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DYNAMICS OF LAKE TROUT REPRODUCTION: DISTRIBUTION AND DENSITY OF EGGS AND FRY ON COBBLE SUBSTRATE

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BACKGROUND

Naturally reproducing populations of lake trout (*Salvelinus namaycush*) were historically present in Lake Ontario. However, by 1960 native lake trout had been extirpated due to the combined effects of overfishing, predation by sea lamprey (*Petromyzon marinus*), and environmental degradation (Christie 1972). During the 1970's, fisheries agencies established a management program to restore naturally reproducing populations of lake trout to Lake Ontario (Schneider et al. 1983). In 1971, sea lamprey control was established to reduce predation lake trout. In 1973, the annual stocking of lake trout as hatchery yearlings was begun. The survival of hatchery lake trout in Lake Ontario was sufficient that in the 1980's aggregations of spawning lake trout were observed and lake trout fry were captured (Marsden et al. 1988). However, few naturally reproduced post-emergent or yearling lake trout have been captured to date. The survival of stocked lake trout suggests that natural recruitment is being blocked prior to the yearling life stage. Spawning, fertilization of eggs, over-winter incubation, and hatching occurs at some locations in Lake Ontario; however, little quantitative information exists about the dynamics of these processes. Our project sought to quantitatively describe information related to the early life history of lake trout spawned by hatchery-origin fish. The main objectives of the research project were as follows:

1. To describe the relationship between the numbers of eggs captured in circular, polystyrene egg traps to the number of eggs present in cobble substrate immediately adjacent to trap locations.

2. To compare relative egg deposition on cobble substrate at the top, middle, and base of the Stony Island reef in order to establish the spatial distribution of eggs with respect to depth contour.

3. To quantitatively estimate egg density, egg mortality, and fry hatch from the cobble area of Stony Island reef.

METHODS

Study Site - Stony Island reef is a flat plateau four to five meters deep which extends 180 m northeast of an exposed cobble-gravel bar at the tip of Stony Island. The plateau is composed of gravel-pebble particles (0.8-6.4 cm) infilled with sand, with occasional flat rocks 20-40 cm in diameter embedded in the gravel. The eastern edge of the reef is oriented NNE-SSW and drops steeply from 4 m to 8-12 m. Most lake trout spawning and fry emergence occurs along a 60 m portion of the slope (Marsden and Krueger 1991). The width of the primary spawning area is 8.33 m. The total spawning area is 500 m^2. The substrate along the 60 m section is composed of large cobbles and boulders (12.8-40 cm) with interstitial spaces extending more than 45 cm below the surface of the substrate. The substrate tends to be larger at the northern end of the slope and smaller at the southern end. South of the spawning area, the substrate becomes increasingly infilled with sand and the substrate size decreases to small pebbles (1.6-3.2 cm). North of the spawning area, the slope flattens out and the substrate becomes infilled with sand. At the base of the slope, the substrate is sand embedded with large cobbles. Hereafter, the portion of the reef used by lake trout for reproduction will be referred to simply as Stony Island reef.

Sampling Devices - Three different egg sampling or holding devices were used in these studies: egg bags, egg traps, and incubators. Egg bags consisted of a ring (32 cm inside diameter) with a 50 cm deep mesh bag attached (surface area = 0.08 m^2; Figure 1). The ring was made of 1.25 cm diameter conduit pipe. The bag was made from 0.16 cm mesh nylon netting. Bags were positioned by SCUBA divers who dug holes in the substrate, placed the bags in the holes with the rings flush with the substrate, and then filled the bags with displaced substrate.

Egg traps used were the same as those developed by Marsden et al. (1991). The traps consisted of hollow polystyrene discs (22 cm diameter x 5 cm high) with cone indentations that funneled eggs into the trap (surface area based on cones = 0.0162 m^2). One trap was attached to each egg bag with wire such that the trap could not flip over into the collection area of the bag. Lead weights (about 250 g) were attached to the traps with plastic clips to reduce current-induced flapping and damage to traps.

Egg incubators used were similar to those developed by Kennedy (1980) and modified by Gunn and Keller (1984). Each incubator consisted of a rectangular piece of plexiglass with 50 holes (one per egg) sandwiched between two similar, but thinner pieces of plexiglass. The two thin pieces were covered with mesh netting.

Field Studies 1990: Trap Capture/Spatial Distribution of Eggs/Egg Density (Objectives 1,2, and 3) - One bag/trap unit was placed at each of 30 sample sites on Stony Island reef in September (Figure 1). The sites were distributed equally among three transects which corresponded to water depths of four, six, and eight meters. The sites were spaced about four meters apart. The shallowest transect was located one meter downslope from the top of the reef. The deepest transect was located just above the base of the reef. The units were all retrieved November 30 with the help of the New York State Department of Environmental Conservation.

Bags and traps were retrieved from a boat after SCUBA divers had removed most of the rocks from the bags, tied the openings shut, and attached buoyed lines to each bag/trap unit. During retrieval, the units were often dragged along sand bottom for roughly seven meters before being lifted to the surface, possibly damaging some eggs.

Bags and traps were brought to Cornell University and contents examined within 24 hours after retrieval. Number of egg chorions and viable (green) and dead (white) eggs were counted and added together for estimates of egg deposition. Undamaged eggs were kept in the hatchery to allow further development. Dead eggs were stored in a glycerin/formaldehyde solution and later examined to determine if fertilization had occurred. Eggs were considered fertilized only if the longitudinal axis of the embryo was clearly apparent. The number and size of sculpin (*Cottus cognatus*) and crayfish (*Orconectes* sp.) captured in the bags were also recorded. Sculpin stomachs were examined for lake trout eggs.

Ten incubators each with 50 eggs were attached at one meter intervals to a chain and buried in-between the six and eight meter transects. Gametes used in the incubators were from 20 female and 60 male fish captured near the reef. Eggs from each female were fertilized

One incubator was buried next to each seeded egg bag (45 total). Gametes used in incubators were the same as those used to seed the egg bags. Incubators were retrieved at the same time as egg bags (i.e., December, April and May). Fifteen incubators were brought to the hatchery at Cornell University to serve as controls. Water temperature in the hatchery during incubation ranged from 5°C to 10°C. Water temperature and dissolved oxygen were recorded between December 10, 1991 and April 10, 1992 with a Hydrolab Datasonde III buried under 20 cm of substrate near the six meter transect.

Data Analysis - Egg density (eggs per m^2) in the substrate at each site was estimated from counts of live and dead eggs collected in egg bags retrieved in the fall (Objectives 1, 2, and 3). Egg density in the trap at each site was estimated based on the area of the cones and compared to egg density in the substrate of the adjacent egg bag. Differences in mean egg density between transects (Objective 2) were tested with t-tests assuming unequal variances (Sokal and Rohlf 1981). The relationship between egg trap capture and egg density in the adjacent substrate (Objective 1) was analyzed with two different linear regression models. The first model was based on data from four and six meter transects only (i.e., data from eight meter transect were excluded). The second model was based on a simulated data set. Five sites were randomly selected from the four and six meter transects and mean trap capture and mean egg density of these sites were calculated. This process was repeated 50 times and then paired data were analyzed.

