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The Meristics and Parasites of Lake Superior Lake Herring

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ABSTRACT

A meristic study of lake herring (Coregonus artedii) from the Apostle Islands, Wisconsin; Thunder Bay, Ontario; Grand Portage, Minnesota; Keweenaw Bay, Michigan; and St. Mary's River, Michigan, was completed during 1972-75. Herring from Lake Superior proper could not be distinguished from each other. The St. Mary's River population (between Lake Superior and Lake Huron) could be distinguished from those herring from Lake Superior. DDT levels in herring could be of use in separating various groups.Excessive parasitism by the larva of the tapeworm Diphyllobothrium sp. may be a contributing factor in the continued decline of the Lake Superior lake herring. Attempts at treatment through sea gulls (Larus spp.), the adult host are feasible and inexpensive.

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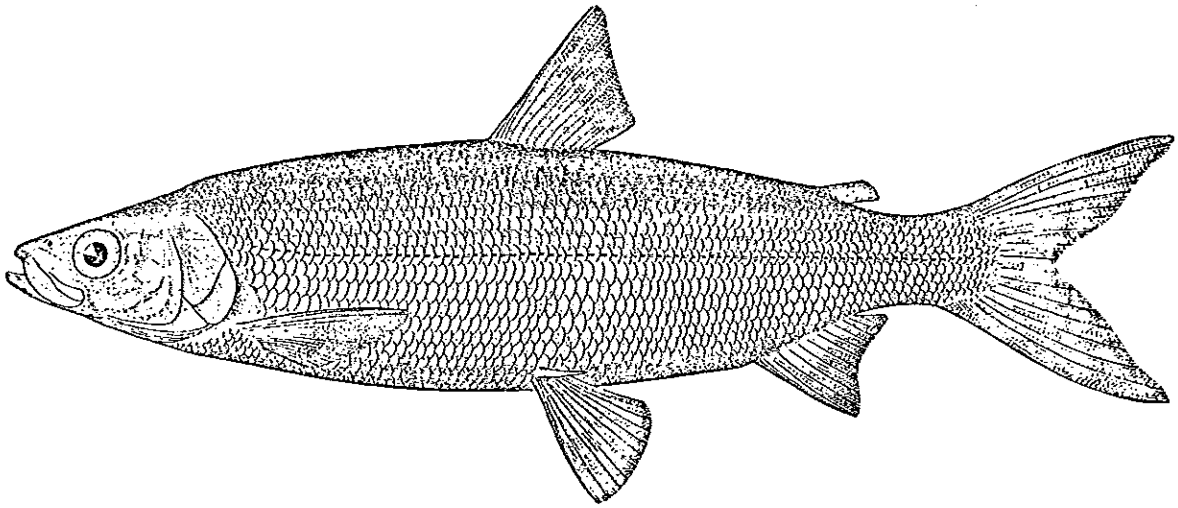
INTRODUCTION

Lake Superior contains the last extensive lake herring (Coregonus artedii) population in the Great Lakes. Nevertheless, most of the American and western Canadian stocks in the lake have declined in abundance, some to the point of commercial extinction. Lake-wide production has declined from a 1941-1960 annual mean of 13.5 million pounds, to 3.8 million pounds in 1971. Production in Wisconsin waters has declined from an annual catch of 4-6 million pounds (1941-54) to 110,000 pounds in 1975, an all time low. The bulk of the commercial herring harvest occurs in November and December when the fish are in spawning concentrations.



Lake herring, Coregonus artedii.

A variety of theories have been expressed in explaining the deterioration of the lake herring community in the upper Great Lakes, Superior and Huron in particular. The most common philosophies are commercial exploitation, smelt predation, and environmental degradation. Whatever the cause(s) of the herring decline, it was generally uniform along the south shore of Lake Superior. The lake herring decline appeared to begin, or was occurring, in the early 1950's in Wisconsin and Michigan waters of Lake Superior, and the late fifties in Minnesota waters. Various herring populations in western Canadian waters have shown decline since the late 1960's and early 1970's. If there is any pattern of herring decline in the western half of Lake Superior, it is that it appears to be occurring in a clockwise fashion from Marquette, Michigan, to Black Bay, Ontario. The most obvious change besides abundance decline in the remaining herring populations is the increase in their mean size.

