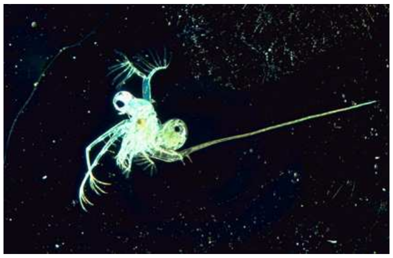

Briefing Booklet
for
Structured Expert Judgment
on the
Ecological and Economic Impacts
of
Ballast Water-mediated Nonindigenous Aquatic Species
in the
Laurentian Great Lakes

Fall 2007

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Ballast water-mediated species discovered in the Great Lakes since 1959

Key to Abbreviations of Vectors		
C - Canals	**R(D)** - Deliberate Release	**R(U)** - Unintentional Release
S(SB) - Shipping - Solid Ballast	**S(BW)** - Shipping - Ballast Water	**S(HF)** - Shipping - Hull fouling
AQ - Aquarium Trade	**BR** - Live Bait Release	**U** - Unknown

	Species	Common Name	Year of Discovery	Vector
1	*Pisidium supinum*	humpback pea clam	1959	S(BW)
2	*Thalassiosira weissflogii*	diatom	1962	S(BW)
3	*Skeletonema potamos*	diatom	1963	S(BW)
4	*Cyclotella cryptica*	diatom	1964	S(BW)
5	*Cyclotella atomus*	diatom	1964	S(BW)
6	*Cyclotella woltereki*	diatom	1964	S(BW)
7	*Chroodactylon ramosum*	red alga	1964	S(BW)
8	*Potamothrix vejdovskyi*	oligochaete	1965	S(BW)
9	*Eubosmina coregoni*	waterflea	1966	S(BW)
10	*Dugesia polychroa*	flatworm	1968	S(BW)
11	*Thalassiosira guillardii*	diatom	1973	S(BW)
12	*Thalassiosira pseudonana*	diatom	1973	S(BW)
13	*Skeletonema subsalsum*	diatom	1973	S(BW)
14	*Nitocra hibernica*	harpacticoid copepod	1973	S(BW)
15	*Sphacelaria lacustris*	brown alga	1975	S(BW)
16	*Hymenomonas roseola*	cocco-lithophorid alga	1975	S(BW)
17	*Biddulphia laevis*	diatom	1978	S(BW)
18	*Chaetoceros hohnii*	diatom	1978	S(BW)
19	*Thalassiosira lacustris*	diatom	1978	S(BW)
20	*Ripistes parasita*	oligochaete	1980	S(BW)
21	*Daphnia galeata galeata*	waterflea	1980	S(BW)
22	***Bythotrephes longimanus***	**spiny waterflea**	**1982**	**S(BW)**
23	*Nitellopsis obtusa*	green alga	1983	S(BW)
24	*Gianius aquaedulcis*	oligochaete	1983	S(BW)
25	***Gymnocephalus cernuus***	**Eurasian ruffe**	**1986**	**S(BW)**
26	***Apeltes quadracus***	**fourspine stickleback**	**1986**	**S(BW)**
27	*Thalassiosira baltica*	diatom	1988	S(BW)
28	***Bosmina maritima***	**waterflea**	**1988**	**S(BW)**
29	***Dreissena polymorpha***	**zebra mussel**	**1988**	**S(BW)**
30	***Dreissena bugensis***	**quagga mussel**	**1989**	**S(BW)**
31	***Neogobius melanostomus***	**round goby**	**1990**	**S(BW)**
32	***Proterorhinus marmoratus***	**tubenose goby**	**1990**	**S(BW)**
33	***Potamopyrgus antipodarum***	**New Zealand mud snail**	**1991**	**S(BW)**
34	*Neascus brevicaudatus*	digenean fluke	1992	S(BW)
35	*Acanthostomum sp.*	digenean fluke	1992	S(BW)
36	*Ichthyocotylurus pileatus*	digenean fluke	1992	S(BW)

	Species	Common Name	Year of Discovery	Vector
37	*Trypanosoma acerinae*	flagellate	1992	S(BW)
38	*Dactylogyrus amphibothrium*	monogenetic fluke	1992	S(BW)
39	*Dactylogyrus hemiamphibothrium*	monogenetic fluke	1992	S(BW)
40	***Echinogammarus ischnus***	**amphipod**	**1994**	**S(BW)**
41	*Scolex pleuronectis*	cestode	1994	S(BW)
42	*Sphaeromyxa sevastopoli*	mixosporidian	1994	S(BW)
43	*Heteropsyllus nr. nunni*	harpacticoid copepod	1996	S(BW)
44	*Acineta nitocrae*	suctorian	1997	S(BW)
45	***Cercopagis pengoi***	**fish-hook waterflea**	**1998**	**S(BW)**
46	*Schizopera borutzkyi*	harpacticoid copepod	1998	S(BW)
47	*Nitocra incerta*	harpacticoid copepod	1999	S(BW)
48	***Gammarus tigrinus***	**amphipod**	**2001**	**S(BW)**
49	*Psammonobiotus communis*	testate amoeba	2001	S(BW)
50	*Psammonobiotus sp.*	testate amoeba	2002	S(BW)
51	*Psammonobiotus linearis*	testate amoeba	2002	S(BW)
52	***VHS virus***	**viral hemorrhagic septicemia**	**2003**	**S(BW)**
53	***Hemimysis anomala***	**bloody red mysid**	**2006**	**S(BW)**

Established Nonindigenous Species in the Laurentian Great Lakes since 1840

Ricciardi, A. 2006. Patterns of invasion in the Laurentian Great Lakes in relation to changes in vector activity. Diversity and Distributions 12:425-433.

Key to Abbreviations of Vectors		
C - Canals	**R(D)** - Deliberate Release	**R(U)** - Unintentional Release
S(SB) - Shipping - Solid Ballast	**S(BW)** - Shipping - Ballast Water	**S(HF)** - Shipping - Hull fouling
AQ - Aquarium Trade	**BR** - Live Bait Release	**U** - Unknown

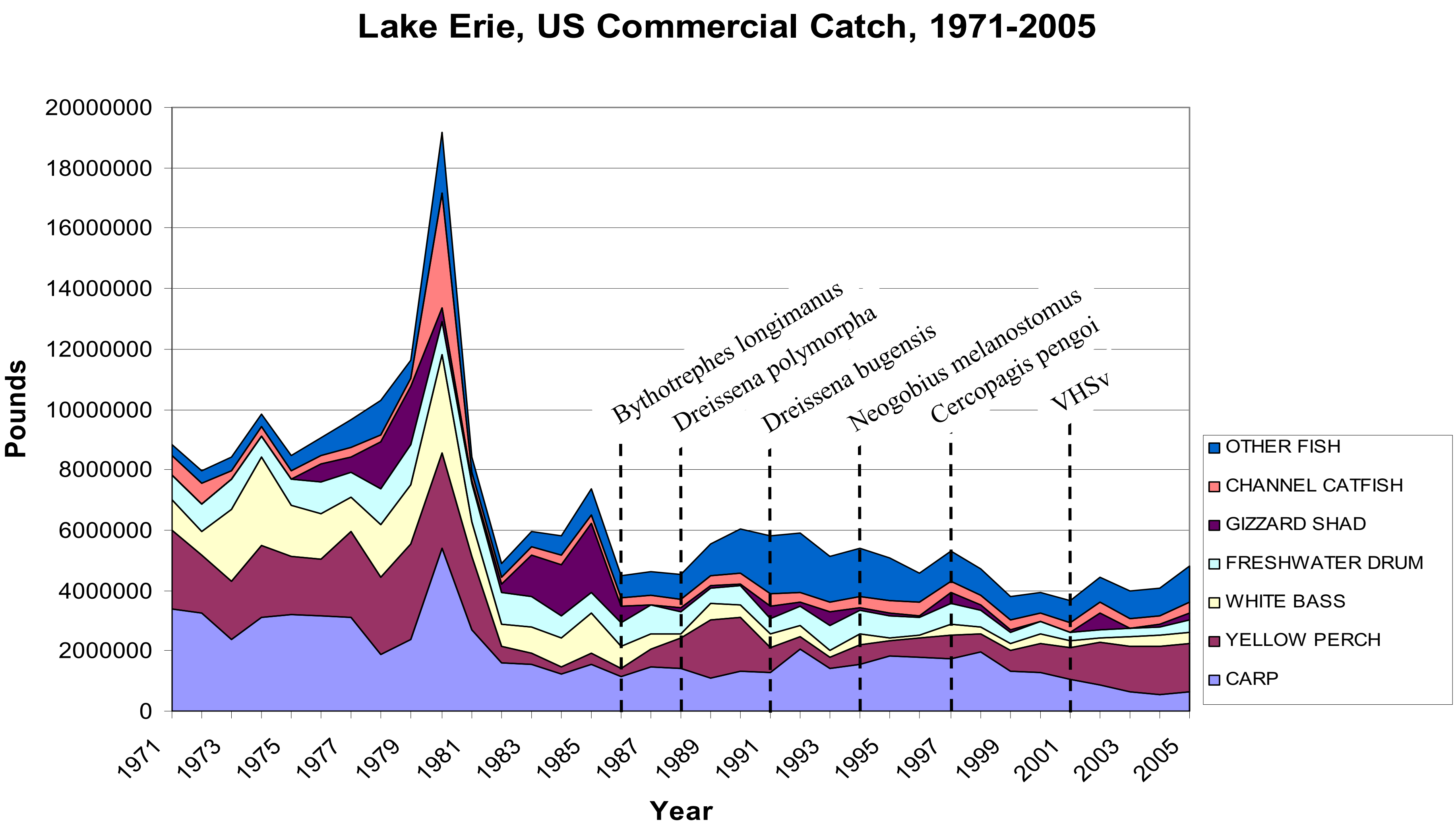
	Species	Common Name	Year of Discovery	Vector
1	*Rumex obtusifolius*	bitter dock	1840	U
2	*Echinochloa crusgalli*	barnyard grass	1843	R(D)
3	*Solanum dulcamara*	bittersweet nightshade	1843	R(D)
4	*Mentha piperita*	peppermint	1843	R(D)
5	*Conium maculatum*	poison hemlock	1843	R(D)
6	*Poa trivalis*	rough-stalked meadow grass	1843	R(D)
7	*Mentha spicata*	spearmint	1843	R(D)
8	*Polygonum persicaria*	lady's thumb	1843	U
9	*Rorippa nasturtium aquaticum*	water cress	1847	R(D)
10	*Elimia virginica*	snail	1860	C
11	*Juncus gerardii*	black-grass rush	1862	S(SB)
12	*Najas marina*	spiny naiad	1864	S(SB)
13	*Sonchus arvensis*	field sow thistle	1865	R(U)
14	*Carex disticha*	sedge	1866	S(SB)
15	*Chenopodium glaucum*	oak leaved goose foot	1867	RH
16	*Lythrum salicaria*	purple loosestrife	1869	C
17	*Bithynia tentaculata*	faucet snail	1871	S(SB)
18	*Alosa pseudoharengus*	alewife	1873	C
19	*Oncorhynchus tshawytscha*	chinook salmon	1873	R(D)
20	*Epilobium hirsutum*	great hairy willow herb	1874	R(U)
21	*Oncorhynchus mykiss*	rainbow trout	1876	R(D)
22	*Carassius auratus*	goldfish	1878	R(U)
23	*Cyprinus carpio*	common carp	1879	R(D)
24	*Potamogeton crispus*	curlyleaf pondweed	1879	R(D)
25	*Typha angustifolia*	narrow leaved cattail	1880	C
26	*Lysimachia nummularia*	moneywort	1882	R(D)
27	*Alopecurus geniculatus*	water foxtail	1882	R(D)
28	*Salmo trutta*	brown trout	1883	R(D)
29	*Agrostis gigantea*	redtop	1884	R(D)
30	*Rorippa sylvestris*	creeping yellow cress	1884	S(SB)
31	*Salix fragilis*	crack willow	1886	R(D)
32	*Salix purpurea*	purple willow	1886	R(D)
33	*Myosotis scorpioides*	true forgot-me-not	1886	R(D)
34	*Salix alba*	white willow	1886	R(D)
35	*Iris pseudacorus*	yellow flag	1886	R(D)
36	*Lycopus asper*	western water horehound	1892	R(D)
37	*Puccinellia distans*	weeping alkali grass	1893	S(SB)
38	*Stellaria aquatica*	giant chickweed	1894	U
39	*Juncus compressus*	flattened rush	1895	R(U)
40	*Pisidium moitessierianum*	pea clam	1895	S(SB)
41	*Carex flacca*	sedge	1896	U
42	*Valvata piscinalis*	European valve snail	1897	S(SB)
43	*Pisidium amnicum*	pea clam	1897	S(SB)
44	*Rumex longifolius*	yard dock	1901	R(D)

	Species	Common Name	Year of Discovery	Vector
45	*Radix auricularia*	European ear snail	1901	R(U)
46	*Aeromonas salmonicida*	furunculosis	1902	R(U)
47	*Sonchus arvensis var. glabrescens*	smooth field sow thistle	1902	R(U)
48	*Lycopus europaeus*	European water horehound	1903	S(SB)
49	*Butomus umbellatus*	flowering rush	1905	S(SB)
50	*Viviparus georgianus*	banded mystery snail	1906	AQ
51	*Impatiens glandulifera*	Indian balsam	1912	R(D)
52	*Osmerus mordax*	rainbow smelt	1912	R(D)
53	*Alnus glutinosa*	black alder	1913	R(D)
54	*Lysimachia vulgaris*	garden loosetrife	1913	R(D)
55	*Rhamnus frangula*	glossy buckthorn	1913	R(D)
56	*Mentha gentilis*	creeping whorled mint	1915	R(D)
57	*Veronica beccabunga*	European brookline	1915	S(SB)
58	*Pluchea odorata var. purpurescens*	salt-marsh fleabane	1916	R(U)
59	*Pisidium henslowanum*	henslow's pea clam	1916	S(SB)
60	*Gillia altilis*	snail	1918	C
61	*Juncas inflexus*	rush	1922	U
62	*Gambusia affinis*	western mosquitofish	1923	R(D)
63	*Sphaerium corneum*	fingernail clam	1924	S(SB)
64	*Marsilea quadrifolia*	European water clover	1925	R(D)
65	*Enteromorpha intestinalis*	green alga	1926	R(U)
66	*Acentropus niveus*	aquatic moth	1927	R(U)
67	*Noturus insignis*	margined madtom	1928	C
68	*Lepomis microlophus*	redear sunfish	1928	R(D)
69	*Lepomis humilis*	orange spotted sunfish	1929	C
70	*Nymphoides peltata*	yellow floating heart	1930	R(U)
71	*Cipangopaludina malleata*	oriental mystery snail	1931	AQ
72	*Najas minor*	minor naiad	1932	R(D)
73	*Oncorhynchus kisutch*	coho salmon	1933	R(D)
74	*Craspedacusta sowerbyi*	freshwater jellyfish	1933	R(U)
75	*Lophopodella carteri*	bryozoan	1934	C
76	*Cabomba caroliniana*	fanwort	1935	AQ
77	*Sparganium glomeratum*	bur reed	1936	U
78	*Actinocyclus normanii fo. subsalsa*	diatom	1938	S(BW)
79	*Stephanodiscus binderanus*	diatom	1938	S(BW)
80	*Diatoma ehrenbergii*	diatom	1938	S(BW)
81	*Misgurnus anguillicaudatus*	oriental weatherfish	1939	R(U)
82	*Cipangopaludina japonica*	oriental mystery snail	1940	R(D)
83	*Glyceria maxima*	reed sweet-grass	1940	R(D)
84	*Tanysphyrus lemnae*	aquatic weevil	1943	U
85	*Stephanodiscus subtilis*	diatom	1946	S(BW)
86	*Cyclotella pseudostelligera*	diatom	1946	S(BW)
87	*Phenacobius mirabilis*	suckermouth minnow	1950	C
88	*Morone americana*	white perch	1950	C
89	*Oncorhynchus nerka*	kokanee	1950	R(D)
90	*Cirsium palustre*	marsh thistle	1950	U
91	*Potamothrix bedoti*	oligochaete	1950	U
92	*Pluchea odorata var. succulenta*	salt-marsh fleabane	1950	U
93	*Branchiura sowerbyi*	oligochaete	1951	R(U)
94	*Carex acutiformis*	swamp sedge	1951	U
95	*Myriophyllum spicatum*	Eurasian watermilfoil	1952	AQ

	Species	Common Name	Year of Discovery	Vector
96	*Potamothrix moldaviensis*	oligochaete	1952	U
97	*Cordylophora caspia*	hydroid	1956	R(U)
98	*Oncorhynchus gorbuscha*	pink salmon	1956	R(U)
99	*Eurytemora affinis*	calanoid copepod	1958	S(BW)
100	*Trapa natans*	water chestnut	1959	AQ
101	*Lasmigona subviridis*	mussel	1959	C
102	*Pisidium supinum*	humpback pea clam	1959	S(BW)
103	*Glugea hertwigi*	protozoan	1960	R(U)
104	*Polygonum caespitosum var. longisetum*	bristly lady's thumb	1960	U
105	*Lepisosteus platostomus*	shortnose gar	1962	C
106	*Thalassiosira weissflogii*	diatom	1962	S(BW)
107	*Skeletonema potamos*	diatom	1963	S(BW)
108	*Cyclotella cryptica*	diatom	1964	S(BW)
109	*Cyclotella atomus*	diatom	1964	S(BW)
110	*Cyclotella woltereki*	diatom	1964	S(BW)
111	*Chroodactylon ramosum*	red alga	1964	S(BW)
112	*Bangia atropurpurea*	red alga	1964	S(BW/HF)
113	*Potamothrix vejdovskyi*	oligochaete	1965	S(BW)
114	*Eubosmina coregoni*	waterflea	1966	S(BW)
115	*Epilobium parviflorum*	hairy willow herb	1966	U
116	*Skistodiaptomus pallidus*	calanoid copepod	1967	R(U)
117	*Myxobolus cerebralis*	salmonid whirling disease	1968	R(U)
118	*Dugesia polychroa*	flatworm	1968	S(BW)
119	*Solidago sempervirens*	seaside goldenrod	1969	R(U)
120	*Enneacanthus gloriosus*	bluespotted sunfish	1971	AQ
121	*Cyclops strenuus*	copepod	1972	C
122	*Hydrocharis morsus-ranae*	European frogbit	1972	R(U)
123	*Thalassiosira guillardii*	diatom	1973	S(BW)
124	*Thalassiosira pseudonana*	diatom	1973	S(BW)
125	*Skeletonema subsalsum*	diatom	1973	S(BW)
126	*Nitocra hibernica*	harpacticoid copepod	1973	S(BW)
127	*Sphacelaria fluviatilis*	brown alga	1975	AQ
128	*Lotus corniculatus*	birdsfoot trefoil	1975	R(D)
129	*Renibacterium salmoninarum*	bacterium	1975	R(U)
130	*Sphacelaria lacustris*	brown alga	1975	S(BW)
131	*Hymenomonas roseola*	cocco-lithophorid alga	1975	S(BW)
132	*Biddulphia laevis*	diatom	1978	S(BW)
133	*Chaetoceros hohnii*	diatom	1978	S(BW)
134	*Thalassiosira lacustris*	diatom	1978	S(BW)
135	*Notropis buchanani*	ghost shiner	1979	BR
136	*Enteromorpha prolifera*	green alga	1979	U
137	*Corbicula fluminea*	Asiatic clam	1980	AQ
138	*Ripistes parasita*	oligochaete	1980	S(BW)
139	*Daphnia galeata galeata*	waterflea	1980	S(BW)
140	*Lupinus polyphyllus*	lupine	1982	R(U)
141	*Bythotrephes longimanus*	spiny waterflea	1982	S(BW)
142	*Nitellopsis obtusa*	green alga	1983	S(BW)
143	*Gianius aquaedulcis*	oligochaete	1983	S(BW)
144	*Salmincola lotae*	copepod	1985	U
145	*Gymnocephalus cernuus*	Eurasian ruffe	1986	S(BW)
146	*Apeltes quadracus*	fourspine stickleback	1986	S(BW)

	Species	Common Name	Year of Discovery	Vector
147	*Argulus japonicus*	parasitic copepod	1988	AQ
148	*Thalassiosira baltica*	diatom	1988	S(BW)
149	*Bosmina maritima*	waterflea	1988	S(BW)
150	*Dreissena polymorpha*	zebra mussel	1988	S(BW)
151	*Scardinius erythrophthalmus*	rudd	1989	BR
152	*Dreissena bugensis*	quagga mussel	1989	S(BW)
153	*Neogobius melanostomus*	round goby	1990	S(BW)
154	*Proterorhinus marmoratus*	tubenose goby	1990	S(BW)
155	*Potamopyrgus antipodarum*	New Zealand mud snail	1991	S(BW)
156	*Neascus brevicaudatus*	digenean fluke	1992	S(BW)
157	*Acanthostomum sp.*	digenean fluke	1992	S(BW)
158	*Ichthyocotylurus pileatus*	digenean fluke	1992	S(BW)
159	*Trypanosoma acerinae*	flagellate	1992	S(BW)
160	*Dactylogyrus amphibothrium*	monogenetic fluke	1992	S(BW)
161	*Dactylogyrus hemiamphibothrium*	monogenetic fluke	1992	S(BW)
162	*Echinogammarus ischnus*	amphipod	1994	S(BW)
163	*Scolex pleuronectis*	cestode	1994	S(BW)
164	*Sphaeromyxa sevastopoli*	mixosporidian	1994	S(BW)
165	*Neoergasilus japonicus*	copepod	1994	U
166	*Megacyclops viridis*	cyclopoid copepod	1994	U
167	*Alosa aestivalis*	blueback herring	1995	C
168	*Heteropsyllus nr. nunni*	harpacticoid copepod	1996	S(BW)
169	*Acineta nitocrae*	suctorian	1997	S(BW)
170	*Cercopagis pengoi*	fish-hook waterflea	1998	S(BW)
171	*Schizopera borutzkyi*	harpacticoid copepod	1998	S(BW)
172	*Daphnia lumholtzi*	waterflea	1999	R(U)
173	*Nitocra incerta*	harpacticoid copepod	1999	S(BW)
174	*Heterosporis sp.*	microsporidian	2000	U
175	*Gammarus tigrinus*	amphipod	2001	S(BW)
176	*Psammonobiotus communis*	testate amoeba	2001	S(BW)
177	*Rhabdovirus carpio*	spring viraemia of carp	2001	U
178	Largemouth Bass Virus	iridovirus	2002	R(U)
179	*Psammonobiotus sp.*	testate amoeba	2002	S(BW)
180	*Psammonobiotus linearis*	testate amoeba	2002	S(BW)
181	*Piscirickettsia cf. salmonis*	muskie pox	2002	U
182	*Enteromorpha flexuosa*	green alga	2003	S(BW/HF)
183	*VHS virus*	viral hemorrhagic septicemia	2003	S(BW)
184	*Hemimysis anomala*	bloody red mysid	2006	S(BW)

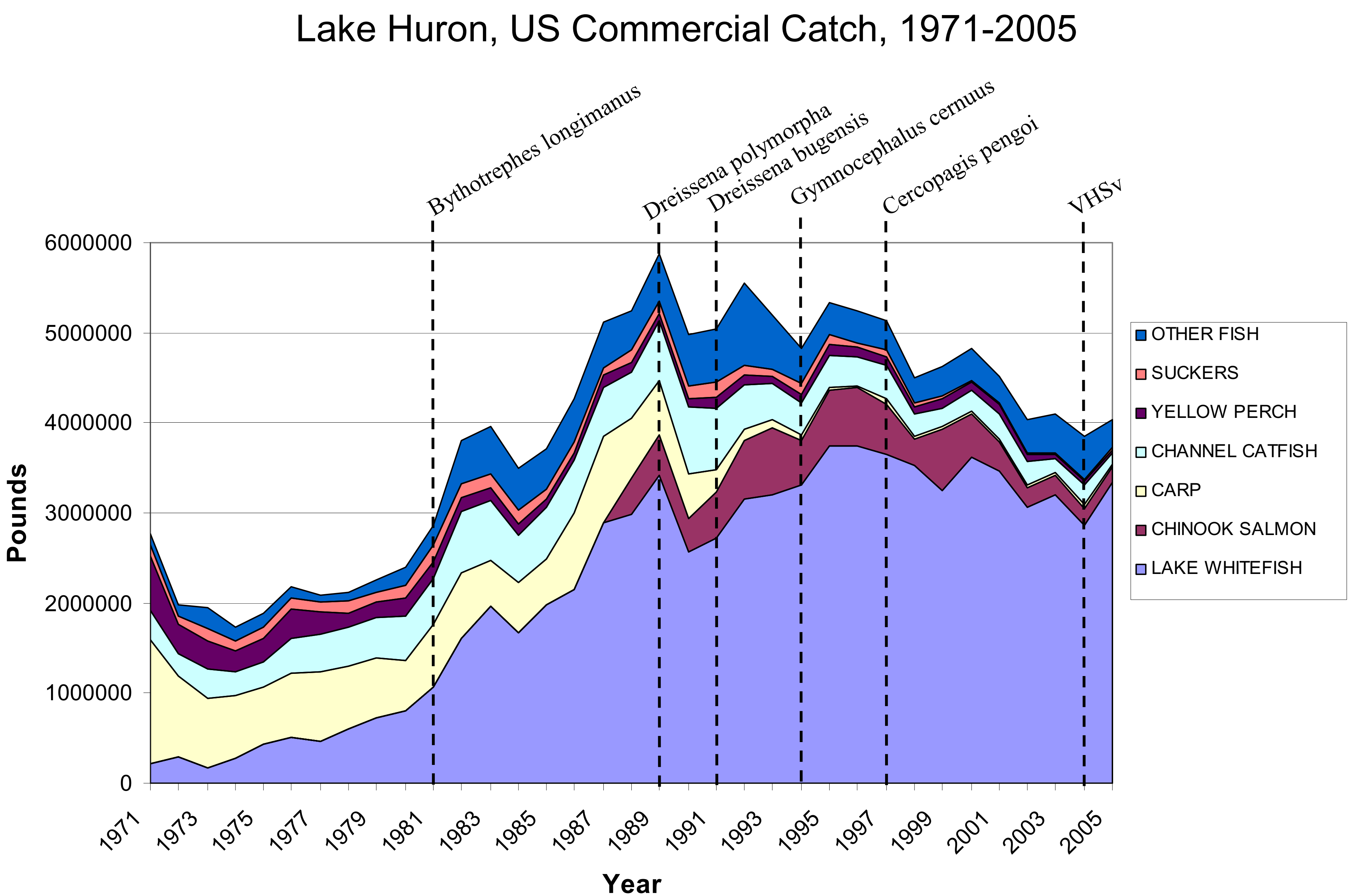
COMMERCIAL FISH SPECIES	Erie	Huron	Michigan	Ontario	Superior	Canadian Waters
ALEWIFE	X	X	X	X	X	
AMERICAN EEL	X	X		X		X
BIGMOUTH BUFFALO	X	X	X			
BLUE PIKE	X			X		
BOWFIN	X	X	X	X		
BROOK TROUT		X	X	X	X	
BROWN BULLHEAD	X	X	X	X	X	
BROWN TROUT	X	X	X	X	X	
BURBOT	X	X	X	X	X	X
CARP	X	X	X	X	X	X
CHANNEL CATFISH	X	X	X	X	X	X
CHINOOK SALMON	X	X	X	X	X	
CHUBS		X	X	X	X	
CISCO (LAKE HERRING)	X	X	X	X	X	X
COHO SALMON	X	X	X	X	X	
CRAPPIES	X	X	X	X		
FRESHWATER DRUM	X	X	X	X		
GAR	X	X	X	X		
GIZZARD SHAD	X	X	X	X	X	X
GOLDFISH	X			X		
KOKANEE		X	X			
LAKE STURGEON	X	X	X	X	X	X
LAKE TROUT	X	X	X	X	X	X
LAKE WHITEFISH	X	X	X	X	X	X
MINNOWS	X	X				
MOONEYE	X	X	X			
NORTHERN PIKE	X	X	X	X	X	X
PADDLEFISH				X		
PINK SALMON		X			X	X
QUILLBACK	X	X	X			
RAINBOW SMELT	X	X	X	X	X	X
RAINBOW TROUT (STEELHEAD)	X	X	X	X	X	
ROCKBASS	X	X	X	X	X	X
ROUND WHITEFISH		X	X		X	
SAUGER	X		X	X		X
SCULPIN					X	
SILVER REDHORSE				X		
SISCOWET (FAT TROUT)		X	X		X	
SMALLMOUTH BASS	X		X	X	X	
SPLAKE (BROOK TROUT X LAKE TR(	X	X	X	X	X	
SPOTTAIL SHINER	X					
SUCKERS	X	X	X	X	X	X
SUNFISH AND BASS	X	X	X	X		X
WALLEYE	X	X	X	X	X	X
WHITE BASS	X	X	X	X	X	X
WHITE PERCH	X	X	X	X		
WHITE SUCKER	X			X		
YELLOW PERCH	X	X	X	X	X	X



** Dashed vertical lines show dates of discovery in Lake Erie for various NIS. **

LAKE ERIE, US COMMERCIAL CATCH (POUNDS)