Estimates of survival (Objective 3) came from three sources: 1) egg bags which sampled naturally deposited eggs, 2) egg bags seeded with a known number of eggs, and 3) incubators. Survival of naturally deposited eggs collected shortly after spawning was calculated for each site by dividing the number of viable fertilized eggs by the total number of eggs retained in the substrate (sum of the viable eggs, dead eggs, and egg chorions). Survival of naturally-deposited eggs in April and May was not calculated for each site because we believe degradation of dead eggs over winter would bias our counts of total egg deposition. Instead, survival was calculated for each transect by dividing the mean number of live embryos and fry per site by the mean number of eggs deposited per site in December. Survival in seeded egg bags and incubators were calculated for each site for every retrieval date. An estimate of the total number of fry produced from Stony Island reef was calculated based on mean egg density, mean survival of naturally deposited eggs to May 15, and total area suitable for incubation. Differences in mean egg survival per transect were tested with t-tests assuming unequal variances (Sokal and Rohlf 1981). Differences between transects in

# of eggs captured in traps = -1.60 + 0.021(# eggs per square meter)

(see Appendix B). The slope of the regression was greater than zero ($P<0.001$). The residual plot indicated that variances were distributed normally. The normal probability plot was light tailed as expected (this type of distribution is caused by a lack of extreme values which were not present because the observations were averages of five sites).

Spatial Distribution of Eggs (Objective 2) - In 1990, egg density was high near the top of the reef, lowest in the mid-depth portion of the reef ($P<0.01$), and high again at the bottom of the reef (Table 2). In 1991, density near the top of the reef was greater than at six or eight meter transects ($P<0.01$). Densities at the six and eight meter transects were not significantly different. In both years, the coefficient of variation was always least at the four meter transect and greatest along the eight meter transect(Table 2).

Egg Density, Fertilization, and Survival (Objective 3)- Overall egg density in 1991 was 3201/m^2 as compared to only 677/m^2 in 1990 (Table 2). Fifty-five percent of the eggs captured in bags in 1990 showed signs of development and were identified as fertilized. In 1991, 64% of the eggs captured were considered fertilized.

Mean survival of naturally deposited eggs decreased from 46.6% just after spawning (December 10, 1991) to 1.3% near time of swim-up (May 15, 1992; Table 3; Figure 4). In 1990, mean survival of naturally deposited eggs just after spawning was less along the six meter transect ($P<0.01$) than in 1991 but not significantly different at the four and eight meter transects. Survival of seeded eggs was similar to the naturally deposited eggs, whereas survival in the incubators was substantially higher (Table 3; Figure 4). Survival along the eight meter transect was often significantly lower than the other transects (Table 3). Survival to the swim-up fry stage in the control incubators held in the Cornell hatchery was 75% (SE=1.6) in 1990-91 and 73% (SE=1.7) in 1991-92.

Fry Production (Objective 3) - Extrapolating mean egg density for 1991 (3201/m^2; Table 2)) and mean survival for naturally deposited eggs (Table 3) over the entire reef area suitable for egg incubation (500 m^2) yielded the following estimates: 2,080,650 eggs retained in the substrate after spawning, of which 969,583 were fertilized and alive by early December; 118,597 hatched fry in early April; and 27,048 swim-up fry in mid-May (54 swim-up fry per

1) Quantitative estimates of egg density from egg capture data in traps may be possible for spawning areas with physical characteristics similar to those of Stony Island reef. The average ratio between egg density in the substrate and egg density in the traps was 0.99 (95% CI=0.77-1.21); data from eight meter transect was excluded). In other words, traps on average appeared to retain eggs (per unit area) at the same rate as the substrate on Stony Island reef. The ratio between trap capture and egg density in the substrate was prone to large variability which could have resulted from: 1) different egg capturing efficiencies of traps at different sites, and 2) variation in the proportion of eggs spawned that were retained in the substrate. Trapping efficiency was probably affected by the slope of the trap while fishing; the closer the trap was to vertical, the less efficiently it captured eggs. In this study, the slope of the traps was known to be fairly uniform, therefore most of the variability in the egg density:trap capture ratio was likely due to within-site variability of substrate retention of eggs. The proportion of eggs retained in the substrate depends largely on the abundance of interstitial spaces and loss of eggs due to water currents. The relationship between trap capture and egg density is likely to vary between reefs with different physical (e.g., substrate size, slope of the bottom) and hydrologic (e.g., wave surge) characteristics. Use of the traps for quantitative estimates on reefs not similar to Stony Island will require a study similar to ours to determine the relationship between trap capture and egg density in the substrate. In our study, traps were placed by divers along precise transects and not set from the surface. If quantitative estimates are desired from traps, this level of effort in trap placement may be necessary. We were surprised at the close correspondence between the trap and bag estimates of egg density and believe a second season of field data is needed to confirm the direct relationship.

2) The mean number of eggs captured per trap can function as a reef-specific index of egg deposition. A significant positive relationship existed between egg trap capture and estimated egg density in the adjacent substrate. Although the ratio of egg density to trap capture was highly variable between individual sites, when data were averaged from only five sites, the variability was substantially reduced. Likely, most researchers will use 25+ traps to arrive at an egg deposition index and the variation in the egg density:trap capture ratio should be reduced to acceptable levels by this sampling effort.

3) Egg traps fished for the entire spawning season will likely capture eggs when deposition into cobble substrate is greater than 60 per m^2. Researcher could use egg

Estimates of the number of adult lake trout spawning on Stony Island do not exist for 1990 or 1991; however, stocking records for eastern Lake Ontario show that the number of Seneca strain fish stocked in 1985 increased 327% from 1984 and was even higher in 1986. Female lake trout mature in five to six years in Lake Ontario; thus, fish from the 1985 stocking would have been able to spawn in 1990 or 1991. In past years, genetic analysis has estimated that 67-87% of the parental contributors to wild fry on Stony Island reef were Seneca strain (Marsden et al. 1989, Grewe 1991). In 1992, genetic analysis indicated that Seneca strain continued to be the dominant parental contributors to wild fry. This supports the explanation that increased stocking of Seneca strain caused increased egg deposition on Stony Island reef.

Several alternative explanations for the increased egg density seem less plausible. One possibility is that egg predation in 1990 was higher than in 1991. However, sculpin density was lower in 1991 than in 1990 and crayfish density was about the same in the two years. A second possibility is that the 1990 bags were retrieved prior to the completion of spawning. Bags were retrieved 10 days earlier in 1990 than they were in 1991 (November 30 vs. December 10). During the spawning season, divers typically observe many lake trout near the reef. Divers did not observe any lake trout on the reef when the bags were retrieved in 1990. If additional spawning did occur after bag retrieval in 1990, we doubt the 10 day difference would explain the almost five-fold difference in egg density.