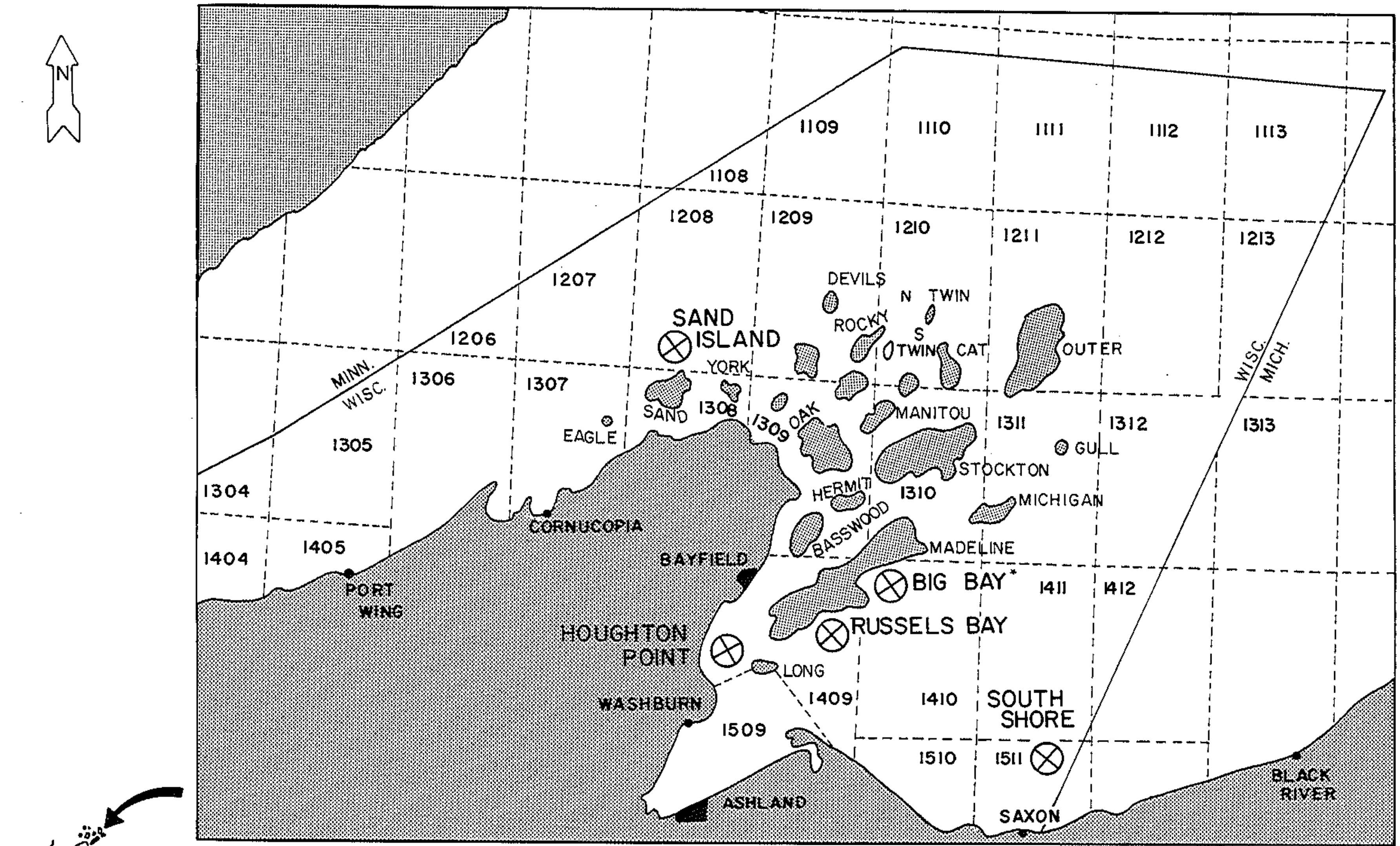
At the request of local fishermen and the Great Lakes Fishery Commission, governmental agencies surrounding Lake Superior gathered available data in an attempt to determine the cause(s) for the herring decline. Inefficiencies were apparent in the data, particularly because of the size of the statistical commercial catch districts. Lawrie and Rahrer (1972) indicated "the analysis of catch statistics using districts that are enormous by comparison with the 'home range' of the stocks, will necessarily provide a picture of sustained yields and stable stocks until the depletion is far advanced." In recognition of the need to identify individual herring stocks for management and research purposes, this study was initiated in 1972 to determine the feasibility of separating herring stocks using meristics. Because herring stocks, as with all living organisms, have been exposed to man-made chemicals, the feasibility of using localized chemical levels in herring as a potential stock separator was also explored in 1974. Parasites found in the lake herring samples were examined, and their use as stock separators and possible role in the herring decline are treated in Part II of this report.

PART I: MERISTICS

METHODS

Lake herring meristic comparisons were made on four geographically close but suspected separate spawning populations in the Apostle Islands region. Wisconsin Department of Natural Resources Fish Management personnel aboard the Hack Noyes annually collect data during the lake herring spawning period (approximately November 27 - December 9) using standard gear. The spawning assessment locations are shown in Figure 1. A total of 2,700 feet of nylon gill nets made up of a 900-foot section of 2½-inch mesh, and 600-foot sections of 1½-inch, 2-inch and 3-inch meshes are fished for a 24-hour period at each site. The present study is based on such sampling carried out in 1972-1975. In addition, lake herring samples were collected lake-wide in 1975-1976 from five spawning stocks using a variety of gear. Collection sites include the Grand Portage area of Minnesota; Thunder Bay, Ontario; Keweenaw Bay, Michigan; and the St. Mary's River (Potagannissing Bay), Michigan (Figure 2).

All measurements are in English units with metric conversions listed at the end of this report. Sample sizes range from 25 herring for Thunder Bay, to 238 for the Apostle Islands. Samples were randomly selected from assessment gear for Wisconsin samples and from commercial gear for Michigan and Minnesota samples. An illuminated overhead magnifying lens was used in counting procedures assisted by sundry disecting tools. Guidelines for meristic categories were patterned after Lowe-McConnell (1968).



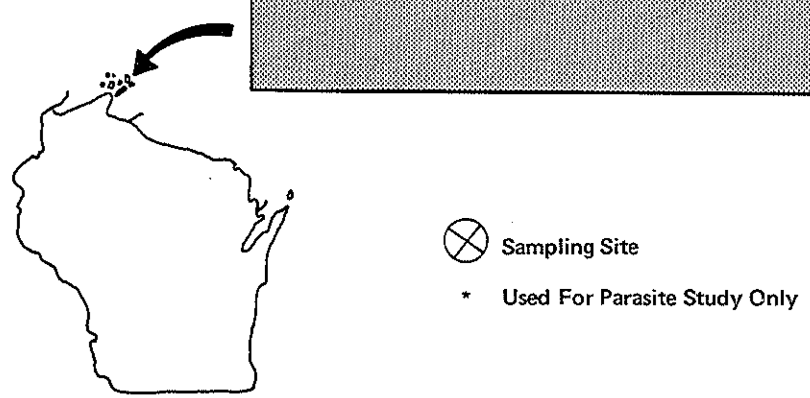


Figure 1. Apostle Islands lake herring spawning assessment locations and areas where samples were collected for meristic study and analyses of DDT, mercury, and PCB's. Dashed lines and associated numbers indicate standard assessment grids.