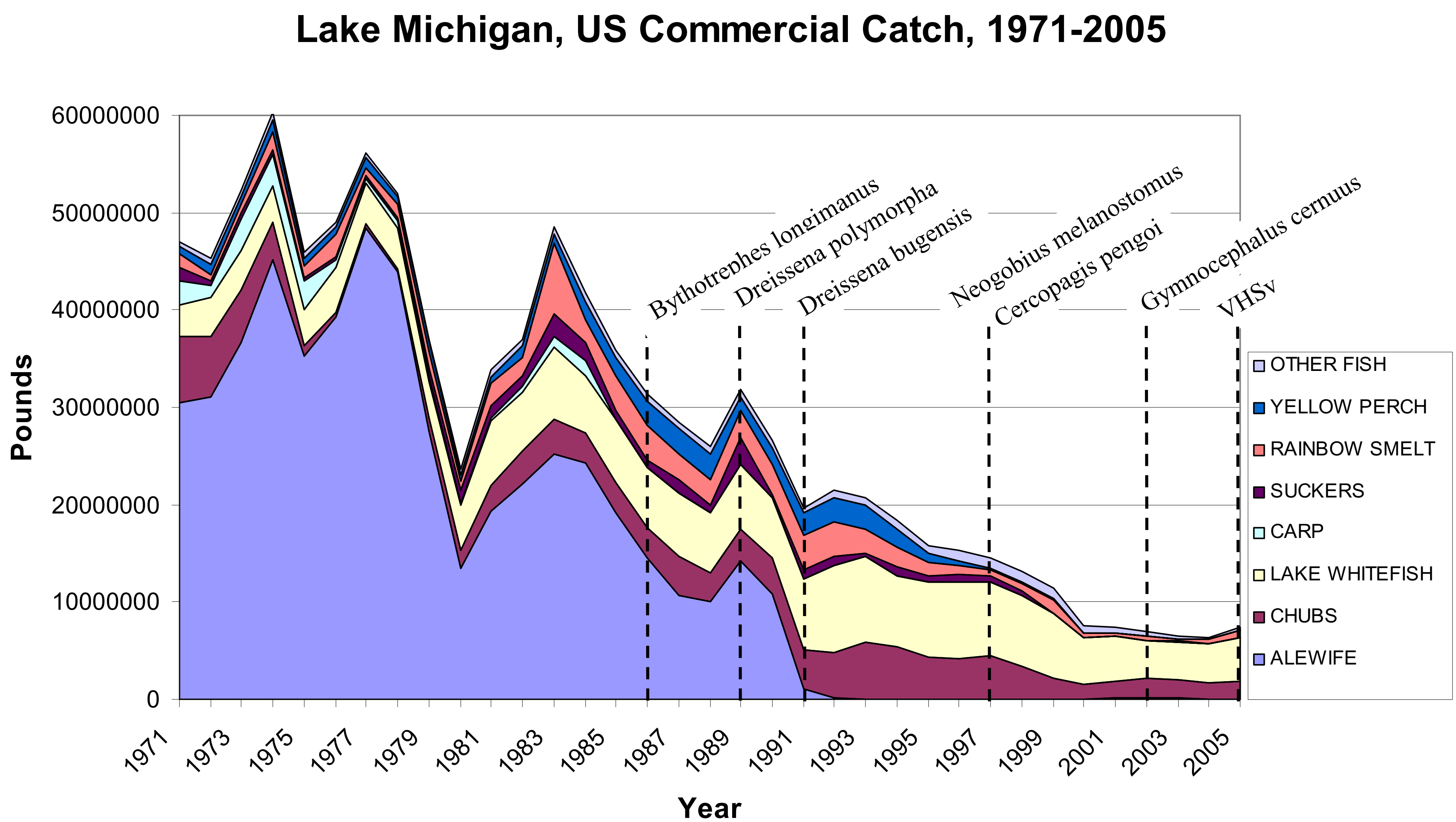
YEAR	CARP	YELLOW PERCH	WHITE BASS	FRESHWATER DRUM	GIZZARD SHAD	CHANNEL CATFISH	OTHER FISH	TOTAL
1971	3367824	2641392	996333	838863	2873	629176	350072	8826533
1972	3250702	1917615	770503	917371	387	684426	438321	7979325
1973	2392635	1887321	2424667	999754	0	254315	471167	8429859
1974	3109344	2376685	2912884	694038	12000	309783	433456	9848190
1975	3221211	1914326	1691852	853832	1656	274201	532321	8489399
1976	3141672	1885272	1523579	1034677	621004	261137	594273	9061614
1977	3089633	2868959	1121201	833458	504480	308021	943363	9669115
1978	1857627	2580025	1732218	1214939	1558460	228740	1139131	10311140
1979	2371090	3147031	1968538	1332971	1957568	267963	590790	11635951
1980	5415563	3157417	3249763	1063793	493510	3773942	2039306	19193294
1981	2712736	2422699	1134536	1281724	69900	313275	463997	8398867
1982	1585249	567314	726804	1064553	246657	239055	457059	4886691
1983	1553019	387748	864901	1006962	1375017	245215	525501	5958363
1984	1223251	235078	980896	735968	1662869	312946	667152	5818160
1985	1566793	349963	1350486	669290	2285849	273993	869681	7366055
1986	1138546	270390	729930	798790	556187	273138	704078	4471059
1987	1483808	588442	474523	976647	9964	311590	798726	4643700
1988	1428342	996187	144706	710775	149150	259861	850256	4539277
1989	1089500	1926620	558100	508929	61993	354263	1042291	5541696
1990	1348150	1765886	398226	658225	45259	367322	1452336	6035404
1991	1261025	858049	446122	514470	413895	377698	1938796	5810055
1992	2075685	396635	383002	621922	116770	338065	1981187	5913266
1993	1415053	381441	227080	809934	453033	335416	1499890	5121847
1994	1533774	670282	366698	761460	110990	376632	1587711	5407547
1995	1846513	473245	95466	750996	77706	398947	1451642	5094515
1996	1788888	632641	103603	600211	47632	452468	962744	4588187
1997	1738421	774729	358196	714839	360889	334641	1012165	5293880
1998	1956597	586754	236230	578764	177413	321754	837985	4695497
1999	1322647	700936	221562	359659	111268	327198	736885	3780155
2000	1269418	959368	319455	429227	7404	276131	668456	3929459
2001	1043189	1042006	227199	288199	2025	339417	740648	3682683
2002	860844	1413030	165496	253086	551806	352094	861882	4458238
2003	647055	1501939	318413	262004	45	327348	922063	3978867
2004	549159	1588901	360635	297708	90660	284204	903548	4074815
2005	660309	1586154	349152	441975	234710	326652	1223373	4822325



** Dashed vertical lines show dates of discovery in Lake Huron for various NIS. **

LAKE HURON, US COMMERCIAL CATCH (POUNDS)

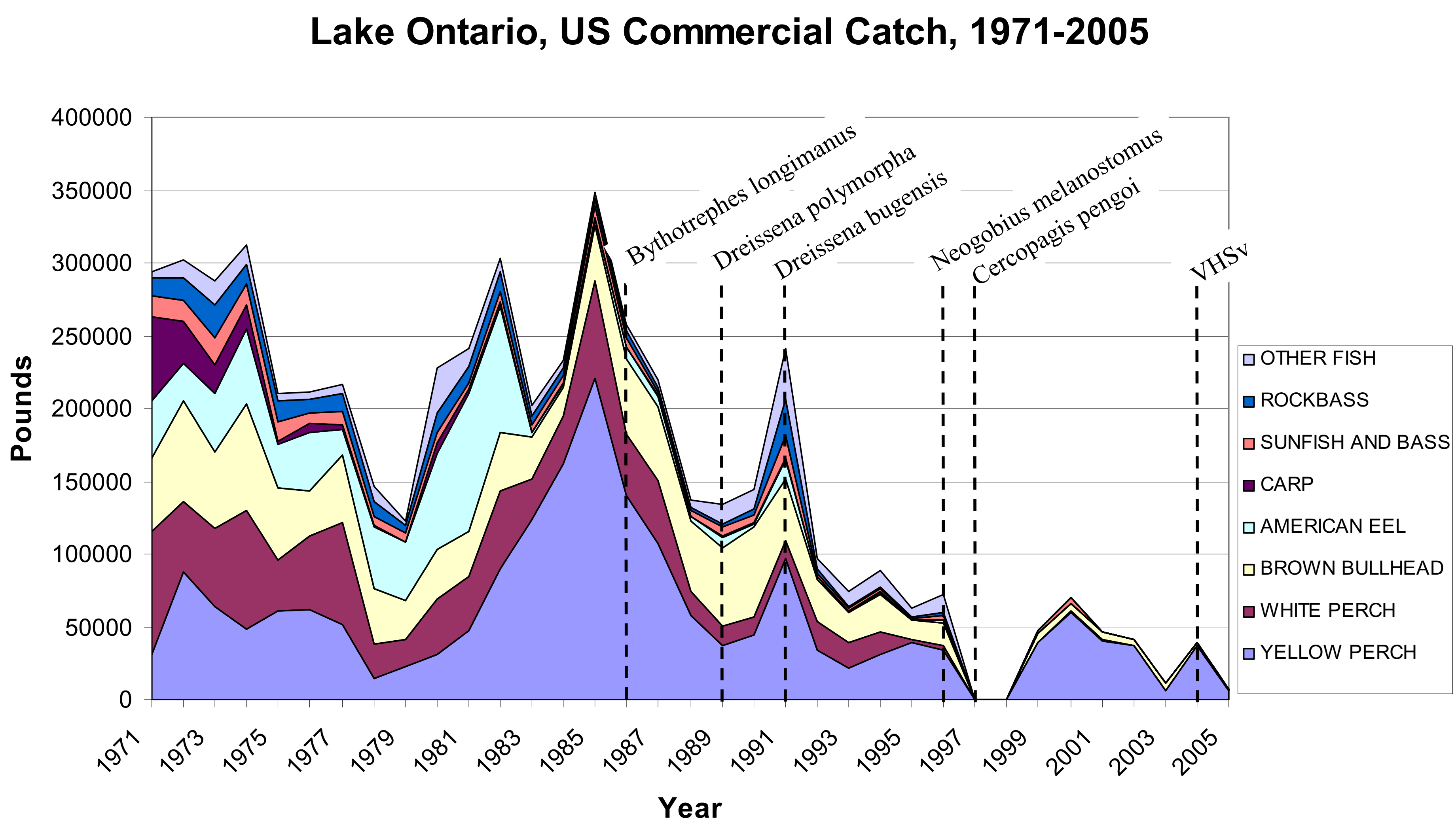
YEAR	LAKE WHITEFISH	CHINOOK SALMON	CARP	CHANNEL CATFISH	YELLOW PERCH	SUCKERS	OTHER FISH	TOTAL
1971	211555	0	1373585	339384	593393	125944	126873	2770734
1972	301318	1	888306	253560	326748	91149	124689	1985771
1973	169754	42	765982	325431	309018	145149	236648	1952024
1974	283422	1	684072	272049	229158	111463	151523	1731688
1975	433442	0	629053	282854	268929	110878	162025	1887181
1976	511716	0	716024	378892	322065	126788	130643	2186128
1977	456787	0	787588	403954	257337	105518	79895	2091079
1978	607832	20	686908	433862	164607	137305	91034	2121568
1979	730928	1	655209	457462	167763	110032	142902	2264297
1980	802935	0	562659	493947	195133	135132	206574	2396380
1981	1068457	0	693661	512938	187885	181967	219827	2864735
1982	1608322	0	727157	675673	158352	151114	479469	3800087
1983	1957401	0	511405	670077	139827	156233	527646	3962589
1984	1670826	160	551956	533264	120364	151992	462694	3491256
1985	1979058	0	509204	579455	79987	109494	451544	3708742
1986	2146981	4168	850801	590414	68827	127335	482770	4271296
1987	2896947	1575	953463	544838	127553	83228	511125	5118729
1988	2976989	404326	673399	512071	107824	132622	441530	5248761
1989	3410396	463046	588142	671932	76985	137009	521491	5869001
1990	2562262	373252	494673	737453	94183	140762	583694	4986279
1991	2726940	507731	252282	670351	123083	170142	584088	5034617
1992	3153223	644173	128591	493292	107401	113193	905982	5545855
1993	3202096	738300	91930	402234	76024	85828	596605	5193017
1994	3316977	491778	56512	352933	100991	125028	374051	4818270
1995	3746880	618884	28022	359280	121654	101774	363927	5340421
1996	3741349	649700	18293	317420	107228	55015	356307	5245312
1997	3648764	551297	65250	375428	93436	80207	313754	5128136
1998	3531141	290271	32405	248946	73974	44692	276554	4497983
1999	3245667	684908	25381	203664	103043	40126	317372	4620161
2000	3622278	470730	34620	230835	91908	18497	350251	4819119
2001	3464788	320249	34540	276490	111556	13089	294068	4514780
2002	3066597	218840	23477	260754	80192	18214	363401	4031475
2003	3202582	222250	16485	157676	44872	26072	420508	4090445
2004	2864575	189307	38889	218009	45725	13289	478483	3848277
2005	3343061	161992	34906	120069	33459	26007	315330	4034824



** Dashed vertical lines show dates of discovery in Lake Michigan for various NIS. **

LAKE MICHIGAN, US COMMERCIAL CATCH (POUNDS)

YEAR	ALEWIFE	CHUBS	LAKE WHITEFISH	CARP	SUCKERS	RAINBOW SMELT	YELLOW PERCH	OTHER FISH	TOTAL
1971	30418546	6858111	3187878	2478510	1498836	1309217	746737	557528	47055363
1972	31033388	6298567	3881884	1326172	434474	704407	1027782	538404	45245078
1973	36702946	5348291	4016766	3211069	712640	883219	749996	627573	52252500
1974	45094490	3888057	3758713	3205551	560572	1746534	1306857	671695	60232469
1975	35215778	1108235	3769721	2880115	345159	1174185	796611	698470	45988274
1976	39212137	505497	4614699	748775	448195	2186130	858419	472344	49046196
1977	48405627	445085	4116962	527846	278330	853796	978524	514276	56120446
1978	43879241	350752	4119577	761847	398144	1370143	715057	391223	51985984
1979	27503329	1471030	3709834	452115	953096	1567463	1122202	249969	37029038
1980	13511874	1766827	4685694	159517	1364883	974202	628004	633480	23724481
1981	19314098	2627996	6642523	384965	1197257	2241762	705395	794145	33908141
1982	22158305	3304882	6111699	636419	1051098	1855680	1246462	630096	36994641
1983	25181806	3611334	7443900	1043804	2374318	7126984	998273	732721	48513140
1984	24345092	3068297	5759332	1569324	1881470	2395314	1861716	872816	41753361
1985	19216701	2979320	6589559	7616	882983	3600056	1784493	888287	35949015
1986	14475539	3214222	6056146	977	852581	3600892	2466022	727021	31393400
1987	10707310	4037336	6452460	822	1307311	2699461	2579012	663766	28447478
1988	10034506	3025151	6120627	1641	735764	2690970	2557748	808193	25974600
1989	14160943	3317966	6590374	2486	2771334	2913895	1338576	703362	31798936
1990	10766828	3754913	6129453	387	412912	3120668	1686082	798499	26669742
1991	1138648	3889651	7326872	993	1008224	3490201	2314102	503740	19672431
1992	101189	4668144	8925434	1963	1059744	3500034	2488757	776275	21521540
1993	7333	5886659	8743604	320	301918	2490688	2502735	765479	20698736
1994	8681	5415390	7263772	0	926019	2049276	1851373	948791	18463302
1995	8	4348183	7668806	605	619812	1422539	879200	792358	15731511
1996	150	4117089	7939134	0	774554	890825	524907	1029315	15275974
1997	3657	4535147	7595001	95	504748	663458	136370	1120375	14558851
1998	49983	3315973	7298965	90	517328	701367	206812	1105151	13195669
1999	15002	2072844	6669033	0	47225	1336238	176772	1116856	11433970
2000	47401	1532514	4793087	0	7852	387819	58000	715127	7541800
2001	105731	1717231	4609495	0	8523	327283	38939	571672	7378874
2002	197372	1998095	3873796	0	2121	452574	20019	356813	6900790
2003	96053	1870903	3959045	436	125459	184587	19360	256080	6511923
2004	62522	1674258	4021338	0	2418	415828	17989	219938	6414291
2005	42922	1809682	4506156	0	24656	675880	23609	279130	7362035

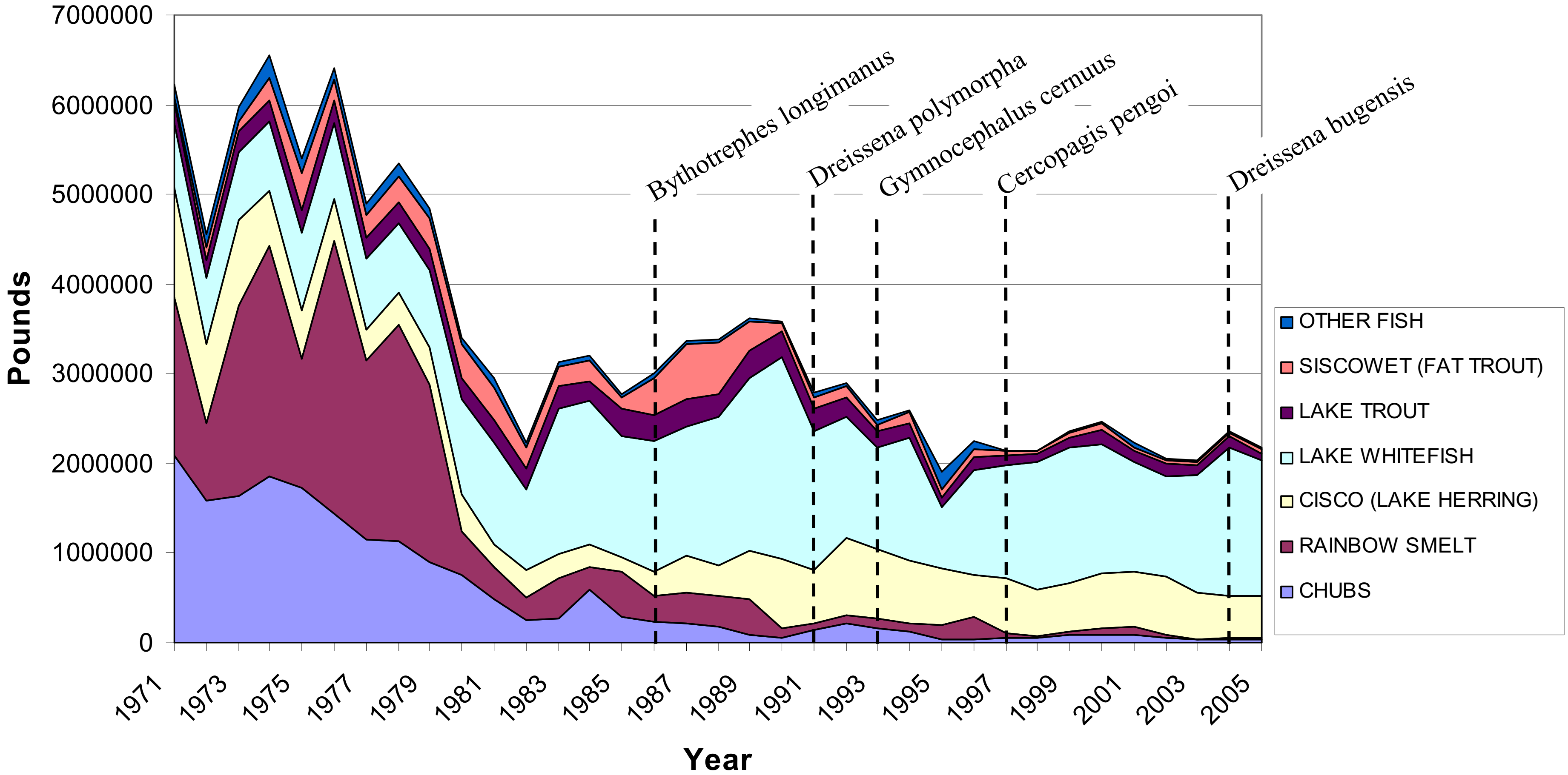


** Dashed vertical lines show dates of discovery in Lake Ontario for various NIS. **

LAKE ONTARIO, US COMMERCIAL CATCH (POUNDS)

YEAR	YELLOW PERCH	WHITE PERCH	BROWN BULLHEAD	AMERICAN EEL	CARP	SUNFISH AND BASS	ROCK BASS	OTHER FISH	TOTAL
1971	30625	84989	50742	38973	57380	14205	13021	4307	294242
1972	87334	48650	69344	25768	28255	14837	15811	12361	302360
1973	63886	53603	52449	40355	19229	19230	22355	16301	287408
1974	48396	81170	73522	51075	17110	14309	13642	13537	312761
1975	60646	35058	49929	30001	1562	13551	14847	4245	209839
1976	61536	50808	30740	40817	5636	7524	8658	5304	211023
1977	51255	70778	45923	17628	2604	9576	12089	6626	216479
1978	14046	24034	38141	42303	766	6299	10293	10348	146230
1979	22860	18763	26449	40113	228	5565	5112	4065	123155
1980	30619	38051	34404	65915	7766	6346	13925	30363	227389
1981	47634	37138	30727	95304	2088	4855	10897	12535	241178
1982	89853	53612	40126	86451	2735	7672	13608	8768	302825
1983	124171	27341	28386	3340	760	4278	6606	6782	201664
1984	161532	33603	19238	2096	812	5523	5049	5132	232985
1985	220713	66869	38161	3734	969	8475	5127	4438	348486
1986	140232	42500	51344	8259	66	6453	4800	4236	257890
1987	107663	42992	49873	7792	841	2174	2954	5647	219936
1988	57942	16119	48630	3151	20	3734	2288	5021	136905
1989	36935	13546	53279	7777	624	6256	2546	12561	133524
1990	44821	11759	61972	2190	1073	5404	3204	14038	144461
1991	96819	12035	43099	13370	1069	15337	24182	35486	241397
1992	33710	19391	29193	2130	531	1903	2492	7649	96999
1993	22094	16778	20763	559	530	2295	1300	9710	74029
1994	31176	15638	25320	1567	535	2468	912	11330	88946
1995	39304	1753	13166	519	84	719	1516	6064	63125
1996	33885	3086	15531	1937	582	2868	1444	12867	72200
1997	0	0	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	0	0	0
1999	38875	13	6744	0	0	2064	233	0	47929
2000	59928	383	5790	0	0	3571	280	0	69952
2001	40323	442	5875	0	0	16	15	0	46671
2002	37113	0	3970	0	0	0	0	0	41083
2003	6153	0	4815	0	0	0	0	0	10968
2004	37066	0	2525	0	0	0	0	0	39591
2005	6354	0	1040	0	0	0	0	0	7394

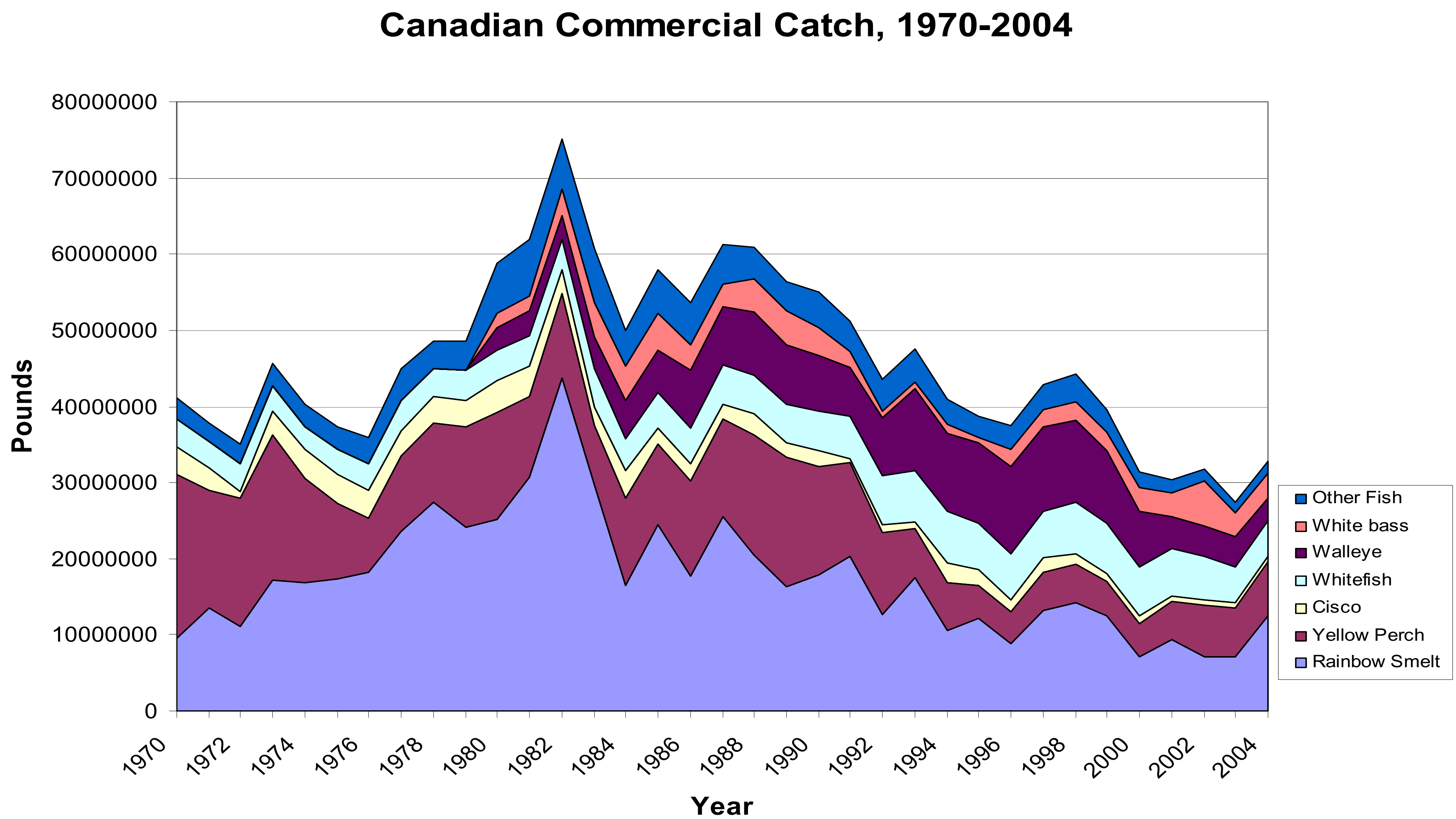
Lake Superior, US Commercial Catch, 1971-2005



** Dashed vertical lines show dates of discovery in Lake Superior for various NIS. **

LAKE SUPERIOR, US COMMERCIAL CATCH (POUNDS)

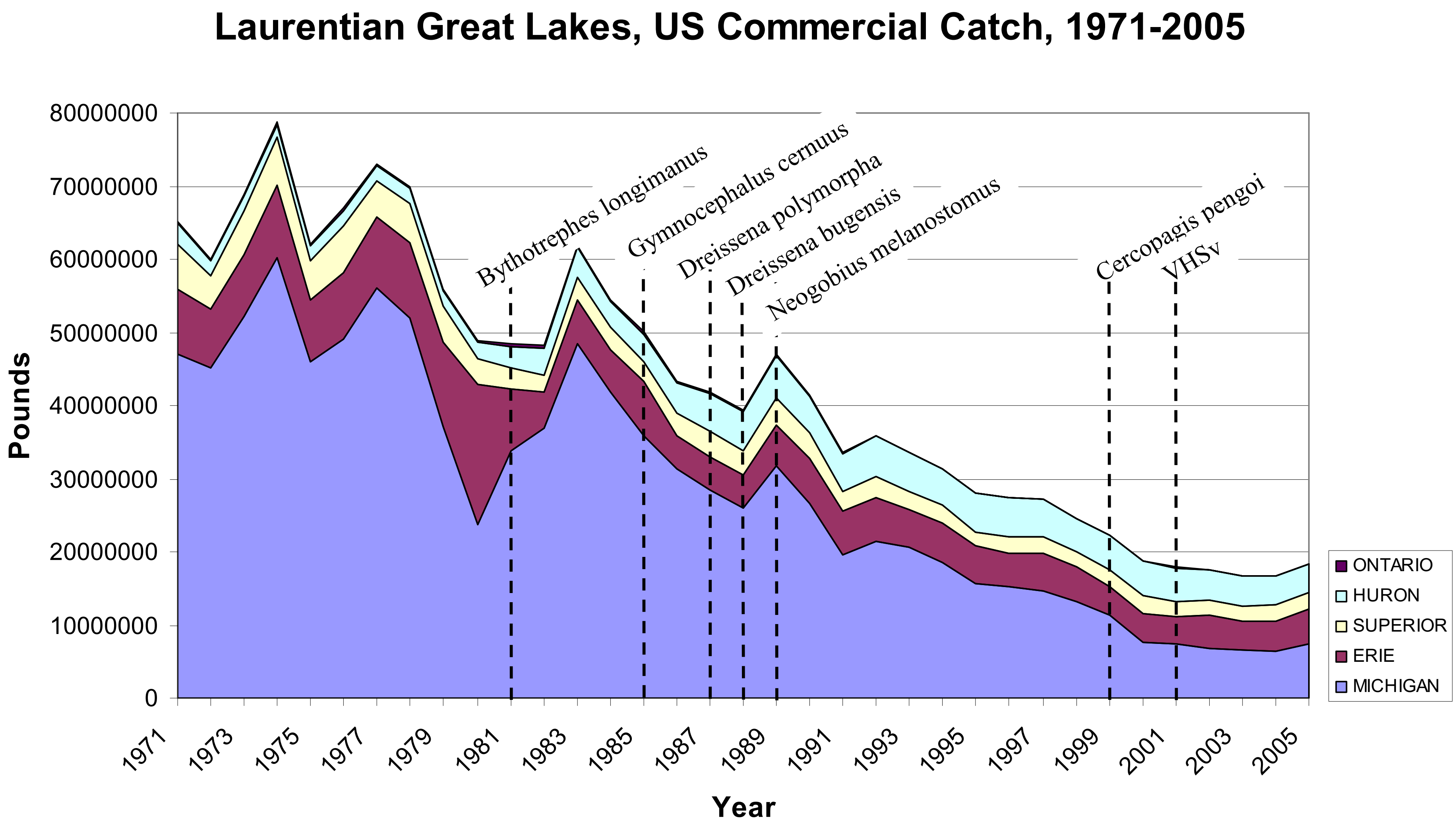
YEAR	CHUBS	RAINBOW SMELT	CISCO	LAKE WHITEFISH	LAKE TROUT	SISCOWET (FAT TROUT)	OTHER FISH	TOTAL
1971	2089757	1761740	1230722	711573	241900	52542	134156	6222390
1972	1582284	870106	883037	732926	203929	128749	155028	4556059
1973	1644204	2110647	951061	764982	231898	115298	159119	5977209
1974	1844584	2591083	605913	766411	230958	259082	250181	6548212
1975	1736304	1436322	529469	859616	261438	405340	166951	5395440
1976	1437878	3043758	470798	846488	240574	237105	121960	6398561
1977	1145713	2000062	347207	791550	234915	241693	137708	4898848
1978	1126849	2425880	353267	779942	231999	287164	131119	5336220
1979	906209	1980282	402933	862578	242700	345668	100899	4841269
1980	757013	489809	406693	1067869	229745	369843	73493	3394465
1981	481670	355591	264033	1129657	254730	354201	109091	2948973
1982	246461	253040	306098	908350	223818	239003	55570	2232340
1983	278805	438593	277392	1608352	258162	211492	64603	3137399
1984	590396	247008	258194	1601716	220755	235218	47256	3200543
1985	288163	506316	165694	1338711	311936	119715	34738	2765273
1986	228755	299712	262537	1456574	297358	410328	49308	3004572
1987	217839	339935	408443	1442344	300319	618971	38175	3366026
1988	176642	348325	341143	1653848	251376	584688	26711	3382733
1989	97275	381546	554959	1914862	302417	326925	31976	3609960
1990	50614	107859	770842	2250341	290982	87932	21562	3580132
1991	140004	70841	605451	1536623	250660	134248	55738	2793565
1992	217782	84956	874485	1348937	201328	127919	36638	2892045
1993	154932	108249	772800	1133466	180834	75715	65724	2491720
1994	125091	89495	696735	1369187	164101	125918	19324	2589851
1995	32196	174133	626121	678904	103738	85862	202670	1903624
1996	27887	260626	474209	1156623	158826	83861	79551	2241583
1997	61367	42290	625116	1245978	105428	52409	10720	2143308
1998	45784	18772	524936	1418576	89273	35241	13348	2145930
1999	93702	28495	546678	1505247	107440	65664	17421	2364647
2000	92424	69881	617042	1429470	170075	61909	18455	2459256
2001	95993	86040	614045	1222311	116293	43170	49883	2227735
2002	59089	34249	650385	1117866	139093	36315	6047	2043044
2003	37638	5419	522087	1305991	108317	33921	18274	2031647
2004	37233	10782	476139	1644500	129169	43305	15096	2356224
2005	34448	13223	480590	1501513	80703	51835	13103	2175415