Based on egg deposition and average fecundity, 595 female lake trout spawned on Stony Island reef in 1991. This estimate did not account for drifting eggs not retained by the cobble substrate (see Marsden and Krueger 1991) and therefore represents a minimum estimate. In addition, Peck (1986) found that spawning population estimates calculated my our methods were roughly 10 times lower than Petersen single census estimates from gill-netting because individual lake trout distributed their eggs among multiple reefs. If lake trout near Stony Island deposited only a fraction of their eggs on the reef and some of these eggs were not retained by the substrate, then the number of spawning females may be substantially more than the estimated 595.

The proportion of naturally deposited eggs on Stony Island reef that were fertilized was likely high (near 90%). Development was observed in 90% of the eggs that were mixed with sperm on the boat and held in the hatchery. In contrast, only 64% of the eggs captured in bags in 1991 could be classified as fertilized. This estimate was likely biased low because methods used to detect fertilization could not distinguish unfertilized eggs from eggs that had died during the first eight to ten days after fertilization. These first few days after fertilization but was likely biased low due to mortality caused by retrieval. Modification of retrieval technique in 1991-92 eliminated this source of mortality.

The high mortality of eggs observed shortly after spawning may have been due to water currents that shocked the eggs prior to completion of the blastopore stage (when eggs are extremely sensitive; Piper et al. 1986). Eggs in the incubators were protected from current-induced movements which could explain why their survival was higher than loose eggs in the substrate.

Mortality overwinter was likely due to a combination of factors. Sedimentation may have suffocated some eggs, particularly in the depositional zone near the bottom of the reef where survival was lowest. Dissolved oxygen levels in the substrate near the middle of the reef were high (14 mg/L) throughout the winter and should not have caused egg mortality. However, localized oxygen deficiencies could have existed and caused egg mortality if currents were insufficient to thoroughly circulate water through the substrate. Sculpins and crayfish, due to their low densities ($<4/m^2$) in 1991, likely contributed little through predation to the total egg mortality. Mortality of live eggs due to fungal infections was observed in the hatchery and many dead eggs retrieved from the reef (both in bags and incubators) were also covered with a white fungus. Martin (1957) considered the fungus *Saprolegnia* to be a prime factor in egg mortality, with infection rates often 50%. However, we presume that dead eggs were also susceptible to infection; thus the question arises as to how many of the infected eggs were dead prior to infection. Another potential source of egg mortality was invertebrate predators. In most of the incubators retrieved from the reef, 5-10% of the egg compartments were empty. The mesh over these compartments was not damaged so the absence is not readily explainable. Briggs (1953) reported high mortality of salmon eggs in coastal streams due to an undescribed species of oligochaete worm. Oligochaete worms were commonly found in the mesh of bags retrieved from Stony Island reef; however, we currently have no information about the worms' feeding habits. Further studies of this potential mortality source are planned.

Fish assessment studies of juvenile lake trout will likely not detect natural recruitment from Stony Island reef alone. Despite high mortality, an estimated 54 fry per m^2 survived to swim-up on Stony Island reef; however, only 500 m^2 of substrate suitable for incubation exists. If survival from swim-up to yearling was 5%, the estimated number of yearlings from Stony Island reef would be 1352. Roughly 30,000 yearlings are needed for detection by the USFWS lake trout surveys (J. Elrod, U.S. Fish and Wildlife Service, personal communication). Therefore, detection of naturally-produced yearlings would require fry

Table 1. Number of eggs (sum of green and white eggs and egg shells) captured on Stony Island reef during Fall 1990. One egg trap and one egg bag were located at each of thirty sites distributed among three depths. No data (n.d.) were recorded for bags/traps that were dislodged or lost. To convert egg density in substrate to eggs per bag divide by 12.5. To convert trap capture to egg denstiy in traps, divide by 0.0162. CV = coefficient of variation.

		Site													
	Depth	1	2	3	4	5	6	7	8	9	10	Range	Mean	SE	CV
	4m	n.d.	25	26	7	9	17	14	15	14	9	7-26	15.1	2.2	44
Trap Capture	6m	n.d.	7	10	n.d.	7	11	6	4	9	5	4-11	7.4	0.9	33
(# eggs)	8m	4	4	5	28	11	6	6	3	4	14	3-28	8.5	2.4	91
Egg Density in Substrate	4m	n.d.	1063	813	838	688	1013	650	513	638	575	513-1063	754.2	63.64	25
(eggs per square meter)	6m	n.d.	875	563	n.d.	288	538	375	375	525	175	175-875	464.1	75.39	30
	8m	663	950	538	1663	1050	738	1038	275	875	338	275-1663	812.5	127.8	50
Egg Density in Traps	4m	n.d.	1543	1605	432	556	1049	864	926	864	556	432-1605	932.8	138.6	44
(eggs per square meter	6m	n.d.	432	617	n.d.	432	679	370	247	556	309	247-679	455.2	53.38	33
based on area of cones)	8m	247	247	309	1728	679	370	370	185	247	864	185-1728	524.7	150.1	91
Substrate Density :	4m	n.d.	0.69	0.51	1.94	1.24	0.96	0.75	0.55	0.74	1.04	0.51-1.94	0.93	0.15	47
Trap Density	6m	n.d.	2.03	0.91	n.d.	0.67	0.79	1.01	1.52	0.95	0.57	0.57-2.03	1.05	0.17	32
Ratio	8m	2.68	3.85	1.74	0.96	1.55	1.99	2.8	1.49	3.54	0.39	0.39-3.85	2.10	0.35	53
Substrate Density:	4m	n.d.	43	31	120	76	60	46	34	46	64	31-120	50	9.1	47
Trap Capture	6m	n.d.	125	56	n.d.	41	49	63	94	58	35	35-125	65	10.6	46
Ratio	8m	166	238	108	59	96	123	173	92	219	24	24-238	134	21.6	53

Table 3. Mean egg and fry survival on Stony Island reef. Data is from 1991-92 unless specified 1990. See Methods for differences in bag handling between the two dates. Superscipts identify survival rates that were significnatly greater (P<0.05) than other transects (^>4m, ">6m, *>8m). Differences between transects in mean survival of naturally deposited eggs could not be tested in April and May because survival was not calculated for individual sites.