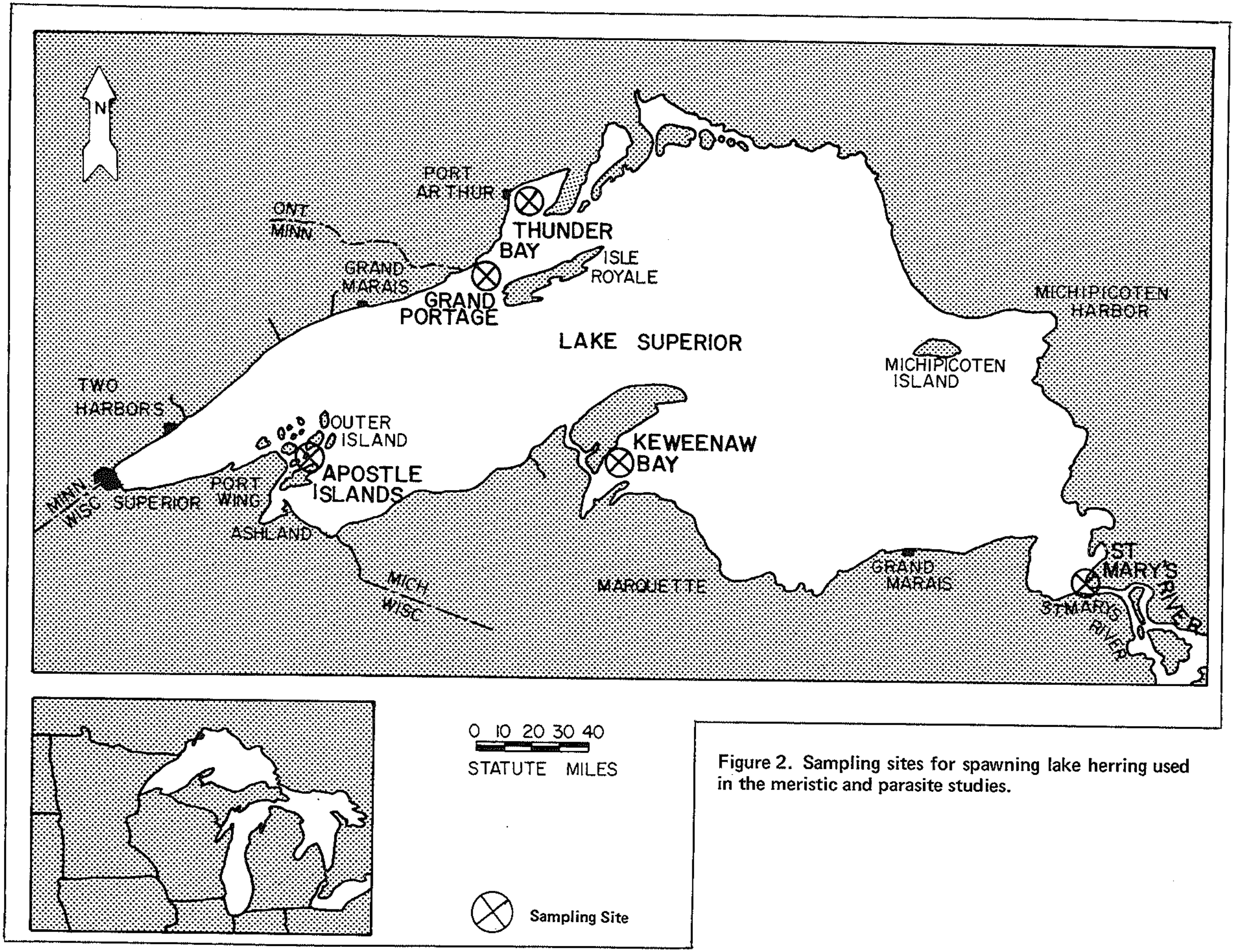


Figure 2. Sampling sites for spawning lake herring used in the meristic and parasite studies.

Meristic Examination

Ray Counts: All rays were counted including segmented anterior ray and soft nonsegmented rays that were separate at the base. Lateral Line: All lateral line scales were counted to the end of spinal column. End of column determined by bending caudal fin anteriorly. Gill Raker Count: Gill raker extracted by cutting first gill arch at posterior dorsal position on each side of vomer, extracting first gill arch (both sides together) by cutting posteriorly to first arch across second arch and then splitting carefully through vomer. Pyloric Caeca: All fat was scraped away from area. Count was made by pulling individual caeca away from intestinal tract. Fat Accumulation: Amount of fat was assessed qualitatively. Medium: very little fat accumulation; described as medium because this was the average amount of fat accumulated by herring in Wisconsin waters at initiation of the study. Heavy: surrounding the pyloric caeca, but external caeca tips visible. Very Heavy: completely covering the pyloric caeca.

Tissue Analysis

Samples for DDT, PCB, and mercury analysis were collected in the same fashion as were the meristic samples for Wisconsin waters, with sampling sites shown in Figure 1. All samples were collected in 1974. The technique for preparation and analysis of fish samples is described in Degurse and Ruhland (1972). Samples were selected at random from the gill net catch and submitted for analysis by the Department of Natural Resources, Bureau of Water Quality. Fish were submitted individually and later grouped in pools of 10 for analysis. The size composition of fish in each pool is not known, although all were spawners.