** Refer to Great Lakes, US Commercial Catch chart for dates of NIS discovery. **

CANADIAN COMMERCIAL CATCH (POUNDS)

YEAR	RAINBOW SMELT	YELLOW PERCH	CISCO	WHITEFISH	WALLEYE	WHITE BASS	OTHER FISH	TOTAL
1970	9583495	21418798	3684917	3730054	0	0	2712823	41130086
1971	13556224	15406764	2950826	3434452	0	0	2526877	37875144
1972	11056182	16866799	945639	3540817	0	0	2684554	35093992
1973	17182829	19020775	3243739	3260166	0	0	2866408	45573917
1974	16902842	13583843	3943476	2891518	0	0	2888064	40209742
1975	17332743	9914656	3806060	3272127	0	0	2959289	37284875
1976	18245457	7049762	3748200	3354144	0	0	3494452	35892015
1977	23516709	9904045	3350417	3932105	0	0	4199409	44902687
1978	27335116	10474902	3565582	3652309	0	0	3477525	48505434
1979	24204552	13029963	3491450	4049150	0	0	3874995	48650110
1980	25190018	13986126	4246103	3904387	2982854	2008411	6547729	58865629
1981	30646459	10617463	4065324	3968321	3243000	1968728	7376667	61885962
1982	43669165	11115707	3179066	3999185	3040175	3507555	6688825	75199678
1983	29590445	7881526	2464768	5006698	4089575	4614275	7063611	60710898
1984	16501600	11386876	3659674	4248308	5026540	4429087	4720097	49972181
1985	24502176	10593212	1997388	4676005	5692336	4695846	5826818	57983780
1986	17747212	12482573	2189190	4720097	7663268	3247409	5650448	53700198
1987	25529530	12828699	1847474	5222751	7634608	2971831	5158817	61193710
1988	20445670	15778484	2804280	5019926	8437091	4340902	4001390	60827743
1989	16245864	17019687	2028253	4955992	7742635	4515067	3957298	56464795
1990	17890513	14292568	2023844	5240388	7299505	3661878	4620889	55029585
1991	20247254	12438481	531314	5445418	6483795	2070141	4038869	51255271
1992	12718468	10734308	1084674	6287584	7663268	892872	4089575	43470749
1993	17581865	6289788	989876	6651346	10813674	877440	4261536	47465525
1994	10639509	6212627	2570590	6847558	10154492	1216952	3302525	40944251
1995	12162903	4259331	2096596	6111214	10551324	701070	2735937	38618374
1996	8776056	4215035	1668791	6050981	11393597	2275000	3105522	37484983
1997	13148785	5108130	1874721	6081012	11162215	2245857	3286646	42907366
1998	14266340	5055678	1320494	6848375	10628348	2449822	3695481	44264538
1999	12545903	4441938	1094317	6637702	9419517	2421249	3072164	39632790
2000	7174424	4361564	885570	6561144	7295960	3118886	1940284	31337833
2001	9349553	4982163	810792	6244801	4054949	3235872	1672312	30350442
2002	7194786	6723005	698530	5677406	3991244	5956593	1498932	31740496
2003	7151796	6444112	623908	4728916	3979344	3066630	1402515	27397220
2004	12538910	7148753	605198	4742386	2909630	3256697	1644133	32845707

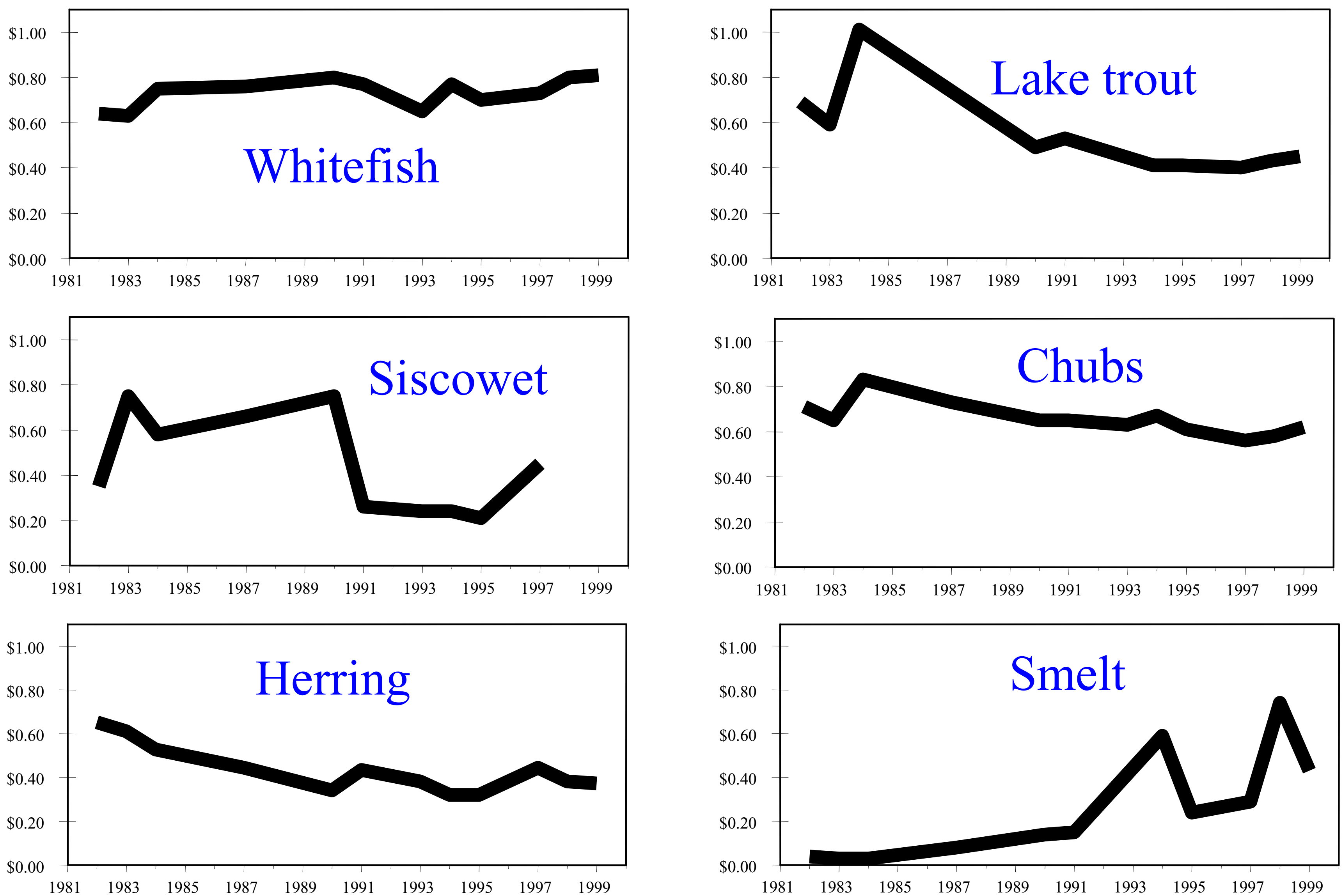


** Dashed vertical lines show dates of discovery in any of the Great Lakes for various NIS. **

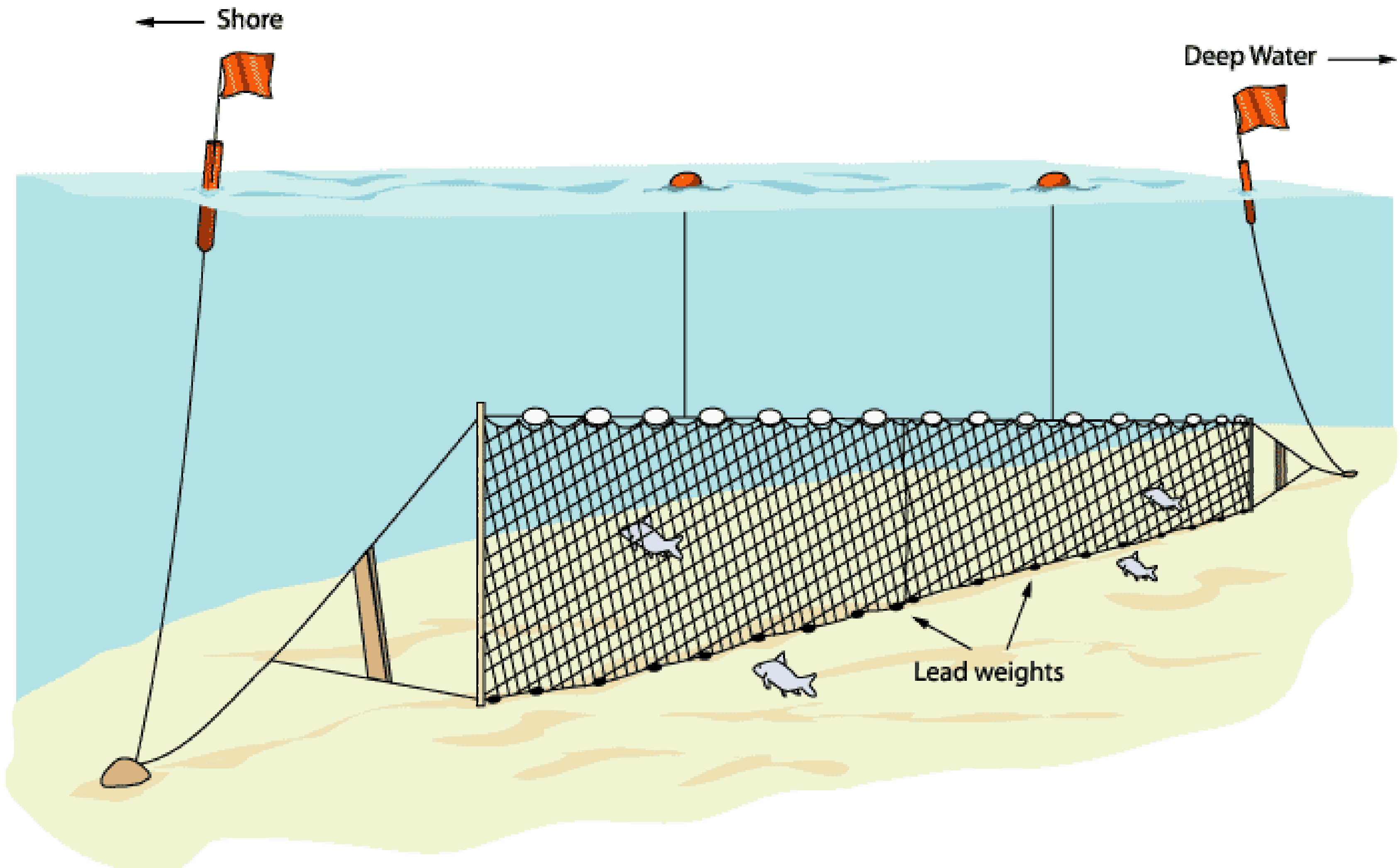
SIDE-BY-SIDE US COMMERCIAL CATCH TOTALS FOR ALL GREAT LAKES (POUNDS)

YEAR	LAKE MICHIGAN	LAKE ERIE	LAKE SUPERIOR	LAKE HURON	LAKE ONTARIO	GRAND TOTAL
1971	47055363	8826533	6222390	2770734	311364	65186384
1972	45245078	7979325	4556059	1985771	330242	60096475
1973	52252500	8429859	5977209	1952024	306526	68918118
1974	60232469	9848190	6548212	1731688	332917	78693476
1975	45988274	8489399	5395440	1887181	235539	61995833
1976	49046196	9061614	6398561	2186128	230349	66922848
1977	56120446	9669115	4898848	2091079	234438	73013926
1978	51985984	10311140	5336220	2121568	192270	69947182
1979	37029038	11635951	4841269	2264297	136205	55906760
1980	23724481	19193294	3394465	2396380	233280	48941900
1981	33908141	8398867	2948973	2864735	250212	48370928
1982	36994641	4886691	2232340	3800087	312002	48225761
1983	48513140	5958363	3137399	3962589	205301	61776792
1984	41753361	5818160	3200543	3491256	237880	54501200
1985	35949015	7366055	2765273	3708742	354645	50143730
1986	31393400	4471059	3004572	4271296	261405	43401732
1987	28447478	4643700	3366026	5118729	227461	41803394
1988	25974600	4539277	3382733	5248761	138951	39284322
1989	31798936	5541696	3609960	5869001	138722	46958315
1990	26669742	6035404	3580132	4986279	154469	41426026
1991	19672431	5810055	2793565	5034617	249238	33559906
1992	21521540	5913266	2892045	5545855	100484	35973190
1993	20698736	5121847	2491720	5193017	80371	33585691
1994	18463302	5407547	2589851	4818270	92251	31371221
1995	15731511	5094515	1903624	5340421	65327	28135398
1996	15275974	4588187	2241583	5245312	79457	27430513
1997	14558851	5293880	2143308	5128136	0	27124175
1998	13195669	4695497	2145930	4497983	0	24535079
1999	11433970	3780155	2364647	4620161	48134	22247067
2000	7541800	3929459	2459256	4819119	70260	18819894
2001	7378874	3682683	2227735	4514780	46671	17850743
2002	6900790	4458238	2043044	4031475	41083	17474630
2003	6511923	3978867	2031647	4090445	10968	16623850
2004	6414291	4074815	2356224	3848277	39591	16733198
2005	7362035	4822325	2175415	4034824	7394	18401993

Price Per Pound, 1981-1999

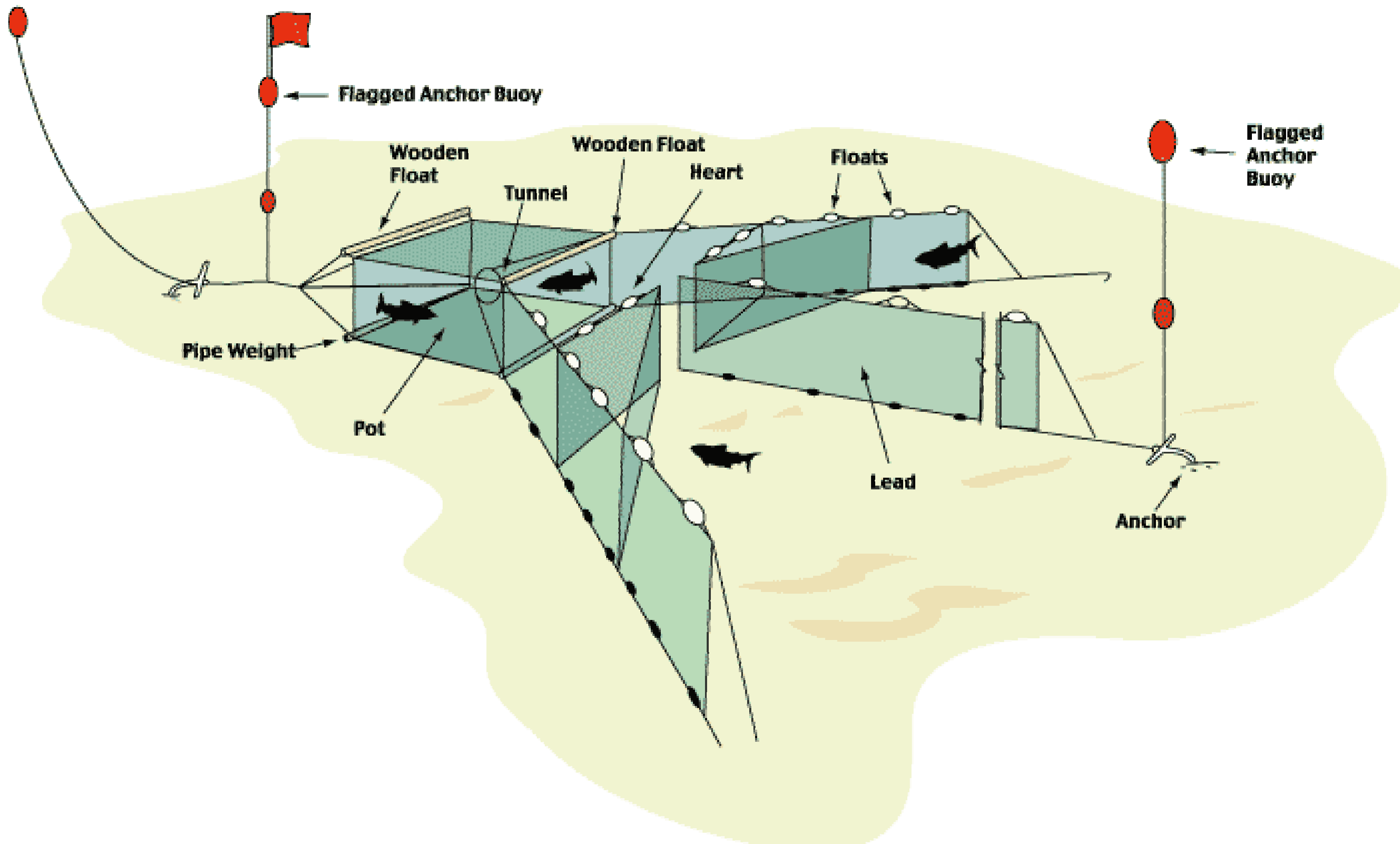


Gill Net



from http://www.miseagrant.umich.edu/nets/largegill.html

Trap Net



from http://www.miseagrant.umich.edu/nets/largetrap.html

CONVERSION FACTORS

WEIGHT

1 short ton = 2,000 pounds

1 tonne = 2,204.62262 pounds

1 tonne = 1.10231131 short tons

1 short ton = 0.90718474 tonnes

LENGTH

1 kilometer = 0.621371192 miles

1 mile = 1.609344 kilometers

Human Population Trends in Great Lakes States

	2006	2000	1990
Illinois	12,831,970	12,419,293	11,430,602
Indiana	6,313,520	6,080,485	5,544,159
Michigan	10,095,643	9,938,444	9,295,297
Minnesota	5,167,101	4,919,479	4,375,099
New York	19,306,183	18,976,457	17,990,455
Ohio	11,478,006	11,353,140	10,847,115
Pennsylvania	12,440,621	12,281,054	11,881,643
Wisconsin	5,556,506	5,363,675	4,891,769

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Exotic Species in the Great Lakes: A History of Biotic Crises and Anthropogenic Introductions

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ABSTRACT. *Through literature review, we documented introductions of non-indigenous aquatic flora and fauna into the Great Lakes basin since the early 1800s. We focused on the origin, probable mechanism(s) of introduction and the date and locality of first discovery of Great Lakes exotic species. The Laurentian Great Lakes have been subject to invasion by exotic species since settlement of the region by Europeans. Since the 1800s, 139 non-indigenous aquatic organisms have become established in the Great Lakes. The bulk of these organisms has been represented by plants (59), fishes (25), algae (24), and mollusks (14). Most species are native to Eurasia (55%) and the Atlantic Coast (13%). As human activity has increased in the Great Lakes watershed, the rate of introduction of exotic species has increased. Almost one-third of the organisms have been introduced in the past 30 years, a surge coinciding with the opening of the St. Lawrence Seaway in 1959. Five categories of entry mechanisms were identified: unintentional releases, ship-related introductions, deliberate releases, entry through or along canals, and movement along railroads and highways. Entry mechanisms were dominated by unintentional releases (29%) and ships (29%). Unintentional releases included escapees from cultivation and aquiculture, bait, aquarium, and other accidental releases. Ship-related introductions included ballast water (63%), solid ballast (31%), and fouling. Introductions via canals represent a small percentage of entries into the Great Lakes. We have identified 13 non-indigenous species (9%) that have substantially influenced the Great Lakes ecosystem, both economically and ecologically. The apparent lack of effects of 91% of the exotic species*

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in the Great Lakes does not mean that they have had little or no ecological impact. Alterations in community structure may predate modern investigations by decades or centuries, and the effects of many species have simply not been studied. As long as human activities provide the means through which future species can be transported into the Great Lakes basin, the largest freshwater resource in the world will continue to be at risk from the invasion of exotic organisms.

INDEX WORDS: Great Lakes, exotic species, non-indigenous flora and fauna, transport vectors.

INTRODUCTION

The rate of dispersal of living organisms and their component genetic material has accelerated with increased anthropogenic activity around the world. Introduced or exotic species, defined as successfully reproducing organisms transported by humans into regions where they did not previously exist, have been brought to new areas of the world for many centuries. The movement of living organisms by aboriginal peoples is well known, ranging from the synanthropic transport of plants and animals by Polynesians across the Pacific Islands to the movement of Mediterranean species by early colonists across the face of Europe. Later, as Europeans began to explore new continents, the influx of non-native species into new regions began and accelerated as technological advancements and development increased. These activities have caused 10-30% of the flora of most regions to be non-native species (Heywood 1989). The success of introduced organisms depends on many factors, including their survivability in unfavorable conditions, adaptability to new environments, high reproductive capability, and their ability to disperse rapidly (Baker and Stebbins 1965). Understanding the effects of introduced species on different ecosystems is critical because successful exotics may render previously stable systems unbalanced and unpredictable. Such global mixing of organisms has contributed to the world-wide loss of diversity in aquatic (Baker and Stebbins 1965) and terrestrial (Heywood 1989) communities.

The Laurentian Great Lakes have been subject to invasion by exotic species since settlement by Europeans. The impacts of some of these species have been enormous. The sea lamprey has cost both millions of dollars in losses to commercial Great Lakes fisheries and millions of dollars in control programs (Fetterolf 1980). The establishment of the zebra mussel, *Dreissena polymorpha,* in the Great Lakes (Hebert *et al.* 1989) poses major economic and ecological threats, costing hundreds of millions of dollars. Zebra mussels are of immediate threat to utilities and industries because they are a major biofouler. There is also concern about the zebra mussel's potential impacts on the structure of freshwater ecosystems as a result of its filter-feeding activities.

Despite the large number of exotics in the Great Lakes, there has been no attempt to prepare a comprehensive list of all known or suspected introduced species. Emery (1985) listed the fish introductions, and workers within other taxonomic groups have identified certain introduced species, but no one has inventoried the entire range of exotic species in the Great Lakes. We present here a comprehensive inventory of the introduced flora and fauna of the Great Lakes. This list includes fishes, invertebrates, aquatic plants, algae, and pathogens that have entered the Great Lakes since the early 1800s. We have attempted to establish the first date of collection and the first recorded locality for each exotic species in the Great Lakes, probable mechanism(s) of introduction, and probable origin. We have not attempted to ascertain the present distribution of each exotic species.

History of Dispersal Mechanisms

In northeastern North America, at least four centuries of European exploration, colonization, and commercial development (Hatcher 1944, Ashworth 1986) have set the stage for biological invasions into the Great Lakes. Long before Europeans arrived, however, invasions and introductions into the Great Lakes probably occurred regularly. As the last Wisconsin glacial ice stage retreated and the Great Lakes were formed between 14,000 and 4,000 years ago (Flint 1971), organisms invaded the basin, making the biological community in the Great Lakes relatively young. Indians living in the region at the time, like the aboriginal peoples of the Pacific and Europe (Heywood 1989), probably transported animals and plants among and into the Great Lakes, beginning a trend that accelerated with European settlement.

The rapid changes that have influenced the Great Lakes for the past four centuries began after the French started colonizing the region in the 17th century. Europeans brought new technology, religion, and conflict into the region and used the basin as a source of furs for their markets. When the French were defeated in the mid-18th century and the English gained control of the Great Lakes, settlers from all parts of Europe arrived, some using the seemingly limitless supply of timber, minerals, and fur-bearing animals to build large businesses that employed thousands of people (Hatcher 1944). Large cities grew around strategic ports where Midwestern grain, ore, lumber, furs, and other products were exported to locations worldwide. The opening of the St. Lawrence Seaway increased trade on the Great Lakes dramatically which in turn increased growth of midwestern port cities. Today, these ports represent 5 of the 15 largest cities in the U.S. and 5 of the 15 largest cities in Canada, attesting to the influence of the Great Lakes as portals to the heart of North America (Ashworth 1986).

During the historical development of the Great Lakes basin, human activities have played a substantial role in the introduction of non-indigenous organisms into the world's largest freshwater resource. These activities, described below, have acted alone or jointly in mediating the introductions of exotic species.

Release (Deliberate)

The early history of deliberate releases of fishes into the Great Lakes is lost in obscurity. DeKay (1842) noted the introduction of common carp into the Hudson River by a "patriotic" citizen and encouraged others to bring fishes from Europe, specifically turbot and sole, for establishment in North American waters. By the early 1870s, deliberate stocking of fish species such as Pacific salmon *(Oncorhynchus* sp.) and common carp *(Cyprinus carpio)* by government fish hatcheries had commenced (Emery 1985). The intentional introduction of native North American mollusks (such as the larger freshwater mussels) into the Great Lakes is not well known, although amateur naturalists were known to have been engaged in such activities throughout North America by at least the mid-nineteenth century. These movements were motivated in part by a perceived desire to increase natural diversity. Kew (1893) for example, noted that a variety of freshwater snails (including *Melantho (=Campeloma), Goniobasis (= Elimia), Somatogyrus, Vivipara (= Viviparus),* and *Bythinia (= Bithynia)* (synonymy from Burch 1989)) were moved by naturalists in the northeastern United States into such localities as the Mohawk River. Erie Canal, and Schuyler's Lake, New York.

Release (Unintentional)

The release of organisms without intention of creating established populations has occurred through a variety of ways. These include:

Release (Aquarium)

The release of aquarium pets into the environment is a practice thought by some to be more humane than other means of disposal. Generally. owners never intended to establish self-sustaining populations of their pets, even though they knowingly released them into favorable habitat (Schmeck 1942).

Release (Cultivation)

The accidental escape of cultivated plants from ornamental gardens and agriculture is a very common mechanism for the introduction of aquatic plants. These introductions have occurred since colonial times when settlers brought over plants to use for medicinal (Torrey 1843 - bittersweet), gastronomical (Green 1962 - water cress), and ornamental purposes (Judd 1953- yellow flag).

Release (Fish)

Release of unused bait by fishermen and transport of fishes from one drainage basin to another in fishing vessels are activities through which fish species are introduced. Rudd, *Scardinius erythrophthalmus,* has been introduced through bait bucket release. Release of disease pathogens (such as the causative agent for furunculosis, *Aeromonas salmonicida* (Bullock *et al.* 1983)) with stocked fish, accidental release of other species of fish with stocked fish (such as the possible introduction of alewife with American shad (Emery 1985)), and introduction of plankton in fish transport water are means through which stocking programs can indirectly and unintentionally introduce organisms.

Release (Accidental)

The accidental introduction of organisms in any other manner is covered under this release mechanism. Examples are the introduction of marine algae into inland brackish habitats from kitchens discarding seafood packaging and shells (Taft 1946), and the accidental release of invertebrates with plants imported for the aquarium trade or ornamental gardens (Goodrich 1911, Aston 1968).

Shipping Activities

The potential for inoculation of the Great Lakes by freshwater organisms from distant drainage basins in North America or from the European continent began in the 1840s and 1850s, with completion of the first passages by ocean-going vessels in and out of the Great Lakes. By the mid- 1840s it was possible to sail from Lake Ontario to Europe (for example the passage of the brigantine *Pacific* in 1844 from Toronto to Liverpool), and by the late 1850s passage from Lake Michigan to Europe had been achieved (for example, the voyage of the steamer *Dean Richmond* from Lake Michigan to Liverpool in 1857) (Mills 1910, LesStrang 1981, Larson 1983). By the early 1860s dozens of vessels were making similar voyages, and presumably many of these were returning from Europe to their home Great Lakes ports. This commerce was facilitated by the completion of: 1) the Welland Canal in 1829, 2) the locks at Sault Ste. Marie in 1855 (permitting complete translake navigation), and 3) the St. Lawrence River canal system in 1847 (permitting vessels to sail from the Great Lakes to the sea). Canals and locks improved steadily throughout the late nineteenth and early twentieth centuries, and ocean commerce expanded considerably.