	Egg traps	Bags with naturally-deposited eggs				Bags seeded with 50 eggs			Incubators			
Depth (m)	Nov. 30 1990	Nov. 30 1990	Dec. 10	April 10	May 15	Dec. 10	April 10	May 15	April 18 1990	Dec. 10	April 10	May 15
4	38.2*	32.7	42.5	9.3	2.6	57.6*	20.4*	6.8*	- - -	82.8	37.2	29.2*
6	27.3*	27.1	61.6^*	5.7	1.0	59.2*	13.6*	4.0*	54.2	75.2	44.0	38.8*
8	3.3	24.3	35.7	2.0	0.4	36.0	3.2	0.4	- - -	83.6	29.6	3.6
Mean per Transect	22.9	28.0	46.6	5.7	1.3	50.9	12.4	3.8	- - -	80.5	36.9	23.9

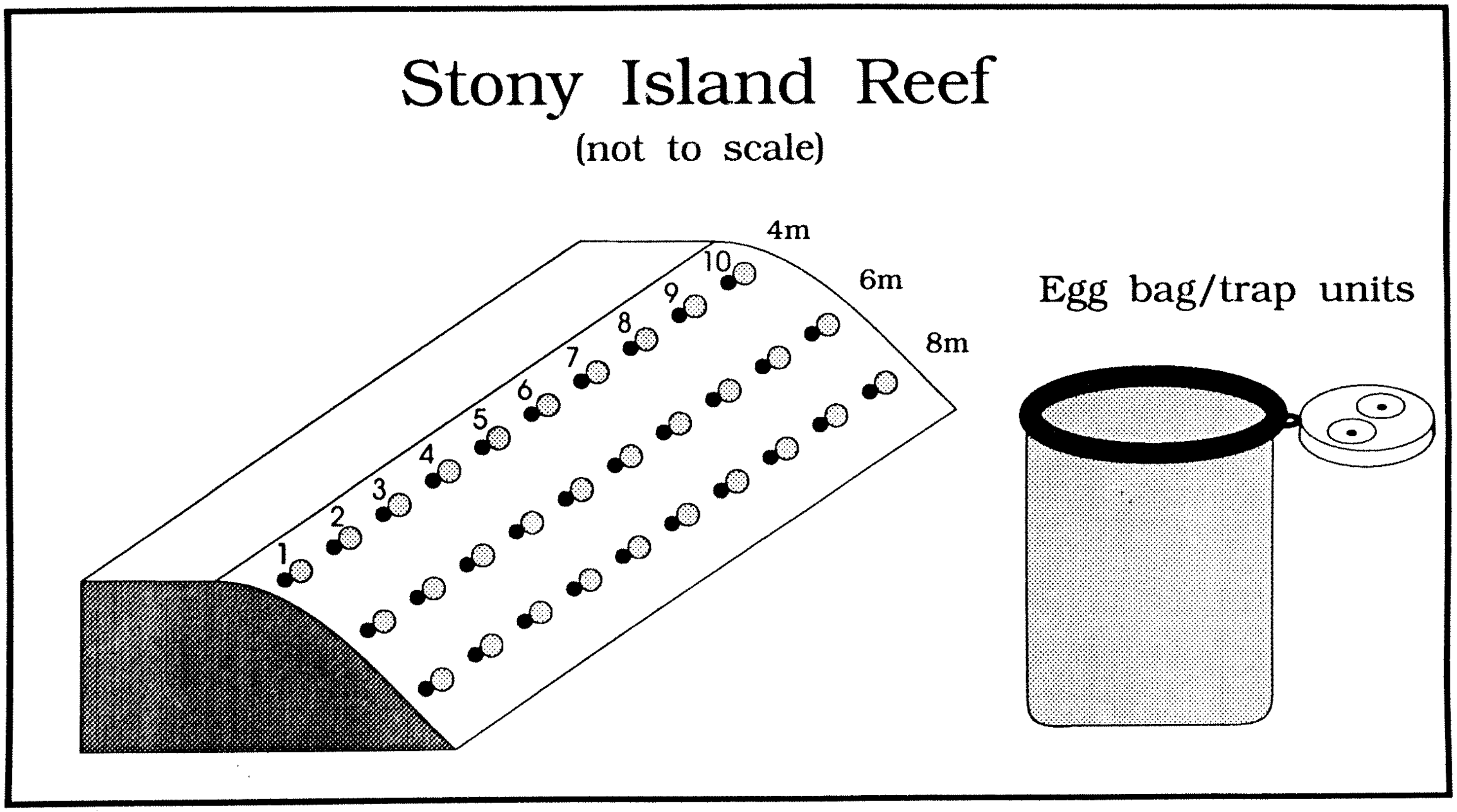


Figure 1. Position of egg bag/trap units along Stony Island reef, 1990.

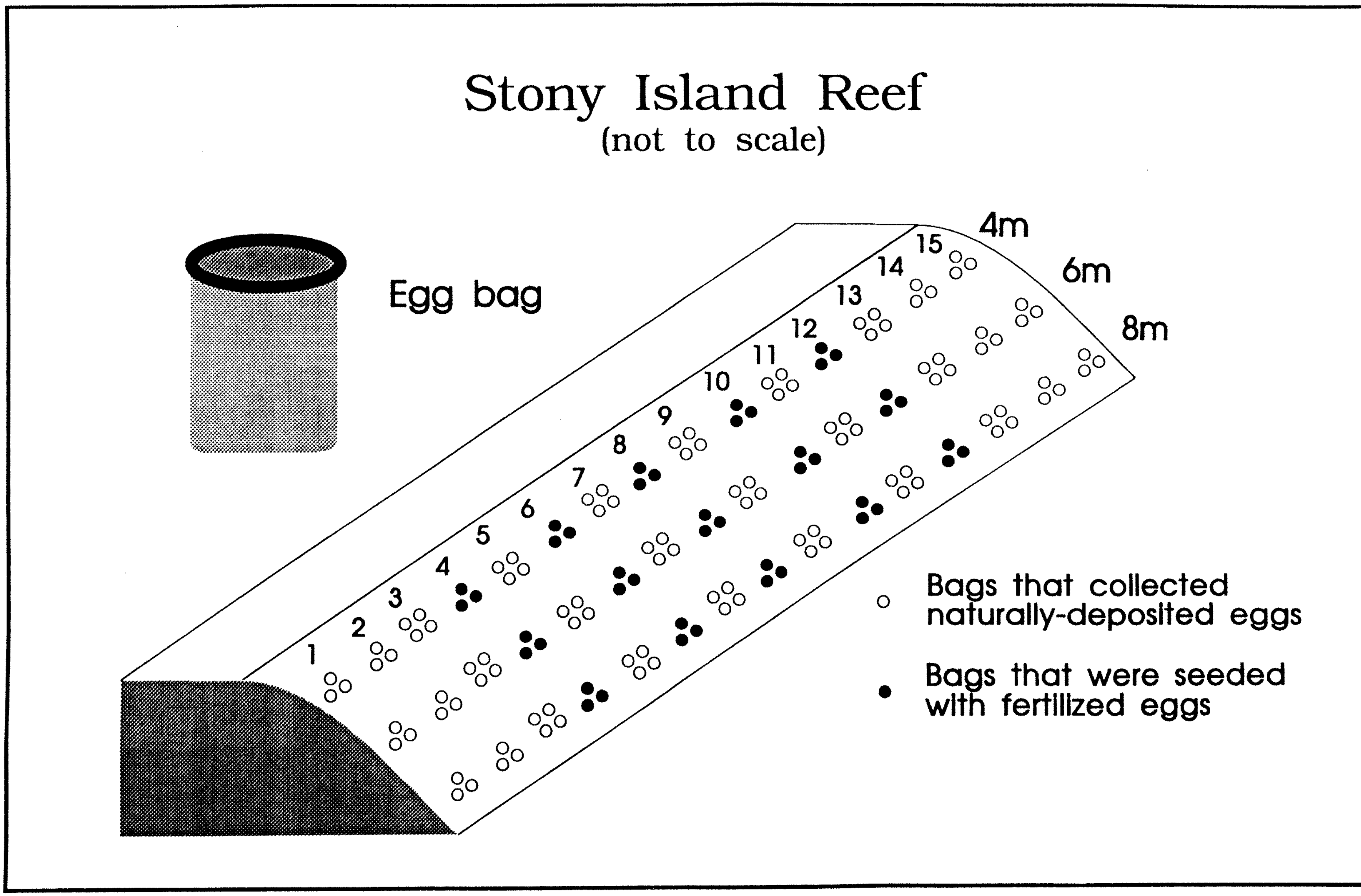


Figure 2. Position of egg bags on Stony Island reef, 1991-92.