RESULTS

Apostle Islands Herring Meristics

The four sampled spawning populations from Wisconsin waters of Lake Superior were not separable as groups using t-tests of significance on meristics listed in Table 1. Sample means for each meristic character and location were used in computing the t-tests.

Lake-Wide Herring Meristics[1]

Results indicate that the St. Mary's lake herring population is separable on the basis of meristics from the other four populations (Table 2). T-tests calculated on sample means indicate that St. Mary's River herring were significantly different (5% level of significance) from Keweenaw Bay, Apostle Island, Thunder Bay and Grand Portage herring in dorsal ray, pectoral ray, lateral line, gill raker, and pyloric caeca counts. No other significant meristic differences between groups were found. St. Mary's River herring were statistically separable as a group but they were not separable as individuals due to overlapping ranges of counts for herring from the three other areas. Fat accumulation varied in all four lake-wide samples. Thunder Bay fish had the lowest fat concentrations, followed by the Apostle Islands and Keweenaw Bay fish. Largest fat concentrations were in Grand Portage and St. Mary's River herring. Sex ratios are not representative of the spawning populations.

Pesticide Residues As Stock Separators

Table 3 lists the DDT, Aroclor (PCB 1254), and mercury levels of spawning herring from the Apostle Islands spawning areas. DDT appears to be the chemical, of the three tested, with promise for separating groups of herring. Russell's Bay and Big Bay samples are likely the same spawning population due to the extremely close sample sites and traditional movement of these spawning herring.

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[1]An interesting phenomenon occurred while examining the results of the right vs. left branchiostegal ray counts. The sample mean of the right ray count was consistently lower than that of the mean left ray count. This occurred in every sample, annually, in each of the four Wisconsin sample sites, the 1972-75 grouping (Table 1) of the four Wisconsin sample sites, and in the five lake-wide samples.

CONCLUSIONS

By the meristic comparisons, we were not able to effectively separate lake herring stocks for management practices. We were capable of differentiating one possibly ecologically remote population (St. Mary's River), although these herring were not from the main lake basin. Pesticide analysis shows promise as a possible tool in detecting or separating herring spawning stocks although sample size was small. Herring coming from such close sample sites are likely not genetically separable due to a degree of mixing of the spawning stocks. It is a general rule of thumb that racial differences can scarcely be distinguished until you have less than about 5% spawning overlap between populations. The separation of stocks, however, through pesticide analysis may be practical for the monitoring of responses of particular herring groups to management actions.

Table 1. Mean count for meristic characters of lake herring from four locations in the Apostle Islands of Lake Superior, 1972-75. Ranges of counts are listed in parentheses.

Meristic Character	Sampling Locations			
	Sand Island	Russell's Bay	Houghton Pt.	South Shore
Anal Ray	13.4 (10-15)	13.2 (11-15)	13.5 (12-15)	13.4 (12-15)
Dorsal Ray	12.0 (10-13)	12.0 (10-14)	12.0 (11-14)	12.1 (11-13)
Pectoral Ray	16.3 (15-18)	16.5 (15-18)	16.4 (14-18)	16.6 (14-20)
Pelvic Ray	11.5 (11-12)	11.4 (11-12)	11.4 (10-13)	11.5 (10-12)
Lateral Line	83.6 (71-94)	83.1 (68-93)	81.4 (69-97)	84.6 (71-99)
Gill Rakers	44.6 (40-48)	46.6 (42-51)	46.2 (38-51)	45.8 (42-51)
Branchiostegal Rays				
Right	8.3 (7-10)	8.5 (7-10)	8.3 (7-10)	8.5 (7-10)
Left	8.6 (8-10)	8.7 (7-10)	8.5 (8-10)	8.7 (7-10)
Pyloric Caeca	144.0 (97-190)	151.6 (100-185)	148.5 (104-198)	155.6 (117-202)
Fat Accumulation*	Not Checked	26 Medium 3 Heavy	26 Medium 3 Heavy 1 Very Heavy	28 Medium 1 Heavy
Average Total Length (In.)	13.6	14.4	14.9	14.2
Sex Ratio - % Females	85.0%	76.7%	83.3%	96.7%
Sample Size	62	62	59	55

* Determined only on 1975 samples.

Table 2. Mean count for meristic characters of lake herring from five locations in Lake Superior, 1975-76. Ranges of counts are listed in parentheses.

Meristic Character	Sampling Location: Grand Portage	Apostle Island	Keweenaw Bay	St. Mary's River	Thunder Bay
Anal Ray	14.0 (13-15)	13.4 (10-15)	13.7 (13-15)	13.6 (12-15)	13.8 (13-15)
Dorsal Ray	12.0 (11-13)	12.0 (10-14)	12.2 (10-14)	12.6 (12-14)	11.8 (10-13)
Pectoral Ray	16.4 (15-18)	16.5 (14-20)	16.3 (15-18)	15.4 (14-17)	16.3 (14-18)
Pelvic Ray	11.4 (11-12)	11.5 (10-13)	11.4 (11-13)	11.3 (7-13)	11.4 (10-12)
Lateral Line	78.7 (69-89)	83.2 (68-99)	79.3 (70-89)	73.7 (67-83)	80.2 (73-86)
Gill Rakers	45.9 (43-49)	45.9 (38-51)	45.7 (41-51)	49.2 (44-55)	44.7 (41-48)
Branchiostegal Rays Right	8.4 (7-10)	8.4 (7-10)	8.3 (7-9)	8.3 (7-10)	8.4 (8-10)
Left	8.9 (8-10)	8.6 (7-10)	8.6 (7-9)	8.4 (7-10)	8.6 (7-10)
Pyloric Caeca	149.6 (120-209)	150.9 (97-202)	149.0 (106-210)	119.5 (82-171)	157.6 (126-201)
Fat Accumulation	5 Medium 25 Heavy 2 Very Heavy	26 Medium 3 Heavy	26 Medium 3 Heavy 1 Very Heavy	28 Medium 1 Heavy	25 Medium
Average Total Length (In.)	13.6 (12.1-15.8)	14.4 (12.5-17.2)	14.9 (12.1-16.1)	14.2 (9.6-15.0)	14.5 (13.2-15.9)
Sex Ratio - % Females	85.0%	76.7%	83.3%	96.7%	92.0%
Sample Size	32	238	50	50	25