Ships (Fouling)

Although freshwater fouling organisms from Europe are not likely to survive a transoceanic voyage of several weeks into North America, introduction of fresh and brackish water Atlantic coastal organisms into the basin is possible. Use of the canals for trading between Great Lakes ports and cities on the Hudson or the St. Lawrence provided an opportunity for fouling organisms to be transported upstream into the Great Lakes. The sea lamprey and several species of algae, for example, are thought to have invaded the Great Lakes basin through natural movement upstream through canals and attachment to ships plying these canals.

Ships (Solid Ballast)

Before technological advances enabled humans to use water as ballast, soil, mud, shoreline rocks, sand, and beach debris were often used. When a ship arrived in port to take on cargo, the ballast was dumped onto ballast grounds or thrown overboard (Lindroth 1957). Plants (often as seeds) and invertebrates (particularly insects) were transported in this material across the ocean or inland through canals and deposited in dumping grounds and harbors in the Great Lakes and along the coast. The occurrence of European plants on ballast dumping grounds is well documented (Martingale 1876, Burk 1877, Brown 1879). In New York City, streets were occasionally filled and resurfaced with ballast, and the plants associated with the ballast were then found in relatively high numbers in the reworked area (Brown 1879). Lycopus *europaeus,* European water horehound, was a well documented solid ballast introduction in New York City (Brown 1879). Since similar types of organisms may occur in packaging materials, dunnage, and other in-port releases (such as plants in animal bedding) and in solid ballast, distinguishing between these mechanisms is nearly impossible. Because of this problem, we will include all these mechanisms with solid ballast.

Ships (Ballast Water)

Ballast water was in use by the 1880s and could have been released into the Great Lakes well before 1900 (Carlton 1985). In 1875, work to enlarge canals from the St. Lawrence River to Lake Superior began and continued until they could accommodate a ship 79 meters long with a 13 meter beam and a 4 meter draught (Anonymous 1922). Although the ships were not the enormous vessels seen today in the St. Lawrence Seaway, ballast they brought into the Great Lakes may have been substantial. With the opening of the enlarged Seaway system on 26 June 1959 (Ashworth 1986), the amount of ballast water released into the Great Lakes increased dramatically because of the larger size and increased frequency of ships transiting directly from Europe and other ports of origin through the St. Lawrence Seaway.

Canals

A vast network of canals began to take shape in northeastern North America by the late 1700s. These canal systems connected adjacent watersheds and thus dissolved many of the natural barriers to the dispersal of freshwater organisms into the Great Lakes. The canals may have particularly altered the distributions of animals and plants not likely to have been dispersed by birds or other terrestrial and semiaquatic animals. Organisms like the sea lamprey have used these dispersal corridors to expand into the Great Lakes. Celebrations marking the completion of the Erie Canal in 1825 ironically illustrate the potential impact of the canals on the Great Lakes. For example, on the arrival of the first boats to officially navigate the Erie Canal from Buffalo to New York, the Governor of New York "performed the ceremony of commingling the waters of the Great Lakes with the ocean, by pouring a keg of...Lake Erie (water) into the Atlantic !" (Mills 1910).

Railroads and Highways

The construction of railroads and highways provided several different types of introduction mechanisms. Railroad and highway building creates corridors of continuously disturbed habitat ideal for the movement of introduced plants into new regions and the establishment of new plants introduced with railroad gravel and lumber. The migration of plants along man-made railroad margins is known to have occurred from the Atlantic Coast and from the midwest into the Great Lakes basin.

METHODS

We define exotic species as successfully reproducing organisms transported by humans into the Great Lakes, where they did not previously exist. The following criteria for data collection outline the methods used in this study. These data are included in species tables at the beginning of the individual case histories for each group of organisms. Tables 1 and 2 list the codes for locations and transfer mechanisms used in the species tables (Tables 3 and 4). When a location is not in the Great Lakes proper but in the watershed of a lake, these codes are used to indicate in which lake's watershed the location occurs.

First Date and Location of Collection

The date and location of the first observation of each exotic species in the Great Lakes drainage were largely ascertained from the literature. In some cases, workers did not indicate first sighting of specimens according to date or location but used a broad period (e.g., "1960s") or a general location (e.g., "widespread"). We have, however, always attempted to distinguish between the actual date of first collection and the publication date of the paper first recording an exotic species. In most cases, of course, the first sighting of a species is likely to be sometime after the date at which it gained entry into the Great Lakes. For consistency we have chosen to use the collection dates (if available) rather than speculated dates of introduction. For example, the zebra mussel *Dreissena* was first collected in the Great Lakes in 1988; the specimens were at least 2 years old, but we list 1988, rather than 1986, as the date of record.

Probable Entry Mechanism(s)

The mechanism or vector of introduction is defined as the most probable means by which a species was introduced into the Great Lakes. We have attempted to identify possible entry mecha nisms for each organism, in part based on knowledge of individual species' biology. For some the transport mechanism remains unknown. For many

TABLE 1. Location abbreviations of exotic species in the Great Lakes.

Location	*Code*
Lake Ontario	O
Lake Erie	E
Lake St. Clair	StC
Lake Huron	H
Lake Michigan	M
Lake Superior	S
tributaries	T

TABLE 2. Codes for transport mechanisms of exotic species entering the Great Lakes.

Mechanism	Code
Release (Deliberate)	R(D)
Release (Unintentional)	R(U)
Release (Aquarium)	R(AQ)
Release (Cultivation)	R(C)
Release (Fish)	R(F)
Release (Accidental)	R(A)
Shipping activities	s
Ships (Ballast Water)	S(BW)
Ships (Solid Ballast)	S(SB)
Ships (Fouling)	S(F)
canals	c
Railroads and Highways	RH

species it is not possible to identify a single mechanism of introduction, and, in these cases, we have discussed several possible entry mechanisms and categorize them under the multiple mechanism.

Geographic Source and Origin of Exotic Species

Although the precise origins of many of the non-native species in the Great Lakes are not known, a broad geographic origin for each species has been determined. In this study, we have identified six different geographic regions of origin including Europe/Eurasia, Asia, North American Atlantic Coast. North American Pacific Coast, Southern U.S., and the Mississippi River drainage system. The Europe and Eurasia origins have been combined here because in many cases authors do not distinguish between these geographic ranges. The native range of an organism, however, may not be the source of the Great Lakes populations of the species. *Corbicula fluminea,* for example, was firmly established in other parts of North America before it was discovered in the Great Lakes. It can be reasonably presumed that the Great Lakes populations of *Corbicula* did not originate in Asia, but from some other part of North America. We have discussed these origins in cases where the invasion history of the exotic species is well known. We have not attempted to document movement of species native to parts of the Great Lakes (such as the threespine sticklebacks, *Gasterosteus aculeatus)* that have expanded their range within the basin (Stedman and Bowen 1985).

RESULTS

Aquatic Fauna

Fish

The fishes (Table 3) are the best studied group of freshwater introduced species in North America. Several publications list the known exotic species of the United States and Canada (Courtenay *et al.* 1984, 1986), Canada (Crossman 1984, 1991), and the Great Lakes (Emery 1985). Other studies have summarized the genetic, ecological, and economic effects of introduced fishes on native species (Christie *et al.* 1972, Berst and Spangler 1973, Hartman 1973, Krueger and May 1991). Additional research has focused on the postglacial dispersal of Great Lakes fishes (Bailey and Smith 1981) and the potential invasion of fishes due to climatic warming (Mandrak 1989). The following discussion will build on Emery's (1985) treatment of Great Lakes introduced fishes and discuss more recently introduced species. The taxonomy of the fishes discussed below is according to Robins *et al.* (1991).

Several fish species have not established self-sustaining populations in the Great Lakes, but have remained consistently abundant due to continued stocking programs. We include these because their impact on the Great Lakes is as substantial, if not more, than most of the established introductions.

Petromyzontidae:
Petromyzon marinus SEA LAMPREY

Because it was not discovered in the Great Lakes until the 1830s in Lake Ontario, the sea lamprey is thought to have migrated through the Erie Canal either from its native habitat in the Atlantic drainage (Emery 1985) or attached to boats plying the Erie and St. Lawrence Canal systems (Morman *et al.* 1980). Another school of thought believes that the sea lamprey is native to the Lake Ontario drainage basin (Lawrie 1970), a possibility Smith (1985) supports because of the discontinuous distribution between the freshwater lamprey populations in the New York Finger Lakes and the Hudson River population. However, DeKay (1842) found the sea lamprey as far upstream in the Hudson River as Albany, New York. The construction and opening of the Erie Canal in the early 1800s probably gave the lamprey a route into the Great Lakes drainage from the Hudson River drainage. The lamprey did not reach Lake Erie until 1921 (Dymond 1922), a delay possibly due to modifications to the Welland Canal in 1881 which altered drainage patterns. Before these alterations, the canal was split into two sections, one draining into Lake Erie and the other draining into Lake Ontario. The Grand River, west of the Welland Canal in Ontario, was used to feed these sections. After 1881, Lake Erie water flowed through the canal directly into Lake Ontario. Ashworth (1986) suggests that fish swimming upstream would have been diverted into the Grand River before the drainage was altered because of their instinct to swim upstream during spawning. When they reached the portion of the canal draining downstream into Lake Erie, they would take the upstream route into the Grand River. Ashworth (1986) also suggests that the final cutting off of the Grand River from the Welland Canal in 1921 could have been the decisive factor in the appearance of the sea lamprey in Lake Erie and its

TABLE 3. *Origin, date and location of first sighting, and entry mechanism(s) for non-indigenous aquatic fauna of the Great Lakes. For location and introduction mechanism codes see Tables 1 and 2.*

Taxon	Species	Common Name	Origin	Date	Location	Mechanism
Fish						
Petromyzontidae	*Petromyzon marinus*	sea lamprey	Atlantic	1830s	Lake Ontario	C, S(F)
Clupeidae	*Alosa pseudoharengus*	alewife	Atlantic	1873	Lake Ontario	C, R(F)
Cyprinidae	*Carassius auratus*	goldfish	Asia	<1878	widespread	R(D), R(AQ) R(F), R(A)
	Cyprinus carpio	common carp	Asia	1879	widespread	R(D)
	Notropis *buchanani*	ghost shiner	Mississippi	1979	Thames River (StC)	R(F)
	Phenacobius mirabilis	suckermouth minnow	Mississippi	1950	Ohio(E)	C, R(F)
	Scardinius erythrophthalmus	rudd	Eurasia	1989	Lake Ontario	R(F)
Cobitidae	*Misgurnus anguillicaudatus*	oriental weatherfish	Asia	I 939	Shiawassee River (H)	R(A)
Ictaluridae	*Noturus insignis*	margined madtom	Atlantic	1928	Oswego River (0)	C, R(F)
Osmeridae	*Osmerus mordax*	rainbow smelt	Atlantic	1912	Crystal Lake (M)	R(D)
Salmonidae	*Oncorhynchus gorbuscha*	pink salmon	Pacific	1956	Current River (S)	R(A)
	Oncorhynchus kisutch	coho salmon	Pacific	1933	Lake Erie	R(D)
	Oncorhynchus nerka	kokanee	Pacific	1950	Lake Ontario (T)	R(D)
	Oncorhynchus tshawytscha	chinook salmon	Pacific	1873	All Lakes but S	R(D)
	Oncorhynchus mykiss	rainbow trout	Pacific	1876	Lake Huron (T)	R(D)
	Salmo trutta	brown trout	Eurasia	1883	Lakes Ontario (T) and Michigan (T)	R(A) R(D)
Poeciliidise	*Gambusia affinis*	western mosquitofish	Mississippi	1923	Cook Co., Illinois	R(D)
Gasterosteidae	*Apeltes quadracus*	fourspine sticklebacks	Atlantic	1986	Thunder Bay (S)	S(BW)
Percichthyidae	*Morone americana*	white perch	Atlantic	1950	Cross Lake (O)	C
Centrarchidae	*Enneacanthus gloriosus*	bluespotted sunfish	Atlantic	1971	Jamesville Res. (O)	R(AQ), R(F)
	Lepomis humilis	orangespotted sunfish	Mississippi	1929	Lake St. Mary's (E)	C
	Lepomis microlophus	redear sunfish	Southern U.S.	1928	Inland Indiana (M)	R(D)
Percidae	*Gymnocephalus cernuus*	ruffe	Eurasia	1986	St. Louis River (S)	S(BW)
Gobiidae	*Neogobius melanostomus*	round goby	Eurasia	1990	St. Clair River (SW)	S(BW)
	Proterorhinus marmoratus	tubenose goby	Eurasia	I 990	St. Clair River (StC)	S(BW)
Molluska						
Valvatidae	*Valvata piscinalis*	European valve snail	Eurasia	1897	Lake Ontario	S(SB)
Viviparidae	*Ciparsgopaludina chinensis malleata*	Oriental mystery snail	Asia	1931	Niagara River	R(AQ)
	Cipangopaludina japonica		Asia	1940s	Lake Erie	R(D)
	Viviparus georgianus	' banded mystery snail	Mississippi	<1906	Lake Michigan (T)	R(AQ)

Continued

TABLE 3. Continued

Taxon	Species	Common Name	Origin	Date	Location	Mechanism
Bithyniidae	*Bithynia tentaculata*	faucet snail	Eurasia	1871	Lake Michigan	S(SB), R(D)
Hydrobiidae	*Gillia altilis*	snail	Atlantic	1918	Oneida Lake (O)	C
Pleuroceridae	*Elimia virginica*	snail	Atlantic	1860	Erie Canal	C
Lymnaeidae	*Radix auricularia*	European ear snail	Eurasia	1901	Chicago (M)	R(AQ), R(A)
Sphaeridae	*Sphaerium corneum*	European fingernail clam	Eurasia	1952	Rice Lake (H/O)	Unknown
	Pisidium amnicum	greater European pea clam	Eurasia	1897	Genesee (O)	S(SB)
Corbiculidae	*Corbicula fluminea*	Asiatic clam	Asia	1980	Lake Erie	R(A), R(AQ), R(F)
Dreissenidae	*Dreissena polymorpha*	zebra mussel	Eurasia	1988	Lake St. Clair	S(BW)
	Dreissena sp.	zebra mussel	Eurasia	1991	Lake Ontario	S(BW)
Unionidae	*Lasmigona subviridis*	mussel	Atlantic	<1959	Erie Canal	C
Crustaceans						
Cladocera	*Bythotrephes cederstroemi*	spiny water flea	Eurasia	1984	Lake Huron	S(BW)
	Eubosmina coregoni	water flea	Eurasia	1966	Lake Michigan	S(BW)
Copepoda	*Eurytemora affinis*	calanoid copepod	widespread	1958	Lake Ontario	S(BW)
	Skistodiaptomus pallidus	calanoid copepod	Mississippi	1967	Lake Ontario	R(A), R(F)
	Argulus japonicus	parasitic copepod	Asia	<1988	Lake Michigan	R(F), R(AQ)
Amphipoda	*Gammarus fasciatus*	gammarid amphipod	Atlantic	<1940	Unknown	S(BW), S(SB)
Oligochaetes						
Naididae	*Ripistes parasita*	oligochaete	Eurasia	1980	North Channel (H)	S(BW)
Tubificidae	*Branchiura sowerbyi*	oligochaete	Asia	1951	Kalamazoo River (M)	R(A)
	Phallodrilus aquaedulcis	oligochaete	Eurasia	1983	Niagara River	S(BW)
Other Invertebrates						
Platyhelminthes	*Dugesia polychroa*	flatworm	Eurasia	1968	Lake Ontario	S(BW)
Hydrozoa	*Cordylophora caspia*	hydroid	Unknown	1956	Lake Erie	R(A)
	Craspedacusta sowerbyi	freshwater jellyfish	Asia	1933	Lake Erie (T)	R(A)
Insects	*Acentropus niveus*	aquatic moth	Eurasia	1950	Lake Ontario, Erie	R(A)
	Tanysphyrus lemnae	aquatic weevil	Eurasia	<1943	Unknown	Unknown
Disease pathogens						
Bacteria	*Aeromonas salmonicida*	furunculosis	Unknown	<1902	Unknown	R(F)
Protozoa	*Glugea hertwigi*	microsporidian parasite	Eurasia	1960	Lake Erie	R(F)
	Myxobolus cerebralis	salmonid whirling disease	Unknown	1968	Ohio (E)	R(F)

subsequent spread to all of the Great Lakes. Sea lamprey predation caused the decline of native lake trout populations in the Great Lakes (Lawrie 1970).

Clupeidae:

Alosa pseudoharengus ALEWIFE

The alewife was discovered in Lake Ontario in 1873 and either expanded through the Erie Canal into the Great Lakes basin from the Atlantic drainage (Emery 1985) or was native to Lake Ontario but was depressed by Atlantic salmon and lake trout until their decline in the late 1800s (Smith 1970). As in the sea lamprey's case, alewife did not expand into Lake Erie until the twentieth century, after alterations were made on the Welland Canal (Ashworth 1986). First records of alewife from Lake Erie were in 1931. Undocumented accidental introductions of alewives with stocked American shad *(Alosa sapidissima)* may have occurred (Emery 1985). DeKay (1842) noted the appearance of alewife with shad in New York coastal waters but noted that alewives were not very abundant compared with the numerous populations found on the Massachusetts coast and in Chesapeake Bay.

Cyprinidae:

Carassius auratus GOLDFISH

Original introductions of the Asian goldfish into North America began as early as the late 1600s and by 1842 goldfish were established in ponds in New York and other nearby states (DeKay 1842). The fish was first officially imported into North America in 1878 when they were propagated in ponds in Washington, D.C. As more fish were propagated, they were distributed to fish hatcheries in Great Lakes states (Jerome 1879) and other parts of the country for use as forage for largemouth bass (Courtenay *et al.* 1984). The original goldfish introductions into the Great Lakes basin probably occurred through bait bucket release. After these initial releases, humans have continued to introduce the fish through direct stocking, escape from or release with fish from hatcheries, release as an unwanted aquarium pet, or escape from private ornamental ponds.

Cyprinus carpio COMMON CARP

The first introduction of the Eurasian common carp into North America was in 1831 when a private citizen imported the fish from France for propagation in his ponds in Orange County, New York (DeKay 1842). For several years, these common carp were released into the Hudson River where they were subsequently caught by commercial fishermen. The fish was not known to be stocked into the Great Lakes basin until after 1879 when the U.S. Fish Commission distributed to Great Lakes states the progeny of fish that were imported from Europe in the 1870s. The fish have since become very abundant, supporting a commercial fishery on Lake Erie and destroying habitat used by more favored fish and waterfowl (Emery 1985).

Notropis buchanani GHOST SHINER

The ghost shiner, a fish native to the Mississippi drainage, was first observed in the Great Lakes drainage in 1979 in abundance in the backwaters of the Thames River (flowing into Lake St. Clair) in Kent County, Ontario (Helm and Coker 198 I). This location is 510 km from the nearest ghost shiner populations and its transfer could have occurred in fishermen's bait buckets with unused bait.

Phenacobius mirabilis SUCKERMOUTH MINNOW

The suckermouth minnow's invasion into the Great Lakes Basin is reviewed by Trautman (1981). The fish is a plains riverine species that favors turbid organically rich streams. It is thought to have been restricted to west of the Mississippi River until 1876 when it was reported from Illinois (Nelson 1876). The fish gradually migrated across Illinois and Indiana until 1920, when it was discovered in Ohio. The migration of the suckermouth minnow parallels the transformation of the natural prairie and forest to farmland by man which converted clear streams with gravel and sandy bottoms to turbid ones with silty bottoms. By 1950, the species was present in Sandusky Bay tributaries. Trautman (1981) observes that it often becomes very abundant in newly invaded areas, but as it becomes established, the population declines. Trautman (1981) also suggests that fishermen using the species as bait may have introduced it into some Ohio Rivers. Like the orangespotted sunfish *(Lepomis humilis), Phenacobius mirabilis* may have entered the Great Lakes basin through Lake St. Mary's, which has a spillway to both Mississippi River and Great Lakes drainages.

Scardinius erythrophthalmus RUDD

The rudd was first introduced from Europe into North America by 1897 when it was discovered in Central Park in New York City (Bean 1897, Bean 1903, and Hubbs 1921). In 1916 the state of Wisconsin deliberately introduced the species into Oconomowoc Lake, Waukesha County, Wisconsin, outside of the Great Lakes drainage (Cahn 1927). This population in Wisconsin, however, did not become permanently established and may have introgressed with the golden shiner, *Notemigonus crysoleucas,* with which it hybridizes (Burkhead and Williams 1991). In 1936 it was established in the Roeliff-Jansen Kill in eastern New York southeast of Albany near the Massachusetts border (Smith 1985) and in the early 1950s, the first rudd from the Great Lakes drainage basin was collected in Cascadilla Creek near Ithaca, New York (Courtenay *et al.* 1984). In recent years, it has been cultured in Arkansas for use as a preferred hardy bait fish similar to golden shiners. Fisheries biologists were not alerted to the spread of rudd until it had been distributed to bait dealers for several years (Burkhead and Williams 1991). In 1989, rudd were discovered in Lake Ontario and the St. Lawrence River (J. Farrell, SUNY College of Environmental Science and Forestry, personal communication 1990) and in 1990, an established population was discovered in Oneida Lake, New York, in the Lake Ontario drainage (J. Forney and D. Green, Cornell University Biological Field Station, personal communication, 1990).

Cobitidae:
Misgurnus anguillicaudatus ORIENTAL WEATHERFISH

An aquarium supply facility in Michigan first imported the Oriental weatherfish into the Great Lakes drainage in 1939 and propagated them in a pond in the Shiawassee River drainage basin, which drains into Saginaw Bay, Lake Huron (Schultz 1960). The escape of the fish was first discovered in 1958 when the Michigan Department of Conservation found them in a private pond that drained into the same stream as the aquarium supply facility's pond. Establishment of the fish probably occurred shortly after its importation in 1939 and its spread from the point of introduction began soon after. Surveys of the Shiawassee River in 1958 and 1959 showed the fish established in a number of localities in the headwaiters of the river (Schultz 1960).

Ictaluridae:
Noturus insignis MARGINED MADTOM

The margined madtom, native to Atlantic drainages, was first reported in the Great Lakes drainage in 1928 in the tributaries on the southern shores of Lake Ontario (Emery 1985). The presence of this fish in these rivers is likely due to the diversion of a Susquehanna stream into the Oswego River drainage. A common bait fish, the margined madtom has also been found in inland areas in Michigan's upper peninsula and in parts of the Lake Ontario watershed.

Osmeridae:
Osmerus mordax RAINBOW SMELT

The earliest known record of rainbow smelt in the Great Lakes basin is from Michigan, where they were stocked in 1912 in Crystal Lake, Michigan, which is in the Lake Michigan drainage (Van Oosten 1937). Although earlier plantings of this species are known from the St. Marys River in 1906, the planting in Crystal Lake is considered the source for the upper Great Lakes populations of rainbow smelt. However, origin of Lake Ontario populations has been debated. These populations are thought to have either been native to the lake or have migrated up the Erie Canal system from the Atlantic drainage. DeKay (1842), however, only noted rainbow smelt from coastal areas and does not record it from the upper Hudson River. At the time, the species was economically valuable in coastal markets. This coastal distribution suggests that rainbow smelt populations in the Lake Ontario basin in central New York are either not native or that they were overlooked in early surveys.

Salmonidae:
Oncorhynchus gorbuscha PINK SALMON

Pink salmon, a native of the west coast, was introduced into Lake Superior and the Current River, in 1956. The introductions resulted from activities of a stocking program to introduce pink salmon into Hudson Bay and occurred at the Port Arthur Fish Hatchery in Ontario. Although several different releases occurred, the disposal by hatchery managers of excess stock, about 21,000 fingerlings. into the Current River after the Hudson Bay stocking program had been completed, is probably the source of the Great Lakes pink salmon population. It was believed from knowledge of the reproductive biology and ecology of the species that these fingerlings would not establish reproducing populations in Lake Superior. In addition to the excess stock, other introductions occurred at the hatchery either as escapees during the transfer of fish to planes for transport to James Bay or as accidental releases into Lake Superior with the stocking of lake trout fingerlings. Since these original introductions, the population of pink salmon has successfully reproduced and has spread to all the Great

Lakes without supplemental stocking (Ryder and Edwards 1985).

Oncorhynchus kisutch COHO SALMON

Although it may have been accidentally introduced earlier, the coho salmon from the west coast was first intentionally stocked into the Great Lakes in 1933 when the Ohio Division of Conservation released them into Lake Erie (Emery 1985). These fish, native to the west coast, survived but did not establish a reproducing population. In 1966, Michigan and Ohio stocked coho salmon which established naturally reproducing populations. Currently, this low level of natural reproduction is supplemented by stocking to enhance the sport fishery.

Oncorhynchus nerka KOKANEE

The first introduction of kokanee, native to the west coast, into the Great Lakes occurred in 1950 when New York stocked Lake Ontario tributaries (Emery 1985). In 1964-72, stocking programs introduced the fish into Lakes Ontario and Huron which resulted in naturally reproducing populations. After the program was discontinued, the population dwindled to the very small numbers that currently persist in Lake Huron and spawn in streams on Manitoulin Island in northern Lake Huron.

Oncorhynchus tshawytscha CHINOOK SALMON

The chinook salmon, a fish native to the west coast, was first introduced into the Great Lakes basin in 1873 when it was stocked into Lakes Michigan, Huron, Erie, and Ontario (Emery 1985). Until 1933, state agencies tried to establish reproducing populations in the Great Lakes, but were unsuccessful. Since 1967, chinook salmon have been stocked to support a sport fishery on the Great Lakes. Studies in Lake Michigan tributaries have estimated that natural reproduction by these fish has contributed an estimated 23% of the total chinook salmon population in Lake Michigan (Carl 1982).

Oncorhynchus mykiss
(=Salmo gairdneri) RAINBOW TROUT

Western rainbow trout have been stocked in the Great Lakes since 1876 when they were planted in a tributary to Lake Huron (Emery 1985). Since then, they have been widely introduced throughout the Great Lakes basin (Trautman 1981, Smith 1985). The original introduced rainbow trout stock was from nonmigratory strains, but in the late 1890s, anadromous steelhead trout were imported to hatcheries in the Great Lakes (MacCrimmon and Gets 1972). Rainbow trout do reproduce in the streams of the Great Lakes basin, but continued stocking is necessary to support the sport fishery.

Salmo trutta BROWN TROUT

European brown trout were first released into the Great Lakes basin in 1883 when Michigan stocked the Pere Marquette River, a Lake Michigan tributary (Emery 1985). In the same year, an accidental release from a fish hatchery in Caledonia, New York, occurred into the Genesee River, a tributary to Lake Ontario. Stocking of brown trout continued after these initial introductions and some tributary populations were established. Currently, stocking supplements the sport fishery for brown trout.

Poeciliidae:
Gambusia affinis WESTERN MOSQUITOFISH

A native of the Mississippi drainage, the mosquitofish has been widely stocked in ponds for mosquito control (Krumholz 1944, 1948; Emery 1985). After its introduction in 1923 into the Great Lakes basin in Cook County, Illinois, it became established in several parts of Cook County as well as in parts of Michigan, Wisconsin, Ohio, New York, and Ontario (Krumholz 1944, 1948: Emery 1985).

Gasterosteidae:
Apeltes quadracus FOURSPINE STICKLEBACK

Helm and Hamilton (1988) reviewed the introduction of this estuarine species (known from the lower St. Lawrence to the coast of North Carolina) into Lake Superior. A reproducing population was first found in 1986 in Thunder Bay, Lake Superior. They note that, because the nearest occurrence of the fish to the Lake Superior population is about 2,100 km away in Quebec near the mouth of the Batiscan River, the most likely mechanism of introduction is through ship's ballast water.

Percichthyidae:
Morone americana WHITE PERCH

The white perch, native to the Atlantic drainage, was first observed in the Lake Ontario watershed in 1950 in Cross Lake in central New York (Dence 1952). The fish is thought to have reached the Great Lakes through the Mohawk River Valley and the Erie Barge Canal from expanding Hudson River populations (Scott and Christie 1963). The migration of the white perch through the Erie Canal is thought to have been induced by unusually warm weather in the 1930s and 1950s (Johnson and Evans 1990). Since its initial invasion into Lake Ontario, the fish has invaded all the other lakes, and populations in the upper Great Lakes are expected to expand as winter temperatures become more tolerable due to climatic warming (Johnson and Evans 1990). White perch has become an important sport and commercial fish in Lakes Ontario and Erie (Emery 1985).

Centrarchidae:
Enneacanthus gloriosus BLUESPOTTED SUNFISH

The bluespotted sunfish, a fish known from the Delaware and Hudson River drainages, was first recorded in the Great Lakes drainage basin in 1916 in Oneida Lake, New York (Smith 1985). The fish was not collected again in Oneida Lake, but in 1971 a reproducing population was found in the Jamesville Reservoir near Syracuse, New York, which was constructed in 1874 as a feeder reservoir for the Erie Canal System (Werner 1972). Smith (1985) noted that the Jamesville Reservoir population could possibly be a relict population because of the earlier Oneida Lake record. Although Werner (1972) suggests aquarium release as an introduction mechanism into Jamesville Reservoir, the introduction of bluespotted sunfish in fishermen's bait buckets is also a possibility. Migration up the Erie Canal is unlikely because sightings of the fish represent substantial skips in distribution from natural Hudson River populations.

Lepomis humilis ORANGESPOTTED SUNFISH

The orangespotted sunfish's invasion into the Great Lakes is described by Trautman (1981). The fish, a native of the Mississippi drainage, was first discovered in the Great Lakes basin in 1929 in Lake St. Mary's, Ohio (Lake Erie drainage) (Trautman 1981). Like the suckermouth minnow, the orangespotted sunfish favors turbid, silty streams and is thought to have spread from the Mississippi River drainage as agricultural practices of the late 1800s converted the clear streams to turbid ones. It expanded into Lake Erie tributaries in northern Ohio through a spillway at Lake St. Mary's that connects the Wabash and Maumee River systems. Trautman (1981) believes that this transfer was mediated by humans. Since its movement into the Great Lakes basin began, the orangespotted sunfish has expanded into Lake Erie and southwestern Ontario (Helm and Coker 1981, Noltie and Beletz 1984).

