.	Metric tons AFDW/yr.
Phytoplankton	65,600	295	193,390
Submersed macrophytes		110	20,710
Emergent wetlands		715	23,160

a/ Ash-free dry weight (AFDW).

REFERENCES

Academy of Natural Sciences of Philadelphia: Dept. of Limnology. 1953. Biological survey St. Lawrence River, Canada for Canadian Industries Ltd. - July, 1952 - August, 1952. Philadelphia, PA.

Adams, J. K., K. A. Benkert, C. Keller, and R. White. 1984. A method for ranking biological habitats in oil spill response planning and impact assessment. U.S. Fish Wildl. Serv. FWS/OBS-82/61.

Alger, G. A. 1979. Ship-induced waves--ice and physical measurements on the St. Marys River. Great Lakes Basin Commission, Rep. Proj. No. 5100, Ann Arbor. 59 pp + app.

Anon. 1987. St. Marys River found to be one of state's finest sport fisheries. Northwoods Call. 35(6):2 Traverse City, Michigan.

Beeton, A. M., and J. W. Strand. 1975. Sources of water quality, lake level, ice, water temperature and meteorological data for the St. Lawrence Great Lakes. Center for Great Lakes Studies. The University of Wisconsin - Milwaukee. Milwaukee, Wisconsin.

Christie, W. J. 1974. Changes in the field species composition of the Great Lakes. J. Fish. Res. Board Can. 31. 827-854.

Cooley, J. L. 1978. Aquatic food web characterization studies. In: Environmental assessment of the FY 1979 Winter Navigation demonstration on the St. Lawrence River. Technical Report II(L). SUNY College of Environmental Science and Forestry. Syracuse, NY. 17 pp.

Derecki, J. 1985. Effect of channel changes in the St. Clair River during the present century. J. Great Lakes Res. 11:201-207.

DOE/MOE (Department of Environment/Ministry of Environment). 1986. Canada-Ontario Agreement Reporting Great Lakes Water Quality. St. Clair River pollution investigation. Toronto, Ontario. 135 pp.

Duffy, W. G. 1985. The population ecology of the damselfly, Lestes disjunctus disjunctus, in the St. Marys River, Michigan. Ph.D. Diss. Mich. State Univ., East Lansing. 119 pp.

Duffy, W. G., and C. R. liston. 1981. Seasonal diet of the shallow water cisco, Coregonus artedii, in the St. Marys River, Michigan/Ontario. Proc. 25th Meeting Int. Assoc. Great Lakes Res., Sault Ste. Marie, Ont.

Duffy, W. G., T. R. Batterson, and C. D. McNabb. 1987. The St. Marys River, Michigan: An ecological profile. U.S. Fish Wildl. Serv. Biol. Rep. 85(7.10). 138 pp.

Edsall, T. A., P. B. Kauss, D. Kenaga, J. Leach, M. Munawar, T. Nalepa, and S. Thornley. 1988a. St. Clair River biota and their habitats: A geographic area report of the Biota Work Group, Upper Great Lakes Connecting Channels Study. 88 pp.

Edsall, T. A., B. A. Manny, and C. N. Raphael. 1988. The St. Clair River and Lake St. Clair, Michigan: an ecological profile. U.S. Fish and Wildl. Serv. Biol. Rep. 85(7.3). 130 pp.

Edwards, C., P. L. Hudson, W. G. Duffy, S. J. Nepszy, C. D. McNabb, R. C. Haas, C. R. Liston, B. A. Manny, and W.-D. Busch. 1987. Hydrological, morphometrical, and biological characteristics of the connecting rivers of the international Great Lakes: A review. Large Rivers Symposium. Can. J. Fish. Aquat. Sci. (In press).

Environment Canada. 1977. Ecological sensitive area inventory for the St. Lawrence and Ottawa Rivers watershed.

Geis, J. W., and N. P. Hyduke. 1978. Shoreline water level monitoring studies. In: Environmental assessment of the FY 1979 Winter Navigation demonstration on the St. Lawrence River. Technical Report II(O). SUNY College of Environmental Science and Forestry. 21 pp.

Gleason, G., D. Behmer, S. Schenden, and S. Sieders. 1981. Fish usage assessment of the U.S. hydroelectric facilities in the St. Marys River. U.S. Army Corps Eng. Rep. Contract No. DACW 35-81-C-0036. Detroit. 29 pp.

Goodyear, C. D., T. A. Edsall, D. M. O. Demsey, G. D. Moss, and P. E. Polanski. 1982. Atlas of spawning and nursery areas of Great Lakes fishes, Vols. 1-14. U.S. Fish Wildl. Serv., Ann Arbor, MI. FWS/OBS-82/52. 164 pp.