Table 3. Results of residue analyses on Lake Superior lake herring, 1974.

Location	Sample*	Total DDT (ppm)	Mercury (ppm)	Aroclor PCB 1254 (ppm)
Sand Island	Composite of 10 Spawning Herring	1.52	.13	.49
Houghton Pt.	"	1.11	.13	.50
Russell's Bay	"	.67	.15	.30
Big Bay	"	.84	.13	.40
South Shore	"	.33	.14	.30

* Size composition of sample is unknown but individual fish submitted for analysis averaged 14 inches.

PART II: PARASITES

METHODS

In 1973 cyst-like structures were observed on the external stomach wall and intestinal tract of spawning lake herring. A study of the macroparasites found on spawning herring was initiated in an effort to determine their role (if any) in the herring decline and their possible use as stock separators. Samples were collected along with those for the meristic study (see Part I).

Identification of Parasites

Samples of herring stomachs with tapeworm cysts were sent to Dr. Alex Dechtiarenko of the Ontario Department of Lands and Forests for identification. The cysts were identified as the plerocercoid stage of the tapeworm Diphyllobothrium sp. Presently, Dr. Steve Taft of the University of Wisconsin-Stevens Point is attempting positive identification of the tapeworm species. Salmincola sp., Cystidicola sp., and Triaenophorus sp. were identified by the authors and selected for study because they were readily observable and past data were available on their occurrence in lake herring allowing a comparison of past and present incidence. The parasites were not identified to species, but past distribution records suggest that they are Salmincola inermis, Triaenophorus crassus, and Cystidicola stignatura.

Parasite Counts

Diphyllobothrium sp. Cysts were usually sphere-shaped and cream-colored or silvery with a pearly appearance. Most of the cysts were attached to some part of the digestive tract, with approximately 50% being located on the external stomach wall and many on the pyloric caeca and just anterior to the stomach. Cysts also occurred in a long irregular form, appearing as a drop of solder. They were usually found in parts of the abdominal cavity either in or near proximity to the digestive tract or on other organs such as the liver, gonads, outside of the air bladder, spleen, adipose tissue and mesenteries. Size of the cysts ranged from .03 - .50 inch. Counts are listed in two categories: total cyst count and cysts on stomach. It was impractical to count the total cysts during the on-board field study; however an accurate index count could be made of the total number of cysts on the stomach only. All cysts found in or attached to organs in the body cavity are listed as total counts. Cysts were counted using only the naked eye.

Cysts of Diphyllobothrium sp. on external stomach wall of lake herring.

Salmincola sp. Counts recorded as total number of Salmincola sp. found on external fish body such as fins, gills, scale areas. Fish were examined by the naked eye.

Triaenophorus sp. Number of infestation sites (usually dorsal muscle tissue close to the skin) observed by the naked eye.

Cystidicola sp. Recorded as present or not present in the air bladder based on visual examination.

RESULTS

Nearly all spawning herring sampled contained macroparasites (Table 4). Salmincola sp. was commonly found attached in the gill cavity area. Triaenophorus sp. was found in approximately 7.0% of the examined herring and Cystidicola sp. was present in 39.0% of the herring. Incidence of parasitism on individual fish varied from a low level for Salmincola sp., usually about 1-2 parasites per fish, to 5 for Triaenophorus sp. and over one hundred for Cystidicola sp. Cyst counts for Diphyllobothrium were high for all locations and highest in the Apostle Islands spawning herring followed by Keweenaw Bay, Thunder Bay, Grand Portage and St. Mary's River. The 12- to 14-inch spawners had the highest cyst count, with few cysts in the 10-12 inch herring and 15.5 inch and larger fish (Table 6).

The four sampled spawning populations from Wisconsin waters of Lake Superior are not separable using incidence of parasites, except the Diphyllobothrium sp. total cyst count in Houghton Point herring was more than twice as great as counts from samples taken at the other three locations in 1975. However 1973-74 cyst data does not show this (Table 6).

Results indicate the St. Mary's lake herring population as a group may be separable on the basis of parasites from the other four lake-wide areas. St. Mary's herring were nearly parasite-free compared to the other locations. Salmincola was not present in St. Mary's herring compared with a presence in 38% of the herring from other samples. Cystidicola sp. was present in only 4% of the St. Mary's sample compared with 38% and greater for herring from the other locations. Triaenophorus was nonexistent in St. Mary's herring compared to a presence in 5.0% or more in herring from the other locations.

Table 4. Incidence of parasites in lake herring from four locations in the Apostle Islands of Lake Superior, 1973-75.