Lepomis microlophus REDEAR SUNFISH

Redear sunfish, native to the southern U. S., was first introduced to the Great Lakes basin in Indiana in 1928 (Emery 1985). The fish was stocked into lakes and streams in the northern part of the state. It has since been widely and successfully introduced into inland areas of the basin but reproducing populations have not been observed in the Great Lakes.

Percidae:
Gymnocephalus cernuus RUFFE

The ruffe, a carnivorous European species, was first collected in the Great Lakes in 1986 in the St. Louis River, a tributary of Lake Superior and a major harbor for Duluth, Minnesota, and Superior, Wisconsin. The fish probably entered the river in the ballast water of grain ships arriving to pick up cargo (Simon and Vondruska 1991). By the summer of 1988, ruffe were clearly established in the St. Louis River. By 1991, the ruffe had become the second-most abundant fish in the St. Louis River and had spread to the mouths of several rivers in southwestern Lake Superior (J. Selgeby, U. S. Fish and Wildlife Service, personal communication 1991). As it spreads, the ecological impacts that the ruffe could bring to systems already disturbed by the zebra mussel and other exotics could be substantial.

Gobiidae:
Neogobius melanostomus ROUND GOBY

This Eurasian benthic species, a fish growing to 100-130 mm, was first observed in North America in July of 1990 when it was caught by anglers in the St. Clair River near Sarnia, Ontario (Jude *et al.* 1992). Round goby was most likely transported to the Great Lakes in the ballast water of ships from its native range in the Black or Caspian Seas. The species has established a reproducing population in the St. Clair River and is likely to expand its range into the other Great Lakes.

Proterorhinus marmoratus TUBENOSE GOBY

The Eurasian tubenose goby, a fish that grows to 100-110 mm, was first observed in North America in April of 1990 in the St. Clair River where it was collected from the traveling screens of a power plant. It was most likely transported to the river in the ballast water of ships entering the Great Lakes from the Caspian or Black Seas. Interestingly, even though this benthic species is endangered in its native European range, it has become established in the St. Clair River and will likely expand its range further into the Great Lakes basin (Jude *et al.* 1992).

Mollusca

The molluscan fauna of the Great Lakes has been studied since the late 1800s when many residents of the region were amateur conchologists (Robertson and Blakeslee 1948). Professional conchologists had identified the mollusks of the Great Lakes by the late 1800s (Baker 1902), so when a European species was discovered, it was generally correctly identified as introduced. The non-indigenous mollusks of the Great Lakes (Table 3) have entered through mechanisms ranging from ship's ballast to aquarium releases.

Class: Gastropoda

Valvatidae:

Valvata piscinalis EUROPEAN VALVE SNAIL

This European snail was first observed in North America in Lake Ontario near the mouth of the Genesee River. The collection occurred at Charlotte and Summerville, New York, in 1897 (Baker 1898) and several years later the snails had reached high densities (Baker 1900). The snail was probably introduced with "straw and marsh grass" packaging used in ships transporting "fragile articles" or "crockery" from England and Eastern Europe (Latchford 1914, 1925). Latchford had first observed the snails among packaging debris along the Lake Ontario shore in Toronto in 1912 (Latchford 1930). Since then, the snail has spread through the lower Great Lakes where it remains common (Oughton 1938, Dundee 1974, Burch 1989).

Viviparidae:

Debate regarding the taxonomy of two species of viviparid snails, *Cipangopaludina chinensis malleata* and *Cipangopaludina japonica,* centers around whether they should be treated as separate species. Burch (1989) discusses them separately but acknowledges their questionable taxonomy and Clarke (1981b) regards them as synonyms. We distinguish between the introduction records for the two snails despite questions about their taxonomy.

Cipangopaludina chinensis malleata ORIENTAL MYSTERY SNAIL

Cipangopaludina japonica

In San Francisco, around 1892, the first live specimens of Japanese *Cipangopaludina* were imported for sale in a Chinese market (Wood 1892). The snails, a species commonly consumed in Asia, soon became established in parts of California (Clench and Fuller 1965). Whether these snails were stocked purposely for cultivation or released accidentally (e.g., with unwanted kitchen waste) is unknown. In the Great Lakes, the first known release of the snail occurred in the Niagara River. In 1942 Eugene H. Schmeck found a well established population of *Cipangopaludina chinensis malleata* in the Niagara River at Cayuga Island. Schmeck suggests that his pair of aquarium specimens, which had been breeding when he lived on the island in 1931, were "inadvertently" released into the Niagara River and reflects an actual documentation of the establishment of a species through aquarium release (Schmeck 1942, Robertson and Blakeslee 1948). Another early introduction of these snails into the Great Lakes occurred in Sandusky Bay, Lake Erie, Ohio, in the 1940s, when a bushel of *Cipangopaludina japonica* was supposedly introduced to feed channel catfish (Wolfert and Hiltunen 1968). As they reached high densities in Sandusky Bay, fishermen often made seine hauls containing "2 tons" of snails (Wolfert and Hiltunen 1968). Widely distributed in the United States, the snail's Great Lakes distribution in 1965 included isolated populations in Michigan and Indiana and abundant populations along the Ohio shoreline of Lake Erie (Clench and Fuller 1965, Jokinen 1982).

Viviparus georgianus BANDED MYSTERY SNAIL

Banded mystery snails are native to the Mississippi River drainage (to northwestern Indiana) and several southeastern states (Clench 1962). A popular aquarium snail, *Viviparus georgianus* has been released throughout the Great Lakes basin (Robertson and Blakeslee 1948, Clench 1962, Harman and Berg 1971, Clarke 1981b). The earliest introduction of the snail outside its native range was documented in 1867 when an amateur conchologist, James Lewis, released several hundred individuals into the Hudson River drainage system (Erie Canal and Mohawk River) (Clench 1962). Clench reports the snail in Michigan after 1926, Lake Erie by 1914, and Lake Michigan tributaries by 1906 but notes that the recent records throughout the Northeast are probably due to aquarium releases. Robertson and Blakeslee (1948) report "thirty-six years ago this species did not occur nearer Buffalo than Rochester, but in 1931 Mr. Robertson discovered it in Lake Erie at the foot of Michigan Avenue in Buffalo, and in Niagara River." These records indicate that the snail must have been established in the Lake Ontario drainage system (Rochester New York) before 1912. Since *Viviparus georgianus* and the European species *Viviparus viviparus* are indistinguishable, some of the populations of *Viviparus georgianus* in North America could actually be introduced *Viviparus viviparus* from Europe (Clarke 1981b).

Bithyniidae:

Bithynia tentaculata FAUCET SNAIL

The earliest observations of *Bithynia tentaculata,* the European faucet snail, in the Great Lakes are from Lake Michigan in 1871 (Robertson and Blakeslee 1948). Believed to have been introduced about 1870 (Berry 1943), it spread rather quickly into all the other Great Lakes except Lake Superior (Baker 1928). *Bithynia* was documented in Lake Ontario at Oswego, New York, in 1879 (Beauchamp 1880), in Lake Champlain in 1882, and in the Hudson River by 1888-1892 (Gray 1883, Strayer 1987). By 1927 it had been found in the Potomac River at Alexandria, Virginia (Pilsbry 1932, Marshall 1933). Several explanations for the snail's occurrence in the Great Lakes have been proposed. Kew (1893) described the introduction of *Bithynia tentaculata* and several other snails into the Erie Canal, the Mohawk River, and Schuyler's Lake by amateur naturalists. The snail is also thought to have been introduced in either the marsh grass used in packaging crockery and other goods brought into the Great Lakes (Latchford 1914, 1925) or the ballast of timber ships that had direct routes between Lake Michigan ports and Europe (Baker 1928). In the early 1900s, *Bithynia* began infesting municipal water supplies, from intake pipes to household faucets (Baker 1902), thus giving rise to the snail's common name. In some cases, these fouling problems reached very large proportions. In Erie, Pennsylvania, the water supplies became so infested that "wagon loads" of snails were removed from municipal water pumping stations (Sterki 1911). Although fossil forms of *Bithynia* are present in Pleistocene deposits near Lake Michigan, modern day populations are descendants of the nineteenth century introduction (Baker 1928). Today, *Bithynia* remains abundant in the Great Lakes system (Dundee 1974, Burch 1989).

Hydrobiidae:

Gillia altilis SNAIL

Gillia altilis is a snail native to the Atlantic coastal drainage (Burch 1989). It invaded the Lake Ontario drainage basin from the Hudson River through the Erie Canal in central New York (Thompson 1984). The earliest records of the snail in the Great Lakes drainage are between 1915 and 1918 from Oneida Lake, New York (Baker 1916, 1918) but later surveys do not record the species from this locality (Harman and Forney 1970). Museum collections of this snail exist from the Erie Canal in Syracuse, New York (UMMZ 69880), Brighton, New York (UMMZ 118415), Clyde, New York (USNM 597809), and Niagara Falls, New York (USNM 47979), but the dates of collection for most of these specimens were not recorded. The snail, however, was collected from Niagara on the Lake, Ontario, in 1936 (MCZ 104863) and the earliest accession date of the specimens listed above is from Niagara Falls, New York, and dated 1940 (USNM 47979).

Pleuroceridae:

Elimia virginica SNAIL

Elimia virginica is an Atlantic coastal riverine snail that invaded the Lake Ontario drainage basin in the mid 1800s. The snail was introduced into the Erie Canal near Mohawk, New York, between 1856 and 1860 (Lewis 1860, 1868, 1872). Later, it was distributed through the Erie Canal to Monroe County, New York (Goodrich 1942, Robertson and Blakeslee 1948), and was abundant in streams near Buffalo (Lewis 1872). The introduced snail *Bithynia tentaculata,* however, has competed with and caused a drastic reduction in abundance of *Elimia virginica* (Harman and Berg 1971). Harman and Berg (1971) suggest that the snail has been "effectively removed from the Oswego watershed" due to competition with *Bithynia tentaculata.* In 1967-1968, *Elimia virginica* was found in low abundance in Oneida Lake, New York (Harman and Forney 1970).

Lymnaeidae:

Radix auricularia EUROPEAN EAR SNAIL

Radix auricularia, a Eurasian aquarium snail (Robertson and Blakeslee 1948), was first found in North America in the Hudson River basin near Troy. New York, before 1869 (Strayer 1987). In 1901, a high school biology teacher found the snail at Chicago's Lincoln Park (Baker 1901a). Baker (1901a) reasoned that since the snail was first found in a propagating greenhouse, it was likely introduced with plants that had just been imported from Belgium. Soon after its first discovery, it was found in a heated ornamental pond in Lincoln Park. Other early Great Lakes records are in Lake Erie (Allen 1911, Goodrich 1911, Robertson and Blakeslee 1948) and western Lake Ontario (Latchford 1930). Goodrich (1911) also noted that the snails he found in a stream 30 meters from Lake Erie were located in the vicinity of greenhouses. He proposed that the snail's eggs were imported into the greenhouses on azaleas from Holland and Belgium and washed into the stream through the drains. Robertson and Blakeslee (1948) note that the snail is a popular aquarium snail, suggesting a second entry mechanism. The snail's current "scattered" (Pennak 1989) and "spotty" (Burch 1989) distribution pattern and the nature of its transport mechanisms support the probability of multiple, widespread introductions into North America.

Class: Pelecypoda
Sphaeriidae:
Sphaerium corneum EUROPEAN FINGERNAIL CLAM

Herrington (1962) suggested that the clam was "recently" introduced from Eurasia and all distribution information is based on specimens that he personally studied. The clam has been sighted in Lake Champlain, Lake Erie, Lake Ontario, St. Lawrence River, Bay of Quinte, and Rice Lake (Herrington 1962). Rice Lake, where the clam was found in 1952 (UMMZ 200802), is a part of the Trent-Severn Canal system, a shallow canal system connecting Lake Huron and Lake Ontario that caters mostly to recreational boat traffic (Ashworth 1986). The introduction mechanism for this clam is unknown.

Pisidium amnicum GREATER EUROPEAN PEA CLAM

Baker (1898) first found this clam in Lake Ontario at Charlotte and Summerville, New York near the mouth of the Genesee River in 1897 and reported it as *Pisidium bakeri,* a new species that was to have been described by H.A. Pilsbry. Later, however, Sterki informed Baker (1900), of the possibility of synonymy between the Eurasian-African *P. amnicum* and the newly discovered *P. bakeri,* a synonymy that Sterki (1916) confirmed. It is widespread in the eastern Great Lakes, in the St. Lawrence River, Lake Champlain, Pennsylvania, and New Jersey (Herrington 1962, Burch 1975a). The clam was probably introduced through shipping activities into Lake Ontario.

Corbiculidae:
Corbicula fluminea ASIATIC CLAM

The history of the Asiatic clam invasion into the waters of the United States is well documented (McMahon 1982, Counts 1986). It was first observed in North America in British Columbia in 1924 when dead specimens were collected (Counts 1981). The first live collections occurred in 1938 in Pacific County, Washington, on the banks of the Columbia River (Burch 1944). The clam steadily spread down the west coast and then into the southern United States (McMahon 1982, Counts 1986) reaching densities in some areas sufficient to damage and clog water intake systems (Clarke 1981a). Until it was collected in Monroe County, Michigan, in western Lake Erie in 1980, it was limited to a warmer southern distribution by its intolerance to temperatures of 2°C and lower (Clarke 198la, McMahon 1982, Scott-Wasilk *et al* 1983, Sickel 1986). The invasion of the clams into western Lake Erie has been estimated to have occurred in 1978 and collections have been primarily associated with heated effluent in industrial areas (Scott-Wasilk *et al.* 1983). White *et al.* (1984) reported the clam from southeastern Lake Michigan. Like those found in western Lake Erie, these clams were associated with heated discharge from a power plant. French and Schloesser (1991) report a reproducing population of *Corbicula* in the St. Clair River downstream from a power plant. This population has a high mortality rate and a possible delay of sexual maturity due to low winter temperatures (French and Schloesser 1991). Counts (1986) reviews the dispersal mechanisms of the clam, including transport by birds, accidental transport with sand or gravel, and release as bait or as aquarium specimens. The Asiatic clam could have been introduced into Great Lakes waters through any of these mechanisms. The clam does have a short planktonic larval stage (Counts 1986) and small specimens of *Corbicula* are known to respond to current conditions by secreting mucous threads that enable them to float downstream (Prezant and Chalermwat 1984). It is also invading Europe in the Netherlands (bij de Vaate and Greijdanus-Klaas 1990), Germany (bij de Vaate 1991), France, and Portugal (Mouthon 1981).

Dreissenidae:
Dreissena polymorpha ZEBRA MUSSEL

Dreissena polymorpha, a European mussel, was first discovered in North America in Lake St. Clair in June 1988 (Hebert *et al.* 1989). The first confirmed sighting in the western basin of Lake Erie was in July 1988, and by 1991, it was spreading rapidly throughout the Great Lakes basin and had reached the Hudson River, upper Mississippi River, and the Susquehanna drainage basins (New York Sea Grant 1990, R. Sparks, Illinois Natural History Survey, personal communication 1991, and C. Lange, Acres International Corporation, personal communication 1992). It will probably soon achieve a wide distribution in North American lakes and rivers and may be limited by soft water and temperatures in the extreme northern and southern areas (Strayer 1991). The mussel arrived in the ballast water of transoceanic ships from Europe. Ballast transport and fouling can also be credited with the discontinuous spread of the mussel into major upper Great Lakes ports in 1990 (New York Sea Grant 1990). The mussel often occurs in very large numbers (Mackie *et al.* 1989), and can exert large and far-reaching impacts on freshwater ecosystems through biofouling and filter-feeding. In Lake St. Clair, as the mussels reached high densities, they were shown to detrimentally affect the native unionid clams in the lake and to improve water clarity in the Detroit River (Hebert *et al.* 1991). In 1992, genetic surveys of Great Lakes zebra mussel populations have isolated a new introduced species of *Dreissena.* The earliest verified collections of this zebra mussel are from the Lake Ontario basin in 1991. The taxonomy of this new introduction remains unclear to date (May and Marsden 1992).

Unionidae:
Lasmigona subviridis MUSSEL

Lasmigona subviridis is a freshwater mussel that is distributed in coastal river systems, several inland systems in Virginia and West Virginia, and in the Erie Canal to the Mohawk River (Burch 1975b). This distribution borders upon the Lake Ontario drainage basin. Clarke and Berg (1959) recorded this clam from two locations in the Lake Ontario drainage, the Erie Barge Canal in Syracuse and Chittenango Creek in Kirkville, New York, and Johnson (1980) reported the clam from the Finger Lakes region of central New York. These records are the first known occurrences in the Great Lakes drainage.

Crustacea

The introduced Crustacea of the Great Lakes (Table 3) are not as well studied as the mollusks. Studies of the zooplankton of the Great Lakes did not begin until the late 1800s (Balcer *et al.* 1984) after potential mechanisms for their dispersal into the region had been present for decades. For this reason, several species considered native to the Great Lakes that have discontinuous or "holarctic" distributions could in fact be introduced.

Order: Cladocera
Cercopagidae:
Bythotrephes cederstroemi **SPINY WATER FLEA**

Bythotrephes cederstroemi, a European predatory cladoceran, was first observed in North America in Lake Huron in December, 1984 (Bur *et al.* 1986). It was soon found in Lake Erie in 1985 (Bur *et al.* 1986), Lake Ontario in 1985 (Lange and Cap 1986), Lake Michigan in 1986 (Evans 1988), and Lake Superior in 1987 (Cullis and Johnson 1988). The cladoceran is thought to have entered the Great Lakes in the ballast water of European ocean going vessels in the late 1970s or early 1980s (Sprules *et al.* 1990). The spiny water flea's rapid dispersal throughout the Great Lakes probably involved ballast transfer in Great Lakes vessels (lakers) and possibly separate introductions at different locations directly from Europe. Sprules *et al.* (1990) speculated that *Bythotrephes* could have originated from the port of Leningrad because of the large amount of ship traffic carrying grain from Great Lakes ports to Leningrad in the late 1970s and early 1980s and because of the high abundance of *Bythotrephes* in the freshwater port of Leningrad.

Bosminidae:
Eubosmina coregoni WATER FLEA

The first Great Lakes record of this European cladoceran was in Lake Michigan in 1966 (Wells 1970). Davis (1968) and Wells (1970) identified it as a form of the native species *Bosmina coregoni.* In their revision of the genus *Eubosmina,* Deevey and Deevey (1971) noted that the major differentiating characteristic of the European species *Eubosmina coregoni* from other species of *Eubosmina* and *Bosmina,* is the lack of a mucro or tail spine, a characteristic of Davis and Well's specimens, thus identifying the North American populations correctly. Deevey and Deevey (1971) mention the possibility of *E. coregoni* being an introduction from Europe, but give it a holarctic distribution because of its widespread abundance. By 1968, it had also been identified in Sanctuary Lake (Pymatuning Reservoir), Pennsylvania, Lake

Huron, Lake Ontario, and Lake Erie (Davis 1968, Deevey and Deevey 1971). Since these early records, *Eubosmina coregoni* has spread into all the Great Lakes and become one of the dominant zooplankters (Leach 1973, Czaika 1974, Patalas 1975, and Evans 1988). *Eubosmina coregoni* was most likely introduced into the Great Lakes in ballast water and, similar to *Bythotrephes,* was transferred from lake to lake by Great Lakes vessels.

Subclass: Copepoda
Suborder Calanoida
Temoridae:
Eurytemora affinis CALANOID COPEPOD

The occurrence of this copepod in Lake Erie in 1961 was first reported by Engel (1962). Earlier studies in 1958 in Lake Ontario had recognized a copepod of the genus *Eurytemora* that was not identified to species but was most likely *Eurytemora affinis* (Anderson and Clayton 1959, Faber and Jermolajev 1966). By 1972 it had spread into Lake Michigan (Robertson 1966), Lake Huron (Faber and Jermolajev 1966), and Lake Superior (Patalas 1972). Native to salt, brackish, and fresh waters, it is more abundant in bays and harbors than in the open waters of the Great Lakes (Balcer *et al.* 1984). *Eurytemora* was most likely introduced from the North American Atlantic Coast (or from the western European coast) in the ballast water of ships coming through the St. Lawrence or Erie Canal systems (Faber and Jermolajev 1966).

Diaptomidae:
Skistodiaptomus pallidus CALANOID COPEPOD

Skistodiaptomus pallidus was first observed in Lake Ontario in 1967 (Patalas 1969). Since then, it has been reported in low numbers from Lakes Ontario, Erie, and St. Clair (Leach 1973; Czaika 1974, 1978; Cap 1979). Wilson and Yeatman (1958) reported that *Skistodiaptomus pallidus* is found in ponds and lakes ranging from north central and plains states south to Texas and Louisiana. Pennak (1978) noted that it is distributed in the Mississippi drainage. Thus, the natural distribution of this copepod may include the outlying parts of the Great Lakes watershed. Citing the records obtained since 1969, Robertson and Gannon (1981) report it as a small lake form that "occasionally" enters the Great Lakes. *Skistodiaptomus pallidus* could have easily been introduced into the Great Lakes watershed with the equipment or bait of fishermen and recreational boaters or with fish introduced from hatcheries in the Mississippi drainage.

Order: Branchiura
Suborder: Arguloida
Argulidae:
Argulus japonicus PARASITIC COPEPOD

Argulus japonicus is a parasitic copepod native to Asia that has been introduced into North America with its host fish goldfish. Now distributed throughout the United States, the species has probably been transported through the aquarium trade (Cressey 1978). In the Great Lakes basin, the species is known from the Fox River, a tributary of Green Bay and Lake Michigan where it was collected in 1988 (Galarowicz and Cochran 1991, LaMarre and Cochran 1992). The copepod, however, was probably present but unreported in the Great Lakes for many years prior to this discovery.

Order Amphipoda
Suborder: Gammaroidea
Gammaridae:
Gammarus fasciatus GAMMARID AMPHIPOD

This common freshwater gammarid represents a possible introduction into the Great Lakes from the Hudson, Delaware, or Chesapeake drainage systems. Early records (Hubricht and Mackin 1940) suggest a striking disjunct distribution of Lake Michigan populations from the main Atlantic drainage populations. Chase *et al.* (1959) noted the disjunct distribution and suggested that it was "probably introduced" into the Great Lakes. Bousfield (1958) however, recorded a more widespread distribution in the freshwater drainages of the Great Lakes and the St. Lawrence, Hudson, Delaware, and Chesapeake rivers. While early studies probably under-sampled these drainage systems, it remains possible that the current distribution of this amphipod is due to the range of human activities that could have altered its natural distribution, including releases with ballast water, aquatic plants, stocked fish, and fish bait. As of 1940, the extent of the ranges of freshwater amphipods was not well studied (Hubricht and Mackin 1940) and, consequently, the natural distribution of *Gammarus fasciatus* cannot be determined. While Weckel (1907) recorded *Gammarus fasciatus* from the Great Lakes and the Mississippi River systems, the natural distribution is further complicated by Hubricht and Mackin's (1940) suggestion (based upon her illustrations and locations) that Weckel's material also contained *Gammurus limnaeus.* A benthic organism, *Gammarus fasciatus* could have easily been introduced in solid ballast or ballast water of ships plying the St. Lawrence or Erie Canal systems.

Annelida

Few studies have focused on the North American oligochaete fauna (Pennak 1989) and, as a result, the distributions of native and introduced species are largely unknown. Some species previously thought to be introduced (e.g., *Stylodrilus heringianus, Potamothrix bedoti, Potamothrix vejdovskyi, Potamothrix moldaviensis,* and *Spirosperma ferox)* now have distributions that are considered holarctic; conversely, some so-called "holarctic" species may in fact be introduced. Taxonomic problems are also associated with the oligochaetes, leading to further uncertainty on the status of native and introduced species (Table 3).

Mechanisms for oligochaete introductions have been present since the earliest settlers arrived in North America. Some of the species listed above could have been introduced through these early mechanisms and reached distributions typical of native species by the time the first comprehensive oligochaete surveys were undertaken. When undergoing sexual reproduction, oligochaetes often form a cocoon which is commonly attached to rocks, plants, and solid debris, materials commonly used as ship's ballast (Stephenson 1930). After the settlement of the Great Lakes basin, oligochaetes were introduced through the importation of aquatic plants which were used in aquaria and ornamental ponds.

Naididae:
Ripistes parasita

The first occurrence of this easily identified species (Brinkhurst 1986) in North America was in 1978 in several New York State rivers and in the New York canal system (Simpson and Abele 1984). These records from outside of the Great Lakes watershed (e. g., Chemung River near Corning, Chenango River near Binghamton, Cohocton River near Campbell, and in the Mohawk River Barge Canal) were obtained from artificial substrates used in biological monitoring studies (Simpson and Abele 1984). Barton and Griffiths (1984) obtained the first Great Lakes specimens from two sites in the North Channel in 1980. Records of the oligochaete for southern Lake Superior at Presque Isle near Marquette, Michigan (Winnell and Jude 1987), give it a fairly wide distribution in North America. *Ripistes parasita* naturally occurs in the European palearctic region (Simpson and Abele 1984, Klemm 1985) and the Great Lakes records are the first outside of its natural distribution. The worm was probably introduced into the Great Lakes in the ballast water of ships plying from Europe (Winnell and Jude 1987). Despite the chronology of these records in the Great Lakes basin, *Ripistes parasita* was probably first introduced into the Great Lakes and later spread into inland canals and rivers.

Tubificidae:
Branchiura sowerbyi

Branchiura sowerbyi, a native of Asian tropical and subtropical areas (China, Burma, India, and Japan), has been widely introduced into Europe, North America, and Africa (Brinkhurst 1965, Aston 1968). It was originally described from aquaria containing tropical plants imported from Asia at the Botanical Gardens in Kew, England (Beddard 1892, Mann 1958). Once described, it was quickly observed in many other localities in Europe that contained Asian imported plants (hothouses, ornamental ponds, and botanical gardens) and in heated effluents in natural bodies of water (Brinkhurst 1965). In 1930, the worm was discovered in Buckeye Lake, Ohio (Spencer 1931). Since this first record, it has been widely introduced throughout North America, most likely with aquatic plants or through the aquarium trade. The first Great Lakes record was from 1951 in the Kalamazoo River in Comstock, Michigan, and later in western Lake Erie and Lake St. Clair in 1963 (Brinkhurst 1965). In 1963 studies in Sandusky Bay, Lake Erie, the worm was the most abundant oligochaete present (Wolfert and Hiltunen 1968).

Phallodrilus aquaedulcis

Phallodrilus aquaedulcis, a European oligochaete previously known only from the River Weser in Germany and inland caves in Spain and France, was first observed in the Niagara River in 1983. This established population is the first record for the species in North America (Farara and Erseus 1991). The oligochaete was probably introduced into the Great Lakes in the ballast water of ships plying from the River Weser region in Germany.

Other Invertebrates

Several other freshwater invertebrates have been introduced into the Great Lakes (Table 3). These include a flatworm, a hydroid, a freshwater jellyfish, and two insects. Although the distributional history and taxonomy of most of the aquatic insects of the Great Lakes is not known well enough to comprehensively determine which species have been introduced, two clear cut introductions have occurred.

Turbellaria:
Dugesia polychroa FLATWORM

Ball (1969) first reported this Palearctic European flatworm in North America. The worm has been found in the St. Lawrence River, Lake Champlain, and Lake Ontario in 1968 (Bail 1969). The Richelieu River, a navigable river, connects the St. Lawrence River and Lake Champlain (Ball 1969), thus all areas where this worm has been found are connected by navigable waterways. Kenk (1974), in his treatment of the triclads (Turbellaria) of the world, noted the species as introduced into the St. Lawrence River system. The worm was probably introduced in the ballast water of ships (Ball 1969).

Coelenterata:
Cordylophora caspia HYDROID

This hydrozoan was first observed in Chagrin Harbor, Ohio, in Lake Erie in 1956 (Davis 1957). *Cordylophora caspia (= Cordylophora lacustris)* is a widespread euryhaline species known from locations in Europe, Australia, Asia, Africa, and both coasts of North America (Davis 1957). The hydroid's distribution in the fresh waters of North America included sporadic records in the South and East before the Lake Erie population was discovered (Davis 1957). Garman (1922) noted an association of *Cordylophora* with the introduced jellyfish *Craspedacusta sowerbyi* (discussed below) in a creek in Kentucky. The simultaneous occurrence of these two species indicates that they may have been introduced through the same mechanism, release through aquarium dumping or with aquatic plants. Hubschman and Kishler (1972) reported that populations of this hydroid in western Lake Erie have become established.

Craspedacusta sowerbyi FRESHWATER JELLYFISH

Craspedacusta sowerbyi, an Asian freshwater jellyfish (Kramp 1950), was first observed in the United States in 1916 near Frankfort, Kentucky, in Benson Creek (Garman 1916). The first collections in the Great Lakes were in 1933 in the Huron River near Ann Arbor, Michigan (Woodhead 1933), and in 1934 in Lackawanna, New York, "a few hundred feet" from Lake Erie (Robertson 1934). Other Great Lakes collections have been from Lake Erie (Hubschman and Kishler 1972) and inland Michigan lakes where it reaches its northernmost distribution (Bushnell and Porter 1967, Smrchek 1970). The organism is often found in artificial bodies of water like ponds and quarries throughout the United States but is not limited to these habitats (Garman 1916, Brooks 1932, Schmitt 1939, Dexter *et al.* 1949, Lytle 1960, Bushnell and Porter 1967). The sporadic nature of this jellyfish's distribution and its preference for artificial habitats indicate that it could possibly be an aquarium release or a release with aquatic plants (Bushnell and Porter 1967).

Pyralidae:
Acentropus niveus AQUATIC MOTH

The European *Acentropus niveus* was first collected in North America in Montreal, Quebec, in 1927 (Sheppard 1945). By 1950, the moth had been found in Lake Erie, Lake Ontario, and various locations within their drainage basins (Forbes 1938, Judd 1950). *Acentropus* males are winged moths and the females are generally flightless (Buckingham and Ross 1981). The larvae do not have gills but obtain air from plant stems (Buckingham and Ross 1981). Munroe (1947) noted that, because of its widespread distribution in the Great Lakes basin and its easily overlooked appearance, the moth is probably a native form that was previously unrecognized. He dismisses introduction of the moth by ship. Lange (1956), however, after examining specimens and distribution, considered the species introduced accidentally. Buckingham and Ross (1981) support the status of this insect as introduced. *Acentropus's* potential for introduction with several plants introduced from Europe (e.g., *Myriophyllum spicatum, Potamogeton crispus,* and *Trapa natans)* (Buckingham and Ross 1981) also support the status of this insect as introduced.