GLBC (Great Lakes Basin Commission). 1975. Levels and flows. Appendix 11 in Great Lakes Basin framework study. Ann Arbor, Mich. 207 pp.

Griffiths, R. W. 1987. Environmental quality assessment of the St. Clair River in 1985 as reflected by the distribution of benthic invertebrate communities. Aquatic Ecostudies, Ltd., Kitchener, Ontario. 51 pp.

Haas, R. C., W. C. Bryant, K. D. Smith, and A. J. Nuhfer. 1985. Movement and harvest of fish in Lake St. Clair, St. Clair River, and Detroit River. U.S. Army Corps of Engineers, Detroit. 286 pp.

Hatcher, C. O., and R. T. Nester. 1983. Status and potential of the St. Clair-Detroit River ecosystem as a spawning and nursery habitat for Great Lakes fishes. U.S. Fish Wildl. Serv., Great Lakes Fish Lab. Admin. Rep. No. 83-5. Ann Arbor, Mich. 124 pp.

Hazzard, A. S. 1931. Stocking policy for the streams, lakes and ponds of the St. Lawrence watershed including the Grass, St. Regis, Salmon, Chatequgay systems and the St. Lawrence between Ogdensburg and the International boundary. Pages 14-43 in A biological survey of the St. Lawrence watershed (including the Grass, St. Regis, Salmon, Chateaugay sytems and the St. Lawrence between Ogdensburg and the International Boundary). Suppl. 20th Annu. Rep. (1930), N.Y. Conserv. Dep.

Herdendorf, C. E., S. M. Hartley, and M. D. Barnes. 1981. Fish and wildlife resources of the Great Lakes coastal wetlands within the United States. Vol. 4: Lake Huron, Part 1. U.S. Fish Wildl. Serv. Biol. Serv. Prog. FWS/OBS-81/02-V4. 423 pp.

Holland, L. E. 1987. Effect of navigation-related dewaterings on fish eggs and larvae. North American Journal of Fisheries Management. 7:145-147.

Hoyt, R. D. 1988. A bibliography of the early life history of fishes. Vol. 1. Dept. of Biology, Western Kentucky University, Bowling Green, KY.

Hudson, P. L., B. M. Davis, S. J. Nichols, and C. M. Tomcko. 1986. Environmental studies of macrozoobenthos, aquatic macrophytes, and juvenile fish in the St. Clair-Detroit River system. U.S. Fish Wildl. Serv., Great Lakes Fish. Lab. Admin. Rep. 86-7. 303 pp.

IGLLB (International Great Lakes Levesl Board). 1973. Regulation of Great Lakes water levels, Appendix D Fish, Wildlife and Recreation. 171 pages. 3 Annexes.

IJC (International Joint Commission). 19B2. Guidelines and register for evaluation of Great Lakes dredging projects. Windsor, Ontario. 305 pp.

IJRT (International Joint Response Team). 1982. Supplement to the Detroit-St. Clair River joint Canadian-U.S. marine pollution contingency plan for spills of oil and other noxious substances. Environmental Emergency Branch-EPS, Toronto, Canada.

International Lake Erie Regulation Study Board. 1981. Lake Erie water level study. Main Report. International Joint Commission. Washington, D.C. and Ottawa, Ontario. 231 pp.

Jaworski, E., and C. N. Raphael. 1979. Impact of Great Lakes water level fluctuations on coastal wetlands. U.S. Dep. Int. Office Water Resour. Tech., East Lansing, Mich. 351 pp.

Jaworski, E., and C. N. Raphael. 1981. Impact of Great Lakes water level fluctuations on coastal wetlands. Pages 103-297 in C. E. Herdendorf and S. M. Hartley, eds. A summary of the knowledge of the fish and wildlife resources of the coastal wetlands of the Great Lakes of the United States. Vol. 1. Ohio State University. Columbus. 468 pp.

Johnson, J. H. 1983. Summer diet of juvenile fish in the St. Lawrence River. N.Y. Fish and Gam J. 30(1):91-99.

Jude, D. J., M. Winnell, M. S. Evans, F. J. Tesar, and R. Futyma. 1986. Drift of zooplankton, benthos and larval fish and distribution of macrophytes and larval fish during winter and summer 1985. University of Michigan, Great Lakes Research Div. 174 pp + Appendices.

Kelso, J. R. M., and G. S. Milburn. 1979. Entrainment and impingement of fish by power plants in the Great Lakes which use the once-through cooling process. J. Great Lakes Res. 5(2):182-194.