Sample Location	Sample Size	% of Fish Sampled Having			Mean No. Diphyllobothrium Cysts		Av. Tot. Leng. of Fish (In.)	Percent Female
		Salmincola	Cystidicola	Triaenophorus	Total Viscera	Stomach		
Sand Island	62	--	--	--	--	5.9	13.6	85.0
Russell's Bay	62	44.8	30.7	--	12.7	9.6	14.4	76.7
Houghton Pt.	59	26.7	53.3	3.3	38.4	16.7	14.9	83.3
South Shore	55	50.4	40.0	6.7	16.2	12.1	14.2	96.7

Table 5. Incidence of parasites in lake herring from four locations in Lake Superior, 1975-76.

Sample Location	Sample Size	% of Fish Sampled Having			Mean No. Diphyllobothrium Cysts		Av. Tot. Leng. of Fish (In.)	Percent Female
		Salmincola	Cystidicola	Triaenophorus	Total Viscera	Stomach		
Grand Portage	32	43.8	43.8	6.3	7.9	5.8	14.2	84.4
Apostle Islands	238	40.4	38.2	5.0	22.2	11.1	14.6	85.4
Keweenaw Bay	50	44.0	60.0	14.0	17.5	7.5	13.9	60.0
St. Mary's River	50	0.0	4.0	0.0	2.4	0.8	13.3	64.0
Thunder Bay	25	24.0	52.0	12.0	11.3	10.0	14.5	92.0

Table 6. Total cyst counts (Diphyllobothrium sp.) for Apostle Island stations, 1973-1974.*

Size Group (Inches)	Sand Island		Houghton Point		Russells Bay		South Shore		Wisconsin Total	
	Sample Size	No. of Cysts	Sample Size	No. of Cysts	Sample Size	No. of Cysts	Sample Size	No. of Cysts	Sample Size	No. of Cysts
10.4-10.9	1	1.0							1	1.0
11.0-11.4	2	1.5							2	1.5
11.5-11.9	1	0.0							1	0.0
12.0-12.4	2	0.5	1	19.0	4	11.0	1	23.0	8	10.9
12.5-12.9	5	15.8			4	3.5			9	10.4
13.0-13.4	8	10.1	5	21.6	4	16.0	12	11.6	29	13.5
13.5-13.9	10	14.2	9	14.9	6	43.5	9	22.3	34	21.7
14.0-14.4	8	16.9	6	5.2	12	13.7	11	8.6	37	11.5
14.5-14.9	12	9.3	6	5.7	8	12.9	6	12.0	32	10.0
15.0-15.4	5	5.4	4	9.0	3	2.3	5	10.0	17	7.1
15.5-15.9	2	3.0	5	7.0	4	1.3			11	4.2
16.0-16-4	2	6.5	6	5.5					8	5.8
16.5-16.9			1	5.0					1	5.0
17.0-17.4			2	11.0					2	11.0

* 1975 Apostle Island and Lake-wide individual herring cyst counts were lost.

Diphyllobothrium sp. cyst counts were low for St. Mary's herring although this may be partially due to the small average size of 13.3 inches. The problem of mean size was eliminated through examination of the number of cysts (stomach count) by half-inch groups comparing Wisconsin with St. Mary's River (Table 7). Unfortunately individual total cyst counts for St. Mary's were lost. As illustrated the number of cysts per size group is much lower for St. Mary's River herring than Wisconsin herring.

A personal communication with Asa T. Wright of the Michigan Department of Natural Resources states that the St. Mary's (Potagannissing Bay Area) population may be isolated to the area and currently receives only exploitation from the sport fishery. There has been no commercial fishery on this stock for over 40 years. From recent surveys, herring appear abundant throughout the St. Mary's system below Sault Ste. Marie area, however, whether the population is static, increasing or decreasing is as yet unknown.

Table 7. Lake herring stomach cyst counts (Diphyllobothrium sp.) for Wisconsin and St. Mary's River.

Size Group (Inches)	Wisconsin (1973-75)		St. Mary's River (1975)	
	Average No. Stomach Cysts	Sample Size	Average No. Stomach Cysts	Sample Size
12.0-12.4	5.67	6	0.00	3
12.5-12.9	5.89	9	1.00	8
13.0-13.4	10.10	39	0.89	9
13.5-13.9	9.02	68	1.00	11
14.0-14.4	7.75	112	0.14	7
14.5-14.9	5.61	115	2.00	3
15.0-15.4	5.05	100	1.50	2

Lake Superior chub populations (mostly Coregonus hoyi and Coregonus zenithicus) are also being examined. Preliminary findings indicate that some of the larger chubs have Diphyllobothrium cysts but in lower numbers than the spawning lake herring.

DISCUSSION

Unfortunately, parasite data for Lake Superior herring prior to their decline are not available except for two surveys conducted in 1946 off Duluth and Bayfield. The Duluth herring survey (Johnson, 1946) shows very little work done on parasites except by the Minnesota agricultural inspector who examined herring fillets for the nematode Cystidicola stignatura and cestode Triaenophorus crassus. No mention was made of any other parasite. The Bayfield herring survey (Klick, 1946) states that only a few herring were infected by Triaenophorus sp. (approximately 6%) and approximately 7% of the examined herring were infected with Cystidicola stignatura. Herring stomachs were examined for content during the survey but no mention of cysts on the stomach or exterior intestinal tract was noted.