Curculionidae:
Tanysphyrus lemnae AQUATIC WEEVIL

Tanysphyrus lemnae, an aquatic weevil, is a species introduced from Europe that has reached a very wide distribution (Pennak 1953, Tanner 1943). In or near the Great Lakes, it is known from Wisconsin (Bayer and Brockmann 1975), New York, and Michigan (Tanner 1943).

Disease Pathogens

Only three fish diseases are known to have been introduced into the Great Lakes, one bacterium and two protozoans (Table 3). These diseases were introduced with fish imported into aquaculture facilities. The number of disease pathogens introduced into the Great Lakes (3) is relatively low compared to the number of native fish diseases (374 in Canada) (Dobson and May 1984). As with the aquatic insects, however, the distributional history and description of many parasites, diseases, and other pathogens are not clear enough for a comprehensive treatment of the introduced species in these groups.

Bacteria:

Aeromonas salmonicida FURUNCULOSIS

Aeromonas salmonicida is a gram-negative bacterium that causes furunculosis, trout and goldfish ulcer disease, common carp erythrodermatitis, and other infections in warmwater and marine fishes (Bullock *et al.* 1983). First discovered as the disease agent of trout and salmon furunculosis in Germany, *Aeromonas salmonicida* was first introduced to the Great Lakes before 1902 (McCraw 1952). Although effective control measures using antimicrobial drugs are known to treat trout ulcer disease, these procedures are not as successful for the other diseases that the pathogen causes (Bullock *et al.* 1983).

Protozoa:

Glugea hertwigi PROTOZOAN PARASITE

Glugea hertwigi, a protozoan fish parasite native to Europe, was introduced to the Great Lakes with its host fish rainbow smelt (Sly 1991). *Glugea* was previously known as a parasite of marine fishes (Hoffman 1973) and was first discovered in Lake Erie in 1960 (Dechtiar 1965). In the 1960s and 1970s, the parasite caused high mortalities of rainbow smelt in Lake Erie and Lake Ontario (Nepszy and Dechtiar 1972, Dechtiar and Christie 1988). The cultural eutrophication during this time is thought to have provided favorable conditions for the free swimming stage of *Glugea hertwigi* (Sly 1991). The infestation of rainbow smelt by the parasite has not occurred at high levels since the 1960s and 1970s (Sly 1991).

Myxobolus cerebralis **WHIRLING DISEASE**

Whirling disease, caused by the protozoan *Myxobolus cerebralis,* is a disease that causes abnormalities in the skeletal structure and pigmentation of fish in the Salmonidae family (Wolf and Markiw 1985). The protozoan infects and damages the cartilage of the fish causing abnormal skeletal structure, which induces the tale-chasing swimming behavior for which the disease was named (Wolf and Markiw 1985). A black discoloration of the tail of the fish or "blacktail" is also a sign of the disease (Wolf and Markiw 1985). The protozoan spends part of its life cycle in the oligochaete *Tubifex tubifex.* Although thought to have arrived in the 1950s, the disease was first observed in the Great Lakes drainage in 1968 in Ohio at a private aquaculture facility (Anonymous 1988). The disease is mostly known from hatcheries and has not been seen extensively in the wild (Wolf and Markiw 1985). Fish hatcheries have found that the protozoan can be controlled by using concrete in their facilities to reduce inhabitation by *Tubifex tubifex* (Anonymous 1988).

AQUATIC FLORA

Algae

Algal species continue to be discovered in the Great Lakes (Stoermer and Kreis 1978) and consequently it is difficult to determine which species are introductions and which are uncommon native forms that only appeared in abundance after favorable environmental conditions arose. Increased salinity and other environmental changes in the Great Lakes have enabled introduced algae often found in marine and brackish environments to more readily adapt to freshwater habitat (Sheath 1987) and have caused shifts in the native algal community (Stoermer *et al.* 1985). Work done on diatoms, however, has shown that a regular sequence of introduced species that was originally described from the Baltic region (e.g., *Stephanodiscus binderanus, Stephanodiscus subtilis, Skeletonema potamos, Skeletonema subsalsum, Actinocyclus normanii* fo. *subsalsa,* and *Thalassiosira weissflogii)* arrived in the twentieth century (Stoermer *et al.* 1979). Interestingly, several of the introduced diatoms are present in the sediments of the Great Lakes 20-30 years before their discovery through conventional phytoplankton sampling regimes (Stoermer *et al.* 1979). The recent discovery of *Compsopogon coeruleus,* an introduced benthic red alga, on Six Fathom Bank in Lake Huron illustrates that new species of algae continue to be introduced into the Great Lakes (Manny *et al.* 1991). Below, we outline the introduced planktonic algae and macrophytes of the Great Lakes (Table 4).

Chlorophyceae:

Enteromorpha intestinalis GREEN ALGA

Muenscher (1927) reported the first records of *Enteromorpha intestinalis,* a green alga native to

TABLE 4. Origin, date and location of first sighting, and entry mechanism(s) for non-indigenous aquatic plants and algae of the Great Lakes. For location and introduction mechanism codes see Tables 1 and 2.

Tax on	Species	Common Name	Origin	Date	Location	Mechanism
Algae						
Chlorophyceae	*Enteromorpha intestinalis*	green alga	Atlantic	1926	Wolf Creek (O)	R(A)
	Enteromorpha prolifera	green alga	Atlantic	1979	Lake St. Clair	Unknown
	Nitellopsis obtusa	green alga	Eurasia	1983	Lake St. Clair	S(BW)
Chrysophyceae	*Hymenomonas roseola*	coccolithophorid	Eurasia	1975	Lake Huron	S(BW)
Bacillariophyceae	*Actinocyclus normanii fo. subsalsa*	diatom	Eurasia	1938	Lake Ontario	S(BW)
	Biddulphia laevis	diatom	widespread	1978	Lake Michigan	S(BW)
	Cyclotella atomus	diatom	widespread	1964	Lake Michigan	S(BW)
	Chaetoceros hohnii	diatom	unknown	1978	Lake Huron	S(BW)
	Skeletonema potamos	diatom	widespread	1963	Toledo, Ohio (E)	S(BW)
	Skeletonema subsalsum	diatom	Eurasia	1973	Sandusky Bay (E)	S(BW)
	Stephanadiscus binderanus	diatom	Eurasia	1938	Lake Michigan	S(BW)
	Stephanodiscus subtilis	diatom	Eurasia	1946	Lake Michigan	S(BW)
	Thalassiosira guillardii	diatom	widespread	1973	Sandusky Bay (E)	S(BW)
	Thalassiosira lacustris	diatom	widespread	<1978	Lake Erie	S(BW)
	Thalassiosira pseudonana	diatom	widespread	1973	Ohio (E)	S(BW)
	Thalassiosira weissflogii	diatom	widespread	1962	Detroit River	S(BW)
	Diatoma ehrenbergii	diatom	widespread	1930s	Lake Michigan	S(BW)
	Cyclotella cryptica	diatom	widespread	1964	Lake Michigan	S(BW)
	Cyclotella pseudostelligera	diatom	widespread	1946	Lake Michigan	S(BW)
	Cyclotella woltereki	diatom	widespread	1964	Lake Michigan	S(BW)
Phaeophyceae	*Sphacelaria fluviatilis*	brown alga	Asia	1975	Gull Lake (M)	R(AQ), R(A)
	Sphacelaria lacustris	brown alga	unknown	1975	Lake Michigan	S(BW)
Rhodophyceae	*Bangia atropurpurea*	red alga	widespread	1964	Lake Erie	S(BW), S(F)
	Chroodactylon ramosum	red alga	Atlantic	1964	Lake Erie	S(BW)
Submerged Plants						
Marsileaceae	*Marsilea quadrifolia*	European water clover	Eurasia	<1925	Cayuga Lake (O)	R(D)
Cabombaceae	*Cabomba caroliniana*	fanwort	Southern U.S.	1935	Kimble Lake (M)	R(AQ), R(A)
Brassicaceae	*Rorippa nasturtium aquaticum*	water cress	Eurasia	1847	Niagara Falls (O)	R(C)
Haloragaceae	*Myriophyllum spicatum*	Eurasian watermilfoil	Eurasia	1952	Lake Erie	R(AQ), S(F)
Trapaceae	*Trapa natans*	water chestnut	Eurasia	<1959	Lake Ontario (T)	R(A), R(AQ)
Menyanthaceae	*Nymphoides peltata*	yellow floating heart	Eurasia	1930	Conneaut River (E)	R(A)
Hydrocharitaceae	*Hydrocharis morsus-ranae*	European frog-bit	Eurasia	1972	Lake Ontario	
R(AQ),R(D,S(F)						
Potamogetonaceae	*Potamogeton crispus*	curly pondweed	Eurasia	1879	Keuka Lake (O)	R(D), R(F)
Najadaceae	*Najas marina*	spiny naiad	Eurasia	1864	Onondaga Lake (O)	S(SB)
	Najas minor	minor naiad	Eurasia	1932	Lake Cardinal (E)	R(D)
Marsh Plants						
Chenopodiaceae	*Chenopodium glaucum*	oak leaved goose foot	Eurasia	1867	Onondaga Lake (O)	RH
Caryophylliaceae	*Stellaria aquatica*	giant chickweed	Eurasia	1894	Lake St. Clair	unknown
Polygonaceae	*Polygonum caespitosum var. longisetum*	bristly lady's thumb	Asia	1960	Ohio (E)	unknown
	Polygonum persicaria	lady's thumb	Eurasia	<1843	widespread	unknown
	Rumex longifolius	yard dock	Eurasia	1901	isle Royale (S)	R(C)
	Rumex obtusifolius	bitter dock	Eurasia	<1840	widespread	unknown

Continued

TABLE 4. Continued

Taxon	Species	Common Name	Origin	Date	Location	Mechanism
Brassicaceae	*Rorippa sylvestris*	creeping yellow cress	Eurasia	1884	Rochester, NY (O)	S(SB)
Primulaceae	*Lysimachia nummularia*	moneywort	Eurasia	1882	central NY (O)	R(C)
	Lysimachia vulgaris	garden loosestrife	Eurasia	1913	central NY (O)	R(C)
Lythraceae	*Lyhrum salicaria*	purple loosestrife	Eurasia	1869	Ithaca, NY (O)	C, S(SB)
Onagraceae	*Epilobium hirsutum*	great hairy willow herb	Eurasia	1874	Ithaca, NY (O)	R(A), S(SB)
	Epilobium parviflorum	small flowered hairy willow herb	Eurasia	1966	Benzie Co., MI (M)	unknown
Apiaceae	*Conium macalatum*	poison hemlock	Eurasia	<1843	widespread	R(C)
Solanaceae	*Solarium dulcamara*	bittersweet nightshade	Eurasia	<1843	widespread	R(C)
Boraginaceae	*Myosotis scorpioides*	true forget-me-not	Eurasia	1886	central NY (O)	R(C)
Lamiaceae	*Lycopus asper*	western water horehound	Mississippi	1892	Lake Erie	R(A)
	Lycopus europaeus	European water horehound	Eurasia	1903	Lake Ontario	S(SB)
	Mentha gentilis	creeping whorled mint	Eurasia	1915	central NY (O)	R(C)
	Mentha piperita	peppermint	Eurasia	<1843	widespread	R(C)
	Mentha spicata	spearmint	Eurasia	<1843	widespread	R(C)
Scrophulariaceae	*Veronica beccabunga*	European brookline	Eurasia	1915	Monroe Co., NY (O)	S(SB)
Asteraceae	*Cirsium palustre*	marsh thistle	Eurasia	<1950	Lake Superior	unknown
	Pluchea odorata					
	var. succulents	salt-marsh fleabane	Atlantic	<1950	central NY (O)	unknown
	var. purpurescens	salt-marsh fleabane	Atlantic	1916	Lake Erie (T)	R(A)
	Solidago sempervirens	seaside goldenrod	**Atlantic**	1969	Chicago (M)	R(A)
	Sonchus arvensis	field sow thistle	Eurasia	1865	central NY	R(A)
	Sonchus arvensis *var. glabrescent*	smooth field sow thistle	Eurasia	1902	Ohio (E)	R(A)
Butomaceae	*Butomus umbellatus*	flowering rush	Eurasia	<1930	Detroit River (E)	S(SB)
Balsaminaceae	*Impatiens glandulifera*	Indian balsam	Asia	1912	Port Huron (H)	R(C)
Juncaceae	*Juncus compresses*	flattened rush	Eurasia	<1895	Cayuga Lake (O)	R(A)
	Juncus gerardii	black-grass rush	Atlantic	1862	Chicago	S(SB)
	Juncus inflexus	rush	Eurasia	1922	central, NY	unknown
Cyperaceae	*Carex acutiformis*	swamp sedge	Eurasia	1951	St. Joseph Lake (M)	unknown
	Carex disticha	sedge	Eurasia	1866	Belleville, Ontario (O)	S(SB)
	Carex flacca	sedge	Eurasia	1896	Detroit River	unknown
Poaceae	*Agrostis gigantea*	redtop	Eurasia	1884	Ontario (S)	R(C)
	Alopecurus geniculatus	water foxtail	Eurasia	1882	Lake Erie	R(C)
	Echinochloa crusgalli	barnyard grass	Eurasia	<1843	widespread	R(C), S(SB)
	Glyceria maxima	reed sweet-grass	Eurasia	1940	Lake Ontario	R(C), S(SB)
	Poa trivalis	rough-stalked meadow grass	Eurasia	<1843	widespread	R(C), S(SB)
	Puccinellia distans	weeping alkali grass	Eurasia	1893	Montezuma, NY (O)	S(SB). RH
Sparganiaceae	*Sparganium glomeratum*	bur reed	Eurasia	1936	Lake Superior	unknown
Typhaceae	*Typha angustifolia*	narrow leaved cattail	Eurasia	1880s	central NY (O)	C, R(A)
Iridaceae	*Iris pseudacorus*	yellow flag	Eurasia	1886	Ithaca, NY (O)	R(C)
Shoreline Trees and Shrubs						
Betulaceae	*Alnus glutinosa*	black alder	Eurasia	<1913	widespread	R(C)
Salicaceae	*Salix alba*	white willow	Eurasia	<1886	widespread	R(C)
	Salix fragilis	crack willow	Eurasia	<1886	widespread	R(C)
	Salix purpurea	purple willow	Eurasia	<1886	widespread	R(C)
Rhamnaceae	*Rhamnus frangula*	glossy buckthorn	Eurasia	<1913	Ontario	R(C)

the Atlantic Coast in the Great Lakes drainage from Wolf Creek near Silver Springs, New York, in 1926. Taft (1964b) reported collections of *Enteromorpha inrestinalis* from the Portage River west of Elmore, Ohio, in 1951 on a fault in the limestone bedrock where water was upwelling. Catling and McKay (1980) reported the first records of *Enteromorpha intestinalis* in Ontario in saline habitat near the Ojibway Salt Mine near the Detroit River in 1979. They noted that their findings were the first records of this algal species in Ontario. Neither of the forms are noted inland by Collins (1928).

Enteromorpha prolifera GREEN ALGA

Catling and McKay (1980) found this green alga in a pool near a salt factory in Windsor, Ontario, in 1979 in the Lake St. Chair drainage. They noted that this record was the first known of the alga in Ontario. This algal species, although primarily marine, was reported from inland salt springs by Collins (1928). The mechanism through which this species was introduced remains unknown.

Nitellopsis obtusa GREEN ALGA

First records of this Eurasian green alga in North America were in 1978 when the plant was found in the St. Lawrence River (Geis *et al 1981).* At the time of this study, the plant was found to be present in many sites along the St. Lawrence River from east of Clayton, New York, to east of Ogdensburg, New York (Geis *et al.* 1981). More recent studies document the alga in the St. Clair-Detroit River system in 1983 (Schloesser *et al.* 1986). Ranked as the ninth-most frequently collected macrophyte in the St. Clair-Detroit River system, *Nitellopsis* was more frequently observed there than *Potamogeton crispus,* another common Great Lakes exotic. This alga is considered a ballast water introduction.

Chrysophyceae:

Hymenomonas roseola COCCOLITHOPHORID

Stoermer and Sicko-Goad (1977) first collected this coccolithophorid in the Great Lakes in Saginaw Bay, Lake Huron, in 1975. It normally inhabits eutrophic areas, ponds, and small lakes, polluted rivers, and "slightly brackish upper reaches of coastal estuaries" in Europe (Stoermer and Sicko-Goad 1977). In Ohio, *Hymenomonus roseola* was rare in the Scotio River which is in the Mississippi River basin in 1937-1938 (Lackey 1939). *Hymenomonas roseola* could have been introduced in the ballast water of ocean going ships from Europe or transferred from Ohio to Lake Huron through another mechanism.

Bacillariophyceae:

Actinocyclus normanii fo. subsalsa DIATOM

This diatom is common in coastal waters of Germany and Norway, the Baltic and Caspian Seas, and freshwaters of Northern Germany (Hasle 1977, 1978). Studies of the sediments of Lake Ontario have determined that *Actinocyclus normanii* fo. *subsalsa* arrived around 1938 (Stoermer *et al.* 1985). The species is known from the plankton of Lakes Michigan, Erie, Ontario, and Huron (Stoermer and Yang 1969, Stoermer and Theriot 1983, Stoemner *et al.* 1985).

Biddulphia laevis DIATOM

This diatom, known from lakes and streams in the south and midwest (Weber 1971) and from North Sea estuaries and the west coast of Africa (Sheath 1987), was not known in the Great Lakes until 1978 when it was observed at the Wyoming water treatment plant on the southern basin of Lake Michigan (Wujek and Welling 1981). This diatom comprised 1% of the total phytoplankton population in an area of Lake Michigan which has higher concentrations of chloride ions than other sites in the lake (Wujek and Welling 1981). Wujek and Welling (1981) noted the halophyllic nature of this diatom and implicated an increase in chloride concentrations in the establishment of this species in the Great Lakes. This diatom is likely a ballast water invader as species of *Biddulphia* were identified in the ballast of foreign ships entering the Great Lakes in the early 1980s (Bio-Environmental Services Ltd. 1981).

Cyciotella atomus DIATOM

Cyclotella atomus is found in European coastal waters of varied salinity, Java, and South Africa (Belcher and Swale 1978, Nicholls 1981). In Lakes Michigan, Ontario, Huron, and Erie, this diatom has become common (Stoermer and Yang 1969, Sreenivasa and Nalewajko 1975, Stoermer 1978, Nicholls and Carney 1979, Stoermer and Theriot 1983) in localities of "high loadings of dissolved solids" (Sheath 1987). It was collected in 1964 in Lake Michigan (Stoermer and Yang 1969) and was discovered in the sediments of Lake Ontario before it was found in the plankton (Duthie and Sreenivasa 1972). *Cyciotella atomus* is also widespread in North American rivers (Hohn and Hellerman 1963, Weber 1971, Lowe and Busch 1975), thus, the origin ot the Great Lakes populations cannot be determined.

Chaetoceros hohnii DIATOM

Chaetoceros honhii was first described as a new species in Saginaw Bay, Lake Huron, in 1978 (Wujek and Graebner 1980). Because the populations were found in areas of high ion content (Wujek and Graebner 1980) and since *Chaetoceros is* generally a marine genus, the species is thought to have originated in a marine or brackish environment (Sheath 1987). The transcontinental introduction of a previously undescribed species in ballast water is a probable explanation for the presence of this diatom in Great Lakes waters. Many non-indigenous species are known to have been first described in the region into where they have been introduced, rather than their native localities (Carlton 1979). Species of *Chaetoceros* non-indigenous to the Great Lakes have been found in surveys of ballast water entering the Great Lakes (Bio-Environmental Services Ltd. 1981).

Skeietonema potamos DIATOM

Skeletonema potamos, first described by Weber (1970) from the Little Miami River at Cincinnati, is a diatom with a wide salinity tolerance. It is known from German waters and from North American rivers (Hasle and Evensen 1976). In North America, the diatom is widespread, common in the Atlantic, Pacific, and Mississippi drainages and was present in the Great Lakes basin at Toledo, Ohio, by 1963 (Weber 1970). In the Great Lakes, the diatom has been found in Sandusky Bay, Lake Erie (Hasle and Evensen 1976), the north shore of Lake Erie (Nicholls *et aI.* 1983), Lake Ontario (Stoermer 1978, Nicholls and Carney 1979), and Saginaw Bay, Lake Huron (Stoermer and Theriot 1983). This diatom could have either been introduced with ballast water from the North American rivers listed above. from the German waters where it has been a common component of the phytoplankton since 1922, or from rivers in England and France (Hasle and Evensen 1976, Belcher and Swale 1978).

Skeletonema subsalsurn DIATOM

The earliest report of this brackish diatom, known from the Baltic Sea, the Caspian Sea, and Northern Germany, was in North America in Sandusky Bay, Lake Erie, in 1973 (Hasle and Evensen 1975). Stoermer (1978) noted its occurrence in Lake Erie, Lake Ontario, and nearshore areas of Lake Michigan and southern Lake Huron.

Stephanodiscus binderanus DIATOM

The earliest records of this Eurasian diatom from. North America are from Lake Michigan in 1938 (Stoermer and Yang 1969). Originally described from the Baltic (Stoermer *et al.* 1979), it is known from the sediments of Lake Ontario and is estimated to have first occurred there in 1952 (Stoermer *et al.* 1985). Although the diatom was present in the Great Lakes-St. Lawrence River system since as early as 1938, it was not discovered until 1955 in the St. Lawrence River at Montreal (Brunei 1956). After its introduction into the Great Lakes basin, *Stephanodiscus binderanus* became established in the St. Lawrence River (Brunei 1956), Lake Ontario (Nalewajko 1966, Nicholls and Carney 1979), Lake Erie (Wujek 1967, Nicholls ***et al.*** 1983), Lake Michigan (Stoermer and Yang 1969), and Saginaw Bay, Lake Huron (Stoermer and Theriot 1983). Dominant populations of this species are known to cause water quality problems in municipal water treatment facilities (Brunei 1956, Vaughn 1961, Stoermer and Yang 1969).

Stephanodiscus subtilis DIATOM

This diatom was not discovered in Lake Michigan until 1946. In the 1960s it was common in eutrophic areas and habitats contaminated with chloride (Stoermer and Yang 1969). In 1972, the species was found in Lake Ontario where it had reached high densities (Stoermer *et al.* 1975). The diatom is also a component of the Lake Erie (Stoermer 1978) and Saginaw Bay, Lake Huron, phytoplankton (Stoerrner and Theriot 1983). *Stephanodiscus subtilis* is also known from the North Sea, rivers in Holland, and in Sweden (Nicholls 1981).

Thalassiosira guillardii DIATOM

The earliest records of ***Thalassiosira guillardii*** in North America are from Sandusky Bay, Lake Erie, in 1973 (Hasle 1978). It is common in coastal waters of the Pacific and Atlantic, the Baltic Sea, the River Weser in Germany, and the River Thames in Great Britain (Hasle 1978). Early Great Lake diatom collections either do not contain this diatom, or contain inconclusive fragments (Hasle 1978).

Thalassiosira lacustris DIATOM

Hasle (1978) noted *Thafassiosira lacustris* from Pacific and Atlantic coastal waters, the Baltic Sea, the Caspian Sea, the River Weser in Germany, Lake Erie, and U.S. inland waters.

Thalassiosira pseudonana DIATOM

The earliest reported collections in the Great Lakes of *Thalassiosira pseudonana* are from 1973 from Miller Blue Hole, Ohio, an artesian well in the Lake Erie drainage (Lowe and Busch 1975). Stoermer (1978) reported the diatom from nearshore areas of Lake Michigan and bays of Lakes Ontario and Erie. The only other North American records of the diatom, also known from Europe (Belcher and Swale 1977), are from coastal waters near Long Island, New York, and from a brackish pond on Long Island (Lowe and Busch 1975). Although the locality where this diatom was first found in the Great Lakes (e.g., an artesian well) is obscure, it is most likely a ballast introduction. This diatom could have been introduced secondarily from Lake Erie into the artesian well and reflects the potential time lag between the actual introduction of an algal species and its discovery. For example, *Stephanodiscus bideranus* was not reported from North America until 1955 but it was present in Lake Michigan phytoplankton collections from 1938 (Brunel 1956, Stoermer and Yang 1969).

Thalassiosira weissflogii
(= Thaiassiosira fluviatilis) DIATOM

Hasle (1978) noted the synonymy of *Thalassiosira fluviatilis* Hust and *Thalassiosira weissflogii* G. Fryx. & Hasle. The earliest reports of *Thalassiosira fluviatilis* are from the Detroit River in 1962-1963 (Wujek 1967), from Lake Michigan in 1967 (Stoermer and Yang 1969), and the Portage River, Ohio, in 1973 (Lowe and Busch 1975). Stoermer (1978) reported the diatom common from nearshore areas of Lake Michigan and bays of Lakes Erie and Ontario. The diatom is also known from the Potomac River, from Midwestern rivers and streams (Lowe and Busch 1975), and is common in estuaries in Europe and in Asia (Belcher and Swale 1977). It thrives at salinities ranging from 5% to full-strength seawater (Belcher and Swale 1977).

The four diatom species listed below are species that were not discovered in the lakes until the mid-twentieth century. The published information on these diatoms is scant and their source or origin unknown. All are widespread species.

Diatoma ehrenbergii DIATOM

Diatoma ehrenbergii is found in eutrophic areas of Lake Michigan and was not discovered in Lake Michigan until the late 1930s (Stoermer and Yang 1969). Stoermer and Theriot (1983) report the species from Saginaw Bay, Lake Huron, in low abundance.

Cyclotella cryptica DIATOM

This diatom was first discovered in Lake Michigan in 1964 (Stoermer and Yang 1969). In the 1960s, it was a rare part of the flora of harbors and inshore areas with high chloride concentrations (Stoermer and Yang 1969). It is now known from Lake Michigan, Ontario, Huron, and Erie (Stoermer 1978, Stoerrner and Theriot 1983).

Cyclotella pseudostelligera DIATOM

This diatom was first discovered in Lake Michigan in 1946 and has become abundant in eutrophic waters close to shore and estuaries in the lake (Stoermer and Yang 1969). Stoermer (1978) reported it from Lakes Michigan, Ontario, and Erie, and Nicholls and Carney (1979) reported it from the Bay of Quinte, Lake Ontario. More recently, the diatom was found in Saginaw Bay, Lake Huron (Stoermer and Theriot 1983).

Cyclotella woltereki DIATOM

This diatom species was first discovered in Lake Michigan in 1964 and was originally described from the tropics (Stoermer and Yang 1969).

Phaeophyceae:
Sphacelaria fluviatilis BROWN ALGA

Sphacelaria, a genus of brown algae generally considered marine, was first observed in 1975 in the Great Lakes watershed when *Sphacelaria fluviatilis* was found in Gull Lake, Michigan, which drains into Lake Michigan (Thompson 1975, Timpano 1978). It was previously known from western China (Jao 1943). *Sphacelaria fluviatilis* was most likely introduced through aquarium or another type of accidental release.

Sphacelaria lacustris BROWN ALGA

Soon after the discovery of *Sphacelaria fluviatilis* in 1975, the brown alga *Sphacelaria lacustris* was first described in Lake Michigan (Schloesser and Blum 1980). As in the case of *Chaetoceros honii, Sphacelaria lacustris* could be a previously undescribed ballast or aquarium introduction.

Sheath (1987) noted, as in the case of other marine algal invaders, the freshwater populations of the two species of brown algae discussed above are not known to undergo sexual reproduction, indicating that the populations evolved dependent upon the marine environment. The unexpected occurrences of these algal species in Lake Michigan waters and their lack of sexual reproduction prompted Sheath (1987) to consider the genus *Sphacelaria* non-indigenous to the Great Lakes basin.

Rhodophyceae:

Bangia atropurpurea RED ALGA

This filamentous red alga native to the Atlantic Coast was observed in Buffalo Harbor in Lake Erie in 1964 (Lin and Blum 1977). After this sighting, records for the western basin of Lake Erie (Kishler and Taft 1970), Lake Ontario (Damann 1979), Lake Michigan (Lin and Blum 1977, Weik 1977), Lake Simcoe, Ontario (Jackson 1985), and Lake Huron (Sheath 1987) were reported. It has become a major species of the littoral flora of these lakes, generally occupying the littoral zone with *Cladophora* and *Ulothrix* (Blum 1982). Earliest records of this algae in the basin, however, go back to the 1940s when Smith and Moyle (1944) found the alga in Lake Superior tributaries. Matthews (1932) found the alga in another inland location at Quaker Run in the Allegheny drainage basin. The early records of this alga in Lake Superior tributaries could have been either unestablished introductions or misidentifications (Smith and Moyle 1944). The alga was not known in Lake Superior as of 1987. The prevailing belief is that this alga was transferred to the lower Great Lakes through ship fouling or ballast water.

Chroodactylon ramosum RED ALGA

This red alga, native to the Atlantic Ocean, was first reported in 1964 in the Great Lakes from western Lake Erie (Taft 1964a). An epiphyte on *Cladophora,* it is found in the Great Lakes from Lake Ontario to Lake Huron (Sheath and Morison 1982). The St. Lawrence River does not have the wave action to support the growth of *Chroodactylon ramosum* (Sheath and Morison 1982), so its natural migration up the river from the Atlantic is unlikely. The alga probably arrived in the ballast water of ships.

Plants

Botanists have observed the presence of non-indigenous plant species in the Great Lakes since the 1840s. Although many later invasions have been well documented through the examination of herbarium specimens (Stuckey 1966, 1980), invasions occurring early in the settlement of the Great Lakes region, like bittersweet nightshade, were not documented and the details of their introduction remain unknown. Many of the plants introduced into the Great Lakes have historically had medicinal or practical uses and were released from cultivation (Usher 1974). Plant taxonomy presented in Table 4 follows Gleason and Cronquist (1991).