Koshinsky, G. D., and C. J. Edwards. 1983. The fish and fisheries of the St. Marys Rapids "An analysis of status with reference to water discharge, and with particular reference to "condition 1(b)". Report to the Int. Joint Comm. 164 pp. & Appendices.

Kreis, R. J., Jr. (Ed.). 1988. Final report to the upper Great Lakes connecting channels study activities workgroups for tasks in activities C, G, and H. Integrated study of exposure and biological effects of in-place pollutants in the upper Great Lakes Connecting Channels: interim results. Executive Summary U.S. Environmental Protection Agency. Grosse Ile, Michigan. 102 pp.

Lawler, Matusky, and Skelly Engineers. 1977. Lake Ontario and St. Lawrence River ecosystems and power plant impacts. Tappan, NY.

Lawrie, A. H. 1978. The fish community of Lake Superior. J. Great Lakes Res. 4:513-549.

Lee, D. S., C. R. Gilbert, C. H. Hocutt, R. E. Jenkins, D. E. McAllister, and J. R. Stauffer, Jr. 1980. Atlas of North American freshwater fishes. North Carolina State Museum of Natural History, Raleigh. 854 pp.

Limno-Tech, Inc. 1985. Summary of the existing status of the upper Great Lakes connecting channels data. Prepared for Upper Great Lakes Connecting Channels Study. Ann Arbor, Mich. 156 pp. + app.

Liston, C. R., W. G. Duffy, D. E. Ashton, C. D. McNabb, and F. E. Koehler. 1980. Environmental baseline and evaluation of the St. Marys River Dredging Great Lakes - St. Lawrence Seaway Navigation Season Extension Program. Mich. State Univ. Dept. Fish. and Wildl. Report prepared for U.S. COE. September 1980. 295 pp.

Liston, C. R., W. G. Duffy, D. E. Ashton, T. R. Batterson, and C. D. McNabb. 1981. Supplementary environmental baseline studies and evaluation of the St. Marys River, 1980. U.S. Fish Wildl. Serv., FWS/OBS-80/62.1. 167 pp.

Liston, C. R., C. D. McNabb, W. G. Duffy, D. Ashton, R. Ligman, F. Koehler, J. Bohr, G. Fleischer, J. Schuette, and R. Yanusz. 1983. Environmental baseline studies of the St. Marys River near Neebish Island, Michigan, prior to proposed extension of the navigation season. U.S. Fish Wildl. Serv. FWS/OBS-80/62.2. 202 pp.

Liston, C. R., C. D. McNabb, D. Brazo, J. Bohr, J. Craig, W. Duffy, G. Fleischer, G. Knoecklein, F. Koehler, R. Ligman, R. O'Neal, M. Siami, and P. Roettger. 1986. Limnological and fisheries studies of the St. Marys River, Michigan, in relation to proposed extension of the navigation season, 1982 and 1983. Mich. State Univ., Dept. Fish. & Wildl. Report to U.S. Fish & Wildl. Serv. 764 pp & appendices.

Manny, B. A., T. A. Edsall, and E. Jaworski. 1988. The Detroit River, Michigan: an ecological profile. U.S. Fish Wildl. Serv. Biol. Rep. 85(7.17). 86 pp.

Manny, B. A., and D. Inman. 1986. Potential threat to fish and wildlife resources and ecologicall-sensitive areas posed by spills of hazardous substances in the St. Clair-Detroit River system. U.S. Fish and Wildlife Service, National Fisheries Research Center-Great Lakes, Ann Arbor, Mich. Unpubl. MS.

McNabb, C. D., T. R. Batterson, J. R. Craig, P. Roettger, and M. Siami. 1986. Ship-passage effects on emergent wetlands. Michigan State University, Department of Fisheries and Wildlife. 78 pp.

MDNR (Michigan Department of Natural Resources). 1976. Michigan's major electric generating plants data. Mich. Dep. Nat. Resour., Water Qual. Div. (Biol. Sec.), Lansing. 14 pp.

Muth, K. M., D. R. Wolfert, and M. T. Bur. 1986. Environmental study of fish spawning and nursery areas in the St. Clair-Detroit River system. U.S. Fish Wildl. Serv., Great Lakes Fish. Lab., Admin. Rep. 86-6. Ann Arbor. 55 pp. + App.

N.Y. State Dept. of Envionmental Conservation. 1978. Environmental assessment of the FY 1979 Winter Navigation Demonstration on the St. Lawrence River. Technical reports: Summary. SUNY College of Environmental Science and Forestry. Syracuse, NY.