Figure 3. Relationship between the number of lake trout eggs captured in traps and egg density in the adjacent substrate, Stony Island reef.

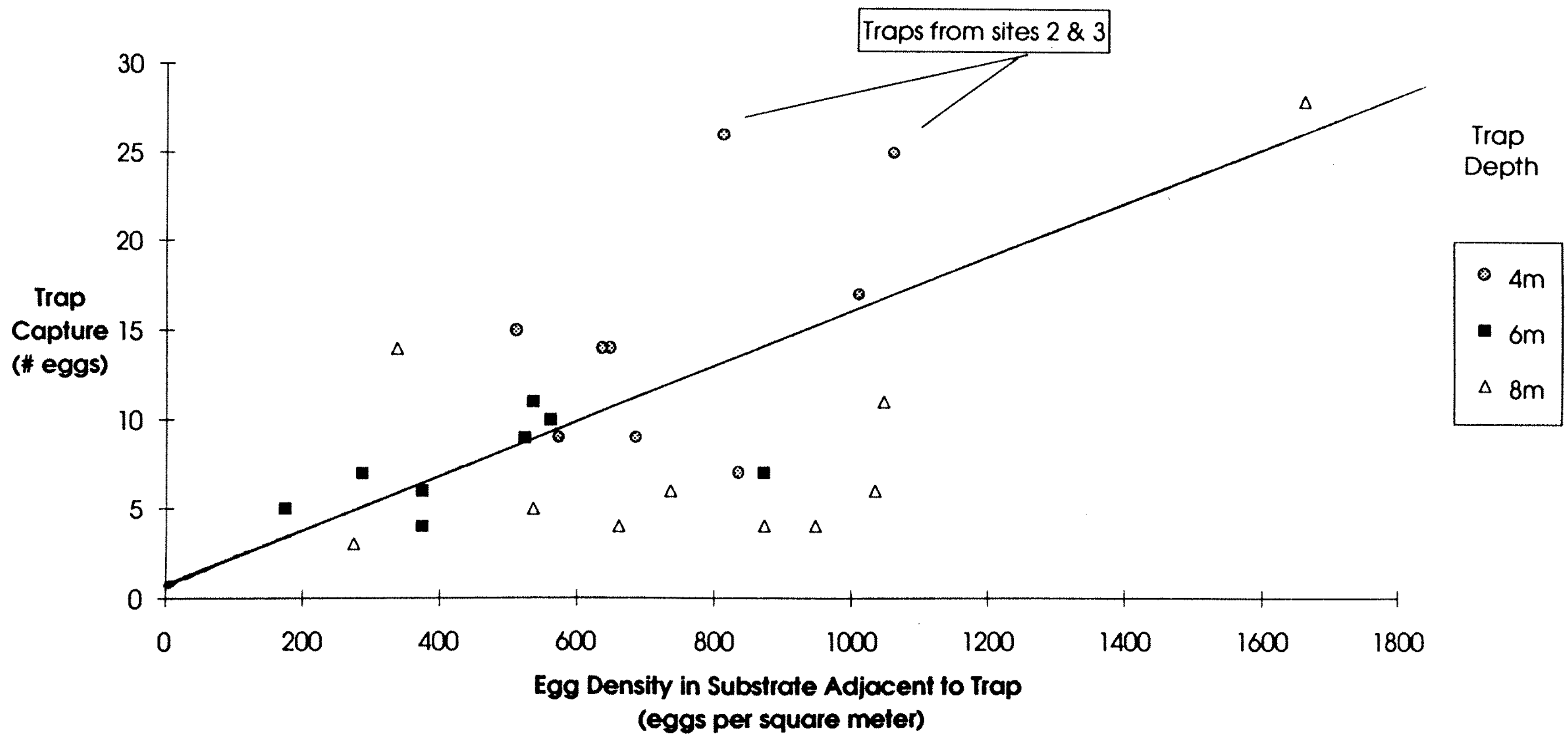


Figure 4. Survival of lake trout from egg to emergent fry stage on Stony Island reef, 1991-92.