Submersed Plants

Marsileaceae:

Marsilea quadrifolia EUROPEAN WATER CLOVER

European water clover, a plant native to Europe and Asia, was first found in North America at Bantam Lake in Litchfield, Connecticut (Gray 1867, Britton and Brown 1913). From this population, the plant was transferred into other parts of the eastern United States (Britton and Brown 1913). *Marsilea quadrifolia* will spread rapidly once it is established (Fernald 1950, Hotchkiss 1972). In the Great Lakes basin, Wiegand and Eames (1925) reported the plant from the Cayuga Lake basin and noted that it was introduced by early botanists of the region. The earliest flora of the Cayuga Lake basin was published by Dudley (1886), so introduction of the plant probably occurred before 1900. Dudley's (1886) *Cayuga Flora* did not, unfortunately, treat the Polypodiophyta, *Marsilea's* taxonomic group. Another population of *Marsilea quadrifolia* in the Great Lakes basin occurs in Nanticoke, Ontario, where it was well established in 1951. Nanticoke is near the north shore of Lake Erie east of Port Dover, Ontario. In the Great Lakes basin, the plant was also released near the Niagara River, above the falls, and to a pond near Lewiston, New York, but did not become established in these localities (Zenkert 1934).

Cabombaceae:

Cabomba caroliniana FANWORT

Cabomba caroliniana is a common aquarium and ornamental pond species that has been brought into the northeastern and midwestem United States and Canada from the southeastern United States (Voss 1985). In the Great Lakes basin, fanwort was first discovered in the St. Joseph River system during 1935 in Kimble Lake, Kalamazoo County, Michigan (Hanes 1938). The plant was soon found to be well established in other areas of this tributary (Voss 1985). In Ohio, the plant was first discovered in 1933 in Mosquito Creek, an Ohio River tributary (Rood 1947). The location of this collection, however, was not in the Great Lakes drainage basin. Montgomery (1948) reported the plant from Wellington, Ontario. Fanwort has also been released into Kansas (Magrath 1971), New Hampshire (Hodgdon 1959), and Massachusetts (Manning 1937, Gates 1958, Harris 1958).

Brassicaceae:
Rorippa nasturtium aquaticum WATER CRESS

The importation of water cress and its escape from cultivation was so widespread in the early-to-mid 1800s that its naturalization was not well documented. Established populations, most likely rising from plants cultivated for culinary purposes, were first observed in North America near Niagara Falls, Canada, in 1847 (Gray 1848). At this time, however, water cress was probably established in many areas of the Great Lakes watershed. Voss (1985) cited records from Ann Arbor, Michigan, from 1857. Since these early records, water cress has become established throughout North America (Green 1962).

Haloragaceae:
Myriophyllum spicatum EURASIAN WATERMILFOIL

Although this submersed aquatic plant is thought to have arrived much earlier, the first validated occurrence of Eurasian watermilfoil, a common aquarium species, in North America is from the Potomac River, Virginia, in 1881 (Reed 1977). The plant, although present in North America from the 1880s onward, did not cause any problems until the late 1950s when, due to increased concentrations of calcium in Chesapeake Bay, the populations grew to problematic proportions. For years, taxonomy of the North American watermilfoil was under debate, and, in most cases, all species of *Myriophyllum* were referred to as *Myriophyllum exalbescens.* Reed (1977) reviewed the taxonomic difficulties and documented the arrival and spread of the plant in the United States in more detail. In the Great Lakes basin, the first record occurred in 1882 in Paddy's Lake near Oswego, New York. No specimens, however, were collected again until 1960 when the plant was found at Sodus Bay, Lake Ontario, and in Rochester, New York. The first observations of established populations of the plant in the Great Lakes basin were in 1952 at Put-in-Bay in western Lake Erie (Stuckey 1988). Many new collections were made in New York and in other Great Lakes states in the years immediately following these first records. Eurasian watermilfoil was found in Michigan in 1965 (Coffey and McNabb 1974) and in the St. C1air-Detroit River system in the 1960s (Schloesser and Manny 1984). Although the plant has not yet become a major problem in the Great Lakes, the abundance of Eurasian watermilfoil in the watershed has caused many problems. The extensive beds of the plant have created problems in recreational and industrial use of water, have competed with native aquatic plants, and can alter water temperatures (Aiken *et al* 1979). Such methods as cutting and harvesting, water drawdown, and herbicides, have been used to control the plant (Coffey and McNabb 1974). Eurasian watermilfoil most likely entered the Great Lakes basin through aquarium release and transport in or attached to boats or ships.

Trapaceae:
Trapa natans WATER CHESTNUT

The water chestnut was first introduced to North America in Concord, Massachusetts, before 1859 (Eaton 1947). This population became widely distributed and aggressive in the Concord and Sudbury rivers in Massachusetts (Eaton 1947). In the Hudson-Mohawk River drainage system, the plant was introduced into Sanders Lake in Scotia, New York (Wibbe 1886). Some authors credit this introduction to a "local sportsman" planting it as waterfowl food (Winne 1935, Anonymous 1938). The population at Sanders Lake, which is connected to the Mohawk River and Erie Canal system, spread into the Hudson-Mohawk drainage system and became a nuisance (Muenscher 1934). Muenscher (1935) later reported that the fruit was being sold at fairs in western New York and an aquarium plant dealer was selling the seeds. The first records of the water chestnut in the Great Lakes basin are unpublished. In two sites in central New York, Kendig Creek and Keuka Lake, mechanical control eliminated water chestnut populations by 1959 and the early 1970s, respectively. The plant is currently known, however, from Sodus Bay, Lake Ontario, where mechanical control has been practiced annually since the 1960s (W. Abraham, New York State Department of Environmental Conservation, personal communication, 1991). The water chestnut was probably released into the Great Lakes basin through aquaria or escape from private ponds. in areas of infestation, the tough stems and leaves of the plant impede boating, and the fruits of the water chestnut, which have four very sharp spines, are a nuisance to bathers (Anonymous 1938). Interestingly, the name *Trapa* was derived from the calci -

trapa, a four spined iron sphere which was used in Roman times to injure calvary horses' feet (Brown 1879, Anonymous 1938).

Menyanthaceae:
Nymphoides peltata YELLOW FLOATING HEART

The first records of the escape of this European plant from cultivation in North America were in the District of Columbia and in eastern New York (Fassett 1957). It is commonly used in ornamental ponds and garden pools and often gets out of control in nutrient rich pools (Muhlberg 1982). Stuckey (1973) reviewed its North American history and noted that the only known Great Lakes basin record is from 1930 in Ashtabula County, Ohio, at the mouth of the Conneaut River. The current status of this population is unknown (Stuckey 1973).

Hydrocharitaceae:
Hydrocharis morsus-ranae EUROPEAN FROG-BIT

Hydrocharis morsus-ranae, a floating aquatic plant, was imported into the Central Experimental Farm in Ottawa, Canada, from Zurich, Switzerland, in 1932 (Minshall 1940, Roberts *et al.* 1981). The species was planted in a trench connecting an arboretum pond to the Rideau Canal, but it was not observed until 1936 when it had invaded the pond (Minshall 1940). By 1953, frog-bit had gradually spread into the Rideau Canal, its connecting waters, and the Ottawa River and by 1958 it was well established in the St. Lawrence River near Montreal (Dore 1954, 1968). In 1972, *Hydrocharis morsus-ranae* was found in the Bay of Quinte, Lake Ontario, and in 1976 it was discovered in Rondeau Park on the north shore of Lake Erie (Catling and Dore 1982). Lumsden and McLachlin (1988) note the plant's continued spread into western Lake Ontario marshes. The plant will likely spread farther into the Great Lakes drainage. Although the primary introduction occurred through cultivation release, the spread of the species into the Great Lakes probably occurred through aquarium release, deliberate release as a food for waterfowl (Catling and Dore 1982), and entanglement on boats.

Potamogetonaceae:
Potamogeton crispus CURLY PONDWEED

Stuckey (1979) reviews the introduction and spread of this common European submersed aquatic plant into North America. Although reports of the species date back to 1807, the earliest verifiable records of the plant in North America are from the 1860s in Wilmington, Delaware, and Lancaster, Pennsylvania. In the 1880s, it was found in Arlington, Massachusetts. The first Great Lakes basin record is Keuka Lake, New York in 1879. By 1884 *Potamogeton crispus* was reported throughout central New York and near Niagara Falls. It is currently very common throughout the Great Lakes basin. It is more abundant in Lakes Ontario, Erie, and Michigan than in Lakes Superior and Huron, where it continues to spread. *Potamogeton crispus* is known to have been introduced into parts of the Great Lakes basin deliberately as food for waterfowl and has been associated with fish hatcheries, indicating potential transport between basins associated with fish stocking activities (Stuckey 1979).

Najadaceae:
Najas marina SPINY NAIAD

Spiny naiad, a plant preferring to grow in brackish and alkaline waters, was first found in North America in 1864 in central New York's Onondaga Lake near Salina, New York (Stuckey 1985). The plants were growing near a salt mine in brackish water. Soon after this initial record, the plant was discovered in other areas of central New York. Spiny naiad is also known from the western Great Lakes region where it invaded in the 1930s. Fossil records of this plant from the midwest indicate that it was present in North America prior to glaciation, supporting debate about whether the newly discovered populations were indigenous or non-native. Two interpretations of the plant's distribution in the Great Lakes have been outlined by Stuckey (1985). He theorizes that the plant was pushed south during glaciation and reinvaded glacial lakes when the ice receded. He suggests that the species persisted in areas where the habitat remained favorable and reinvaded some areas, such as the western Great Lakes region, more recently. The introduction of the plant from Europe or another region where it is common in habitats made brackish and alkaline by human activities (such as areas around salt mines) is also possible. Central New York was a very active botanical center in 1864 and the possibility that the plant was overlooked for years is unlikely. The area around Onondaga Lake has been industrialized since the early 1800s when humans began developing the salt resources around the lake. The salt from this area was transported into other parts of the United States and the salt industry had the power to instigate the construction of the Erie Canal (Murphy 1978). We consider the introduction of spiny naiad into the industrialized area around Onondaga Lake to be a more likely scenario than the persistence of preglacial populations. Spiny naiad is now also known from Europe, Asia, Africa, Australia, South America, and Central America (Stuckey 1985).

Najas minor MINOR NAIAD

This European native was first found in North America in 1932 in Lake Cardinal, Ashtabula County, Ohio, in the Lake Erie drainage basin (Wentz and Stuckey 1971). In 1934 it was discovered in the Hudson River near Troy, New York (Clausen 1936). The plant was clearly established in this location in "great beds" in shallow water (Clausen 1936). In the same year, Muenscher and Clausen found populations of the plant growing in several different areas in and near the Hudson River (C1ausen 1936). The plant was soon introduced in 1935 at Ithaca, New York, by W.C. Muenscher, who wanted to see if it would persist in Cayuga Lake (Clausen 1936). After these original introductions, the plant rapidly spread into the Great Lakes system. It was identified in Monroe County, New York, in 1939 (Merilainen 1968), in Point Moullee State Game Area in Michigan in 1949 (Voss 1972), and by the late 1960s, it had become widespread throughout Ohio (Wentz and Stuckey 1971). Merilainen (1968) suggests bird migration and shipping as transfer mechanisms for this plant, but these mechanisms would apply to secondary dispersal after its initial introduction. The initial introduction mechanism for this plant into the Great Lakes at Cayuga Lake is deliberate release and into Lake Cardinal, Ohio, is unknown.

Marsh Plants

Chenopodiaceae:

Chenopodium glaucum OAK LEAVED GOOSE FOOT

Gray (1867) first reported this European plant from city streets and the brackish shores of Onondaga Lake near Syracuse, New York. Since then, it has been introduced or expanded into areas throughout the Great Lakes basin and is common in cultivated land, roadsides, shores and riverbanks, and marshy areas (Day 1882, Wiegand and Eames 1925. Montgomery 1957, Swink and Wilhelm 1979, Voss 1985). The spread of this plant into and throughout the Great Lakes region was probably mediated by railroads (Wiegand and Eames 1925, Voss 1985, Swink and Wilhelm 1979).

Caryophyllaceae:

Stellaria aquatica GIANT CHICKWEED

Britton and Brown (1913) recorded this European plant from Quebec and Ontario to Pennsylvania. Early Ontario records are from 1894 when the plant was found in Stratford, a town in the Lake St. Clair drainage (Montgomery 1957). Giant chickweed later became widely established in southern Ontario where it grew along the Thames River, Rideau River, Welland Canal, and in other areas (Montgomery 1957). The plant has become distributed throughout the Great Lakes basin (Zenkert and Zander 1975, Swink and Wilhelm 1979, Voss 1985, Gleason and Cronquist 1991). The mechanism through which this plant gained access to the Great Lakes remains unknown.

Polygonaceae:

Polygonum caespitosum var. longisetum BRISTLY LADY'S THUMB

Bristly lady's thumb, a rice paddy weed in Eastern Asia, was first discovered in North America in 1910 near Philadelphia (Kochman 1991). After its initial introduction, the plant spread to the south and the west. The first Great Lakes drainage records are from Erie County, Ohio, in 1960. The mechanism through which the plant was introduced remains unknown. Bristly lady's thumb is common in the Chicago area (Swink and Wilhelm 1979) and was first discovered in Michigan in 1978 (Voss 1985).

Polygonum persicaria LADY'S THUMB

Michaux (1803) noted *Polygonum persicaria* from Kentucky and by 1843 the plant was considered naturalized (Torrey 1843). Native to Europe, the marsh plant is found throughout-the Great Lakes basin in a variety of habitats (Day 1882, Dudley 1886, Wiegand and Eames 1925, Zenkert 1934, Fassett 1957, Montgomery 1957, Swink and Wilhelm 1979, Soper *et al* 1989). The mechanism through which it was introduced remains unknown.

Rumex longifolius YARD DOCK

Voss (1985) noted that *Rumex longifolius* and *Rumex domestics* are synonymous and reported records of the Eurasian plant from Isle Royle from 1901-1960. The 1901 date is the earliest validated date available even though an earlier record may exist, since some of the collections reported in Robinson and Fernald (1908) of *Rumex patientia* were actually *Rumex longifolius* (Fernald 1950). Robinson and Fernald (1908) reported *Rumex pati-*

entia from Newfoundland, New York, and Pennsylvania and a variety from Michigan, Montana, and westward. Britton and Brown (1913) reported *Rumex patientia* from various localities on the east coast and in the mid-west. Gray (1889) noted *Rumex patientia* from New England and New York. The plant is occasionally cultivated (Usher 1974).

Rumex obtusifolius BIITER DOCK

Bitter dock, a European plant known from rich, moist habitat, has been reported from the Great Lakes drainage since the earliest botanical surveys of the region (Voss 1985). In Michigan, it was discovered in the first survey, which occurred between 1837 and 1840 (Voss 1985). Also common in New York during this period (Torrey 1843), the weedy species has spread throughout the Great Lakes region in many moist, disturbed habitats (Dudley 1886, Wiegand and Eames 1925, Fassett 1957, Swink and Wilheim 1979, Voss 1985).

Brassicaceae:

Rorippa sylvestris CREEPING YELLOW CRESS

This European native was first reported in North America from Philadelphia in 1818 (Stuckey 1966). In the early 1890s, it was also found in the Chicago area, but these records were in the Mississippi drainage basin despite their proximity (15 to 20 km) to Lake Michigan (Hill 1892). The first observations of creeping yellow cress in the Great Lakes drainage were from 1884 in Rochester, New York. After these first introductions, the plant spread quickly into many areas of the Great Lakes region (Stuckey 1966). The collection of the plant on solid ballast dumping grounds in Mobile, Alabama, in 1883 indicates its potential for introduction with solid ballast (Stuckey 1966). Stuckey (1966) suggested that, due to the distance between the Great Lakes populations and those in eastern ports, the introduction of creeping yellow cress into the Great Lakes basin was directly from Europe. The plant is known from shores and other wet habitat (Fassett 1957, Voss 1985).

Primulaceae:

Lysimachia nummularia MONEYWORT

in central and western New York, moneywort was first reported by Dudley (1886) and Day (1882), and by the 1920s it had become naturalized throughout the area in ditches and on stream banks (Wiegand and Eames 1925, Zenkert 1934). The plant, a native of Europe, is known to have escaped from gardens in many areas of northeast North America and the Great Lakes basin (Fernald 1950, Swink and Wilhelm 1979). Usher (1974) noted that the leaves of moneywort have been used to heal wounds and can be ingested as tea.

Lysimachia vulgaris GARDEN LOOSESTRIFE

This ornamental Eurasian plant was first known to escape from cultivation in eastern Massachusetts between 1867 and 1889 (Gray 1867, 1889). By 1913, it was observed from Maine to Ontario, southern New York, and Pennsylvania (Britton and Brown 1913). Although specific locations for the Ontario observations are unknown, they were probably in the Great Lakes drainage since many of the major population centers in Ontario at the turn of the twentieth century were Great Lakes ports. Montgomery (1957) noted that the plant occasionally escapes from cultivation. Garden loosestrife can be used as an astringent and to treat bleeding (Usher 1974). Several large populations in mudflats and shallow water exist in the Chicago area (Swink and Wilhelm 1979). Zenkert (1934) also recorded the species from near Buffalo, New York, in 1921.

Lythraceae:

Lythrum salicaria PURPLE LOOSESTRIFE

Thompson *et al.* (1987), Stuckey (1980), and Mal *et al.* (1992) reviewed the introduction and spread of purple loosestrife into North America and Canada. Purple loosestrife is thought to have been introduced to Atlantic Coast ports in the early 1800s with imported sheep, in solid ballast, or as a cultivated plant. The first record of purple loosestrife in the Great Lakes basin is from 1869 in Ithaca, New York (Dudley 1886). Although it was reported in the earliest Michigan botanical surveys, the first herbarium collections are from 1879 (Voss 1985). The plant is thought to have spread into the Great Lakes basin through railroads and along canals. The rapid spread of this wetland species throughout the United States and Canada occurred after its initial invasion of the Great Lakes (Thompson *et al.* 1987). The ecological impacts associated with often monospecific stands of purple loosestrife are their competitive effects on native plants (cattails and other species) and the loss of prime habitat for waterfowl and other marsh animals (Rawinski and Malecki 1984).

Onagraceae:

Epilobium hirsutum GREAT HAIRY WILLOW HERB

The first records for this Eurasian marsh species in North America are from Newport, Rhode Island, in 1829. Early records show it from cultivated ground and on solid ballast grounds (Stuckey 1970). The first record in the Great Lakes basin is from 1874 near a mill west of Cascadilla Place in Ithaca, New York (Dudley 1886). In 1882 the plant was observed from Clifton, Ontario and later, in 1890, it was collected in Niagara Falls (Stuckey 1970). The Niagara Falls specimens are thought to have been introduced with garden seed. By 1948, the plant had spread into the Great Lakes basin as far as Cook County, Illinois (Stuckey 1970).

Epilobium parviflorum SMALL FLOWERED HAIRY WILLOW HERB

The earliest known North American record for *Epilobium parviflorum* is from solid ballast ground at Hoboken, New Jersey (Trelease 1891). It was not reported again until Purcell (1976) found it in Toronto, Ontario, in 1973. On finding the species in Ontario, Purcell examined herbarium specimens of *Epilobium hirsutum* and found many of them to be misidentified specimens of *Epilobium parviflorum.* From this study, eight localities containing this plant in Ontario were found, the earliest being from 1969 in Midland, Ontario (Purcell 1976). Voss (1985), however, reported *Epilobium parviflorum* in Benzie County, Michigan, as early as 1966. The Michigan record is the earliest known collection of the plant in the Great Lakes drainage but how the plant was introduced remains unknown (Purcell 1976).

Apiaceae:

Conium maculatum POISON HEMLOCK

This highly poisonous plant, once valued medicinally as a powerful narcotic, was established in eastern North America by the early 1800s (Nuttall 1818, Torrey 1843). By 1843, the plant was established in many areas of New York state, probably including the Lake Ontario drainage (Torrey 1843), and by the 1890s it was established in Michigan (Voss 1985). A native of Europe, poison hemlock is common in waste places, on stream banks, and in other damp areas in the Great Lakes region (Dudley 1886, Wiegand and Eames 1925, Montgomery 1957, and Voss 1985).

Solanaceae:

Solarium dulcamara BITTERSWEET NIGHTSHADE

Early settlers imported this European plant that was becoming naturalized by the early 1800s (Nuttall 1818); in colonial times it was used as a remedy for scurvy and rheumatism (Torrey 1843). Although its early distributional history in the Great Lakes is obscure, the plant was widely distributed in New York State and probably in the Great Lakes basin by 1843 (Torrey 1843). The plant is common in lowlands and swamps (Fassett 1957) throughout the Great Lakes basin (Dudley 1886, Swink and Wilhelm 1979, Soper *et al*. 1989).

Boraginaceae:

Myosotis scorpioides TRUE FORGET-ME-NOT

An ornamental and medicinal plant escaping from cultivation, the European forget-me-not is a common and widespread member of the Great Lakes flora. Early records of the plant in North America date to the earliest flora (Nuttall 1818, Torrey 1824), but later records note that a native species was misidentified as the European one. By 1867, early records of the European species escaping from gardens were documented in the Boston area and by 1889 the plant was widely distributed (Gray 1867, 1889). In the Great Lakes drainage the plant is recorded by Dudley (1886) from Ithaca, New York. Known from wet habitats and sometimes shallow water, it is now very common from Lake Superior (Soper *et al.* 1989) to central New York (Zenkert 1934).

Lamiaceae:

Lycopus asper WESTERN WATER HOREHOUND

This plant is thought to have been introduced into the Great Lakes from the Mississippi River drainage basin. Stuckey (1969) reviewed the distributional history of *Lycopus asper* in western Lake Erie and Lake St. Clair. Using the wealth of historical botanical data for the region, Stuckey concluded that the *Lycopus aspe* populations in the region are non-indigenous. Swink and Wilhelm (1979) consider this species adventive and record it from industrialized areas, polluted habitat, and other man-made habitats. Although records of the plant in other parts of the Great Lakes region are not supported by the historical distributional data that the western Lake Erie data provide, botanists generally agree that the plant has been introduced into the Great Lakes watershed. In western Lake Erie, the earliest records of the plant are from 1892 at Port Huron . *Lycopus aspe* is thought to have been transported with grain into the Great Lakes basin in the late 19th century.

Lycopus europaeus EUROPEAN WATER HOREHOUND

The first two North American records for this plant are from Norfolk, Virginia, around 1860 and from solid ballast ground in the Delaware River in New Jersey in 1867 (Stuckey and Phillips 1970). Many of the early collections of this plant came from ballast grounds or from port areas. In New York City, the plant was a well documented solid ballast introduction (Brown 1879). in 1903 ,*Lycopus europaeu s* was found in Lake Ontario on Toronto Island. The plant has since spread into the western edge of Lake Erie, through Lake Ontario into the St. Lawrence River (Stuckey and Phillips 1970). The distributional history of the Great Lakes populations indicates that they are not the result of a spread into the watershed from Atlantic populations but represent a separate introduction from Atlantic ports or Europe (Stuckey and Phillips 1970).

Mentha spp. MINTS

Hybrids between and among the native and introduced mint species have resulted from the introduction of mints from Europe. Because of the hybridizations, the taxonomy of the genus is complex and has changed many times in the past 150 years. The determination of which mint species have been introduced into the Great Lakes watershed from Europe and the details of their introductions, therefore, must be accomplished through herbarium specimen examination and is beyond the scope of this study. Listed below are three of the more prominent species of mint that are known from marsh habitats in the Great Lakes basin.

Mentha gentilis CREEPING WHORLED MINT

Gray (1867) noted this mint from river banks in Lancaster, Pennsylvania, and later (Gray 1889) gave it a distribution from Massachusetts to Pennsylvania. Britton and Brown (1913) described its distribution from Nova Scotia to northern New York, Iowa, North Carolina, and Tennessee. Wiegand and Eames (1925) reported the plant as rare and have records from 1915 and 1917 in the Cayuga Lake basin in central New York. In 1922 and 1924, it had escaped from cultivation in the Buffalo, New York area (Zenkect 1934). This plant is thought to be a hybrid of *Mentha spicata* and *Mentha arvensis,* the only native North American mint (Fernald 1950, Gleason and Cronquist 1991). If this is so, it would account for its rare and sporadic occurrence.

Mentha piperita PEPPERMINT

Torrey (1843) reported this mint from moist ground and river shores from the Hudson River and Western New York. Gray (1867) reported that the mint became naturalized quickly because of its use of underground shoots for asexual propagation. Gray (1889) noted that the mint was "everywhere" along brooks. This mint is a sterile hybrid of *Mentha spicata* and *Mentha aquatica* and is cultivated for peppermint oil (Usher 1974).

Mentha spicata SPEARMINT

Torrey (1843) and Gray (1848) noted this species as "perfectly naturalized" in wet meadows and on stream margins. Because the plant was so widespread in 1843, introduction probably occurred long before this date. This species is known from damp or wet habitats in the Great Lakes region (Dudley 1886, Swink and Wilhelm 1979). This mint is the source of spearmint oil and has been used medicinally (Usher 1974).

Scrophulariaceae:

Veronica beccabunga EUROPEAN BROOKLIME

Veronica beccabunga was first observed in North America in 1876 in Hudson County, New Jersey, at the Bergen Tunnel (Les and Stuckey 1985). An early record from solid ballast ground at Hunter's Point, Long Island, New York in 1880, indicated that the plant was introduced in the solid ballast of ocean-going ships arriving from Eurasia. The first observation of European brooklmne in the Great Lakes watershed is from Irondequoit, New York (Monroe County), in a wet meadow in 1915. The plant is currently distributed in northeastern North America from Michigan and Ohio to the St. Lawrence River in Quebec. Several subspecies of the plant occur. Studies of these species show that the plants present in eastern North America are of the *beccabung a* subspecies which is distributed in Europe (Les and Stuckey 1985). In the past, this plant was occasionally used to treat scurvy (Usher 1974).

Asteraceae:

Cirsium palustre MARSH THISTLE

Britton and Brown (1913) treated the marsh thistle as a species introduced from Europe and cited only one population, in East Andover, New Hampshire. Fernald (1950) indicated that this plant is indigenous to Newfoundland and "partly adventive" from Nova Scotia to Northern Michigan. Gleason and Cronquist (1991) however, note that the plant is widely introduced into the United States and Canada but can seem "native" when it invades forests. The plant has been introduced into the marshes around Lake Superior (A. Reznicek, University of Michigan Herbarium, personal communication, 1990).

Pluchea odorata* var. *succulenta SALT-MARSH FLEABANE

This variety of *Pluchea odorata,* an eastern coastal marsh species, is known in the Great Lakes basin from areas of southern Ontario affected by brine from salt deposits, mines, and factories (Catling and McKay 1980), from western New York (Fernald 1950), and from the Chicago area (Swink and Wilhelm 1979). Zenkert (1934) did not note this plant in hi s*Flora of the Niagara Frontier Region ,*which included most of western New York. The plant was probably introduced into the Great Lakes drainage in western New York between 1933 and 1950.

Pluchea odorata* var. *purpurescens SALT-MARSH FLEABANE

This variety is known from an area around a salt mine in Michigan near Detroit (Frwvell 1916, Fernald 1950). Farwell's (1916) reports of *Pluchea camphorat e* from Michigan must have been *Pluchea odorata* var. *purpurescen s* because the plants are similar and Femald (1950) cited distributions for *Pluchea odorata* var. *purpurescen s*in Michigan. Farwell (1916) suggested that these plants were imported with rail way freight and survived high salt content in areas adjacent to salt mines.

Solidago sempervirens SEASIDE GOLDENROD

The first inland records for this Atlantic coastal species are from the Chicago area in 1969 (Swink 1969). The plant is common in industrialized parts of Chicago and other areas (Swink and Wilhelm 1979). In 1974, the plant was also found near Windsor, Ontario, in areas near salt mines and salt processing plants (Catling and McKay 1980). These two populations represent the only known successfully established inland sites for seaside goldenrod.

Sonchus arvensis FIELD SOW THISTLE

Torrey (1843) noted this aggressive European species from Staten Island. New York, near [he quarantine area, possibly indicating an introduction with animal bedding or forage. Between 1863 and 1865, the plant was identified from Cayuga Lake, New York, and Rochester, New York (Dudley 1886). The plant has become widespread in the Great Lakes basin (Zenkert 1934, Britton and Brown 1913, Deam 1940).

Sonchus arvensis* var. *glabrescent SMOOTH FIELD SOW THISTLE

The earliest records for smooth field sow thistle in the Great Lakes basin are from Erie County, Ohio, in 1902 and from Ithaca, New York, in 1916 (Long 1922). The taxonomy of these specimens. however, is questionable (Long 1922, Wiegand and Eames 1925). Zenkert (1934) noted that this variety of the European common field sow thistle was most likely "more recently" imported with grain from the northwest into the Buffalo, New York, region. It was not included in Britton and Brown (1913). Fernald (1950) noted it from locations throughout northeastern North America.

Butomaceae:

Butomus umbellatus FLOWERING RUSH

This European marsh species was observed in North America in La Prairie, Quebec. a town across the St. Lawrence River from Montreal, in 1897 and first collected there in 1905 (Core 1941). In 1930, collections of the plant were made in the vicinity of the town of River Rouge, south of Detroit, Michigan, along the Detroit River (Farwell 1938). The plant quickly spread and became established along a large part of the St. Lawrence River and in localities in Ontario and New York (Gaiser 1949). In many cases the spread of flowering rush after its initial introduction is due to deliberate introductions (Gaiser 1949). The over 800 km disjunct distribution from the nearest population in Quebec to the population in Michigan indicates that the Michigan population was derived either from the La Prairie population or directly from Europe (Stuckey 1968). Montreal was a port where cargo was transferred from ocean going ships to lake ships until the canal system was expanded to accommodate larger vessels. Because this practice was much more common than a direct sail through existing canals that would limit ship size, *Butomus umbellatus* was probably released by a lake ship from Montreal. The introduction into Detroit must have occurred earlier than the 1930 collections suggest because Farwell knew of observations of a large population of the plant in the River Rouge area before 1918. These populations were diminished when Ford Motor Company apparently reclaimed the marshland where these immense stands of flowering rush had occurred (Farwell 1938). The introduction of *Butomus umbellarus* with shipping activities into Montreal and Detroit is likely, although it is known to have been used as a local food source in Russia (Usher 1974). Other theories concerning the introduction of flowering rush into North America date it much earlier. Farwell (1938) suggested that the introduction could have occurred as early as the mid 1600s. Stuckey (1968) however, noted that the rate that the populations have spread after their initial discovery was more characteristic of a recently invading species.