Patch, S. P. and W.-D. N. Busch. 1984. St. Lawrence River bibliography. In The St. Lawrence River - past and present. A review of historical natural resource information and habitat changes in the International Section of the St. Lawrence River. U.S. Department of the Interior, Fish and Wildlife Service, Cortland, N.Y. 340 pp.

Poe, T. P. 1983. Food habits of larval yellow perch as a potential indicator of water and habitat quality. U.S. Fish and Wildlife Service, Great Lakes Fishery Laboratory. Adm. Rep. 83-2. Ann Arbor, Mich. 21 pp.

Poe, T. P., and T. A. Edsall. 1982. Effects of vessl-induced waves on the composition and amount of drift in an ice environment in the St. Marys River. U.S. Fish. Wildl. Serv., GLFL/AR-80/6 Ann Arbor. 45 pp.

Poe, T. P., T. A. Edsall, and J. K. Hiltunen. 1980. Effects of ship-induced waves in an ice environment on the St. Marys River ecosystem. U.S. Fish. Wildl. Serv., GLFL/AR-80/6 Ann Arbor. 125 pp.

Quinn, F. H. 1988. Detroit River flow reversals. Internat. Assoc. Great Lakes Res. J. Great Lakes Res. 14(4):383-387.

Raphael, C. N., and E. Jaworski. 1982. The St. Clair River Delta: a unique lake delta. Geogr. Bull. 21:7-28.

Raynal, D. J., and J. W. Geis. 1978. Winter studies of littoral vegetation. Technical Report G. Environmental Assessment of the FY 1979 Winter Navigation Demonstration on the St. Lawrence River. Volume 1. State University of New York. Institute of Environmental Program Affairs, Syracuse, New York. 21 pp.

St. Lawrence - Eastern Ontario Commission. 1978. Coastal resources - the area's fishery. Watertown, NY.

Schloesser, D. W., T. A. Edsall, and B. A. Manny. 1985. Growth of submersed macrophyte communities in the St. Clair-Detroit River system between Lake Huron and Lake Erie. Can. J. Bot. 63:1061-1065.

Schnick, R. A., J. M. Morton, J. C. Mochalski, and J. T. Beall. 1982. Mitigation and enhancement techniques for the upper Mississippi River System and other large river systems. U.S. Fish Wildl. Serv., Resour. Publ. 149. 714 pp.

Sibley, C. K., and V. Rimsky-Korsakoff. 1931. Food of certain fishes in the watershed. Pages 109-120. In: A biological survey of the St. Lawrence Watershed (including the Grass, St. Regis, Salmon, Chateaugay systems and the St. Lawrence between Ogdensburg and the International Boundary). Suppl. 20th Annual Report (1930), NY Conservation Dept.

Texas Instruments Inc. Ecological Services. 1975. Report of fish and macrozooplankton studies on the St. Clair River in the vicinity of the proposed Belle River Power Plant. Dallas, Texas. 98 pp. & Appendix.

UGLCCS (Upper Great Lakes Connecting Channel Study). 1988. Draft final report. Vol. II. U.S. Environmental Protection Agency, Chicago, Ill. and Envrionment Canada, Toronto, Ontario. 583 pp.

USACE (U.S. Army Corps of Engineers). 1984. Great Lakes Water Level Facts. Detroit District, Michigan.

USACE. 1989. Monthly bulletin of lake levels for the Great Lakes. Detroit District, Michigan. January 1989. 3 pp.

U.S. Coast Guard. 1980. Pollution incident reporting system. Marine Environmental Division, 2100 Second St., N.W., Washington, D.C. Computer Files.

USDC-NOAA (U.S. Department of Commerce - National Atmospheric and Oceanic Administration). 1982. United States Coast Pilot 6. Lakes Ontario, Erie, Huron, Michigan, Superior and St. Lawrence River, Washington, D.C. 424 pp.

USEPA (U.S. Environmental Protection Agency. 1985. Upper Great Lakes connecting channels literature search. Great Lakes National Program Office, Chicago, Ill. 100 pp.

Werner, R. G., and D. Ford. 1972. St. Lawrence-Eastern Ontario shoreline study: technical report - fisheries. SUNY College of Environmental Science and Forestry. Syracuse, NY. 63 pp.

Wuebben, J. L. 1979. Vessel passage during winter ice conditions, observations of 25 January 1978. Pages 29-32 in J. K. Hiltunen. Investigation of macrobenthos in the St. Marys River during an experiment to extend navigation through winter, 1974-75. Admin. Rep., U.S. Fish Wildl. Serv. Ann Arbor. 177 pp.