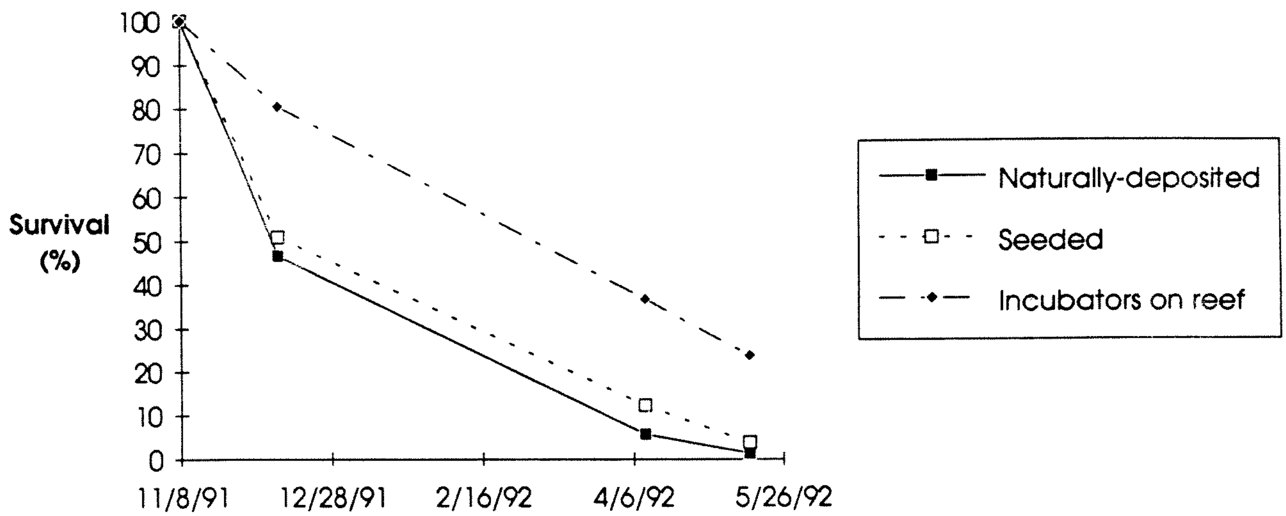
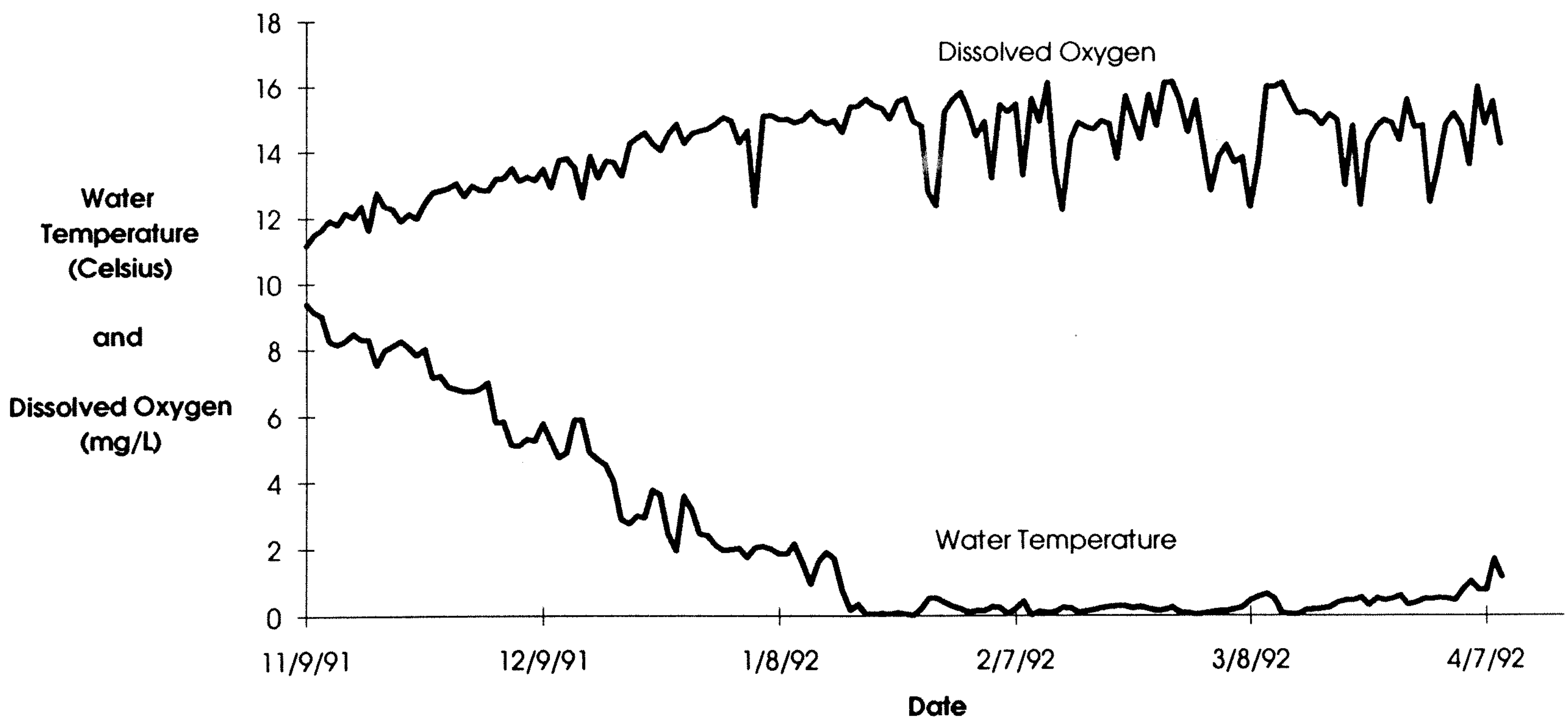


Figure 5. Daily water temperature and dissolved oxygen on Stony Island reef, Nov. 9, 1991 to April 9, 1992.



Appendix A. Egg and fry capture in mesh bags buried on Stony Island reef prior to spawning 1991. Mean values are reported when two bags were retrieved on a given date.

		Dec. 10		April 10		May 15	
Depth	Site	total # eggs	live eggs	fry	live eggs	fry	live eggs
4m	1	104.0	6.0	0.0	0.0	0.0	0.0
	2	162.0	19.0	1.0	0.0	2.0	1.0
	3	589.0	383.0	51.0	22.0	11.0	0.5
	5	561.0	322.0	31.0	20.5	12.0	0.0
	7	515.5	252.0	48.0	21.0	10.0	0.0
	9	545.0	351.0	66.5	21.5	23.0	2.0
	11	502.0	255.0	44.0	12.0	17.0	0.0
	13	512.0	292.0	27.0	8.0	17.5	0.5
	14	366.0	134.0	1.0	1.0	5.0	0.0
	15	178.0	49.0	0.0	0.0	2.0	0.0
6m	1	120.0	88.0	2.0	1.0	0.0	0.0
	2	105.0	52.0	1.0	1.0	0.0	1.0
	3	345.0	244.0	16.0	9.0	2.0	0.0
	5	362.0	202.0	11.0	3.0	3.0	0.0
	7	387.0	281.5	17.0	6.0	6.0	0.0
	9	171.0	86.0	6.5	2.5	2.0	0.0
	11	163.5	120.5	2.0	2.0	0.0	1.0
	13	202.0	162.0	19.0	6.0	1.0	0.0
	14	249.0	100.0	13.0	3.0	0.0	1.0
	15	70.0	35.0	0.0	3.0	4.0	0.0
8m	1	45.0	9.0	0.0	0.0	0.0	0.0
	2	134.0	22.0	1.0	1.0	0.0	0.0
	3	63.0	28.0	0.0	1.0	0.5	0.0
	5	329.0	68.0	4.0	2.5	2.0	0.0
	7	585.5	136.5	10.0	4.0	1.0	0.0
	9	132.0	53.0	3.0	0.5	0.0	0.0
	11	71.5	46.0	1.0	0.0	0.0	0.0
	13	34.0	25.0	0.0	0.0	0.0	0.0
	14	48.0	14.0	1.0	0.0	2.0	0.0
	15	32.0	8.0	0.0	0.0	0.0	0.0

Appendix B. Linear regression analysis of egg capture data from bags and traps on Stony Island reef, 1990.

Table B1. Summary statistics for regression analysis of egg trap capture and egg density in the adjacent substrate on Stony Island reef, 1990. Data from the eight meter transect was excluded.

	df	Sum of Squares	Mean Square	F	Significance F	
Regression	1	279.0735	279.0735	11.04041	0.004638	
Residual	15	379.1618	25.27746			
Total	16	658.2353				

	Coefficients	SE	t Statistic	P-value	Lower 95%	Upper 95%
Intercept	0.973937	3.386234	0.287617	0.777332	-6.24365	8.191529
Egg Density (x1)	0.016995	0.005115	3.322711	0.004308	0.006093	0.027896

Multiple R	0.651131
R Square	0.423972
Adjusted R Square	0.38557
Standard Error	5.027669
Observations	17

Table B2. Summary statistics for regression analysis of egg trap capture and egg density in the adjacent substrate on Stony Island reef, 1990. Paired data for the regression were the averages of five paired samples randomly selected from the four and six meter transects.

	df	Sums of Square	Mean Square	F	Significance F
Regression	1	159.3331	159.3	53.67943	2.07E-09
Residual	49	145.4434	3.0		
Total	50	304.7765			

	Coefficients	SE	t Statistic	P-value	Lower 95%	Upper 95%
Intercept	-1.60296	1.786303	-0.9	0.373826	-5.19267	1.986747
Egg density (x1)	0.020964	0.002861	7.3	1.85E-09	0.015214	0.026714

Multiple R	0.72304
R Square	0.522787
Adjusted R Square	0.513048
Standard Error	1.722856
Observations	51

Figure B1. Residual plot from regression analysis using data from the four and six meter transects only.