Comparing Klicks 1946 herring samples with the present, Cystidicola stignatura has increased from 7% off the Bayfield area, to over 40% presently. C. stignatura was found to heavily infest some brook trout but did not appear to affect the host (MacLulich, 1943). Dechtiar's (1972) Lake of the Woods investigation found over 15% of the herring were infested with C. stignatura. Round whitefish (Prosopium cylindraceum) in the Apostle Islands are commonly found to be infested by C. stignatura without any apparent harm. Miller and Kennedy (1948) reported finding enough of these nematodes in a lake trout to fill a solid half pint with no evidence of harmful effects to the trout.

No comparative data are available on past incidence of infestation by Salmincola sp., but according to Davis (1956) and Warren (1975) fish losses are seldom attributable to this parasite. Triaenophorus sp. was found in 7% of the lake herring examined during this study which is similar to the 6% found off Bayfield in 1946 by Klick. Dechtiar (1972) found nearly 33% of the Lake of the Woods herring "lightly" infected with Triaenophorus crassus.

No information is available on the past incidence of Diphyllobothrium parasites in Lake Superior herring. However, fish mortalities associated with parasites of this genus are well documented. Along with his identification of the parasite for this study, Dr. Dechtiarenko stated that plerocercoids of Diphyllobothrium sp. are pathogens and sometimes cause considerable damage to the fish by migration. Heavy mortality was observed among adult lake herring and whitefish of Big Trout Lake, Ontario, in 1963 (unpublished data). Migrating larvae (plerocercoids) were found in the heart of 66% of the dead fish. The plerocercoids migrated through the body of the cisco and punctured different vital organs including the sinus venosus or auricles of the heart. No evidence was found in any cisco of bacterial or protozoan disease. The ciscoes of Big Trout Lake averaged 5.5 - 6 inches total length. The herring in Big Trout Lake were only lightly infested with Diphyllobothrium sp. while the Apostle Island samples were listed as medium infestation. Light infestation is 1-10 parasites, medium is 11-50 and heavy is greater than 50.

According to Dr. Reino S. Freeman, University of Toronto, Ontario, (1976) at least three species of Diphyllobothrium parasitize fish in Algonquin Park: D. dendriticum, D. ditremum, and Diphyllobothrium sp. (probably vogeli). Dr. Freeman's evidence suggests that only D. dendriticum is the great migrator and killer. In White Partridge Lake there is evidence of fish mortality due to blockage of the heart, at least in Coregonus zenithicus and possibly Salvelinus fontinalis. The number of plerocercoids is usually not great, one or two in the right place being lethal.

Warren (1975) states that plerocercoids migrate through the body cavity and internal ograns causing adhesions to develop. Severe adhesions in adult females render them virtually incapable of normal egg production and spawning. In small fish, the migrating plerocercoids may actually kill the fish by penetrating a vital organ. Scott (1935) states that when abundant, the plerocercoid larvae may cause the death of the host. Heavily parasitized fish become listless and swim lazily near the surface.

Death caused by Diphyllobothrium plerocercoids have also been reported by Moore (1924) for round whitefish (Prosopium cylindraceum), Hoffman and Dunbar (1961) for brook trout, Jorgensen (1958) for hatchery trout, and Sheppard (1944) for brown trout.

The Diphyllobothrium tapeworm may not be the initial cause for the herring decline, however, it may have become a contributing factor to the inability to recover, if recovery is possible. The high incidence of infestation may be related to the increased size of the lake herring in recent years which has been viewed as a reaction to their greatly reduced abundance. The reduced abundance has been blamed on smelt predation, commercial exploitation, environmental degradation, or a combination thereof.

According to Dryer and Beil (1964) the lake herring generally declined over the 1946-55 period. Klick (1946) observed the fall 1946 commercial herring in the Bayfield - Cornucopia area. He stated the smallest herring from collected samples was 9.7 inches (total length) and weighed .25 lbs, while the largest was 13.0 inches (total length) and weighed .53 lbs. Commercial fishermen mostly used 2¼ inch stretched-mesh gill nets and stated that 2 7/16 inch mesh caught approximately two-thirds less herring than 2¼ inch. At the same time, Johnson (1946) was examining the fall herring fishery off Duluth - Superior. The 2¼ inch mesh was most commonly used. Equal lengths of 2¼ inch (30 meshes deep) and 2½ inch (70 meshes deep) were sampled. The 2¼ inch yielded 415 lbs whereas the 2½ inch only 160 lbs. The spawning herring ranged from 9.4 to 12.8 inches and averaged 10.8 inches.

Dryer and Beil (1964) stated that off Bayfield in 1950-54, the spawning herring averaged 11.3 inches and 12.0 inches in 1956-59. In Duluth in 1957-59, spawning herring averaged 11.9 inches. Presently the average length of spawning herring off Bayfield is 14.4 inches with 2½ - 3 inch stretch mesh nets the most effective.

As depicted by Beil and Dryer (1964), herring off Bayfield, Wisconsin, Portage Entry, Michigan, and Marquette, Michigan, increased in weight during the same time period (Table 8). In the early 1950's, spawning herring averaged nearly 2.5 to a pound. By 1957-58 they were nearly 2 to a pound. In the early 1960's the lake herring had dropped to less than 2 to a pound and at present they are approaching one pound apiece, over twice the size of the early fifties herring.

Table 8. Number of spawning lake herring per pound.