Balsaminaceae

Impatiens glandulifera INDIAN BALSAM

Voss (1985) reported three Michigan records for this Himalayan ornamental plant: from Port Huron in 1912, Sugar Island in 1956, and on Lake Superior at Grand Marais in 1984. Indian balsam is also known from aquatic habitats in southwestern Thunder Bay and Thunder Cape on Lake Superior (Soper *et al.* 1989). Fernald (1950) reported the plant from several northeastern Canadian provinces, including Ontario, and New England. This species is also known to be highly invasive in disturbed or polluted sites in the British Isles (Usher 1986).

Juncaceae:

Juncus compresses FLATTENED RUSH

Stuckey (1981) reviewed the introduction of the Eurasian flattened rush into North America. Although Bartlett (1906) first reported its presence in North America from 1904 collections, *Juncus cumpressus* was misidentified as *Juncus gerardii* prior to 1904 (Stuckey 1980). According to Stuckey, Marie-Victorin (1929) believed that *Juncus compresses* was brought to North America in forage used to feed military horses. A species favoring brackish, calcareous marshes (Gleason and Cronquist 1991), its introduction into locations in the interior often can be associated with commerce and disturbed man-made areas. For example, prior to 1895, the rush was observed near Cayuga Lake at a glass factory and around a railroad station within the Cayuga Lake drainage basin (Wiegand and Eames 1925). Wiegand and Eames (1925) believed the plant had been brought to the lake with the sand used in manufacturing the glass. Flattened rush is also known from the Toronto, Ontario, area (Stuckey 1980).

Juncus gerardii BLACK-GRASS RUSH

Black-grass tush, a dominant salt marsh species, is found on the Atlantic and Pacific coasts and has invaded inland habitats (Muenscher 1944, Stuckey 1980, Zenkert 1934). The earliest known Great Lakes records of the plant are from saline marshes in Salina, New York, in 1864 and near Chicago in 1862 (Stuckey 1980). Because its occurrence inland is associated with man-made, often saline habitats, it is probable that the introduction of the plant was aided by commerce. The occurrence of the rush on ballast grounds and its use as packaging material support this argument. The plant is known from Lakes Ontario, Erie, Huron. and Michigan (Stuckey 1980).

Juncus inflexus RUSH

Juncus inflexus was first found in North America near Sangerfleld and Waterville, New York in 1917 in the Mohawk-Hudson River drainage basin. The plant was well established in the "boggy" and "springy" habitat at this locality and probably had been introduced many years before its discovery (Clarke and House 1921). Clarke and House (1921) noted that the site had never been cultivated but had earlier been used for pasturage. In 1922, the plant was discovered in the Great Lakes basin in Ithaca, New York (Wiegand and Eames 1925). Farwell (1941, 1945) reported a population of this European species in 1936 near Hancock, Michigan, and Voss (1972) noted that this population persisted in 1958. The means through which this plant was introduced remains unknown.

Cyperaceae:

Carex acutiformis SWAMP SEDGE

Carex acutiformis, a Eurasian and African sedge, was first discovered in North America in 1865 in eastern Massachusetts (Hermann 1952). In 1951, the plant was found on the shores of St. Joseph Lake, Notre Dame, Indiana (Hermann 1952). By 1976, the population in Indiana had increased in abundance (Swink and Wilhelm 1979). The means through which it was introduced remain unknown.

Carex disticha SEDGE

The first North American records for *C. disticha,* a Eurasian sedge known from swamps, wet meadows and prairies, and fens, are from Belleville, Ontario.

in 1866 (Fernald 1942, Catling *et al.* 1988). Although it was originally thought to be native at this site. Catling *et al.* (1988) noted that the population is probably non-indigenous. Since this early record, the plant has been recorded from several locations, including Iles de Boucherville near Montreal, Quebec, in 1927, 1929, and 1940 and at Collingwood in Simcoe County, Ontario, in 1972 (Catling *et al.* 1988, Fernald 1942). The plant is a dominant forage crop in parts of the former USSR (Catling *et al.* 1988). Its use for hay and straw indicates possible introduction with animal forage and bedding or in packaging materials (Usher 1974). Fernald (1942) suggests that the populations near Montreal and Iles de Boucherville were introduced in "straw and litter thrown out" at the port of Montreal.

Caru flacca SEDGE

Fernald (1950) noted ***Carex flacca*** from “dry fields and roadsides” from Nova Scotia Quebec, Ontario, and Michigan. Voss (1972) reported early collections of this European plant by Farwell in the Detroit River on Belle Isle in 1896 and 1903. Currently, the plant is known horn Lake Huron’s calcareous meadows (A. Reznicek, University of Michigan, personal communication, 1990). Since Fernald’s (1950) habitat description was so general, we will consider the plant a Great Lakes marsh species based on Voss (1972) and Reznicek’s observations.

Poaceae:

Agrostis gigantea REDTOP

This introduced European species is common in moist habitats in the United States and southern Canada (Gleason and Cronquist 1991). In Ontario, two genetic variants of *Agrostis gigantea* have been introduced. Cultivated for hay and pasturage, one of the variants has escaped into waste areas and moist habitats in Ontario (Dore and McNeill 1980). The first collection of this species in Ontario was from 1884 at Nipigon House (Dore and McNeill 1980) and it was known from Michigan in 1892 (Voss 1972). Redtop can occur in dry areas, however it is known to be common along stream banks in moist soil in Wisconsin (Shinners 1943) and very invasive in moist meadows in the Chicago region (Swink and Wilhelm 1979).

Alopecurus geniculatus WATER FOXTAIL

Early North American records of water foxtail, a marsh species native to Eurasia, are reported by Torrey (1843) from wet meadows. Early records in the Great Lakes basin are from 1882, at Amherstburg, Ontario, on Lake Erie (Dore and McNeill 1980) and from the Cayuga Lake basin in central New York (Dudley 1886). In 1970, the plant was collected in the Chicago area (Swink and Wilhelm 1979). Voss (1972) noted observations of water foxtail in Michigan that were not backed up with herbarium specimens. At one locality in Ottawa. Ontario, the species was introduced in a lawn grass mixture (Dore and McNeill 1980).

Echinochloa crusgalli BARNYARD GRASS

Barnyard grass, a weedy Eurasian native, is noted in some of the earliest American flora (Michaux 1803, Nuttall 1818, Torrey 1824). Because it arrived before the flora of the Great Lakes was well studied, records of its introduction do not exist. although it is thought to have arrived in colonial times. The plant is commonly found around barnyards (Fassett 1957) and has been cultivated for fodder and grain (Dore and McNeill 1980). The plant is now considered “nearly cosmopolitan” (Fernald 1950) and is known throughout the Great Lakes basin (Dudley 1886, Voss 1972, Swink and Wilhelm 1979, Dore and McNeill 1980, Soper *et al.* 1989). Although *Echinochloa crusgalli* has a close North American relative, *Echinochloa muricata,* the species are distinct and early identifications were likely correct (Fassett 1949).

Glyceria maxima REED SWEET-GRASS

The first records of this Eurasian species in North America were from a Lake Ontario marsh between Hamilton and Dundas, Ontario, in 1940 (Dore 1947). By 1952, *Glyceria maxima* was discovered from four additional sites in Ontario (Dore 1947, Gutteridge 1954). These firmly established populations had probably been present for years before they were first observed (Dore 1947). The grass, a favorable and economical forage species for marshy land, could have been released as early as the 1780s (Dore and McNeill 1980) through cultivation or as discarded packaging material for crockery imported by settlers (Dore 1953). The oldest stands of the plant seem to be concentrated in areas of “Old Ontario” and other early settlements (Dore 1953), and other sites of introduction may have been derived from the original stand (Dore and McNeill 1980).

Pou trivialis ROUGH-STALKED MEADOW GRASS

Naturalized from Europe by the early 1800s (Nuttall 1818), *Pou trivialis* is a grass species commonly used for hay or pasturage (Torrey 1843). Dudley (1886) reported the plant from marshes, fields, and deep swamps in the Cayuga Lake basin in central New York and considered it indigenous. Although the details of this plant's introduction into North America are unknown, it could have been introduced early as a forage species for livestock or imported with the livestock as feed or bedding. The grass is known throughout the Great Lakes basin in moist fields, moist woods, and marshes (Wiegand and Eames 1925, Zenkert 1934, Montgomery 1956, Voss 1972). More recently, it may have been transported and introduced with lawn seed (Swink and Wilhelm 1979, Dore and McNeil 1980).

Puccinellia distans WEEPING ALKALI GRASS

Gray (1867) first reported Eurasian and North African weeping alkali grass in North America from coastal salt marshes and later Gray (1889) noted that it was also found on ship ballast dumping grounds. The species was not reported in the Great Lakes basin until it was discovered in brackish meadows in Montezuma New York, in 1893 and in Syracuse, New York, in 1915 (Fernald and Weatherby 1916, Wiegand and Eames 1925). In Syracuse, weeping alkali grass was found "on refuse from chemical works, flats along Onondaga Lake," indicating possible accidental introduction in materials imported to the industrial site (Fernald and Weatherby 1916). In Ontario the plant was found in railroad yards, at Rainy River in the Lake Superior drainage (Montgomery 1956), and in southern Ontario in alkaline and calcareous areas (Catling and McKay 1980). More recent records from the Great Lakes indicate that the plant is common on saline highway margins and other salty ground (Voss 1972, Swink and Wilhelm 1979).

Sparganiaceae:

Sparganium glomeratum BUR REED

The first occurrence of the European bur reed, known from shallow water and bogs, in North America is from Lake Itasca, Minnesota, in the earl y 1890s (Lakela 1941, Gleason and Cronquist 199 1). This introduction was not successful, however, and the plant was not collected again in North America until 1927 when an apparently established population was discovered in Saguenay County, Quebec, in the Natashaquan River region (Lewis 1931). In the late 1930s, a population of bur reed was found in Duluth, Minnesota, in a bog near Superior Bay (Lakela 1941). Other North American populations of *Sparganium glomerutum* exist in Dawson, Yukon (Porsild 1942, 1951) and from Labrador, British Columbia, and Alberta (Boivin 1967). Gleason and Cronquist (1991) consider this species "interrupted" circumboreal, and Fassett (1957) noted its European distribution and the Duluth record. Although this plant has been considered native in these botanical works, this patchy distribution is indicative of a non-indigenous species. The mechanism through which it was released remains unknown.

Typhaceae:

Typha angustifolia NARROW LEAVED CATTAIL

The narrow leaved cattail has been considered native to the Atlantic Coast of North America since it was first discovered in North American shores and marshes. The distributional history of the plant, however, is indicative of an introduced species (Stuckey 1987). This Eurasian plant has developed from a rare part of the flora of the Atlantic Coast in the 1820s to an abundant plant that currently reaches inland to the Great Plains. Stuckey (1987) theorizes that the plant was brought to North America by the early colonists, established on the east coast, and then spread inland first through canals, then railroads and finally highways. The plant's increase in abundance in inland areas and spread into new regions are well documented (Gray 1889, Voss 1972, Gleason and Cronquist 1991). In the Lake Ontario drainage basin in central New York, narrow leaved cattail was established by the 1880s (Dudley 1886). It is also known from Europe, Asia, South America, and California and could almost be considered cosmopolitan (Britton and Brown 1913, Wiegand and Eames 1925). Much of this distribution, however, probably represents non-indigenous populations. Although this plant entered the Great Lakes drainage basin primarily through canals, use of plant parts for food pillow stuffing, and matting have also likely influenced its dispersal (Usher 1974).

Iridaceae:

Iris pseudacorus YELLOW FLAG

The yellow flag often escaped from cultivation to form established stands in marshes, shores, and other wet areas (Cody 1961, Dudley 1886, Judd 1953, Voss 1972, Soper *et al.* 1989). The plant has medicinal uses ranging from relief of gastrointestinal problems to toothaches and can be used in tanning leather and as a dye (Usher 1974). These practical uses, along with its showy flower, made it a popular garden flower until other varieties gained favor. Dudley (1886) first reported the plant from a swamp near Ithaca, New York. This record, along with a report of a Massachusetts population, were the first recorded escapes of yellow flag from cultivation (Gray 1889). Cody (1961) reviews the Canadian records of *Iris pseudacorus,* which was first observed in Ontario in 1940.

Shoreline Trees and Shrubs

Betulaceae:

Alnus glutinosa BLACK ALDER

This Eurasian species has been widely introduced as an ornamental tree and commonly escapes to swampy river banks, lake shores, and stream beds (Fassett 1957, Voss 1985). The tree's wood is favored for carving, the bark is used for tanning leather, and the bark and leaves are used medicinally (Usher 1974). The tree clones by spreading through its roots (Wiegand and Eames 1925). The earliest known records of this species escaping from cultivation are from the late 19th century, when it was reported from "Newfoundland to New Jersey and Illinois" (Britton and Brown 1913). It was not noted in Gray (1889). The black alder is now known throughout the Great Lakes basin (Wiegand and Eames 1925, Swink and Wilhelm 1979, Voss 1985).

Salicaceae:

Salix alba WHITE WILLOW

Salix alba is an ornamental tree that was known to escape from cultivation along stream banks and lake shores by the early to mid 1800s and has been widely introduced in North America (Nuttall 1818, Gray 1848, Dudley 1886, Zenkert 1934, Voss 1985). The tree was imported for ornamental purposes and its wood, bark, and leaves had medicinal and practical uses (Usher 1974). White willow is known in the Great Lakes from Lake Superior (Soper *et al* 1989), the Chicago region (Swink and Wilhelm 1979), Michigan (Voss 1985), and central New York (Dudley 1886, Wiegand and Eames 1925). White willow and the other willow species listed below regularly hybridize with each other and with other willow species forming several varieties (Fernald 1950, Voss 1985).

Salix fragilis CRACK WILLOW

Salix fragilis is an ornamental tree that also escaped from cultivation by the early to mid 1800s. The branches of *Salix fragilis* often break and root in favorable habitat (Deam 1940). Crack willow is known from throughout the Great Lakes drainage basin (Dudley 1886, Wiegand and Eames 1925, Swink and Wilhelm 1979, Voss 1985).

Salix purpurea PURPLE WILLOW

Known to escape from cultivation along stream banks and lake shores by the early to mid 1800s (Nuttall 1818, Gray 1848, Dudley 1886, Zenkert 1934, Voss 1985), purple willow has been widely introduced into North America (Fernald 1950). *Salix purpurea* was used for basket weaving (Fernald 1950) and is used commercially in the pharmaceutical industry (Usher 1974). Purple willow is known from throughout the Great Lakes drainage basin (Dudley 1886, Wiegand and Eames 1925, Swink and Wilhelm 1979, Voss 1985).

Rhamnaceae:

Rhamnus frangula GLOSSY BUCKTHORN

The first records of this Eurasian plant in the Great Lakes region are from Ontario prior to 1913 (Britton and Brown 1913). It was collected in Michigan's Delta County in 1934 (Voss 1985) and is known from the Chicago area (Swink and Wilhelm 1979). The glossy buckthorn is an aggressive species that is often considered a pest in many habitats (Swink and Wilhelm 1979, Voss 1985). This deciduous plant was introduced as an ornamental shrub (Bailey 1949). The wood of this shrub has many uses and the bark has medicinal purposes (Usher 1974).

Characterization of Entry Mechanisms, Temporal Patterns, and Origins

Since the early 1800s, at least 139 new organisms have been introduced into the Great Lakes (Fig. I). The majority of these species are-aquatic plants (42%), fishes (18%), and algae (17%). The mollusks, oligochaetes, crustaceans, flatworms, bryozoans, cnidarians, and disease pathogens combined represent 22% of the non-indigenous species in the Great Lakes.

Exotic organisms have entered the Great Lakes basin through a variety of vectors (Fig. 2). These include unintentional releases, introductions related to ships, deliberate releases, entry through or along canals, and movement along railroads and highways. We attempted to determine the most probable entry vector for each species, but in some cases vectors were either unknown (10%) or we were not able to distinguish among several mechanisms (i.e., multiple mechanism category) (19%). Within the multiple mechanism category, uninten-

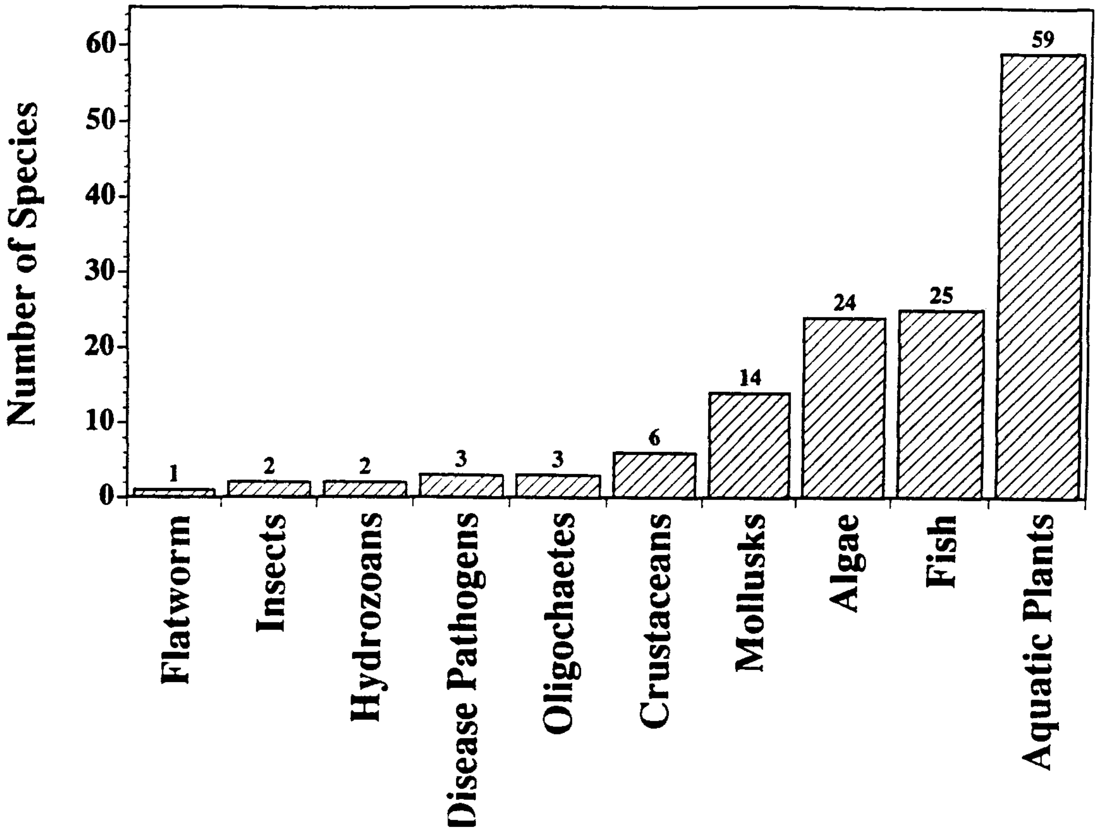

FIG. 1. Introduced aquatic species (N= 139) in the Great Lakes sorted by taxonomic group. Number of species is indicated above each bar.

tional releases (55%), releases associated with ships (25%), canal migration (9%), deliberate releases (9%), and disturbances associated with railroads or highways (2%) have served as entry mechanisms.

Shipping activities alone brought 29% of the exotic species to the Great Lakes (Fig. 2) and contributed to an additional 25% of the multiple releases. Within the ship introduction mechanism, 63% of the introductions have been linked to ballast water, 31% have arrived in solid ballast, and 6% were brought into the Great Lakes on the hulls of ships. The high percentages of algae that have been introduced through shipping activities (Fig. 2) are reflective of the large number of diatoms that were introduced to the Great Lakes through ballast water release in the 20th century.

The second-most common mechanism, unintentional release, has played a substantial role in the transfer of non-native species into the Great Lakes **(Fig. 2).** As with the shipping introduction mechanism, however, unintentional releases play a part in 55% of the species introduced through several different mechanisms. Within this category, 30% of the introductions are plants that have escaped from cultivation. Accidental releases (33%), introductions associated with fish stocking or bait (19%), and aquarium releases (17%) have also made substantial contributions in this category.

Fewer than 10% of the organisms entering the Great Lakes have been associated with canals, railroads or highways, and deliberate releases. Although the most common entry vectors used by Great Lakes introduced species were associated with either unintentional releases or ships, other categories played a major part in Great Lakes introductions. The sea lamprey, alewife, and white perch, for example, entered the Great Lakes through canals and have had substantial impacts on Great Lakes resources.

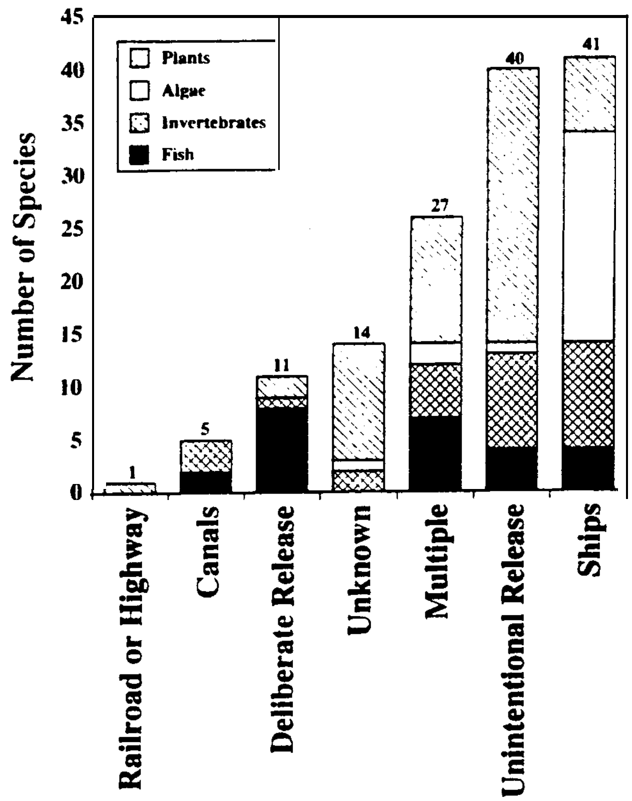

FIG. 2. Entry mechanisms of exotic species (N= 139) in the Great Lakes sorted by taxonomic group. Number of species indicated above each bar.

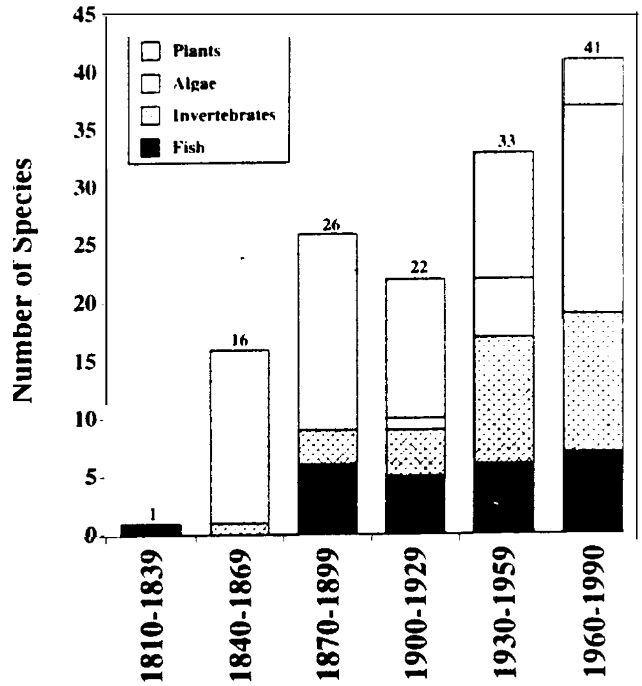

FIG. 3. A timeline of introductions (N = 139) in the Great Lakes sorted by taxonomic group. The total number of species is indicated above each bar.

Since the 1800s, as human activity and the intensity of introduction mechanisms into the Great Lakes basin has increased, the rate of introduction of exotic species has also increased (Fig. 3). Almost one-third of the non-indigenous species in the Great Lakes have been discovered in the past 30 years. When introductions are classified by entry mechanism over time (Fig. 4), the role of ship-related activities in the recent transport of organisms becomes more evident. Since 1959, most Great Lakes exotic species entries have been related to shipping activities and this surge in ship-related introductions has coincided with the opening of the St. Lawrence Seaway. Historically, ships have also played an important role in the transfer of aquatic organisms. particularly in the late 1800s with the release of aquatic plants in solid ballast materials. In addition, for all Great Lakes exotic species: 1) deliberate releases have declined, 2) canal migrations have remained consistently low, 3) railroad and highway migrations have been sporadic, and 4) unintentional releases have been consistently high (Fig. 4).

Although most exotic species in the Great Lakes are native to Eurasia (55%) and the Atlantic Coast (13%) (Fig. 5), the source of Great Lakes populations may not be from their original native range. Purple loosestrife, Eurasian watermilfoil, and Asiatic clam are only a few examples of organisms that invaded the Great Lakes from locations outside their native range. The large number of organisms native to Eurasia and introduced to the Great Lakes is most likely associated with (1) the settlement of the Great Lakes basin by Europeans who transported goods primarily from Europe and (2) the similarity of the climate of the Great Lakes region and Europe. While most exotic species in the Great Lakes are Eurasian in origin, species such as sea lamprey, alewife, white perch, and the Pacific salmon have been introduced from the North American Atlantic and Pacific coasts and have substantial ecological and economic impacts.

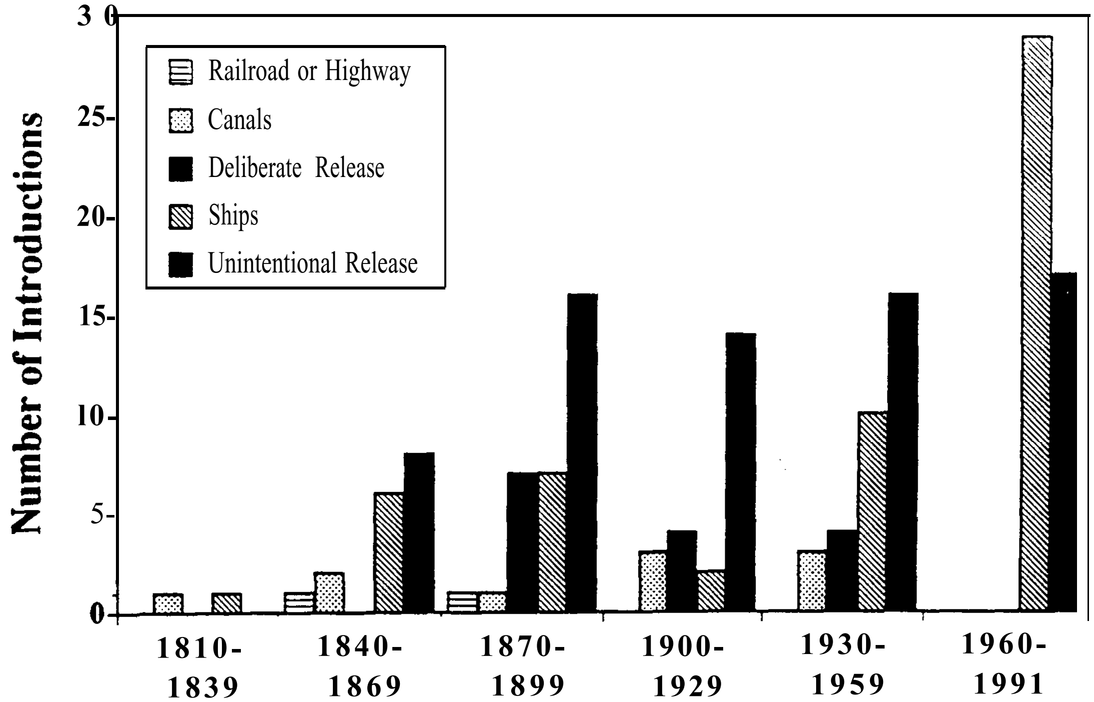

FIG. 4. A timeline of entry mechanisms for aquatic species introduced to the Great Lakes. Data includes sum of mechanisms from ***Figure 2*** *and the multiple mechanism category and dates from Figure* ***3.***

Environmental Modifications Influencing Invasion

Exploitation and environmental modifications of the Great Lakes due to human activities have been occurring since at least the mid 1800s and many of these changes have resulted in the establishment of introduced species (Ashworth 1986). In the mid 1800s, the increases in sedimentation and release of sawdust and other debris caused by the deforestation of the Great Lakes basin caused major disturbances in the diatom community and the sediments of the Great Lakes (Stoermer *et al.* 1985, Ashworth 1986). Deforestation and farming practices in the midwest caused streams to increase in turbidity and enabled several fish species (e.g., *Phenacobius mirabilis* and *Lepomis humilis)* that favor turbid habitats to gain access to the Great Lakes basin (Trautman 1981). In addition, power plants and industries have created pockets of habitat in which species otherwise unable to survive the winter temperatures of the Great Lakes (e.g., *Corbicula fluminea)* have become established.

Heavily industrialized areas, urban areas, and areas around salt mines and processing plants have created polluted, saline marshlands in the Great Lakes region (Muenscher 1927, Catling and McKay 1980). This alteration of natural habitat has enabled coastal species to become established (through various transport mechanisms) into areas where they previously would not have succeeded (Farwell 1916). When road salt became widely used as a deicing agent on highways, the roads became a favorable habitat for Atlantic coastal marsh species to migrate inland. The input of road salt and industrial waste into the Great Lakes has also changed the salinity of the lower Great Lakes to three times their concentration in the 1850s (Sheath 1987). Sheath (1987) asserts that these changes in concentrations have facilitated the introduction of marine algae and their adaptation to freshwater environments.

DISCUSSION

One of the most pervasive and perhaps the least appreciated anthropogenic effects on the world's aquatic ecosystems is the global transfer of exotic organisms. Such transfers of exotic species to new