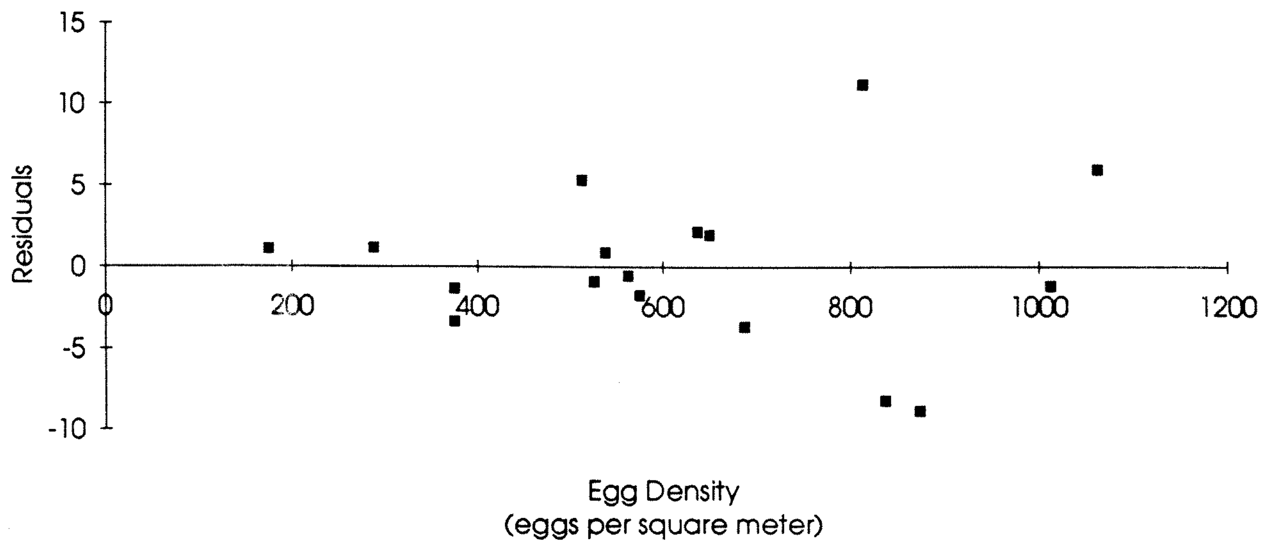


Figure B2. Normal probability plot from regression analysis using data from the four and six meter transects only.

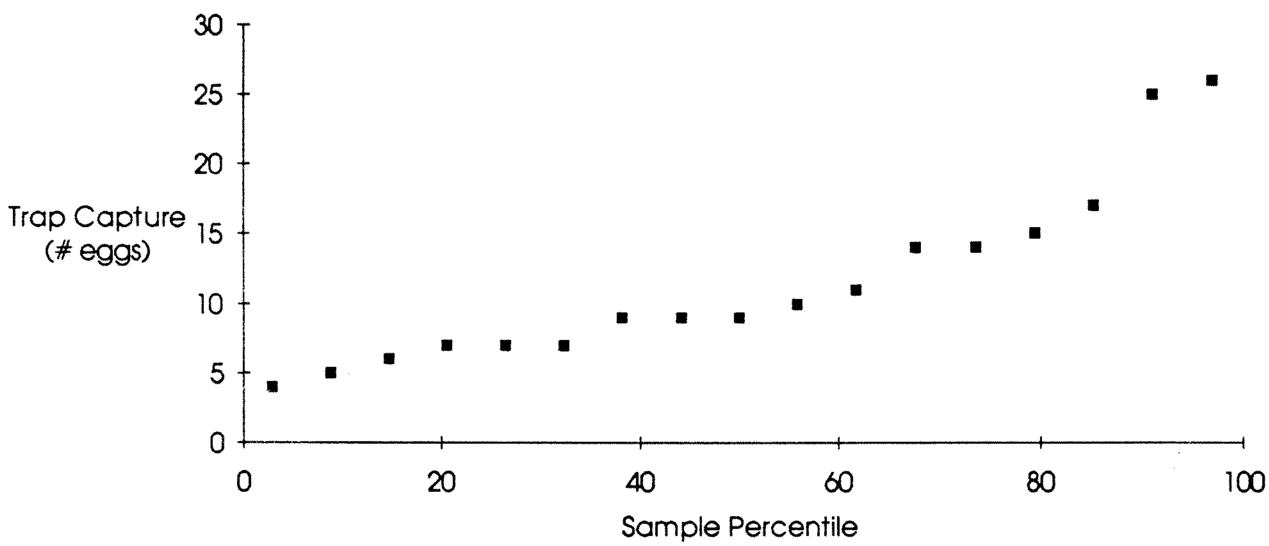


Figure B3. Relationship between the number of lake trout eggs captured in traps and egg density in the adjacent substrate, Stony Island reef. Data used were the averages of five paired samples randomly selected from the four and six meter transects.

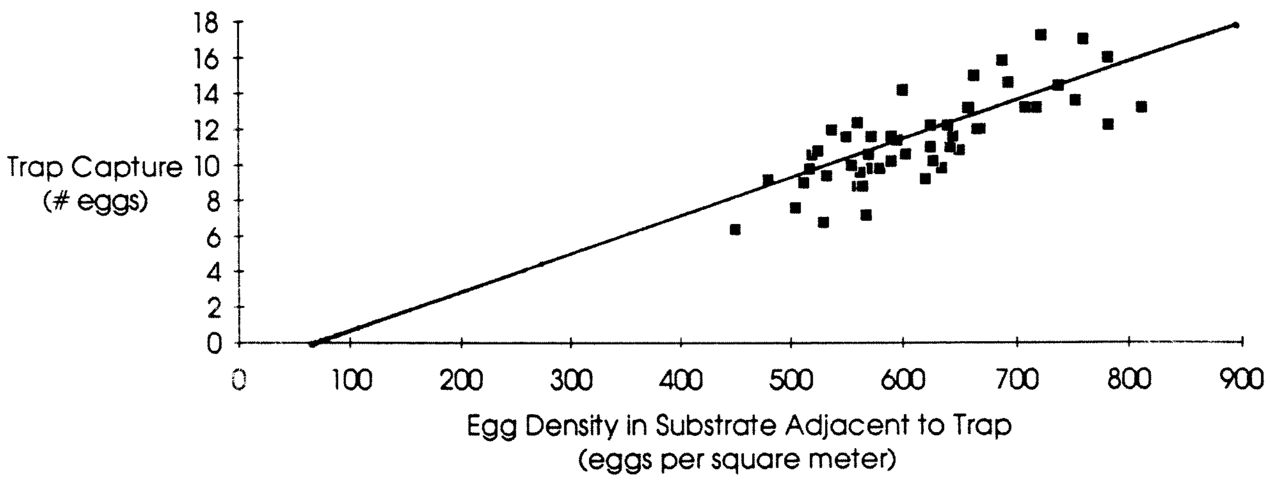


Figure B4. Residual plot from regression analysis. Data used were the averages of five paired samples randomly selected from the four and six meter transects.