Year	Minnesota	Wisconsin	Portage Entry	Marquette
1950	--	2.67	2.35	2.43
1951	--	2.76	2.54	2.22
1952	--	2.39	2.17	2.05
1953	--	--	2.37	2.05
1954	--	2.33	2.62	2.00
1955	--	--	2.22	2.15
1956	--	2.35	2.00	1.95
1957	2.39	2.05	2.05	1.42
1958	2.22	2.11	1.74	1.63
1959	1.95	1.90	1.82	1.66
1960	2.00	1.67	1.72	1.60
1961	--	1.95	1.60	1.51

The herring of the 1940's and early 1950's may not have been vulnerable to the plerocercoid because they seldom grew over 12 inches. The herring in recent years may have altered its feeding pattern or food supply, consuming food in which the plerocercoid stage of the tapeworm is present. Limited information exists concerning food of herring in Lake Superior which lists specific food species. James Selgeby of the U.S. Fish and Wildlife Service (Ashland, Wisconsin) analyzed stomach contents of 16 adult herring from the Apostle Islands region collected during April-November, 1971-72. The stomach contents are expressed as percent of total biomass (ash-free dry weight) in the stomachs. He found that the zooplankton Limnocalanus macrurus made up 96.1% of the total biomass of the lake herring stomach contents, followed by a distant Diaptomus sicilis (1.3%) and Senecella calanoides (1.2%). Chironomid pupae made up 1.3%. Other zooplankton found in trace amounts were Diaptomus ashlandi, Cyclops bicuspidatus thomasi, Epischura lacustric, and Daphnia galeata mendotae. Whether any of these organisms are plerocercoid carriers is unknown.

Occasionally a small forage fish will show up in the stomachs of larger herring. Several times large herring (16+ inches) have been found to have their stomach full of young smelt. No extensive quantitative data presently exists on the year around feeding habits of lake herring. Dr. Freeman (pers. comm.) states that D. dendriticum and Diphyllobothrium sp. mature in sea gulls easily, although he has not been able to get D. ditremum to mature in seagulls. All species of Diphyllobothrium utilize various copepods as first hosts. As a general rule, when only 1 or 2 plerocercoids per fish are found, (a relatively low frequency of infection), direct infection from copepods is suggested. Dr. Freeman theorizes that when many cysts are found on a fish, they are acquired by eating smaller infected fish.

The cycle of the tapeworm prevalent in the Lake Superior herring can only be speculated on, using limited available literature concerning the genus Diphyllobothrium. The cycle possibly functions as outlined below.

1. Sea gull is definitive adult tapeworm host. Herring gull (Larus argentatus) and ring-billed gull (Larus delawarensis) are the principal species in the study area.

2. Gravid proglottids passed with feces.

3. Parasite eggs sink to bottom and mature to a coricidium stage.

4. Motile coricidium picked up by copepod (possibly Diaptomus): first intermediate host.

5. Mature in hemocoel of copepod (procercoid stage).

6. A copepod eaten by lake herring or small forage fish: second intermediate host. Forage fish eaten by lake herring.

7. Develops into plerocercoid stage and migrates through alimentary canal and throughout organs.

8. Dead or dying herring picked up by sea gull.

9. Parasite matures in intestinal tract of sea gull.

If any treatable link exists, the adult stage in the sea gull is likely the most feasible. Various veterinary schools and agriculture departments were contacted concerning tapeworm treatment in birds. Avian tapeworm treatment is confined to chickens and turkeys, using the compound "Dibutyl tin dilaurate". Dibutyl tin dilaurate is commercially available in tablets or granules. Recommended dosage is one tablet per chicken over eight weeks old (roughly equivalent to an adult sea gull). Usually one or two treatments are sufficient to remove the tapeworm.

An approach to tapeworm treatment and monitoring is listed below.

1. Continue to seek professional advice from parasitologists on what and how to monitor, and continue examination of specimens. Both Drs. Taft and Freeman have suggested to be absolutely certain of the tapeworm identification before a feeding study using sea gulls as a host should be undertaken.

2. Reduce availability of infected herring guts to sea gulls by the commercial fishery and also dumps near fishing communities. The easy access of infested herring guts to sea gulls may have greatly increased and concentrated the spread of the tapeworm in sea gulls. This may be a possible factor for the early decline of herring near commercial ports.

3. Obtain monthly samples of lake herring when feasible to determine if plerocercoids migrate during particular time periods and amount of damage. Obtain samples for herring food study. Mortalities of lake herring in Big Trout Lake, Ontario, occurred in June.

4. If future evidence indicates that the Diphyllobothrium sp. parasite causes extensive mortality in lake herring, develop effective techniques for eventual experimental sea gull population treatment. Hundreds of sea gulls are easily attracted to commercial fish boats, easily providing an opportunity for massive treatment. Carefully measured dosage in 10-inch menominees would prevent overdoses because a sea gull may be temporarily satisfied with one menominee of this size rather than several. Harris (1975) estimated the 1974 herring gull population at 3,500 birds in the Apostle Island area and 1,200 ring-billed gulls in the Duluth - Superior area, totaling 4,700 birds. Estimated annual drug cost at one tablet per bird for two treatments would be $250.00. The initial step would be to capture and treat two adult sea gulls to determine proper dosage. This may be accommodated in step one when attaining adult tapeworm samples.

5. Treat sea gull population after August 1 when nesting and feeding of young is completed. Monitor effects to sea gull population through direction of ornithologist and game managers.

6. Continue to monitor spawning herring to determine effectiveness of project.

7. Obtain lake herring from supposedly healthy stocks in eastern Ontario waters to compare parasite abundance.

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English - metric conversion factors.

To Convert	Multiply By	To Obtain
Inches	25.4	Millimeters
Millimeters	0.03937	Inches
Grams	0.03527	Ounces
Pounds	0.4536	Kilograms
Pounds per acre	1.121	Kilograms per hectare
Number per 100 sqaure cm	9.29	Number per square foot
Fahrenheit	$5/9(^{o}F-32)$	Centigrade
Acres	0.4047	Hectares

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jg