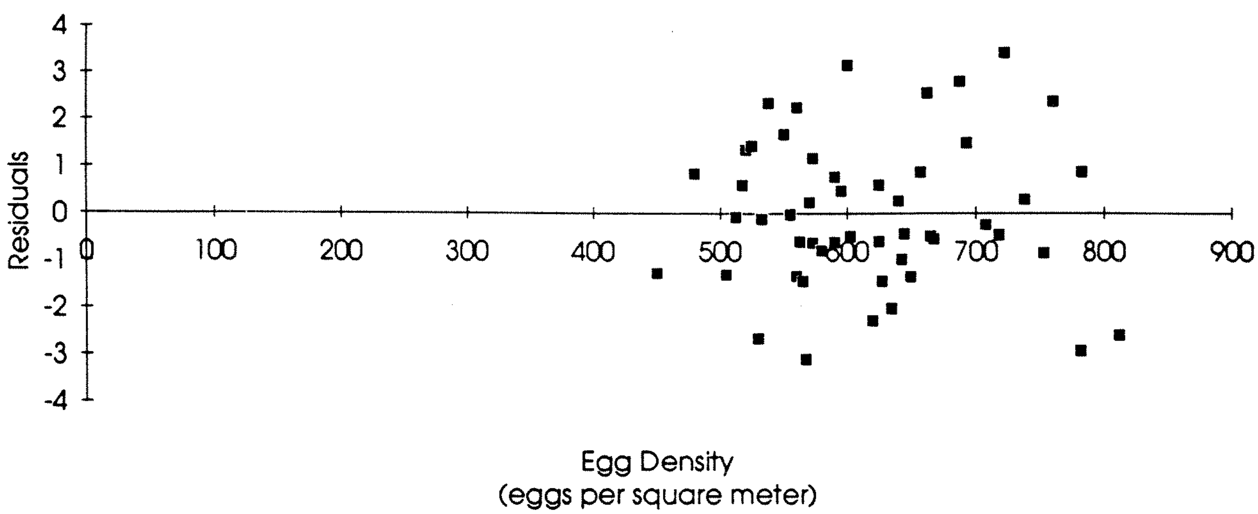
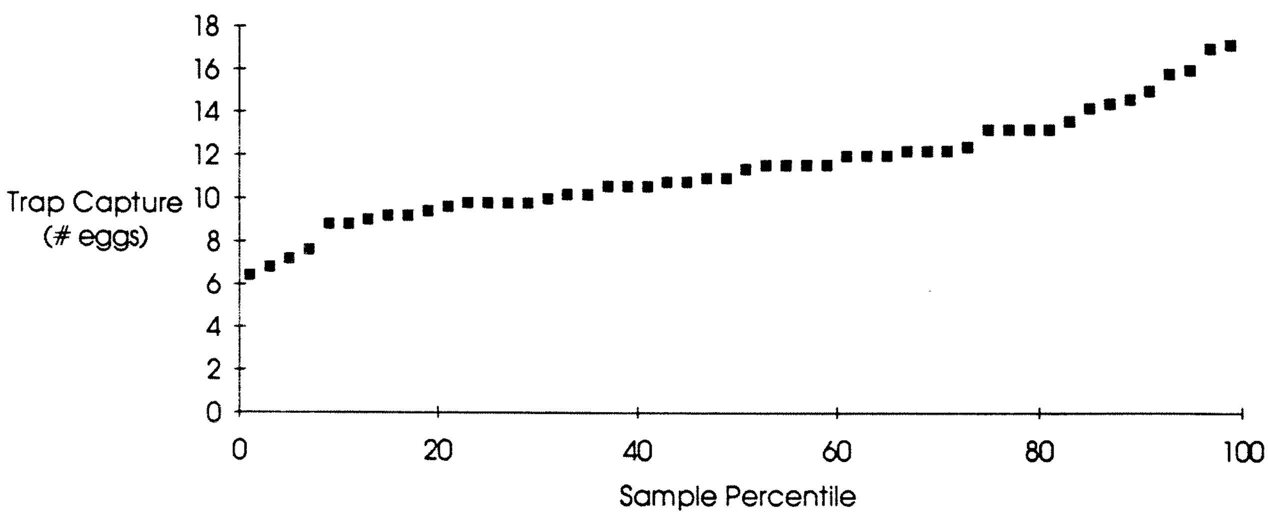


Figure B5. Normal probability plot from regression analysis. Data used were the averages of five paired samples randomly selected from the four and six meter transects.



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Abstract

Mesh bags buried in spawning substrate on Stony Island reef (Lake Ontario) were used to capture lake trout eggs and quantify egg deposition and survival. Some bags collected naturally deposited eggs whereas others were seeded with a known number of eggs. Egg traps were placed next to bags to determine the relationship between trap capture and egg density in the substrate. Incubators buried in the substrate and incubators kept at the Cornell University hatchery also provided estimates of survival. A significant positive relationship was observed between the number of eggs captured in traps and egg density in the substrate adjacent to the traps. Average ratio between egg density and trap capture (in traps that were not filled with sediment) was 58 (SD=24). Mean egg density calculated from the traps (based on area of traps) was not significantly different from mean egg density in adjacent substrate ($P<0.01$). Average ratio between egg density in the substrate and egg density in the traps was 0.99 (95% CI=0.77-1.21). Quantitative estimates of egg density from egg capture data in traps may be possible for spawning areas with physical characteristics similar to those of Stony Island reef. Trap capture data can more readily be used as an index of egg deposition. Egg densities on the reef varied significantly with depth. High egg densities near the top of the reef and diver observations indicated that lake trout focused their spawning activity along the top edge of the reef drop-off. Egg density increased dramatically between 1990 ($677/m^2$) and 1991 ($3201/m^2$). We suspect a strong year-class of Seneca strain fish was recruited into the 1991 spawning population and was responsible for the increased egg deposition. Survival of eggs to swim-up fry in the incubators buried in the reef (24%) was substantially greater than the survival of naturally deposited eggs (1.3%) or seeded eggs (3.8%) but less than survival in the incubators held in the hatchery (75%). About 50% of the mortality in the bags occurred shortly after spawning; most of the remaining mortality occurred over winter. Total number of eggs in the substrate (post-spawning) estimated for Stony Island reef (60 m x 8.33 m) in 1991 was 2,080,650. Estimated emergence of swim-up fry from the reef in 1992 was 27,048 ($54/m^2$). If survival from swim-up to yearling was 5%, then detection by current fish assessment activities of natural recruitment at the yearling life stage would require fry production from about 20 other "Stony Island" reefs.